Assessing Surface Water Potential and Water Demand in Genale Dawa River Basin

By

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ABSTRACT

This study is intended to quantify the amount of surface water potential leaving the entire basin (Genale Dawa) as surface runoff and water demand considering the large scale projects in Genale Dawa river basin which covers an area of 168,000 km^2. Land use, land slope, soil and hydro – meteorological data were used to characterize the hydrology of the study area. Soil and Water Assessment Tool (ArcSWAT) model was used to determine the surface water potential leaving the entire basin as surface runoff in mean annual basis while for the water demand assessment Water Evaluation and Planning (WEAP) model was used.

The estimated mean annual precipitation of the basin is 810.5 mm. The estimated mean annual actual evapotranspiration is 469.8 mm while the estimated potential evapotranspiration is 1304.4 mm. The estimated mean annual runoff leaving the entire basin is 6.37 billion cubic meters which corresponds to 37.92 mm mean annual runoff depth. The source of surface water availability is directly surface runoff generated from the catchments of the area as there are no water islands or lakes in the basin.

The water demand assessment was done for only selected large scale irrigation, hydropower and water supply projects. Two large scale irrigation projects, one large scale hydropower project and five water supply schemes were selected. The five water supply schemes were intended to serve 143,865 people in the base year. The water supply demand is very small as compared to the irrigation water demand. The irrigation water demand covers 98.13% of the total annual water demand for all demand sites. Both water supply and hydropower take 1.87% of the total annual water demand in the current account year 2013. But the water supply and hydropower demand coverage increased to 2.84% of the total annual demand in the year 2025 due to fast population growth.

Keywords: ArcGIS, ArcSWAT, WEAP, Water Demand, Runoff, Genale Dawa River Basin

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List of Acronyms

a.m.s.l.	Above Mean Sea Level
AnnAGNPS	Annualized Agricultural Non-Point Source model
CFCAS	Canadian Foundation for Climatic and Atmospheric Sciences
CSA	Central Statistical Agency
DewPOINT	Dew Point temperature calculator/computer program
DEWPT	Average daily dew point temperature in the month
DFID	Department for International Development
DSS	Decision Support System
EMA	Ethiopian Map Agency
E_{NS}	Nash – Sutcliff's simulation Efficiency
FAO	Food and Agricultural Organization of United Nations
GDMP	Genale Dawa Master Plan
GIS	Geographic Information System
GTP	Growth and Transformation Plan
HBV	Hydrologiska Byrans Vattenbalansavdelning (Hydrological Bureau Water balance Section)
HEC-HMS	Hydrologic Engineers Center – Hydrologic Modeling System
IACoWD	Interagency Advisory Committee on Water Data
IIASA	International Institute for Applied Systems Analysis
ISRIC	International Soil Reference and Information Center
ISS - CAS	Institute of Soil Science – Chinese Academy of Science
IWRM	Integrated Water Resource Management
JRC	Joint Research Center of the European Commission

MCM	Million Cubic Meters
MODSIM	Modular Simulation Model
MoWIE	Ministry of Water, Irrigation and Energy
MoWR	Ministry of Water Resources
PCP_MM	Average monthly precipitation
PCPD	Average number of days of precipitation in the month
PCPSKW	Skew coefficient of precipitation
PcpSTAT	Precipitation Statistical parameters calculator/computer program
PCPSTD	Standard deviation of precipitation
PET	Potential Evapotranspiration
PR_W1	Probability of a wet day following a dry day
PR_W1	Probability of a wet day following a wet day
PRMS	Precipitation Runoff Modeling System
R^2	Coefficient of determination
RIBASIM	River Basin Simulation Model
SCS	Soil Conservation Service
SNNP	Southern Nations, Nationalities and Peoples
SOLARAV	Average solar radiation
SWAT	Soil and Water Assessment Tool
TMP_MAX	Average daily maximum temperature in the month
TMP_MIN	Average daily minimum temperature in the month
TMPSTDMN	Standard deviation of minimum temperature on the month
TMPSTDMX	Standard deviation of maximum temperature in the month
TOPMODEL	Topographic Model

U.S.A.C.E.	US Army Corps of Engineers
UNDP	United Nations Development Program
USDA-ARS	US Department of Agriculture – Agriculture Research Service
WAGRI-SIM	Water Resources Graphical Interface – Simulation Tool
WAPCOS	Water and Power Consultancy Service
WEAP	Water Evaluation And Planning
WinSRM	Windows version of Snowmelt Runoff Model
WMO	World Meteorological Organization
WNDAV	Average wind speed
WRDA	Water Resources Development Association

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Although Ethiopia's water resource is large, very little of it has been developed for agriculture, hydropower, industry, water supply and other purposes this is due to lack of well-organized researches on integrated water resource management and finance (Tadesse, 2006).

Knowing the potential and availability of surface water is vital in wise use of the resource, designing economical and suitable hydraulic structure for water supply, hydropower, irrigation and other purposes.

Integrated water resource management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment (Global Water Partnership, 2012). Water resource and demand assessment is the important component of IWRM in a global or local aspect. So, knowing the water resource potential and their corresponding demands or users in a given river basin locally, nationally or globally is a basic tool to implement the integrated water resource management approach efficiently.

Off course, the assessment of water resources includes the quantification of water resources (both surface and ground water) as well as the determination of its suitability in terms of quality for various uses. But the scope of this study is limited to the quantification of surface water availability and water demand of my study area using ArcSWAT and WEAP models respectively.

As a contribution to regional and national efforts on integrated water resource management (IWRM), this study will have a great importance in understanding and having up to date information on the surface water potential and water demand assessment of Genale Dawa river basin. Genale Dawa river basin is the third largest and transboundary river basin in Ethiopia which needs water potential and water demand investigation for a better picture. The river flows to the Somalia deserts and terminates in joining the Indian Ocean.

1.2. Problem Statement

A comprehensive assessment of the water resources available in a region or a river basin is essential for finding sustainable solutions for water-related problems concerning both the quantity and quality of the water resources. It is a pre-requisite to undertake an analysis of the stress on the water resources and to subsequently adopt appropriate management strategies to avoid adverse environmental effects and reconcile conflicts between users (C.-Y. XU and V. P. SINGH, 2004).

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 basic 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 (WMO, 2012).

Assessment of water resources at the basin, regional or national scales has been undertaken on many occasions in many countries of the world. Often, however, such assessments have not always been as effective as they might have been and have been constrained by a lack of sufficient good quality data. Good quality, long-term records of climate (particularly precipitation), river flows, reservoir levels and groundwater levels are vital to ensure that current assessments of available freshwater resources are accurate. Unfortunately, in many parts of the world, national decision-makers and ministries of finance consistently have failed to appreciate the importance of maintaining long-term, good quality environmental records. Throughout much of Africa in particular, there is marked annual variability in both precipitation inputs and in resulting river flows, lake storages and groundwater levels (Servat et al., 1998).

Since every sector of development needs the value of water in quantity and quality, the surface water quantification and demand assessment in a given river basin will be of great importance. The randomness nature, temporal and spatial variability of precipitation all over Ethiopia leads to the conclusion researches should be done on water resources and demand assessment timely to efficiently implement Integrated Water Resource and Management (IWRM).

Therefore, this study will have a profound importance and contribution to the national efforts on implementing Integrated Water Resource and Management (IWRM).

1.3. Research Questions

- Are the rainfall data and stream flow data consistent in the river basin?
- What will be the surface water potential in the basin?
- What will be the quantity of demand in the basin for the selected demand sites sharing surface water?
- What will be the future trend of water demand in the basin for the selected demand sites?

1.4. Objective of the Study

1.4.1. General Objective

The general objective of this study is to assess the surface water potential and water demand of Genale Dawa river basin using ArcSWAT model and Water Evaluation and Planning (WEAP) models respectively.

1.4.2. Specific Objectives

The specific objectives of the study are

- To assess the rainfall and stream flow data consistency
- To simulate rainfall – runoff modeling using ArcSWAT model
- To quantify the water demand using WEAP model
- To quantify the large scale irrigation and hydropower demands using WEAP model
- To show the future trend of water demand by developing scenarios.

CHAPTER TWO

2. DESCRIPTION OF THE STUDY AREA

2.1. Location

Ethiopia is located in the eastern part of Africa between 3^0 30‘and 18^0 12‘N latitude and 32^0 42‘and 48^0 12‘east longitude. The country has great geographical, topographical and climatological diversity: From high rugged mountains to deep gorges; from lowest altitude at about 120m below sea level to highest altitude of 4600m above sea level; from 2000mm high annual rainfall to 200mm of low annual rainfall. Besides, the Great Rift Valley divides the country in two parts forming the eastern and western high lands (Belay, 2011).

Genale Dawa river basin lies in the southern part of Ethiopia, covering parts of Oromia, SNNP, and Somali regions. Geographically located between 3^0 30' and 7^0 20' North latitude and 37^0 05' and 43^0 20' East longitude. The basin covers an area of 168,000 km^2. It is the third largest river basin, after Wabi Shebelle and Abbay river basins. Neighboring river basins are the Wabi-Shebelle to the north and east, Rift Valley basin to the west (Awulachew *et al*., 2007).

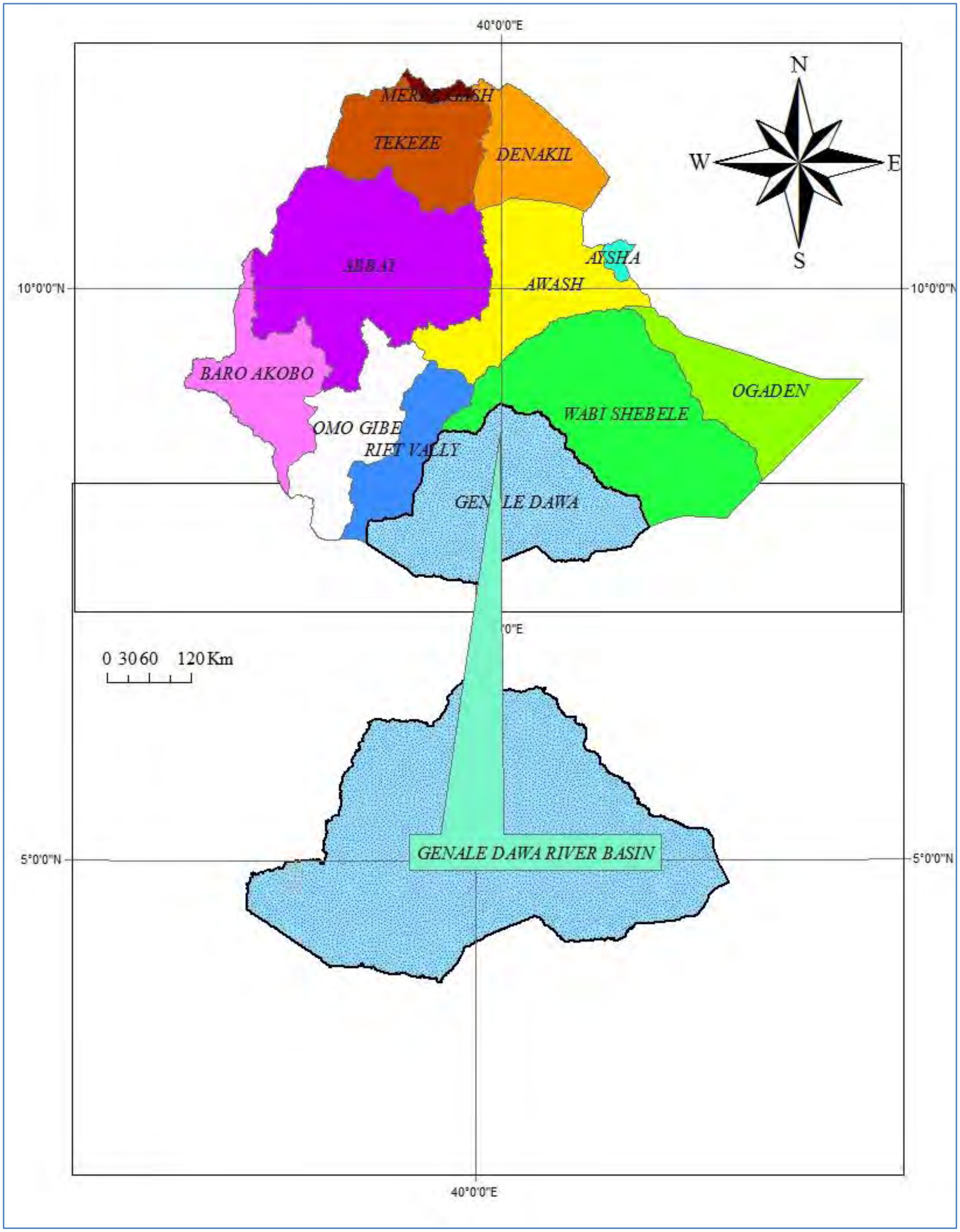

Figure 2.1 Location map of the study area

2.2. Topography

Genale Dawa basin is located in the southernmost part of Ethiopia characterized by great geographical diversity with high and rugged mountains, flat topped plateau, deep gorges and plains. On the northern side of the basin, the highest peak is Mount Tulu Dimtu (4,377m a.m.s.l). The altitude decreases from north to south and west to east to attain an elevation of 176m a.m.s.l. at both Genale and Dawa sub basins.

The basin can be defined in terms of four major land forms:

- Highlands and plateau surrounded by a range of volcanoes.
- Steep sloping escarpments
- Gently sloping lowlands adjacent to the foot of the escarpments
- Lowlands and flood plain basins

The main drainage system is defined by three principal rivers: Genale, Dawa and Weyb, and their respective sub-basins.

- Tributaries of centrally located Genale River originate from the southern flanks of the Bale Mountains and Sidamo Mountains in the north – west which is the divide separating Genale from Rift Valley basin mountains an elevation approaching 3000m a.m.s.l.. The major tributaries are Wabe Mena, Dumel and Yadot from the north and Welmel, Geberticha and Logita from west.
- The Dawa River headwaters are located in the Sidamo Mountains along which the western catchment boundary diminishes gradually in elevation to around 1500m a.m.s.l. in southerly direction. The major tributaries are Awata, Mormora and Kilekile covering the upstream of the main river gauging station at Melka Guba. In its lower reaches, it receives water from a Sizeable area draining Kenyan territory, and along the final reach the river marks national border with Somalia.
- The Weyb River originates from the northern flanks of the Bale Mountains and first flows generally north – eastwards before changing direction to east and south eastwards for the

remainder of its course. Its major tributaries are Shaya, Tegona and Tebel. The Tebel River originates close to the northern Wabi-Shebelle divide near Ginir and joins Weyb Main River at elevations of 1000m a.m.s.l. (GDMP – Main Report, 2005).

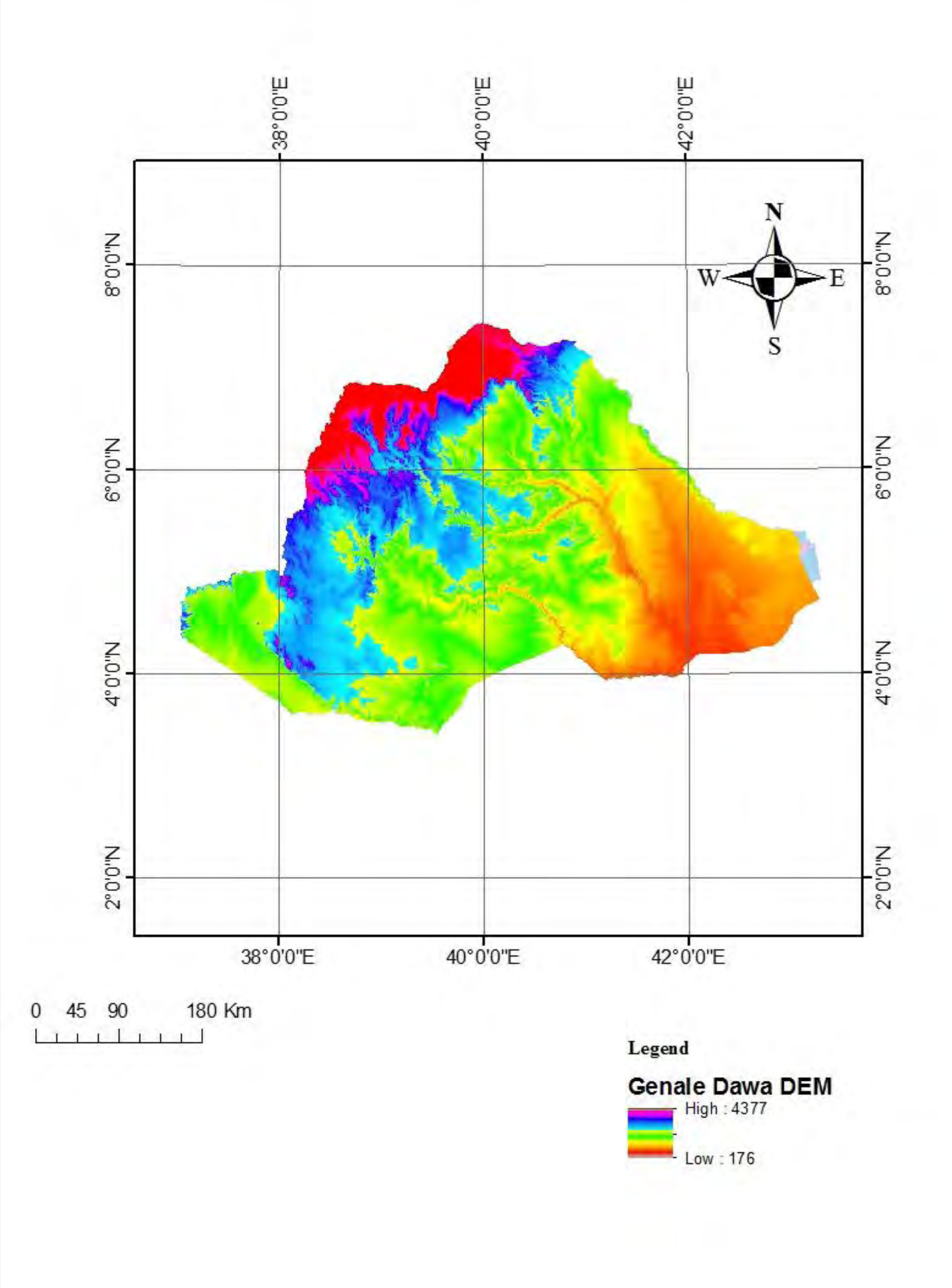

Figure 2.2 Digital Elevation Model of the study area

2.3. Climate and Hydrology

The climate of the country is mainly controlled by the seasonal migration of the Inter-tropical Convergence Zone (ITCZ), which is conditioned by the convergence of trade winds of the northern and southern hemisphere and the associated atmospheric circulation. It is also highly influenced, regionally and locally, by complex topography of the country.

The easterly and southeasterly moist air currents ascend over the highlands in spring, produce the main rainy season in southeastern Ethiopia in general, and in Genale Dawa basin in particular and bring “small rains” of spring (March to May) to most parts of the country. Southeast (Genale Dawa river basin), therefore, gets its first maxima rainfall during spring and receives the year’s secondary maxima rainfall during autumn from the Indian Ocean easterlies. While the basin receives little rainfall in summer compared to spring (March to May) and autumn (September to November) due to the case that the Southerly Indian Ocean air currents lie in the lee side of the highlands in summer and Atlantic westerlies reach the southeastern lowlands (Genale Dawa) after losing their moisture on the highlands to west.

In general, the foregoing outline of variation in pressure systems and air currents partially explains seasonal variation of rainfall in Ethiopia: namely, all year rainfall in southwest with minor maxima in summer; spring primary and autumn secondary maxima in the southeast (Genale Dawa); winter primary and autumn secondary maxima along the Red Sea Coast; and pronounced summer maxima in the rest of the country.

Orographic effects generate some rainfall in winter from southeasterly air currents along the Ethiopian Red Sea Coast producing main rainy season in this area and this gives some rainfall to the basin. Therefore, winter rainfall in the basin may in general due to convection storms coupled with orographic rainfall from the easterly air currents (Master plan of GDRB – Sector Report, 2005).

In general, the Genale Dawa river basin climatic zone comprises (Lemma, 1996)

- Hot arid climate to the south-eastern region along the Somalia border and border to the Wabi-Shebelle basin.

- Hot Semi-arid in the lower central zone of the basin and south-west region.
- Tropical rainy climate in the extreme south and high central basin areas.
- Warm temperate climate in the mid-western area and boundary divide.
- Warm temperate rainy climate in the Sidamo Mountains and intermediate zone south of the Bale Mountains.
- Cool highland climate at the highest elevations in the Bale Mountains

The mean monthly temperature and mean monthly rainfall of different stations in the study area are given graphically in figures 2.3 and 2.4 below.

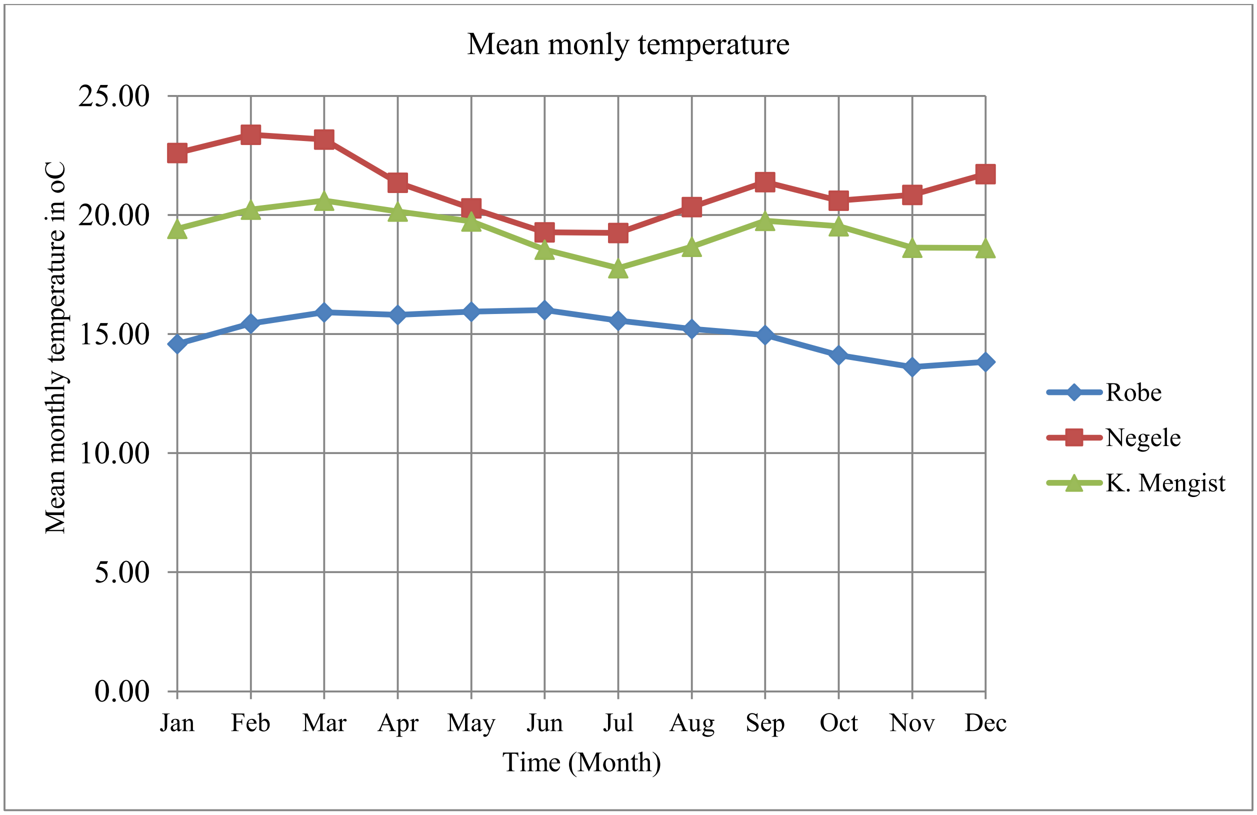

Figure 2.3 Mean monthly temperature of different stations in the study area

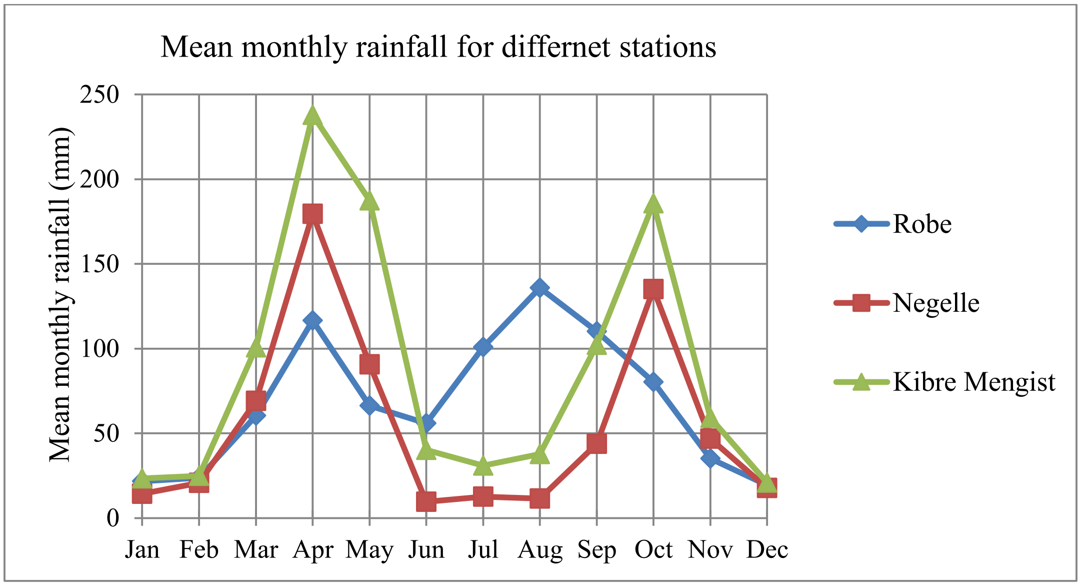

Figure 2.4 Mean monthly rainfall of different stations in the study area

2.4. Land Use/ Land Cover

2.4.1. Land Use

The actual meaning of land use is the way in which land is used by people in an area to produce what is needed by the people for use through involvement of labor, capital and available technology.

According to (FAO, 2000), land use is characterized by arrangements, activities and inputs people undertake under a certain land cover type to produce, change or maintain it. Definition of land use in this ways establishes a direct link between land cover and the action of people in their environment.

However, according to (Master plan of GDRB – Sector Report, 2005), cultivation has been expanded both in the lowland and highland areas at the expense of natural vegetation cover including forest areas as demands of people changed through time and as land use/ land cover are dynamic. The climate of Genale Dawa river basin ranges from lowland Kolla up to highland Wurch. As related to terrain, slope, stoniness and soil properties strongly influence land cover and land use activities in the basin as have been observed elsewhere in the country and the world.

In general, rainfed agriculture and extensive livestock production are extremely constrained by the physical environment, the terrain conditions, and poor technology management systems prevailing in the remote areas of the basin.

2.4.2. Land Cover

Land cover is observed physical cover on the earth's surface. In other words, land cover is what is physically appearing on the surface of the ground as a natural or manmade entity.

According to (Master plan of GDRB – Sector Report, 2005), Genale Dawa river basin is characterized by different land cover types.

Built up areas (settlements and infrastructures), cultivated land, afro-alpine and sub afro-alpine vegetation, forest, woodland, bushland, grassland, exposed surface (bare land) and water body are the main land cover types in the basin.

The dominant land cover type in the basin is grassland which accounts about 50% of the total basin area while water body and built up areas account the least less than 0.3%. The other is covered by the remaining land use/ land cover types like agriculture, forests, settlements, brushes and bare land.

CHAPTER THREE

3. LITERATURE REVIEW

3.1. Overview of Surface Water Assessment

The eradication of poverty and hunger in rural areas is closely related to a fair and equitable access for the most vulnerable people to basic livelihood assets (including land and water) for most domestic and productive uses (UN, 2006).

Therefore, water resource management is one of the most important challenges the world is facing today. In order to meet the demands of different users, efforts should be intensified on the efficient use of all water resources (surface water, ground water, and rainfall) and also on water allocation plans that maximize the resultant economic returns to limited water resources and, at the same time, protect the fragile ecosystem (Adeboye *et al.,*2008).

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 water courses 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 (Tadesse, 2006).

If it is important to quantify the surface water potential in Genale Dawa river basin in terms of surface runoff; one can ask what hydrologic models are available to simulate the surface runoff and which one is the most suitable in the study area solve this problem? Really critical question that has to be answered. Off course there are different types of hydrologic models capable of simulating surface runoff in a given catchment.

There is wide variability in their characteristics and potential applications, for example, spatial and temporal scale, processes modeled and the basis of relationships and algorithm used. With this increasing number of availability, wide ranging characteristics and potential applications of the models, it is becoming challenging job for the potential model users to choose a particular model best suited for the given problem. In addition, modifications are made to existing models and new models are available each year. Therefore, updated, consistent and comprehensive evaluations of hydrological models are a continuous need (Dhami and Pandey, 2013).

In this study, five recently developed or regularly updated hydrologic models were taken in to comparison and based on different evaluation and selection criteria to reach in a conclusion SWAT model is comparably suited to simulate surface runoff in Genale Dawa river basin.

The Precipitation Runoff Modeling System (PRMS) is a modular designed, physically-based, distributed- parameter watershed model developed to evaluate the effects of various combinations of precipitation, climate and land use on stream flow, sediment yields, and general basin hydrology. PRMS simulates snowpack formation and melt, and is well suited for simulating stream flow and its hydrologic components from snowmelt dominated basins (Markstrom et al., 2008). It is suitable for coupling with other models but it may subject to computational instability problem due to its governing equations requiring numerical approximation for their solutions (Dhami and Pandey, 2013).

The Hydrologic Modelling System (HEC-HMS), developed by US Army Corps of Engineers Hydrologic Engineering Center, is designed for both continuous and event-based hydrologic modelling. It provides several different options to the users for modelling various components of hydrologic cycle. Initially it was developed to simulate the precipitation-runoff processes of dendritic watershed systems but later it was improved to solve widest possible range of problems including large river basin water supply, flood hydrographs, and small urban or natural watershed runoff (USACE HEC, 2010). Limitations of this model, HEC-HMS does not simulate most of the components of land phase of the hydrologic cycle like groundwater flow, it needs other Hec-soft wares to delineate the catchment and it needs smaller data than SWAT model.

Annualized Agricultural Non-point Source Model (AnnAGNPS) is a watershed-scale, continuous simulation model designed to predict the impact of management on water, sediment, nutrients, and pesticides in agricultural watersheds. AnnAGNPS is the next generation of the AGNPS 5.0 single event model developed by USDA-ARS and Natural Resources Conservation Services (NRCS). AnnAGNPS incorporates several components of other models, like the revised universal soil loss equation, Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, the groundwater loading effects (Bingner et al., 2011). AnnAGNPS model is similar to SWAT model but it has a spatial limitation and does not consider point source.

WinSRM is the windows version of the Snow melt Runoff Model (SRM) which is a degree-day (i.e. snow melting per one degree Celsius increase in daily air temperature) based deterministic conceptual model developed to simulate and forecast daily stream flow in mountainous basins where snow melt is a major runoff component and has also been applied to evaluate the effect of changed climate on seasonal snow cover and runoff (Martinec et al., 2008). SRM uses snow cover information and meteorological data (daily precipitation and daily average temperature) as input variables and elevation bands for spatial discretization. The SRM is considered to be the most successful model for simulating snowmelt runoff (Wang and Li, 2006). Limitations of this model are, WinSRM does not simulate most of the components of land phase of the hydrologic cycle, it needs snow cover data and it is most suited to simulate snowmelt runoff.

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998; Arnold and Fohrer, 2005) is a physically-based continuous-time, conceptual, long-term, distributed watershed scale hydrologic Model developed by USDA’s Agricultural Research Service (ARS), designed to predict the impact of land management practices on the hydrology, sediment and contaminant transport in large, Complex catchment. It has Capabilities of simulating surface runoff, percolation, return flow, erosion, nutrient loading, pesticide fate and transport, irrigation, groundwater flow, channel transmission losses, pond and reservoir storage, channel routing, field drainage, plant water use and other supporting processes from small, medium and large watersheds. It can be applied to a large ungauged rural watershed with more than hundred numbers of sub watersheds (Kusre et al., 2010). For this reason, SWAT is increasingly being used to support decisions about alternative water management policies in the areas of land use change, climate change, water re-arrangement, and pollution control. There are numerous applications of SWAT model all over the world (Dhami and Pandey, 2013). Out of the mentioned hydrologic models only SWAT model can simulate all of the components of land phase of hydrologic cycle.

All the above descriptions of different scholarly models to simulate surface runoff potential in a given basin lead to a conclusion that Soil and Water Assessment Tool (SWAT) model is the best fit to solve the problem in my study area (i.e. to simulate the surface runoff in Genale Dawa river basin).

The spatial and temporal scale of the selected hydrologic models are summarized in table 3.1 below.

Model	Spatial scale	Time scale	Computational time step
AnnAGNPS	Watershed scale (only up to $3000km^2$	continuous	daily
HEC-HMS	Flexible	Event and continuous	Minutely, hourly, daily
PRMS	Watershed scale	Event and continuous	Minutely, daily
SWAT	Flexible	continuous	daily
WinSRM	Flexible	continuous	daily

Source: Dhami and Pandey (2013)

Table 3.1 Spatial and temporal scale of selected hydrologic models

3.2. Overview of Water Demand Assessment

Of the factors that determine development potential in a given geographic area, the availability of water for residential, commercial, and industrial purposes is a primary indication of prospective growth. Governmental bodies at the regional, state and federal levels often need to identify water supply availability in order to identify growth potential (Wallace, 2001).

According to Flint (2004) the demand for water resources of sufficient quantity and quality for human consumption, sanitation, agriculture, and industrial uses will continue to intensify as the population increases and global urbanization, industrialization, and commercial development accelerate.

Computer based Decision Support Systems (DDS) are being used worldwide in order to manage more wisely our water resources (Arranz, 2006).

A Decision Support System allows decision-makers to combine personal judgment with computer output, in a user- machine interface, to produce meaningful information for support in a decision-making process. Such systems are capable of assisting in solution of all problems (structured, semi structured, and unstructured) using all information available on request. They use quantitative models and database elements for problem solving. They are an integral part of the decision-maker's approach to problem identification and solution. A DSS must help decision makers at the upper levels, must be flexible and respond to questions quickly, must provide for "what if" scenarios and must consider the specific requirements of the decision makers. Additional important characteristics are accessibility, flexibility, facilitation, learning, interaction and ease of use (Simonovic, 1996).

According to (DFID, 2003), the main factors in estimating water use will be urban population growth and the level of unaccounted for water. In many urban areas in Africa unaccounted for water levels can be as high as 50%. Demand management measures including leakage reduction programmes and other water conservation measures can often significantly reduce the level of unaccounted for water. In some European countries unaccounted for water levels are of the order of 10%. In any demand forecasting that is carried out for urban areas it is important that estimates are made concerning the reduction in unaccounted for water levels in the future.

If assessing water demand in a given basin is essential as discussed but; what available models are there which are capable of modeling water demand and which is best suited to model water demand in the study area(Genale Dawa river basin) is a crucial question any one can ask. Off course there are various models which are capable of modeling water demand in a given catchment or basin. The relevant models which are commonly used in modeling water demand all over the world along with their suitability and limitations are presented here to reach at a conclusion that WEAP model was selected as the best suitable to model the water demand in my study area.

A large variety of generic simulation models within interactive graphics-based interfaces has been developed by public and private organizations. They all are designed to study water related planning and management issues in water systems and to satisfy the needs of those at different levels of planning and decision-making process (Assaf et al., 2008).

Water Resources Graphical Interface – Simulation Tool (WARGI-SIM) developed at University of Cagliari, Italy, is a user-friendly tool specifically developed to help users understanding interrelationships between demands and resources for multi-reservoir water systems under water scarcity conditions, as frequently occur in the Mediterranean regions. The DSS makes it possible to take into account a large number of system components that typically characterize water resources models. The tool is flexible and generalized in the system configuration and data input, in the attribution of planning and operating policies and in processing output (Sechi and Sulis, 2009).

Modular Simulation Model (MODSIM) is a generic system management DSS originally conceived in the late 1970s at the Colorado State University, United State, and continuously maintained. MODSIM simulates water allocation in the system at each time step through sequential solution of a network flow optimization problem where nonlinearities (i.e. evaporation, groundwater return flows, channel losses etc.) are assessed within a successive approximations solution procedure (Sechi and Sulis, 2010).

River Basin Simulation Model (RIBASIM) is a generic model package for simulating the behavior of river basins under various hydrological conditions developed by DELTARES, former DELFT Institute, Delft, The Netherlands. RIBASIM particularly address the hydrological and hydrographical description of the river-basins and links the hydrological water inputs at various locations with the specific water-users in the supply system. It allows the user to define operating/planning scenarios where each scenario is characterized by a particular operating rule and/or water supply projection. Different scenarios can be easily compared based on user-defined objectives through the powerful graphical interface (Sechi and Sulis, 2010).

Water Evaluation And Planning (WEAP) model is a generic simulation model developed at the Stockholm Environment Institute, Boston, Massachusetts. It integrates some physical hydrological processes with the management of demands and infrastructure to allow for multiple scenario analysis, including alternative climate scenarios and changing anthropogenic stressors. WEAP model simulations are constructed as a set of scenarios with different simulation time steps. The physical hydrology model updates the hydrologic state of the system at each time step, and thus provides mass balance constants used in the allocation phase within the same time step. A groundwater module in WEAP allows for the water transfer between stream and aquifer. The main point of the water management analysis in WEAP is the analysis of water demand configuration. These demand scenarios are applied deterministically to a linear programming allocation algorithm where each demand and source is assigned a user defined priority. The linear program solves the water allocation problem trying to maximize satisfaction of demand, subject to supply preferences and demand priorities, and using reservoir operating policies to minimize the distance to ideal conditions. The water allocation problem is solved at each time step using an iterative, computationally expensive approach. Traditional target storage levels, multiple zones, and reduced releases by a buffer coefficient are implemented in WEAP.

MODSIM and WEAP are models where optimization methods are developed on the single time period and results are used as an efficient mechanism for performing simulations, whereas WAGRI-SIM and RIBASIM are simulation-only model based on a more conventional if-then approach and give lower values of performance system index. Operating policies in WAGRI-SIM and RIBASIM are fixed whereas operating policies in MODSIM and WEAP are defined as a combination of system states and hydrologic conditions and can be linked to a more detailed higher dimensional models (e.g. QUAL2E, MODFLOW) to provide comprehensive modeling of water quality conditions and effect of groundwater (Sechi and Sulis, 2010).

Though, MODSIM and WEAP have better advantages over the other models and are equally important to model water demand in the study area, MODFLOW is not an easy task as it needs an extensive calibration phase. Therefore, WEAP model is easy and best suited to model water demand in my study area as it can be licensed online annually free of cost.

A mentioned by (Mounir *et al*., 2011), Water Evaluation And Planning (WEAP) model provides a seamless integration of both the physical hydrology of the region and water management infrastructure that governs the allocation of available water resources to meet the different water needs. It is a priority driven software, employs priority based optimization algorithm as an alternative to hierarchal rule based logic that uses a concept of equity group to allocate water in time of inefficient supply.

According to (Wallace, 2001), with supply and demand data in a base year, projections of future water supply availability can then be made. Detailed projection of future water demand must account for changes in the amount of water use activities and the rates of water use within those activities, but a simplified procedure was applied here. Total off stream water use was averaged over the population in the base year to determine per-capita offstream use, which is assumed to remain constant in the future in this preliminary assessment procedure. Population was then projected and demand was forecasted as a function of the projected population. The supply quantity was projected assuming each flow parameter derived from the historical record will remain constant in the future year. By comparing projected supply and demand estimates, water supply availability in future years can be anticipated in the planning area.

But in this study the projected supply which was done using WEAP model was taken as the water supply demand in the future without comparison as there are no official estimates of water supply demand as USGS in the basin.

As indicated by (Mounir *et al*., 2011), in WEAP the typical scenario modeling effort consists of three steps. First, a Current Accounts year is chosen to serve as the base year of the model; two a Reference scenario is established from the Current Accounts to simulate likely evolution of the system without intervention; and thirdly "what-if" scenarios created to alter the "Reference Scenario" and evaluate the effects of changes in policies and/or technologies.

In this study, the current accounts year was chosen to serve as the base year for the model with input data, reference scenario was developed from the base year without intervention and finally " what if " scenarios were developed using high population growth rate to show how the water supply demand behaves as the population growth rate changes.

3.3. Hydrologic Modeling

A hydrological model is an approximation of the complex reality using a system concept. A system is a group of interacting or inter-dependent components forming a complex whole. The overall intent of the hydrologic system analysis is to study the system function and predict its output. The models treat the hydrological cycle as a system that comprises its different components as inputs like precipitation and outputs like runoff, using a set of equations that links the inputs and outputs (Chow *et al*., 1988).

The existing hydrological simulation models can be grouped according to the runoff generation process considered in each model. When comparing models, stochastic and deterministic models are often considered to be at the top level of the classification tree, in accordance to the way they treat the randomness of hydrologic phenomena (Chow *et al*., 1988). Stochastic models use local hydrometric data to predict flows. These models allow for some randomness that results in different outputs and are based on analysis of past events, commonly rainfall and river discharge

(Ahmad *et al*., 2001; Tesfaye *et al.,* 2006). Deterministic models generally produce a single output of runoff for a given rainfall under identical physical environments. Deterministic models can be classified as; lumped models, where a variable or parameter is assumed to have an average value for the whole catchment, and distributed models, where all variables and parameters have different values that account for the spatial variation in the catchment.

Deterministic models can be further classified as empirical, conceptual and physically-based models. Empirical models, which are usually lumped, are based on analyses of parallel input-output time series with no explicit account of physical processes (Antar *et al*., 2006).

Conceptual models, which can be lumped or distributed, are generally composed of mathematical descriptions of the processes of catchment response. These models represent the catchment as integrated conceptual components but also incorporate some aspects of physical processes. Some examples of the conceptual models are HBV, TOPMODEL and the Soil and Water Assessment Tool (SWAT)). In both empirical and conceptual approaches measured hydrological variables, usually stream flow data, are needed for calibration in order to develop and parameterize the model. Physically-based models are based solidly on an understanding of the physical processes using fundamental hydrodynamic laws (Tessema, 2011).

3.3.1. Hydrologic Model Selection Criteria

There are numerous criteria which can be used for choosing the right hydrologic model. These criteria are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user depended, such as personal preference for graphical user interface, computer operation system, input/output management and structure, or users add on expansibility. Among the various project-depended selection criteria, there are four main common, fundamental ones that must always be considered (Cunderlik 2003).

1. Required model outputs important for the needed purpose and therefore to be estimated by the model – does the model predict the variables required by the project such as peak flow, event volume and hydrograph, long term flows?

2. Hydrologic processes that need to be modeled to estimate the desired outputs adequately – is the model capable of simulating regulated reservoir operation, single event or continuous processes?

3. Availability of input data – can all the inputs required by the model be provided within the time and cost constraints of the project?

4. Price – does the investment appear to be worthwhile for the objectives of the project?

In addition to the above criteria, adaptability of the hydrologic model, the type of the problem what I am addressing are also considered.

One of the various and mostly used conceptual models for assessment of surface water potential is SWAT model. SWAT model is the widely used in all over the world and in many parts of Ethiopia.

Therefore, SWAT model is selected for modeling the surface water potential in my study area based on the above criteria.

3.3.2. Description of ArcSWAT Hydrologic Model

The Soil and Water Assessment Tool (SWAT) model was developed by US Department of Agriculture – Agriculture Research Service (USDA-ARS). It is a conceptual model that functions on a continuous time step (Arkansas, 2005).

The SWAT (Soil and Water Assessment Tool) model is a comprehensive, continuous-time, process based and semi-distributed conceptual river basin model (Arnold et al., 2012).

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 subbasins through which streams are routed. The subunits of the subbasins are referred to as hydrologic response units (HRU's) which are the unique combination of soil and land use characteristics and are considered to be hydrologically homogeneous. The model calculations are performed on a HRU basis and flow variables are routed from HRU to subbasin and subsequently to the watershed outlet. The SWAT model simulates hydrology as a two-component system, comprised of land hydrology and channel hydrology. The land portion of the hydrologic cycle is based on a water mass balance. Soil water balance is the primary consideration by the model in each HRU, which is represented as (Arnold *et al*., 1998):

$$SWt = SW + \sum_{i=1}^{t} \left(R_i - Q_i - ET_i - P_i - QR_i \right) \text{--------------------------------} 3.1$$

Where, *SW* is the soil water content*, i* is time in days for the simulation period *t*, and *R,Q, ET, P* and *QR* respectively are the daily precipitation, runoff, evapotranspiration, percolation, and return flow. The water balance of each HRU in the watershed contains four storage volumes: snow, the soil profile (0-2 m), the shallow aquifer (2-20 m) and the deep aquifer (>20 m). The soil profile can contain several layers. The soil-water processes include infiltration, percolation, evaporation, plant uptake, and lateral flow. Surface runoff is estimated using the SCS curve number equation. Percolation is modeled with a layered storage routing technique combined with a crack flow model. Potential evaporation can be calculated using Penman-Monteith method (Arnold et al., 1998). The flow is also routed using variable storage method.

3.3.3. Description of WEAP Model

Water Evaluation and Planning (WEAP) model is a computer modeling tool for integrated water resources planning developed by Stockholm Environment Institute (SEI). WEAP model considers different demand sites with their respective demand priorities. Therefore, water allocation can easily be done by this model.

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 (Sieber *et al.,* 2012).

Hence, WEAP model becomes a powerful tool to assess the water demand in the study area (Genale Dawa river basin).

3.3.4. Previous Studies Made In Genale Dawa River Basin

In the National Master Plan Study (WAPCOS, 1990), yield estimates were made considering annual rainfall and appropriate runoff factors for different zones and subbasins. Runoff factors of 25 to 30% were computed for the western tributaries in the highland regions, which reduce to around 18% in the middle reaches of Genale and Weyb and to about 7% in the central parts of Dawa. The resulting total was then compared with a mean flow of 5.88 Bm3 measured on the Juba river downstream in Somalia and the figure 5.88 Bm3 appears to be the final figure adopted by the study.

According to National Master Plan Study (GDMP – Main Report, 2005), through utilization and interpretation of all historic/measured data and by combining the results of GIS procedures applied to determine catchment physical parameters and the mean annual rainfall, revised estimates of the annual rainfall (input) and surface water yield (output) of the subbasins and the whole river basin can be made.

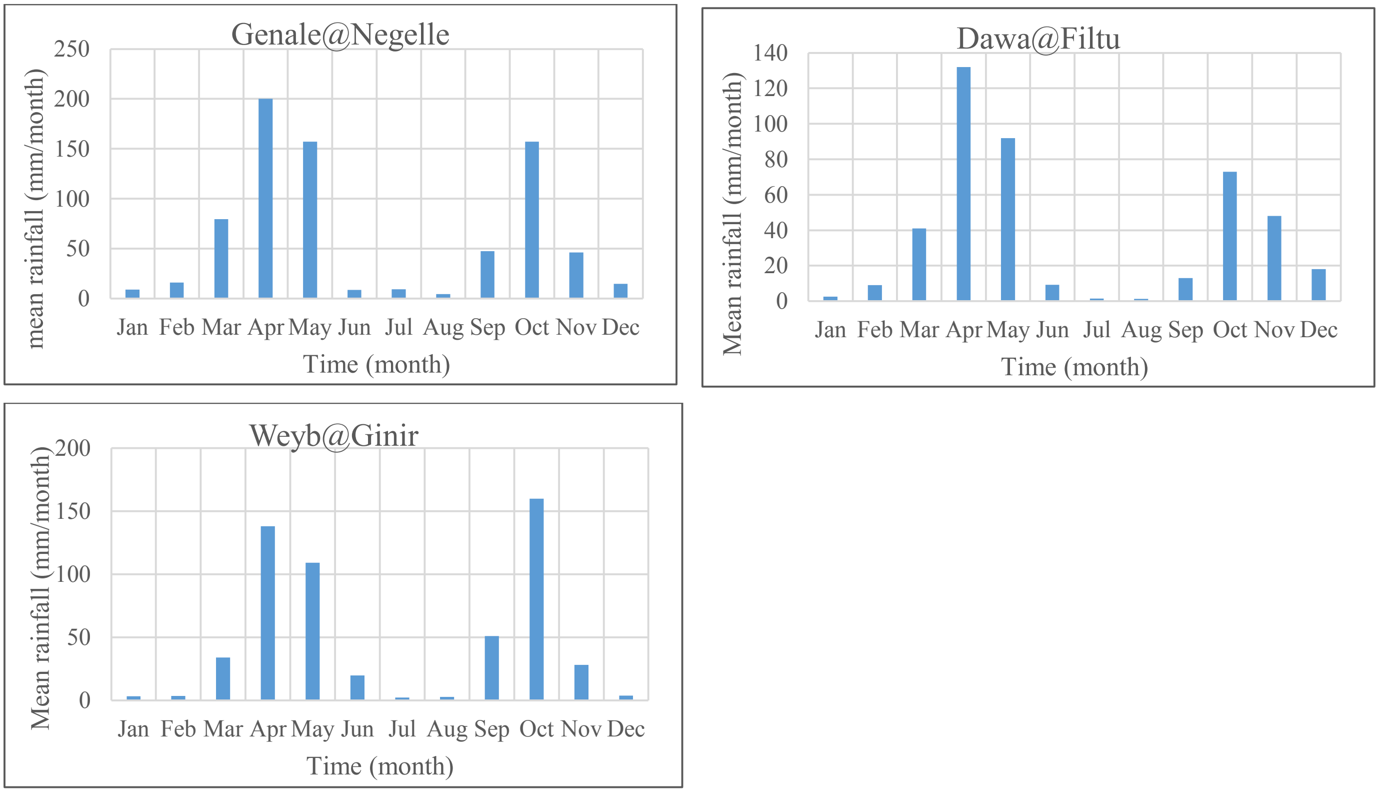

Figure 3.1 Monthly rainfall profiles in different stations

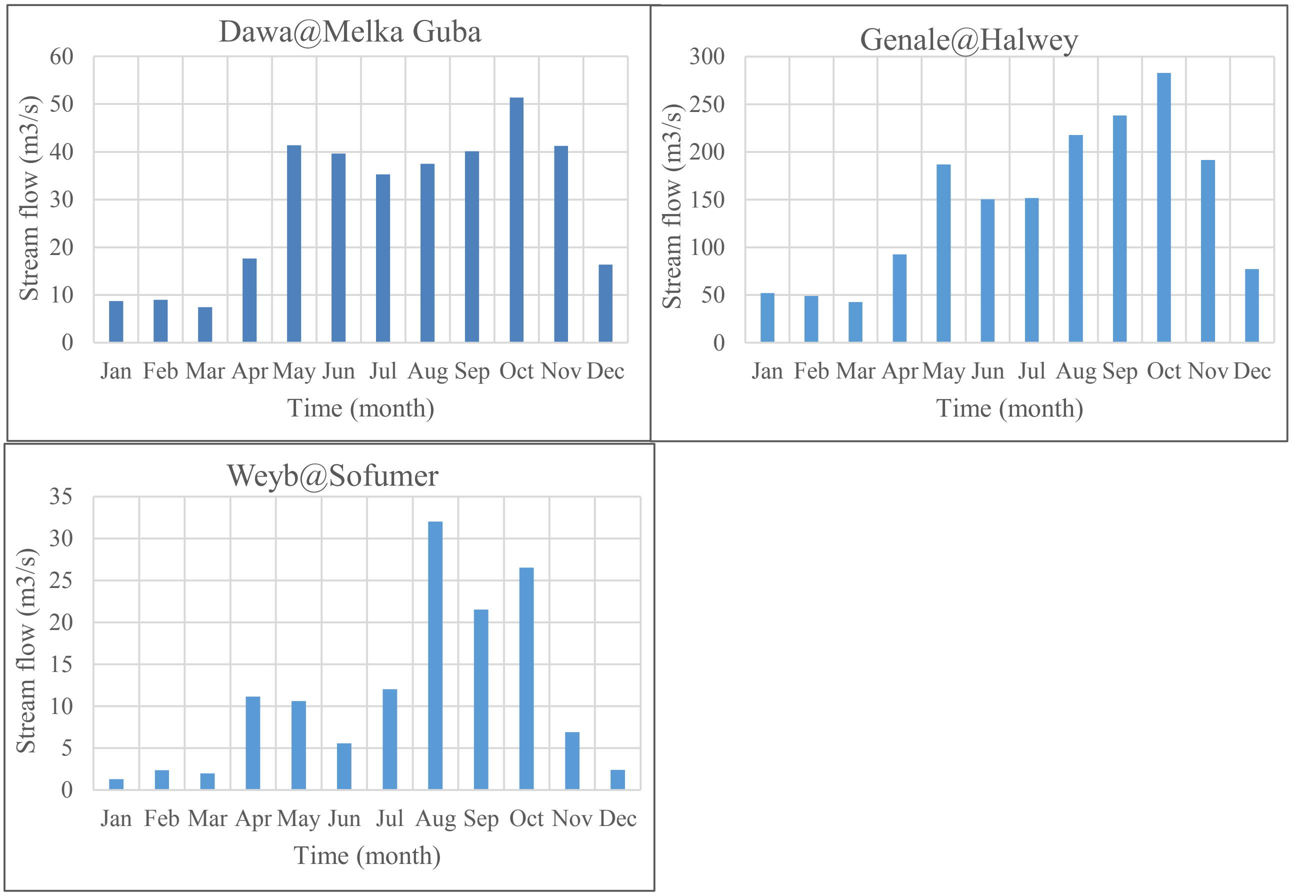

Figure 3.2 Monthly stream flow profiles in different stations

For each of the subbasins, the most downstream station on the main river reach was defined as a control point. From the control point up to the subbasin terminal point, runoff was estimated through application of the runoff curve based on mean elevation for the incremental area. This enabled estimation of incremental flow and total flow, or yield for each respective subbasin.

As can be appreciated the Genale subbasin yield can be almost completely defined from the station at Halwey, located in the lowest reach and which commands some 98% of the total subbasin area. Estimation in Dawa and Weyb are considerably less certain due to the extensive ungauged areas in the lower reaches.

For the whole river basin the total annual yield amounts to about 6.6 Bm3, which is slightly more than the previous WAPCOS estimate. The Genale subbasin yields some 70% of the total annual yield.

As a consequence of high temperatures, high evapotranspiration loss and low rainfall in lower regions, only a very small amount of rainfall is actually effective in producing runoff, Runoff factors predicted by the regional curves amount to around 4% in the reaches of the Dawa and Weyb subbasins, thus concurring with the previous WAPCOS estimates for the incremental dry zone.

As per the WRDA (1987), yield values were calculated for each of the major tributaries and mainstream areas and summed for the three subbasins.

The previous study results are summarized in comparison to my thesis result in Table 3.1.

	WRDA (1987)	Master Plan (WAPCOS, 1990)	Master Plan (MoWIE, 2005)	Thesis Result
Total annual water yield from the entire basin (Bm^3)	6.1	5.88	6.6	6.37

Table 3.2 Estimates of annual water yield (Bm3) of Genale of different studies

As described in Table 3.2, the annual water yield estimate by WAPCOS (1990) which is about 5.88 Bm^3 is slightly less than the estimated value by WRDA (1987). But the annual water yield estimate by the National Master Plan Study (GDMP – Main Report, 2005), which is about 6.6 Bm^3 shows a slight increment from the previous study estimate by WAPCOS (1990) which was 5.88 Bm^3.

According to my study, the estimated annual water yield from the entire basin is found to be 6.37 Bm^3 which shows a slight increment from the estimates of WRDA (1987) and WAPCOS (1990) while it shows a very small decrement from the previous study by National Master Plan Study (GDMP – Main Report, 2005).

According to National Master Plan Study (GDMP – Main Report, 2005), the water supply demand was analyzed. Negelle town is the capital of Guji zone located at a distance of 610 km south of Addis Ababa and situated at a distance of about 40 km from the right bank of Genale River. The town currently gets its water from Genale River. The town has long – suffered from an inadequate and unhealthy water supply.

One of the options for Negelle's water supply with a population of 53,000 (2004) is to draw from the Genale River, about 40 km away but it needs heavy pumping is required as the river is at 1100m, but Negelle is at an elevation of 1500 m.

Yabelo town is the administrative capital of Borena Zone with a population of 16,820 (2004) is getting its inadequate water supply from groundwater. The water supply coverage is about 15%. Due to critical shortage of potable water, services are being currently provided on shift basis. Therefore, the second option for Yabelo town water supply is a possibility to pump water from the nearby (17 km) Gora Dese River, which is a tributary of Dawa River. The raw water would be pumped all the way up to Yabelo, where it would be treated and distributed.

The water supply to Mega town is similar to Yabelo case, it is also an option for the town of Mega to draw water from the nearest river, Gora Dese, tributary of Dawa River. The scheme is expensive, as the distance between the town and the river is 92km.

The long – term solution of water supply for Filtu town and its surrounding areas has to come from Genale River about 40 – 45 km distance from the town. Filtu is not blessed by its location as far as water supply is concerned. Rainfall is rather low, 300 to 400 mm per year and the nearest river with perennial flow is the Genale. The pump head is substantial, as the Genale River at the intake be El. 360m, whereas Filtu town is at El. 1260m.

The scheme, otherwise the same as the one for Negelle water supply is technically feasible, but the supply costs are quite high.

The best choice for a long – term solution of water supply for both human and livestock consumption for Hargele area and its surrounding is to use the Weyb River. The lowest cost scheme would be the supply of Weyb water to initially Hargele and chereti and in a next stage to Afder.

The urban water supply coverage of different towns in Genale Dawa River Basin is summarized in Table 3.3.

Town	Region	Population (2005)	Population (2025)	Water supply coverage	
				Master Plan	Thesis Result
Negelle	Oromia	41,135	121,101	95%	100%
Yabelo	Oromia	17,694	52,437	15%	100%
Mega	Oromia	8,973	26,684	95%	100%
Filtu	Somali	7,525	23,348	<48%	100%
Hargele	Somali	7,529	51,286*	<48%	51%

*the population includes the Hargele surrounds

Table 3.3 Water supply coverage of different towns

As shown in Table 3.3, the thesis result shows the coverage will be better the previous study by the Master Plan due to using surface water as a source in addition to groundwater source.

According to National Master Plan Study (GDMP – Main Report, 2005), included identification of sixty one (61) sites with a total of 1,070,700 ha of land with potential for irrigation development. The study includes almost all previous studied sites, with some difference in estimation of potential area in some sites. The factors causing reduction of estimated area include water availability, land suitability (macro-relief), socio economic aspects etc. The identified irrigation potential sites in the three Genale Dawa subbasins are summarized in Table 3.4.

Subbasins	Genale subbasin	Dawa subbasin	Weyb subbasin	Total
Irrigation Potential	395,500	113,200	562,000	1,070,700

Table 3.4 Irrigation Potential in Genale Dawa River Basin

S.No.	Name of the site	Irrigable Area (ha)	Remark
1	Lower Genale	30,000	Feasibility study
2	Welmel	10,000	Feasibility study
3	Bale Gadula	4,500	Detail design
4	Tebel	1,000	Feasibility study

Table 3.5 Summary of irrigation projects reviewed

Hydropower investigations were carried out with the National Water Resources Master Plan (WAPCOS, 1990). The major findings generally superseded previous studies and, to a large extent, created the basis for potential hydropower development in the Genale Dawa River Basin. Resulting from this study thirty one (31) sites were identified and preliminarily evaluated.

S. No.	Basins	WAPCOS (1990)	MoWR (1998)
1	Genale	9 sites	9 sites
2	Dawa	11 sites	11 sites
3	Weyb	11 sites	9 sites
4	Total	31 sites	29 sites

Table 3.6 Hydropower potential sites in Genale Dawa River Basin

According to Master Plan Study (GDMP – Main Report, 2005), out of the hydropower potential sites previously identified, some of them are under prefeasibility study, some are under detailed design stage. GD – 3 is selected in for the hydropower analysis in my study area which has got its detail design in Genale subbasin and located in the main Genale River.

CHAPTER FOUR

4. Materials and Methods

4.1. Surface Water Assessment

4.1.1. General Framework

The general framework used for the assessment of surface water potential in my study area is illustrated by the following flowchart.

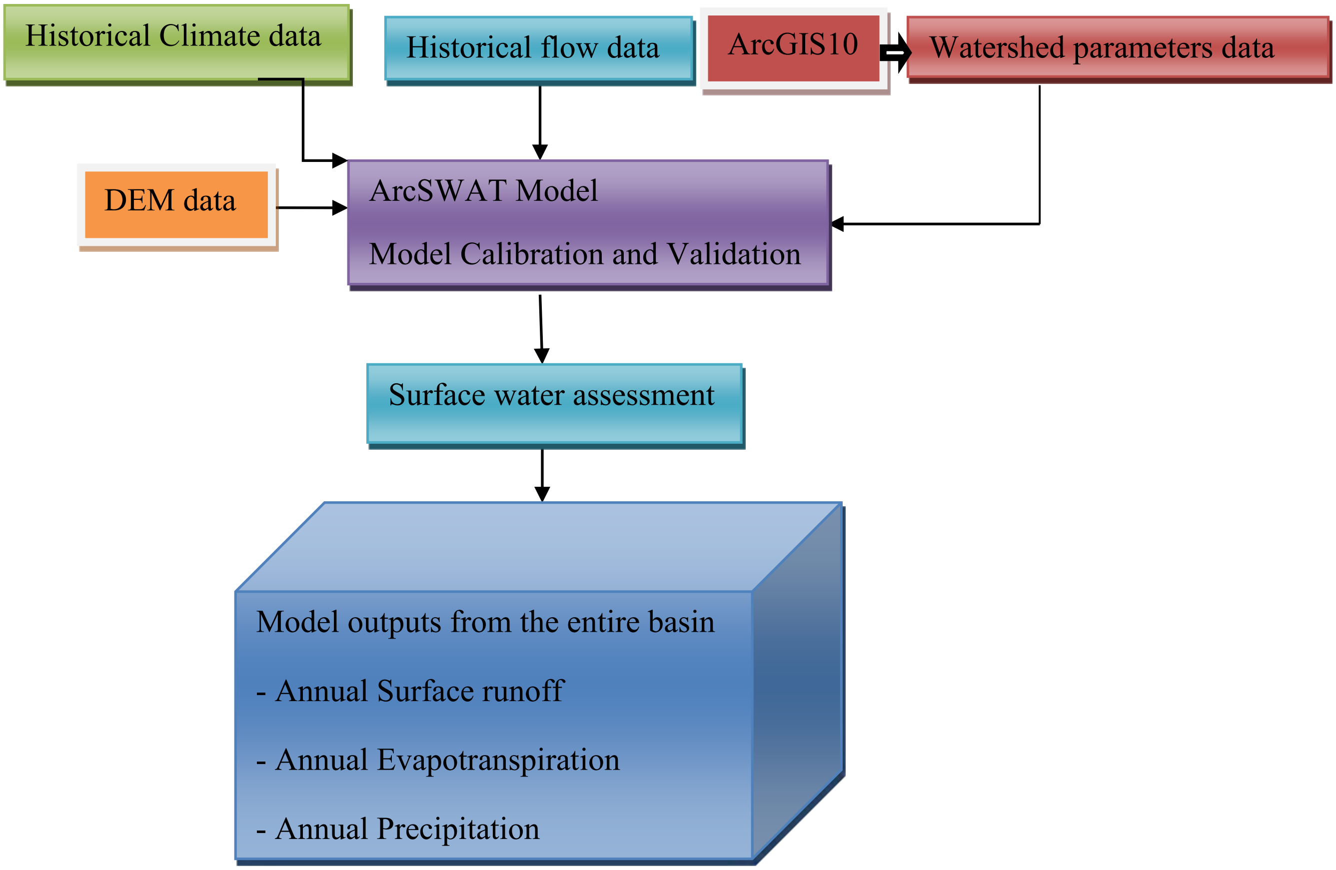

Figure 4.1 General framework flowchart for surface water assessment

As illustrated in figure 4.1, the flowchart shows the general framework that has been used for the surface water assessment in this study. The historical climate data have been collected from National Meteorological Agency of Ethiopia. The historical stream flow, soil, land use/land cover and other related ArcGIS data have been collected from ministry of water resources, irrigation and energy. Digital Elevation Model (DEM) is collected from the Ethiopian Map Agency (EMA).The historical stream flow data has been used for the model calibration and validation. The study area was delineated from DEM in ArcGIS – ArcSWAT interface where all the land use/land cover, soil and land slope data are clipped successfully to it. The precipitation and stream flow data have been analyzed by double mass curve for consistency, and Log-Pearson type III outlier detection method was used to test the existence of outliers for both precipitation and stream flow data and, hence, six stations with better data quality have been selected for the model input. The missing data cells in excel sheet are coded as (-99) to tell ArcSWAT the data is missing which is filled by ArcSWAT weather generator. The ArcSWAT weather generator fills the missing data from neighboring stations by first generating the missing precipitation data independently, and then based on the dry and wet days and their probabilities, it generates maximum and minimum temperature, solar radiation and relative humidity. Finally, it generates wind speed of the missing data independently for the day.

Weather generator stations are synoptic/first class stations with all recording data which are used to fill gaps/missing data in the second, third or fourth class stations with missing values. Weather generator/first class stations are firstly prepared and their input parameters are calculated using PcpSTAT, DewPOINT and excel sheet. Robe, Kibre Mengist and Negelle are the synoptic/first class stations which are used to fill gaps or missing values in the rest of the stations in the study area. There are fourteen input parameters for each weather generator stations which must be prepared.

Watershed parameters, such as soil and land use data have been processed in ArcGIS before their properties were entered in to ArcSWAT data base.

Two years warm up period was used during running the ArcSWAT model.

4.1.2. ArcSWAT Model Setup

Soil and Water Assessment Tool (SWAT) model is an ArcGIS extension with its own user interface including SWAT project setup, watershed delineator, HRU analysis, Write Input Tables, Edit SWAT input and SWAT simulation.

Directory is opened in the SWAT project setup where all the SWAT model outputs are saved; then watershed delineator becomes available where delineation of the river basin is done using the DEM data in which the model uses it for the whole process resulting in twenty eight subbasins and two hundred ninety five HRUs. HRU analysis becomes available again after the water delineation is successfully completed where the basic SWAT inputs; land use/land cover and soil data are clipped to the study area and finally land use/land cover, soil data and land slope are overlaid to the study area. Write input tables become active after HRU analysis is successfully done where all the SWAT input data are written to the SWAT data base for model processing.

Edit SWAT input is where the soil and land use/land cover data properties are entered to the SWAT data base in the form that the model understands the codes.

SWAT simulation is the final stage that becomes active after all the previous stages have been successfully completed. Setting the default simulation the first task in this stage and then running the model. Sensitivity analysis, reading model outputs, auto and manual calibration are also accessed here.

4.1.3. SWAT Model Input Data

4.1.3.1.Weather Input Data

Weather input data is one of the basic input requirements for SWAT model. These weather input data include; precipitation, maximum and minimum temperature, wind speed, relative humidity and solar radiation in daily basis. All these data were prepared in suitable text format for each meteorological station so that the SWAT model can understand. Monthly stream flow data is also used for the model calibration and validation.

4.1.3.2. Land use/Land cover data

The river basin is divided in to subbasins and the subbasins are further divided into Hydrologic Response Units (HRU'S) in SWAT model. Hydrologic Response Units (HRU'S) are sub units of the subbasins with particular landuse, management and soil which are obtained by lamping all similar soil and land use areas into a single response unit. Therefore, this HRU portion of the SWAT model is fed by land use/land cover and soil data. Land slope of the basin was also defined in this portion.

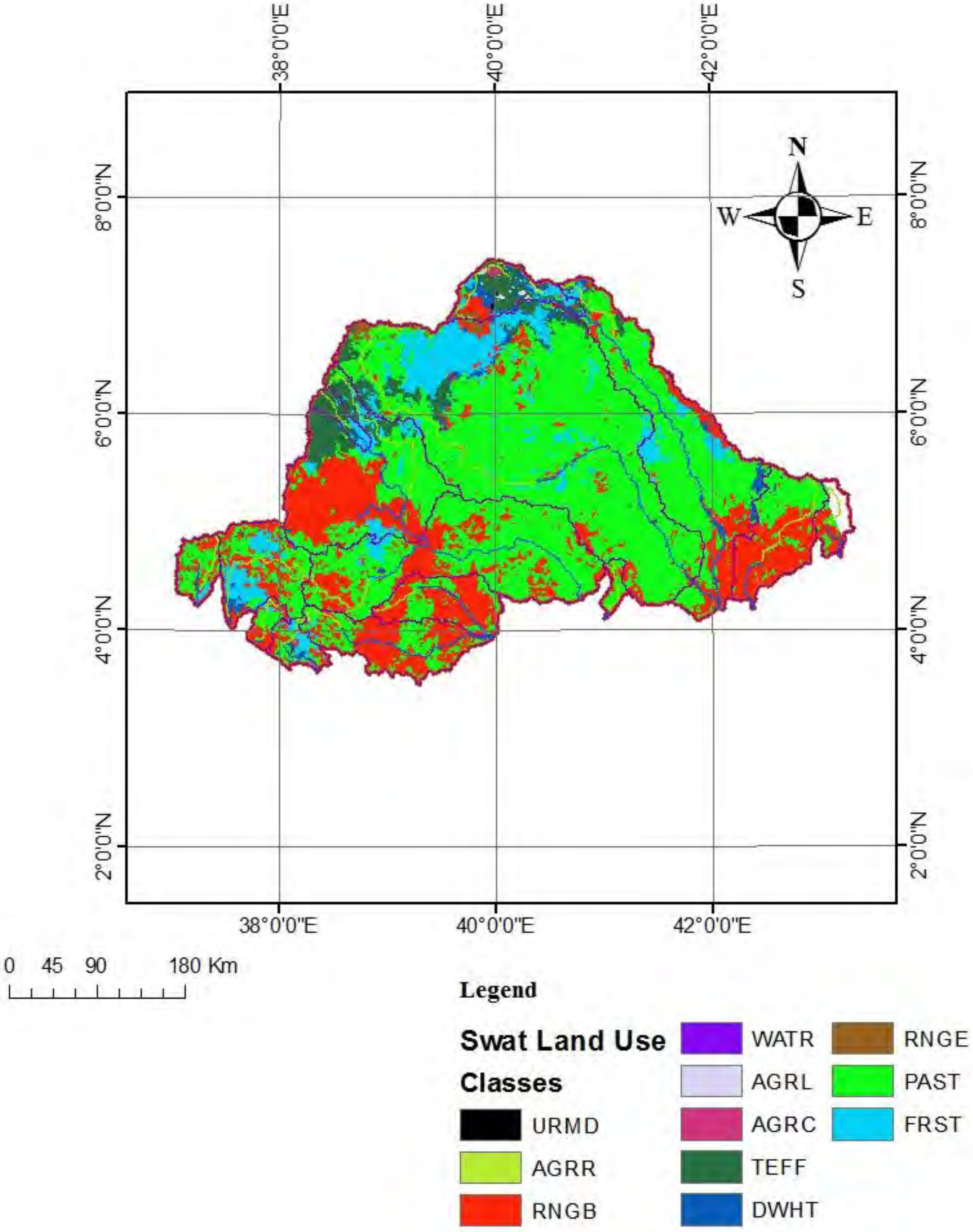

Figure 4.2 Land use map of the study area

4.1.3.3. Land soil data

Land soil data is one of the most important input data in SWAT model. There are fourteen types of soils in the study area. All soil types were entered in to the SWAT data base with their detail properties in the HRU's analysis portion of the SWAT interface. The existing soil types in the study area with their respective hydrological soil groups and their area of coverage which were used for the SWAT model input are given in Table 4.1.

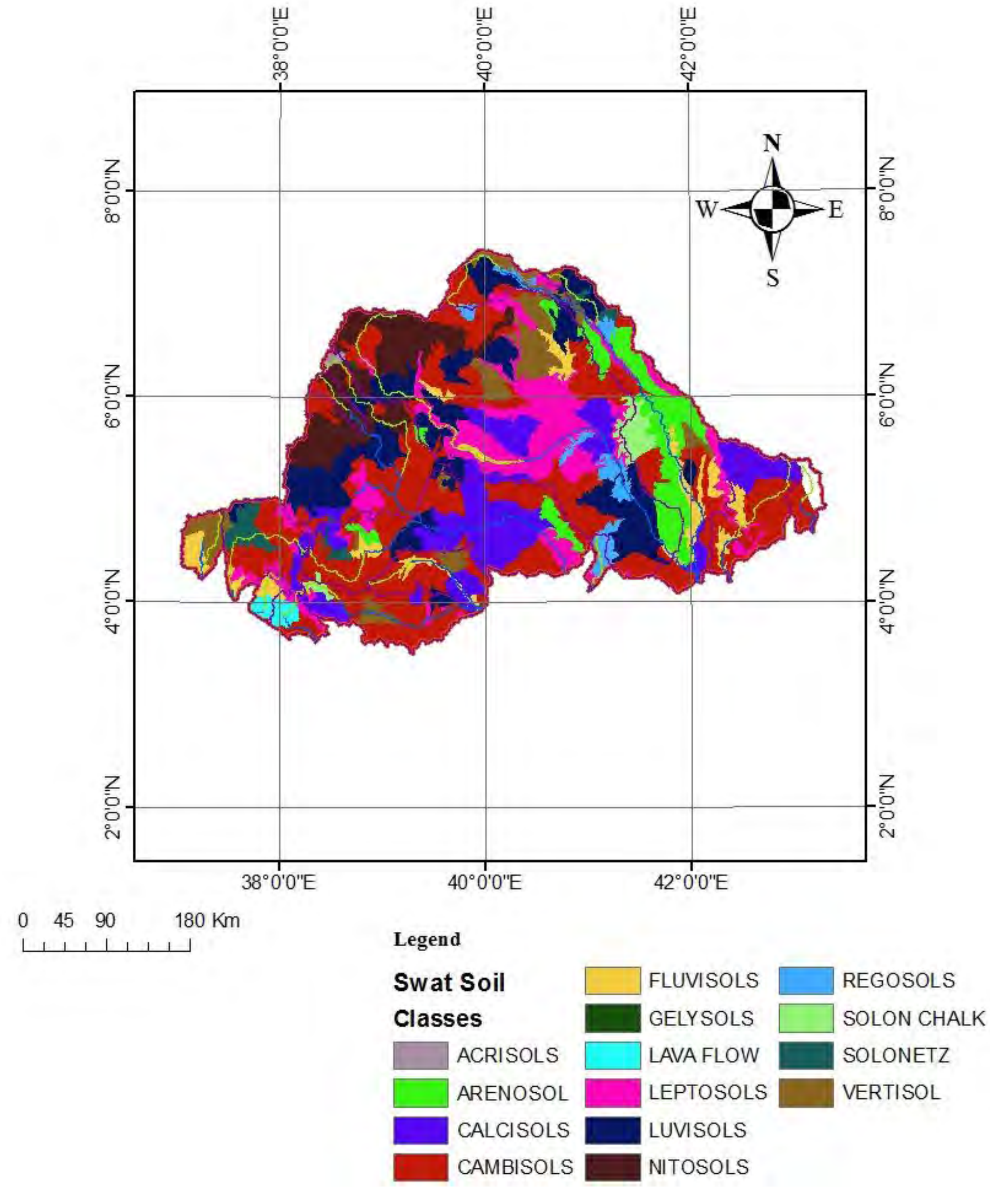

Figure 4.3 Land soil map of the study area

S.No.	Soil Types	Area coverage (km^2)	Hydrological soil group
1	Acrisols	277	A
2	Arenosols	10194	A
3	Calcisols	18792	A
4	Cambisols	58208	D
5	Fluvisols	8304	A
6	Gleysols	82	D
7	Lava flow	1229	D
8	Leptosols	21164	A
9	Luvisols	21238	B
10	Nitosols	11020	B
11	Regosols	2590	B
12	Solonchak	2765	C
13	Solonetz	2520	D
14	Vertisols	9617	D
Total		168,000	

Table 4.1 Different soil types in the study area

Land slope of the study area have been defined along with the land use/land cover and land soil in order to overlay all the data in to the delineated catchment in HRU's portion of ArcSWAT model.

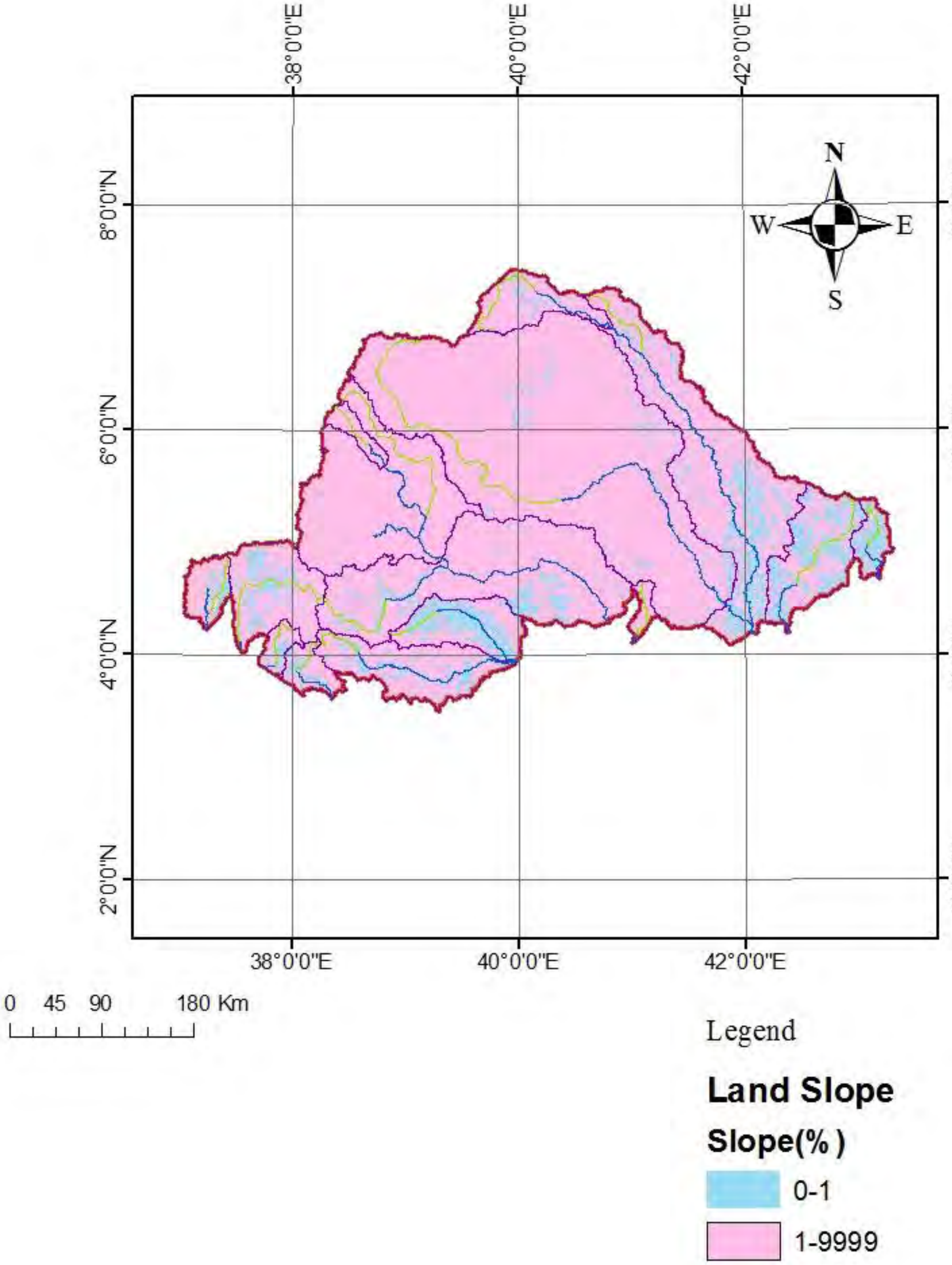

Figure 4.4 Land slope map of the study area

4.1.4. Sensitivity Analysis

There twenty six parameters affecting the model output; making tedious and time consuming to change all these parameters to calibrate the model. Sensitivity analysis ranks these parameters from small to high sensitive values. Parameters with small sensitivity values do not significantly affect the model output, hence, they are neglected in calibration process. Only parameters with medium and high sensitive values which affect the model output significantly are used to calibrate the model.

4.1.5. Model Calibration

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historical meteorological data, to recorded stream flows. In this process, model parameters varied until recorded flow patterns are accurately simulated. Alike other similar conceptual models, SWAT model parameters has to be estimated through calibration. Generally, model calibration involves determination of model parameters that gives the best possible correspondence between observed and simulated runoff from a catchment. Among the different approaches for calibrating the model in order to identify the optimum parameter set; both automated and manual calibration are functional for this model.

Measured flow data of eight years from the period January 1, 1990 to December 31, 1997 was used for calibration.

4.1.6. Model Validation

Once the model is calibrated and the optimized parameters are found, it has to be validated using arbitrary measured flow data. Independent measured flow data set of eight years from the period January 1, 1998 to December 31, 2005 was used to validate the model.

4.1.7. Model Evaluation

There are different ways of evaluating the goodness of fit measures between the simulated and observed values during both calibration and validation process. The three numerical model performance measures are the common ones. The coefficient of determination (R^2), Nash-Suttcliffe simulation efficiency (E_{NS}), and percent difference (D).

The percent difference measures the average difference between the simulated and measured values for a given quantity over a specified period (D is usually less than plus or minus fifteen percent for good fit but may be acceptable if collected observed data is poor quality but D close to (0% is best). D in n number of time steps is computed as:

$$D = 100\left[\frac{\left(\sum_{i=1}^{n} q_{si} - \sum_{i=1}^{n} q_{oi}\right)}{\sum_{i=1}^{n} q_{oi}}\right] \text{------------------------------------- } 4.1$$

($D \le \pm 15\%$, is good fit)

Where, q_{si} is the simulated value of the quantity in each model time step and q_{oi} is the measured value of the quantity in each model time step.

The coefficient of determination (R^2) and Nash-Suttcliffe simulation efficiency (E_{NS}) measure how well trends in the measured data are reproduced by the simulated results over a specified time period and for a specified time step. For example, in this study, these measures were computed for monthly time step.

R^2 for n time steps is computed as:

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(q_{si} - \overline{q_s}\right)\left(q_{oi} - \overline{q_o}\right)\right]^2}{\sum_{i=1}^{n}\left(q_{si} - \overline{q_s}\right)^2 \sum_{i=1}^{n}\left(q_{oi} - \overline{q_o}\right)^2} \text{ --------------------------- } 4.2$$

($R^2 > 0.6$ is good fit)

Where, q_{si} is the simulated value of the quantity in each model time step, q_{oi} is the measured values of the quantity in each model time step , $\overline{q_s}$, is the average simulated value of the quantity in each model time step and $\overline{q_o}$, is the average measured value of the quantity in each model time step.

While E_{NS} for n time steps is computed as follows:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} \left(q_{oi} - q_{si}\right)^2}{\sum_{i=1}^{n} \left(q_{oi} - \overline{q_o}\right)^2} \quad \text{---------------------------------- 4.3}$$

($E_{NS} > 0.5$ is good fit)

Where, q_{si} , is the simulated value of the quantity in each model time step, q_{oi} is the measured value of the quantity in each model time step and $\overline{q_o}$ is the average measured value of the quantity in each model time step.

4.1.8. Data Collection and Analysis

4.1.8.1. Hydro – Meteorological Data

The meteorological data screening and selection was done based on the data availability, data quality and location of the station. Most of the meteorological stations have no data record or have short period and random records. Such types of stations with no data record or short period and random data records are dropped out. Stations located out of the study area or at the periphery are also dropped out. I have selected six stations which have better quality and long period daily records which are well distributed over the study area. The historical climate data collected from NMA are shown in Table 4.2.

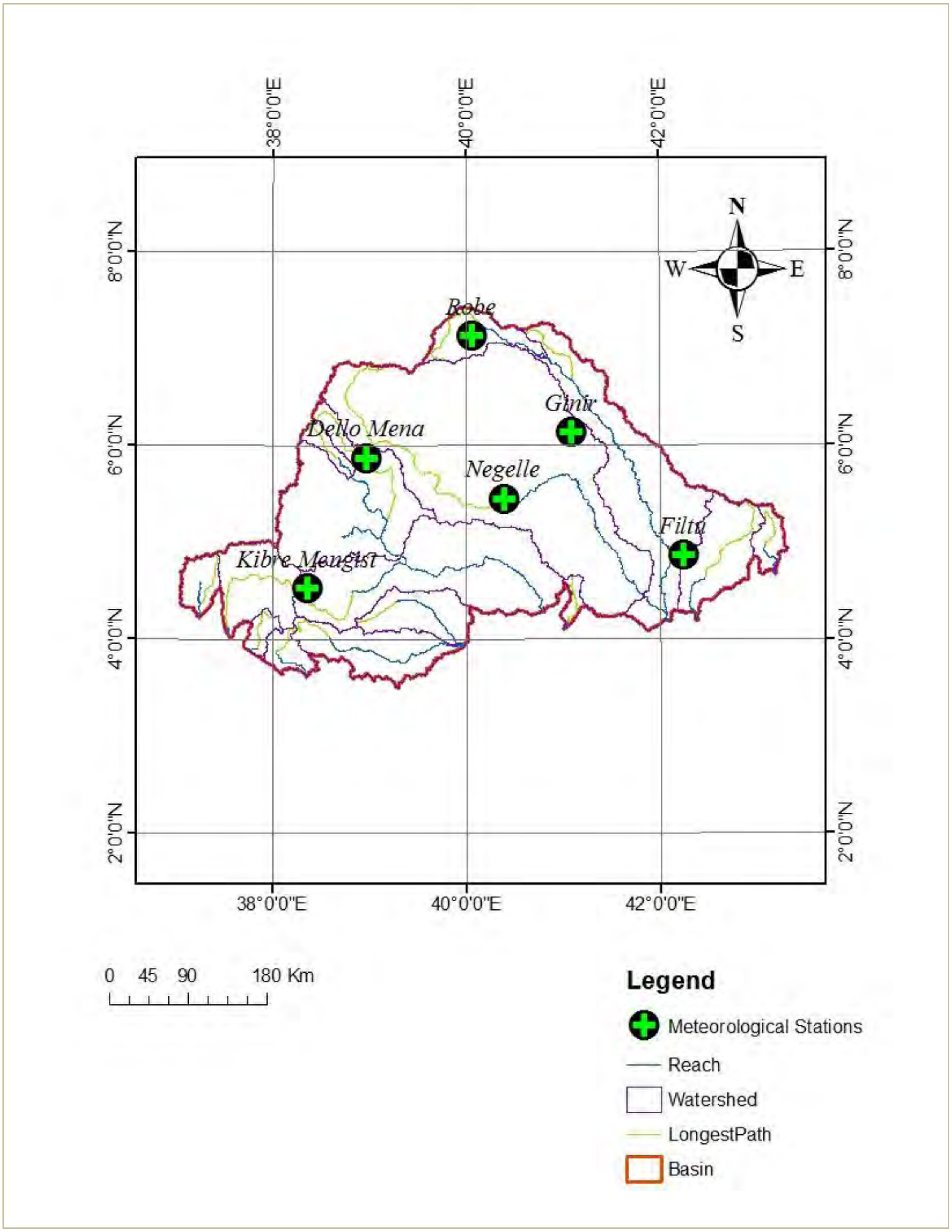

Figure 4.5 Location map of meteorological stations in the study area

Station	Period of record	Type of data collected	Time step	Station class
Dello Mena	1986 - 2013	Precipitation, temperature, humidity, sunshine hours and wind speed	Daily	Class 2
Filtu	1988 -2013	Precipitation, temperature, humidity, sunshine hours and wind speed	Daily	Class 1
Ginir	1988 -2013	Precipitation, temperature, humidity, sunshine hours and wind speed	Daily	Class 2
Kibre Mengist	1987 -2013	Precipitation, temperature, humidity, sunshine hours and wind speed	Daily	Class 1
Negelle	1985 -2013	Precipitation, temperature, humidity, sunshine hours and wind speed	Daily	Class 1
Robe	1985 - 2013	Precipitation, temperature, humidity, sunshine hours and wind speed	Daily	Class 1

Class 1: Stations with all types of records: Class 2: Stations with some missing records

Table 4.2 Selected meteorological stations in the study area

4.1.8.2. Filling Missing Meteorological Data

The integrated ArcSWAT weather generator was used to generate the representative climatic data for the missing data in the selected stations. The ArcSWAT weather generator model WXGEN input file contains statistical data needed to generate representative daily climatic data for the subbasins.

The weather generator stations (Robe, Negelle and Kibre Mengist) have been firstly prepared in the proper text formats in which the ArcSWAT can understand; all the necessary weather generator input parameters have been calculated and fed to WXGEN file in the ArcSWAT data base.

Weather generator input parameters for all weather generator stations are shown in (APPENDIX G, H and I). The ArcSWAT weather generator model selects the suitable or nearer weather generator station if there are multiple weather generator stations used (since there are three weather generator stations used in my study area) to fill the gaps/missing data in the recommended stations(Ginir, Dello Mena and Filtu).

Hence, the ArcSWAT weather generator with all the above inputs first independently generates precipitation for the day missing in the corresponding station; then maximum and minimum temperature, solar radiation and relative humidity are generated for that day based on the presence or absence of rainfall in that specific day and it finally generates wind speed independently.

First – order Markov chain model is used to define the day as wet or dry; when a wet day is generated, a skewed distribution is used to generate precipitation amount (Nicks, 1974). A wet day is defined as a day with 0.1mm of rain more. The probability of wet or dry day is given as follows:

$$P_i\left(\frac{D}{W}\right) = 1 - P_i\left(\frac{W}{W}\right) \text{-- } 4.4$$

$$P_i\left(\frac{D}{D}\right) = 1 - P_i\left(\frac{W}{D}\right) \text{-- } 4.5$$

Where $P_i\left(\frac{D}{W}\right)$ is the probability of dry day on a day i given a wet day on a day i-1 and $P_i\left(\frac{D}{D}\right)$ is probability of dry day on day i given dry day on a day i-1.

To define a day as wet or dry day, ArcSWAT generates a random number between 0.0 and 1.0. This random number is then compared to the appropriate wet-dry probability. If the random number is less than or equal to the wet-dry probability, the day is defined as wet day, but if the random number is greater than the wet-dry probability, the day is defined as dry.

4.1.8.3. Checking Precipitation Data Quality

Even though, it is difficult to carry out direct analysis to detect possible errors of climatic data; it is possible to check the data consistency of individual stations with some reference stations. The data qualities of stations with regard to possible temporal variations have been checked by double mass curve. As a result the stations are found to be consistent. Robe (synoptic station with best data record) was taken as a reference station to check the data consistency of other neighboring stations. Robe station was selected as reference station because this station was found with best data consistency using double mass curve considering the annual cumulative precipitation of all stations.

4.1.8.4. Checking Stream Flow Data Consistency

The annual mean flow of Halwey station which was used for model calibration and validation was cross checked with a reference station Sofumer using double mass curve for consistency as a result the flow data is found to be consistent.

4.1.8.5. Outlier Test for Precipitation and Stream Flow Data

Outliers are data points which depart significantly from the trend of the remaining data. The retention, modification, deletion of these outliers can significantly affect the statistical parameters computed from the data, especially for small samples. All procedures for treating outliers ultimately require judgment involving both mathematical and hydrologic considerations. The detection and treatment of high and low outliers are described below (IACoWD, 1982).

Log-Pearson type III outlier detection method was used to test the existence of outliers in hydro – meteorological data in my study area.

Based on this analysis, both precipitation and stream flow data do not have outliers in my study area. Hence, all data values are found within the limits of high and low outlier threshold values.

Equation 4.6 is used to detect the high outliers:

$$X_H = \overline{X} + K_N S \text{ --- } 4.6$$

Where, X_H is high outlier threshold in log units, $\overline{X}$ is mean logarithm of systemic data, S is the standard deviation in log units and K_N is critical deviate for sample size N at 10% significance level.

Equation 4.7 is used to detect low outliers:

$$X_L = \overline{X} - K_N S \text{ --- } 4.7$$

Where, $\mathrm{X_L}$ is low outlier threshold in log units, $\overline{\mathrm{X}}$ is mean logarithm of systemic data, S is the standard deviation in log units and $\mathrm{K_N}$ is critical deviate for sample size N at 10% significance level ($\mathrm{K_N}$ is table value).

4.2. Water Demand Assessment

4.2.1. General Framework

The general framework used for the assessment of water demand in my study area is illustrated by the following flowchart.

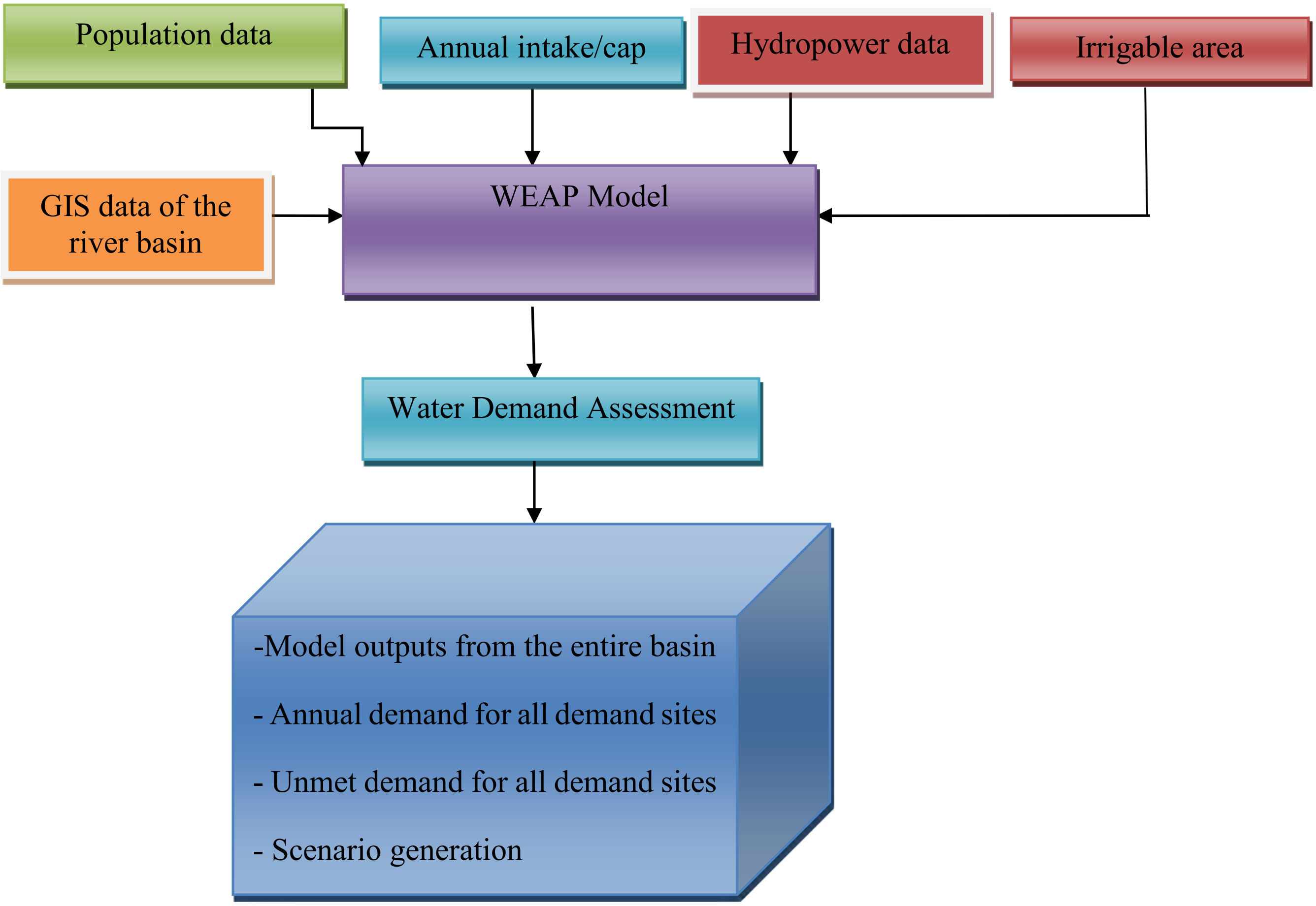

Figure 4.6 General framework flowchart for water demand assessment

As illustrated in Figure 4.5, the flow chart shows the general framework that has been used for the water demand assessment in the study area. The population data of the whole river basin and tows was collected from the Central Statistical Agency (CSA). Additional population data of subbasins and catchments was taken from Ministry of Water, Irrigation and Energy. Hydropower, irrigation and water supply data of the basin were collected from Ministry of Water, Irrigation and Energy. Only large scale irrigation projects, mega hydropower projects and water supply schemes which use surface water are considered. Most of the projects in the basin do not exist, some are under prefeasibility study, some are under feasibility study and only few have got their detail design. I have selected five water supply schemes (under feasibility and detail design stage), two large scale irrigation projects (under feasibility study) and one large scale hydropower project (under detail design stage). Most of the basin population is using ground water source. The selected projects for demand analysis are Negelle water supply scheme, Hargele water supply scheme, Filtu water supply scheme, Yabelo water supply scheme and Mega water supply scheme, Lower Genale irrigation project, Welmel irrigation project and Genale Dawa III hydropower project.

4.2.2. WEAP Model Setup

Schematization, data, result and scenario analysis are the basic model setup views in WEAP model. Schematization is the first task in WEAP model where rivers, demand sites, transmission links, reservoirs and any necessary schematics are added to the study area in WEAP created from ArcGIS raster data done previously in the ArcSWAT model. In the data view all required data (annual activity levels, annual water use rates, consumption and monthly variation) for all demand sites are entered. Then the WEAP model was run in the result view and the results of the model were read here.

Scenario generation is the last task in this model where different scenarios are generated to show the impact of these scenarios on the water demand analysis. High population growth and reference scenarios were used to look at the behavior of water demand by varying the population growth rate.

4.2.3. Structure of Scenarios in WEAP

4.2.3.1.Current Accounts Year

Current Accounts year is chosen to serve as a base year of the model where we feed basic data. With WEAP; we first create Current Accounts of the water system under study. The Current Accounts is chosen based the data available in that year. The year 2013 is chosen as Current Accounts year in study area because the data I have collected was till year 2013. All data entered here are the basic raw data which actually exist in the base year without any projection. Hence, every data was fed to this Current Account year to serve as base year for all processes of the WEAP model.

4.2.3.2. Reference Scenario

Based on a variety of economic, demographic, hydrological and technological trends, a "reference" scenario projection is established called reference scenario. The reference scenario is developed from the current account to simulate the likely evolution of the system without intervention. This scenario serves as reference to all other scenarios created to show different trends. Hence, every scenario developed to show its own trend on the model result is compared to the reference scenario as there are interventions in the reference scenario other than projecting the current account year to the future year. In my study area, I have created the reference scenario from 2014 to 2025 and population projections were done accordingly.

4.2.3.3. High Population Growth Scenario

Policy scenarios can be established from the reference scenario with alternative assumptions about future development. These scenarios can address a broad range of "what if" questions, such as: what if population growth pattern, the flow patterns change and in general what if the economic development patterns change?

One of the dominant factors affecting the water supply demand is population growth. The trend of the population growth in the future may not be as expected today. The population growth rate varies erratically from time to time, hence it is important to simulate the water demand considering assumptions on the population growth rate variation in the future based on the historical nature of the of the basin population. Currently the basin population is considered to grow at growth rate of 3.54% as illustrated by the Central Statistical Agency of Ethiopia (Census 2007). But previously in the year 1984 to 1994, the basin population growth rate was 5.54%. Therefore, I am interested in observing what if the population growth rate attains the high population growth rate 5.54% in the future based on the historical data of the basin population growth rate. Hence, I have chosen the high population growth scenario what if the basin population growth rate will attain 5.54%.

4.2.3.4. Improved Irrigation Techniques and Methods Scenario

This scenario addresses the irrigation water demand variation by developing/improving irrigation techniques and/or changing irrigation methods. Therefore, the impact of using improved irrigation techniques on irrigation water demand will be shown in improved irrigation techniques and methods scenario.

4.2.4. Water Demand Guidelines

In general water demand projections and calculations are done by estimating the domestic water demand, commercial and institutional water demand, industrial water demand, livestock water demand and water losses in systems.

But Ministry of Water, Irrigation and Energy has put guidelines for all these demand categories and additional climatic factors which affect consumption variation in the specific river basin(Genale Dawa river basin) under their master plan study based on the practical situation and life style of the basin population. The following are the guidelines:

1) Domestic Water Demand (DWD)

The domestic water demand is the demand for domestic house hold use; the water consumption per capita per day (lpcd). The per capita demand of the basin is generally based on the newly revised water demand standard of second Growth and Transformation Plan of Ethiopia (GTP II – which goes from 2015 - 2020). Based on the newly revised water demand standard of GTP II, it ranges from 40 – 100 lpcd depending on the population size for urban and 25 lpcd for rural up to the year 2020. But in my study, the water demand is forecasted up to the year 2025 which lies in the third Growth and Transformation Plan (GTP III), therefore, the per capita demand will increase beyond 100 lpcd and assuming 20% increment from GTP II to GTP III, it becomes 120 liters per capita per day for this analysis.

2) Commercial and Institutional Water Demand (CIWD)

In addition to domestic house hold use, water requirements in towns include the normal needs of the community for public schools, clinics, hospitals, offices, shops, bars, restaurants and hotels.

The water demand for commercial and institutional needs is usually linked directly to the population; and is taken as 5% of the domestic demand for this specific basin.

3) Industrial Water Demand (IWD)

Industrial water demand which is consumed by industries is not usually linked directly to population. But for the purpose of planning, it is assumed to use 10% of domestic water demand for all towns in the basin.

4) Livestock Water Demand (LWD)

In order to estimate livestock water demand, it is assumed an average of 2 Livestock Unit (LU) per person for the whole Basin. The average water demand for livestock is taken as 15 liters per LU per day.

5) System losses (SL)

In estimating water losses in the water supply system a percentage of 20% of the total of domestic, commercial, institutional and industrial demands is assumed in the basin.

6) Average Daily Demand (ADD)

The average daily demand is taken to be the combined total of the domestic, commercial, institutional, industrial and livestock demands and the system losses.

Average Daily Demand = Demands for Domestic + Commercial & Institutional + Industrial + Livestock + Losses

7) Maximum Daily Demand (MDD)

The daily water consumption in a town varies depending on time of day, the season and climatic conditions. Therefore, the Maximum Daily Demand (MDD) has been taken as 1.15 times the Average Daily Demand (ADD) for all towns in the basin.

MDD = 1.15 ADD

The Maximum Daily Demand sets the requirements from the sources. Thus, the water demands of urban centers are calculated according to the above methodology.

4.2.5. WEAP Model Input Data

4.2.5.1. Population Data and Population Projection

One of the basic inputs in WEAP model is the population data. The population data collected from Central Statistical Agency is based on census 2007, and the population growth rate of the basin is found to be 3.54% which shows a reduction as compared to the last population growth rate before 1994 which was 5.54% in study area. Hence the census 2007 population is projected to suitable year 2013 which is the current account year in my model. The populations of the selected sites with their projections are given in table 4.3

Water Supply Schemes	Population Census2007	Population Projections				
		2013	2016	2019	2022	2025
Hargele WSS **	19431	26853	31568	37111	43626	51286
Negelle WSS	45847	63360	74485	87560	102937	121101
Filtu WSS	8846	12225	14371	16895	19861	23348
Mega WSS	10110	13971	16424	19308	22699	26684
Yabelo WSS	19867	27456	32276	37944	44606	52437
Total	104101	143,865	169124	198818	233729	274,856

** The surrounding population who use water from the scheme are added to Hargele town population

Table 4.3 Population projection for different water supply schemes

The annual water use rate per person which is calculated for the specific basin (82m^3/year) and the projected population are finally used for the WEAP model.

4.2.5.2. Annual Water Use Rate

The WEAP model needs annual water use rate as a basic input. Based on the specific guidelines given by Ministry of Water, Irrigation and Energy for the Genale Dawa river basin (given in section 4.2.4. above), the annual water use rate per person in the basin is calculated below:

Domestic Water Demand (DWD) = 120 lpcd = 0.12 m^3/c/d

CIWD = 5% DWD = 0.05 x 0.12 = 0.006 m^3/c/d

IWD = 10% DWD = 0.10 x 0.12 = 0.012 m^3/c/d

LWD = 2 x 15 lpd = 30 lpcd = 0.03 m^3 pcd

System Losses = 20% (DWD + CIWD + IWD)

= 20% (0.12 + 0.006 + 0.012)

= 0.2 x 0.138 = 0.0276 m^3/d

Average Daily Demand (ADD) = 0.12 + 0.006 + 0.012 + 0.03 + 0.0276

= 0.1956 $m^3/c/d$

Maximum Daily Demand (MDD) = 1.15 ADD

= 1.15 x 0.1956$m^3/c/d$

= 0.225 $m^3/c/d$

Maximum Demand per person per year = 0.225 x 365 m^3

= 82.1 m^3/ year

Therefore, take annual water use rate per person in the basin as 82m^3 which is the input for WEAP model.

4.2.5.3. Irrigation Data

Since there are no existing large scale irrigation projects in the basin I have taken two large scale irrigation projects under feasibility study to model the irrigation demand in WEAP.

Lower Genale irrigation project with net irrigable area 30,000 ha and Welmel irrigation project with net irrigable area 10,000 ha.

4.2.5.4. Hydropower Data

Genale Dawa III hydropower project, situated in the main river Genale, which is under detail design is taken to model the hydropower demand in WEAP. It produces 256MW power and 1135GWh annual energy with efficiency of 89%. The plant factor of this hydropower project is 53%.

Based on these available data, the annual water use rate of the Genale Dawa hydropower III was calculated and found as 4.47m^3/MW which was used as an input for the WEAP model. Genale Dawa I and II are not included because both are medium scale.

CHAPTER SIX

5. RESULTS AND DISCUSSION

5.1. ArcSWAT Model Results

So many model runs were done during model calibration by changing the model parameters and different model results have been obtained during the process. But model runs continued up to optimized parameters were achieved that give the best correlation between simulated and observed data sets using manual calibration. The best fit between simulated and observed data sets was evaluated by determination coefficient (R^2) and Nash-Sutcliff's efficiency (E_{NS}). Based on these evaluation methods, the model calibration was found to be best correlated between simulated and observed data sets. Model calibration is not enough to accept the model as representative one but it has to be validated for isolated and independent data set for its reliability. The model was found to be valid and results obtained after this process were considered as final results and are presented as follows.

Finally, the ArcSWAT model was successful to give the expected outputs/results. The results of the model were expressed in average annual basis. Average annual outputs (runoff, precipitation and evapotranspiration are modeled). Based on this, the average annual runoff depth is estimated to be 37.92 mm. That is, the average annual runoff volume leaving the entire basin is estimated to be 6.37 billion cubic meter. This result showed a slight increment (8.3%) as compared to the previous study indicated in the National Master Plan Study (WAPCOS,1990) which was estimated to be 5.88 billion cubic meter. This might be due to lad use changes which increase the runoff coefficient or increase in rainfall in the basin. Unlike other parts of Ethiopia that receive considerable rainfall in summer season, Genale Dawa river basin receives the year's first and secondary maxima rainfall in spring and autumn seasons respectively.

The average annual precipitation in the basin is estimated to be 810.5 mm. The annual average actual evapotranspiration is also estimated as 469.8 mm, whereas the average annual potential evapotranspiration in the basin is 1304.4 mm

5.1.1. Hydro – Meteorological Data Consistency Results

5.1.1.1. Precipitation Data Consistency Check Results

The mean annual cumulative rainfall of twenty six years of each stations was drawn in y-axis and the mean annual cumulative rainfall of reference station (Robe) was drawn in the x- axis to check the consistency of each rainfall stations using double mass curve. As the results of the test shown graphically in figures 5.1 and 5.2, the precipitation data is consistent with ($R^2 = 0.9987$) for Kibre Mengist and ($R^2 = 0.9981$) for Negelle stations.

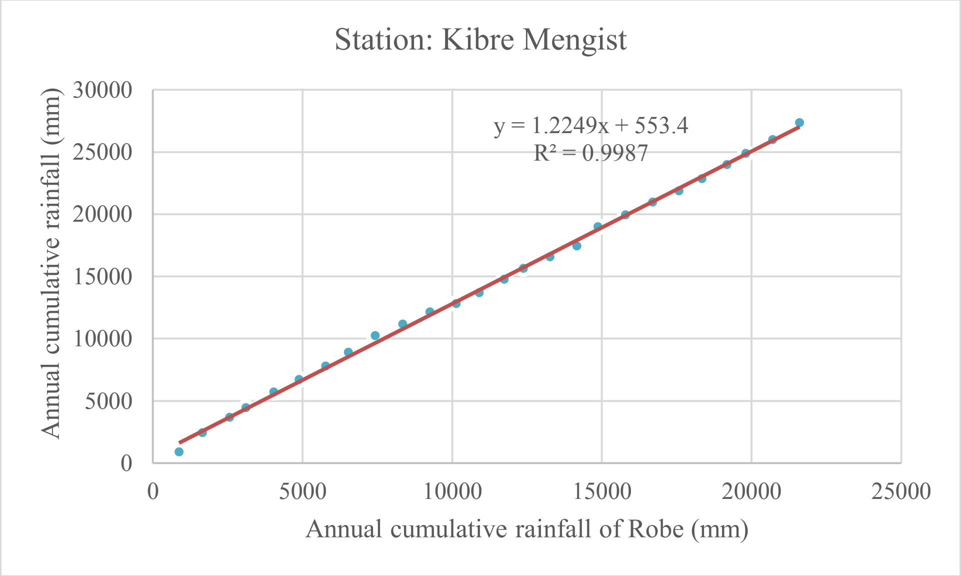

Figure 5.1 Precipitation data consistency check (DMC) for Kibre Mengist station

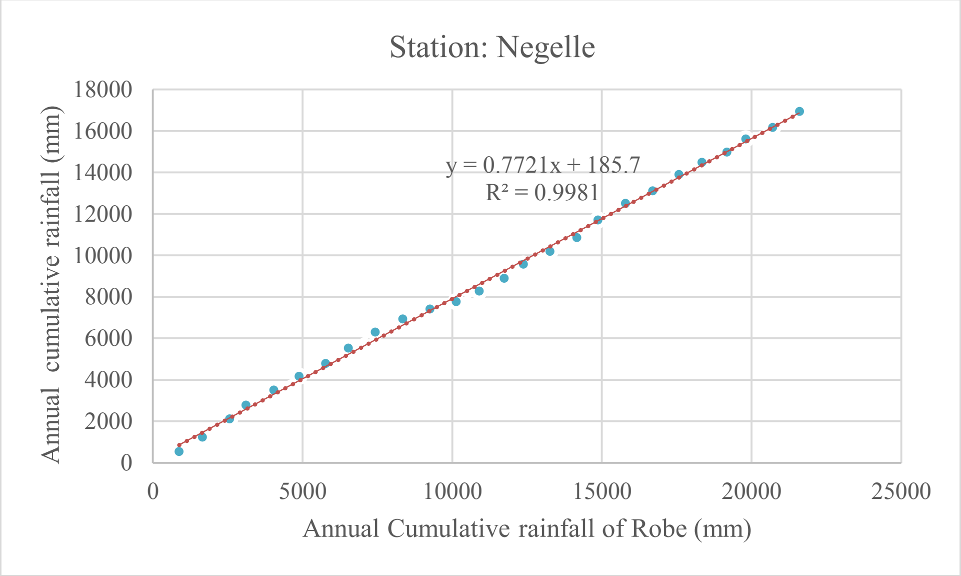

Figure 5.2 Precipitation data consistency check (DMC) for Negelle station

5.1.1.2. Stream Flow Data Consistency Check Result

The stream flow data consistency check was conducted in Halwey station using double mass curve which was used for model calibration and validation. The mean annual cumulative stream flow data of Halwey station is drawn in the y-axis and the mean annual cumulative stream flow data of the reference station (Sofumer) is drawn in the x-axis. The result of the double mass curve is shown graphically in figure 5.3 below.

Hence, the flow data of the station is found to be consistent with ($R^2 = 0.94$).

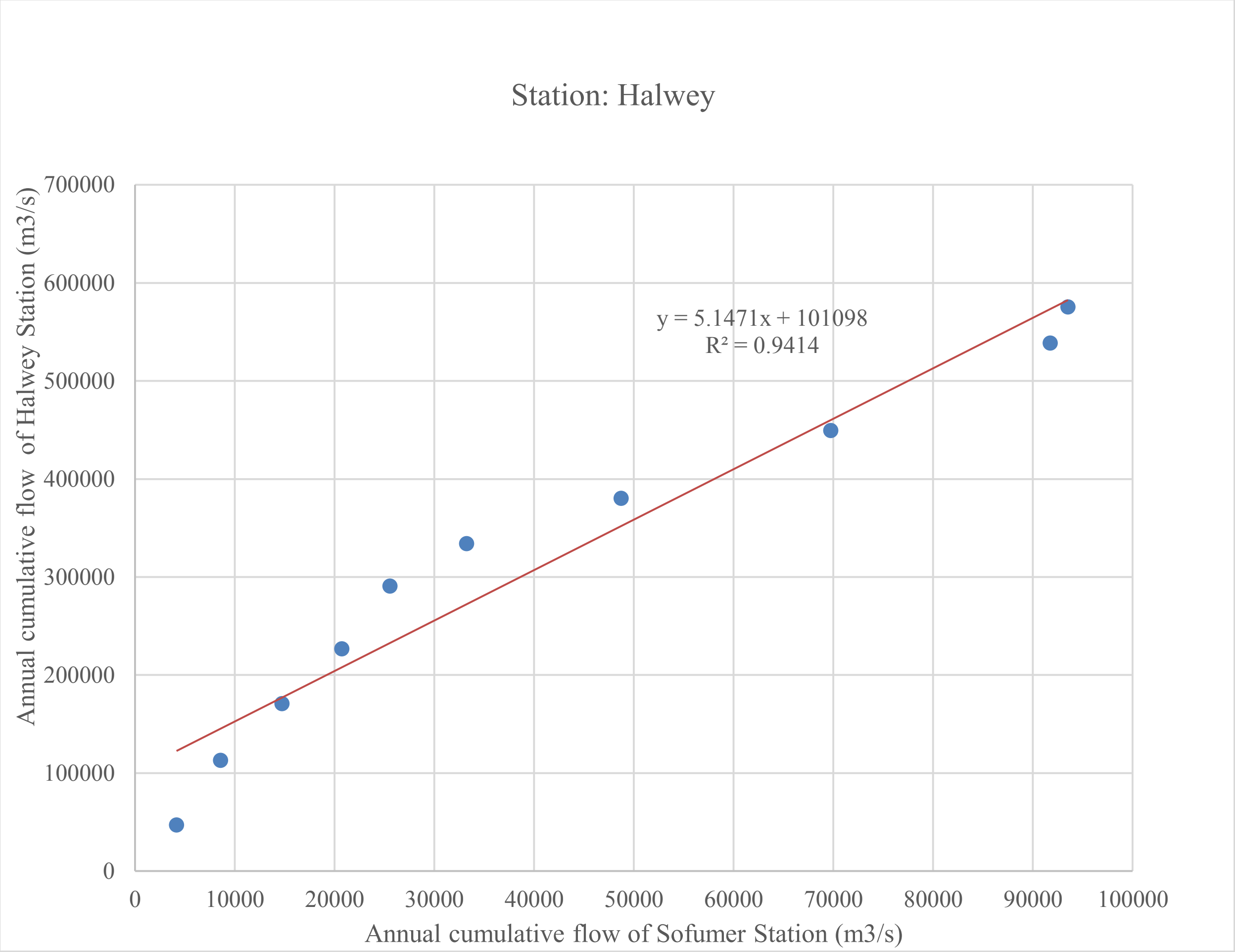

Figure 5.3 Stream flow consistency check (DMC) for Halwey station

5.1.2. Outlier Test Results

5.1.2.1. Outlier Test for Precipitation Data Results

The outlier tests for sample meteorological stations (Robe, Negelle and Kibre Mengist) and Halwey gauging station are graphically presented below. The logarithmic values of both rainfall and stream flow data are drawn in the y-axis and the sample size (number of years in this case) are along the x-axis.

As presented in figure (5.4 to 5.7), all the data values in logarithmic form are with in the upper and lower bounds of the maximum and minimum outlier threshold values. This implies, there are no outliers in the data.

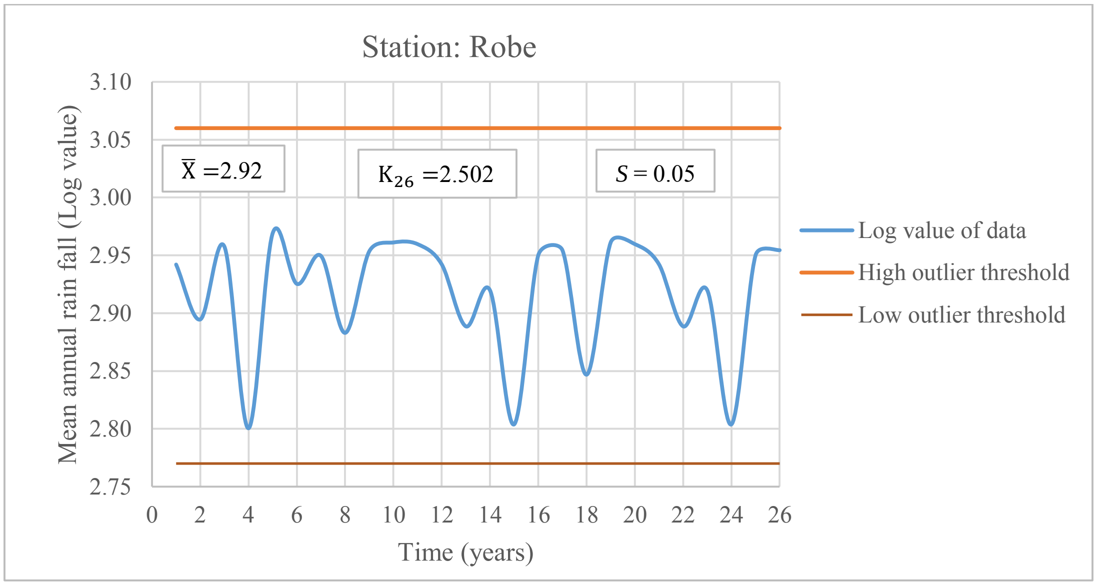

Figure 5.4 Outlier test for Robe station

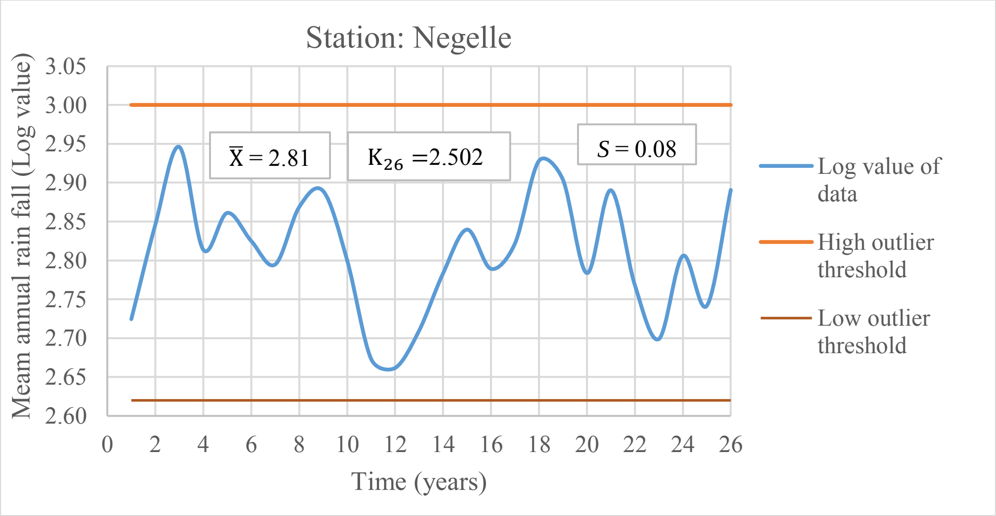

Figure 5.5 Outlier test for Negelle station

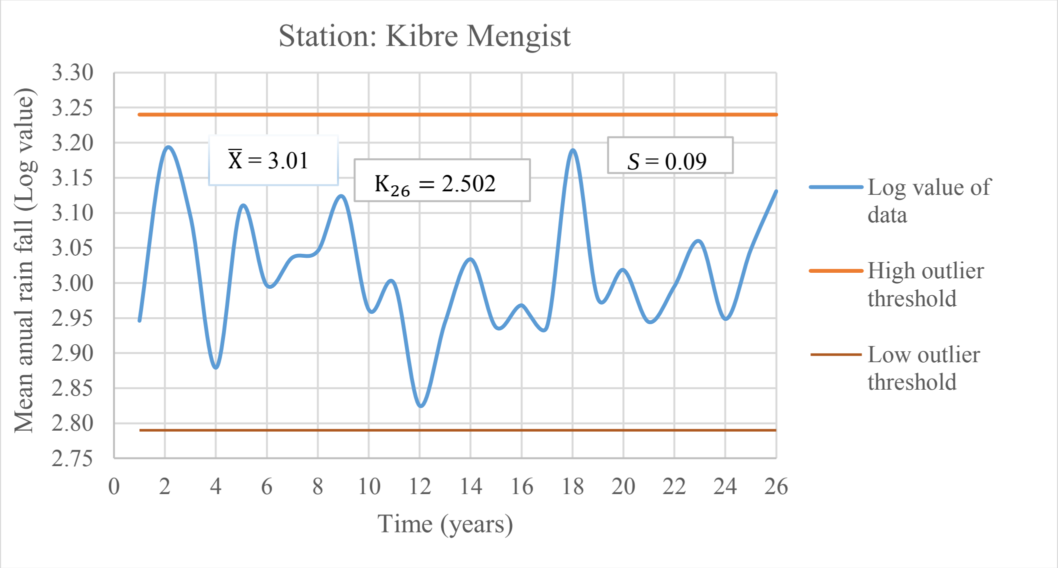

Figure 5.6 Outlier test for Kibre Mengist station

5.1.2.2. Outlier Test for Stream Flow Data Result

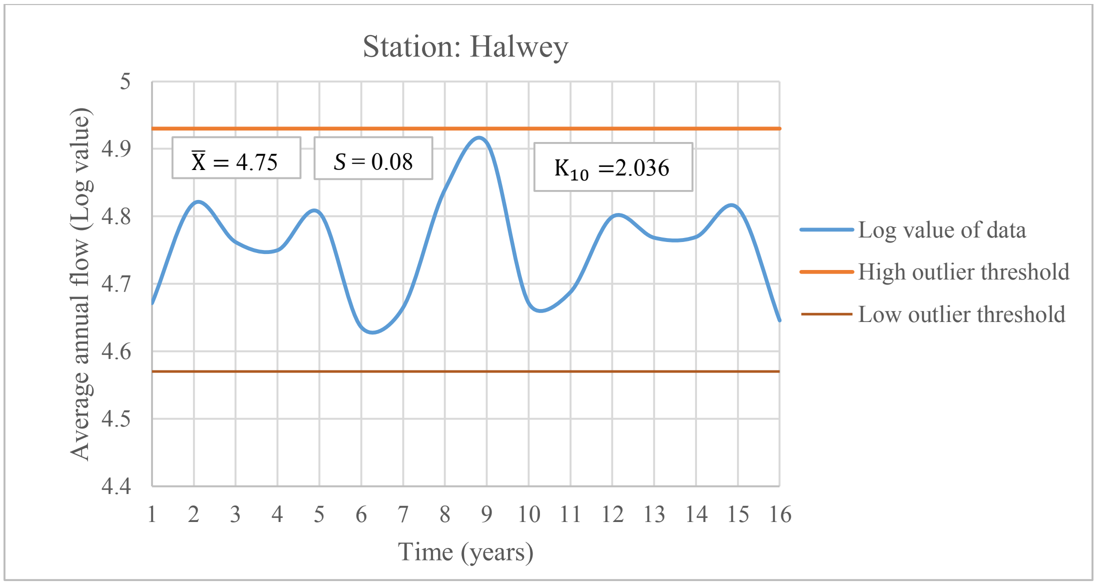

Figure 5.7 Outlier test for Halwey gauging station

Log – Pearson type III outlier detection method was used to test the existence of outliers in hydro – meteorological data in my study area. The data which fall above the high outlier threshold or below the low outlier threshold values are considered as outliers. But as presented the result of the outlier tests for different stations graphically in figures (5.4 to 5.7) above, all the data values of the stations fall in between the high and low outlier threshold values. Hence, there are no outliers in the hydro – meteorological data used as an input in my study area.

Logarithmic values of precipitation and stream flow data, high and low outlier threshold values, mean values of logarithmic values ($\overline{X}$), standard deviation of the logarithmic values (S), critical deviate value (K_N) for N number of sample size (number of years in this case) at 10% significance level parameters were used in testing the outliers using Log – Pearson type III outlier detection method to obtain these results.

5.1.3. Sensitivity Analysis Result

There twenty six parameters affecting the model output; making tedious and time consuming to change all these parameters to calibrate the model. Sensitivity analysis ranks these parameters from small to high sensitive values. Parameters with small sensitivity values do not significantly affect the model output, hence, they are neglected in calibration process. Only parameters with medium, high and very high sensitive values which affect the model output significantly are used to calibrate the model. Based on the sensitivity analysis conducted in my study area, the parameters were ranked and minimized to ten parameters which significantly affect the model output. Initial SCS CN II (curve number) is found very high sensitive in regard to the model output, while soil evaporation compensation factor (ESCO) and average slope steepness (slope) are found to be highly sensitive too. The rest seven parameters (ranked 4 to 10 in table 5.1) are found to be medium sensitive to the model output. The rest of the parameters were neglected as they are found to be small sensitive and less, that is, they do not affect the model output significantly so that they can be dropped during model calibration.

Therefore, the model was calibrated considering only ten parameters which are medium, high and very high sensitive parameters.

The sensitivity analysis results of different parameters with their relative sensitivity values are ranked in table 5.1 below.

Rank	Parameters	Sensitivity value	Range	Initial value	Final calibrated value
1	Initial SCS CN II value;CN2	3.75	±25	69	66.24
2	Soil evaporation compensation factor ; ESCO	0.87	0 - 1	0.95	0.92
3	Average slope steepness [m/m]SLOPE	0.54	±25	0.8	0.6
4	Maximum canopy storage [mm]; CANMX	0.20	0 - 100	0	1.5
5	Threshold water depth in the shallow aquifer for flow [mm]; GWQMN	0.14	0 - 5000	200	490
6	Available water capacity [mm WATER/mm soil]; SOL_AWC	0.12	0 - 1	0.7	0.67
7	Soil depth [mm]; sol_z	0.107	0 - 3500	2000	1500
8	Threshold water depth in the shallow aquifer for "revap" [mm]; REVAPMN	0.102	0 - 500	0	0.16
9	Groundwater "revap" coefficient ;GW_REVAP	0.05	0.02 – 0.2	0.1	0.11
10	Saturated hydraulic conductivity [mm/hr]; sol_k	0.04	0 - 2000	36	34

Table 5.1 Relative sensitivity, initial and calibrated values of different parameters used for calibration

5.1.4. ArcSWAT Model Calibration Result

Measured flow data of eight years from the period January 1, 1990 to December 31, 1997 were used for calibration.

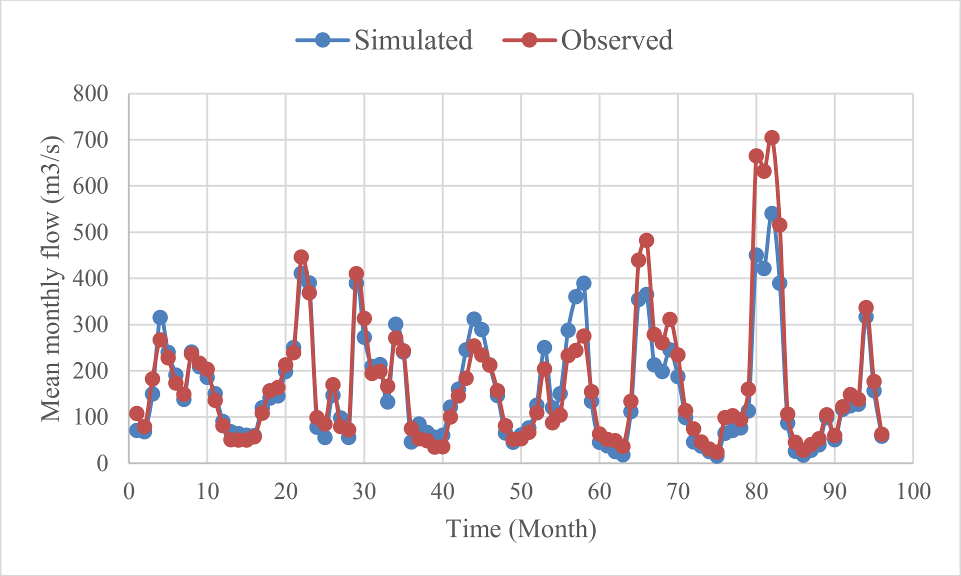

Figure 5.8 Simulated versus observed monthly flows in model calibration

The model was calibrated using monthly time step data of eight years in which the model showed the best performance than the daily basis. As the model calibration result shown in figure 5.8 there are some under and over estimations in the model output in some points but the overall result assures that the simulated flow is best correlated with the measured/observed data with ($R^2 = 0.88$) and ($E_{NS} = 0.86$) which shows the best performance of the model.

5.1.5. ArcSWAT Model Validation Result

Independent measured flow data set of eight years from the period January 1, 1998 to December 31, 2005 was used to validate the model.

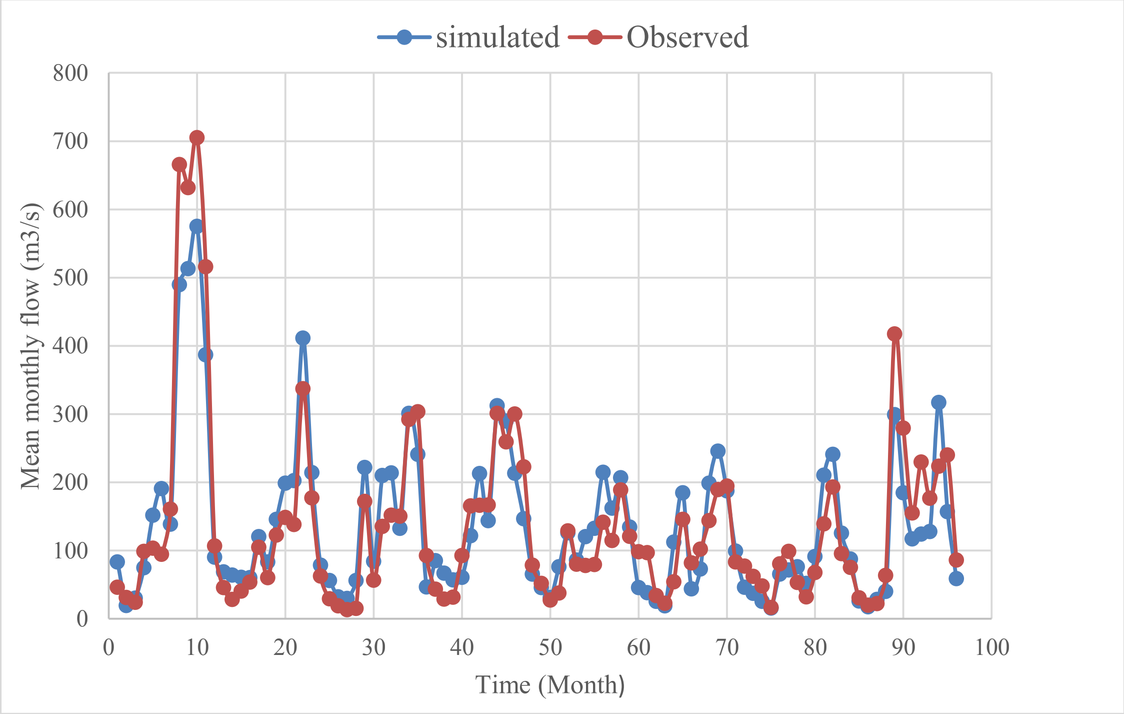

Figure 5.9 Simulated versus observed monthly flows in model validation

As model calibration is not enough to say the model output is representing the study area, it has to be validated using an independent dataset. Therefore, it was validated using monthly time step isolated data to check its reliability as shown in figure 5.9 above.

The model validation result shows that there are some under and over estimations in the model output as compared to the measured data but the overall validation result evidences there is a best correlation between the simulated model output and observed/measured data.

Based on the model performance evaluation parameter numerical values of determination coefficient (R^2 = 0.85) and Nash-Sutcliff's simulation efficiency (E_{NS} = 0.84) assures that the model shows a good performance during validation so as to able to simulate the runoff in the study area.

The model performance evaluation parameters determination coefficient (R^2) and Nash-Sutcliff's simulation efficiency (E_{NS}) and percent difference (D) with their allowable range and estimated numerical values during model calibration and validation are summarized in table 5.2 below.

Model runs	Model performance evaluation parameters			
	R^2	E_{NS}	D	Remark
Calibration	0.88	0.86	-6.51	OK
Validation	0.85	0.84	0.26	OK
Range	>0.6	>0.5	±15%	

Table 5.2 Summary of model evaluation estimated numerical values

5.2. WEAP Model Results

The WEAP model needs the annual activity levels, annual water use rates of different demand sites in addition to river flow as basic inputs. Having all these and other inputs, the WEAP model was successful to model the water demand of the river basin considering the only large scale projects. The model was intended to analyze the demand, unmet demand and the impact of different scenarios on demand variation in the current account year and in the near future.

5.2.1. Water Demand Results in the Current Account Year 2013

The Current Accounts represent the basic definition of the water system as it currently exists. It is also assumed to be the starting or base year for all scenarios where we feed the current available data. Hence, it is important to look at the nature of the demand in the current account year as it is the base for all scenarios and future demands.

The annual water demands for the selected demand sites for the current account year 2013 are shown in figure 5.10 below.

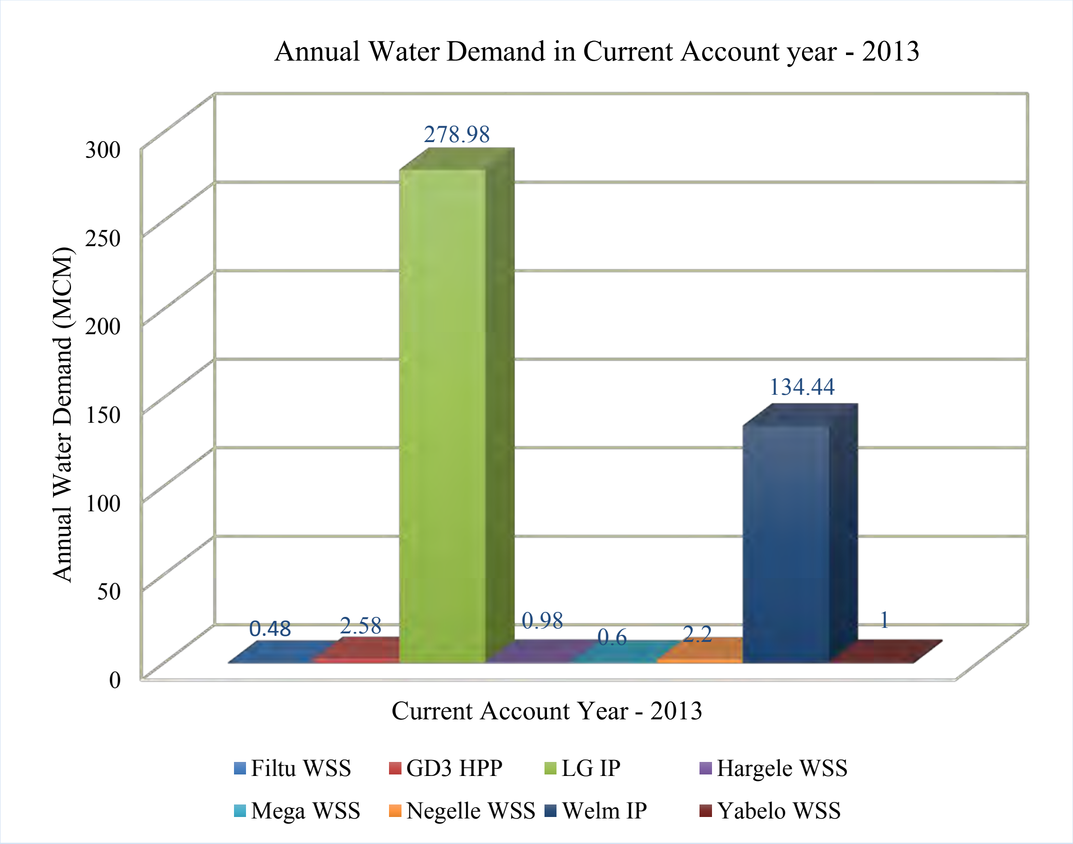

Figure 5.10 Annual water demand in current accounts year (2013)

The result shows that most of the total annual water demand is consumed by the irrigation demand sites as compared to the water supply and hydropower. The two irrigation demand sites consumed 98.13% of the total annual demand of all sites. Both water supply and hydropower consumed 1.87% of the total annual demand in the current account year.

5.2.2. Unmet Water Demand in the Current Year 2013

The unmet demand result showed that all most all water supply demand sites are fully supplied except Hargele which has got 7.1% unmet demand. Welmel irrigation demand site got water stressed by 4.49% while Lower Genale irrigation met its full demand. Genale Dawa III hydropower demand site fell in water stress in the base year.

But the overall unmet demand of all demand sites in the current account year is found to be 1.72%. This implies the overall coverage of supply is 98.28%.

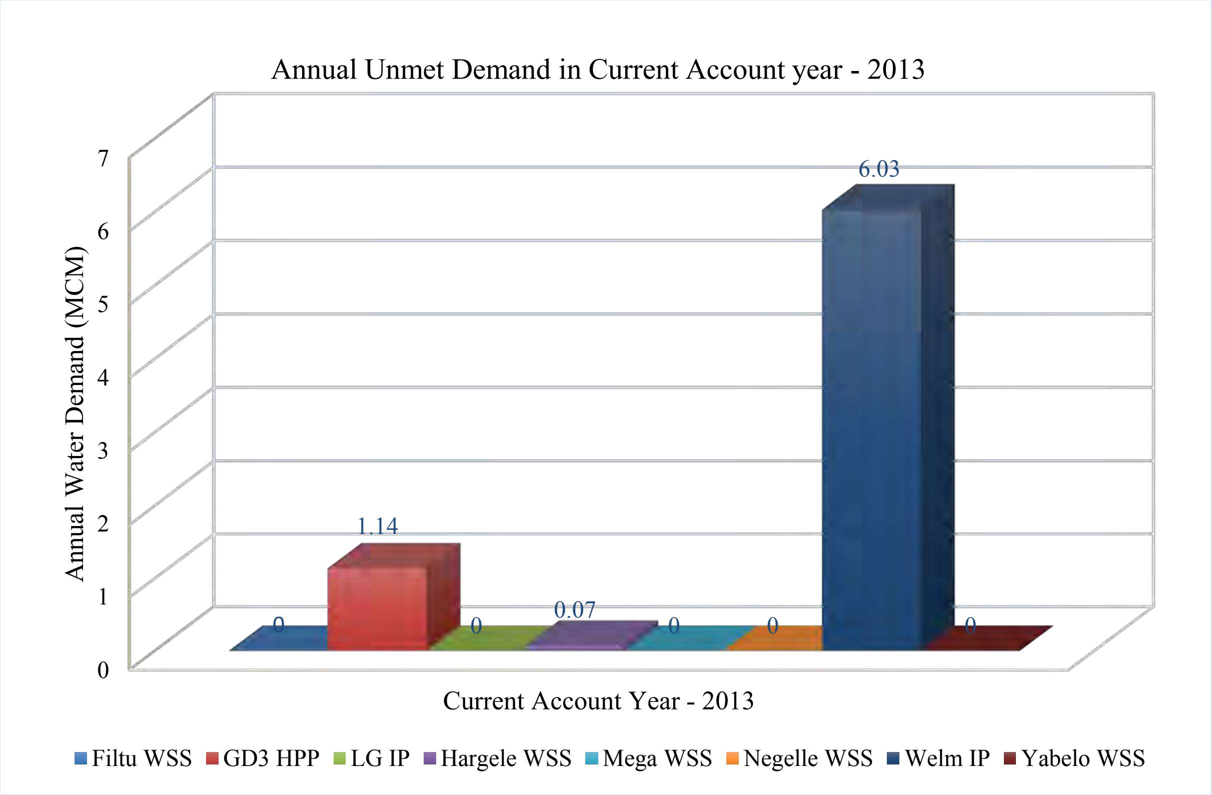

Figure 5.11 Annual unmet water demand in the current account year (2013)

5.2.3. Annual Water Demand Results of All Demand Sites (2013-2025)

After analyzing the demand in the current account year 2013, the population was projected to the future year 2025 and the demand was analyzed how it will look like in the near future.

Even though the population is increased to the year 2025 the irrigation demand sites are still dominating the other demand sites. In the year 2025, both water supply and hydropower demands cover 2.84% of the total annual demand. This shows that the demand of both water supply and hydropower demand will grow from 1.87% in the current account year 2013 to 2.84% of the total annual demand in the year 2025.

This tells us that there will be an increment in water supply demand by 51.87% (including hydropower demand) in the year 2025 in reference to the current account year 2013. This is clearly due to the population growth.

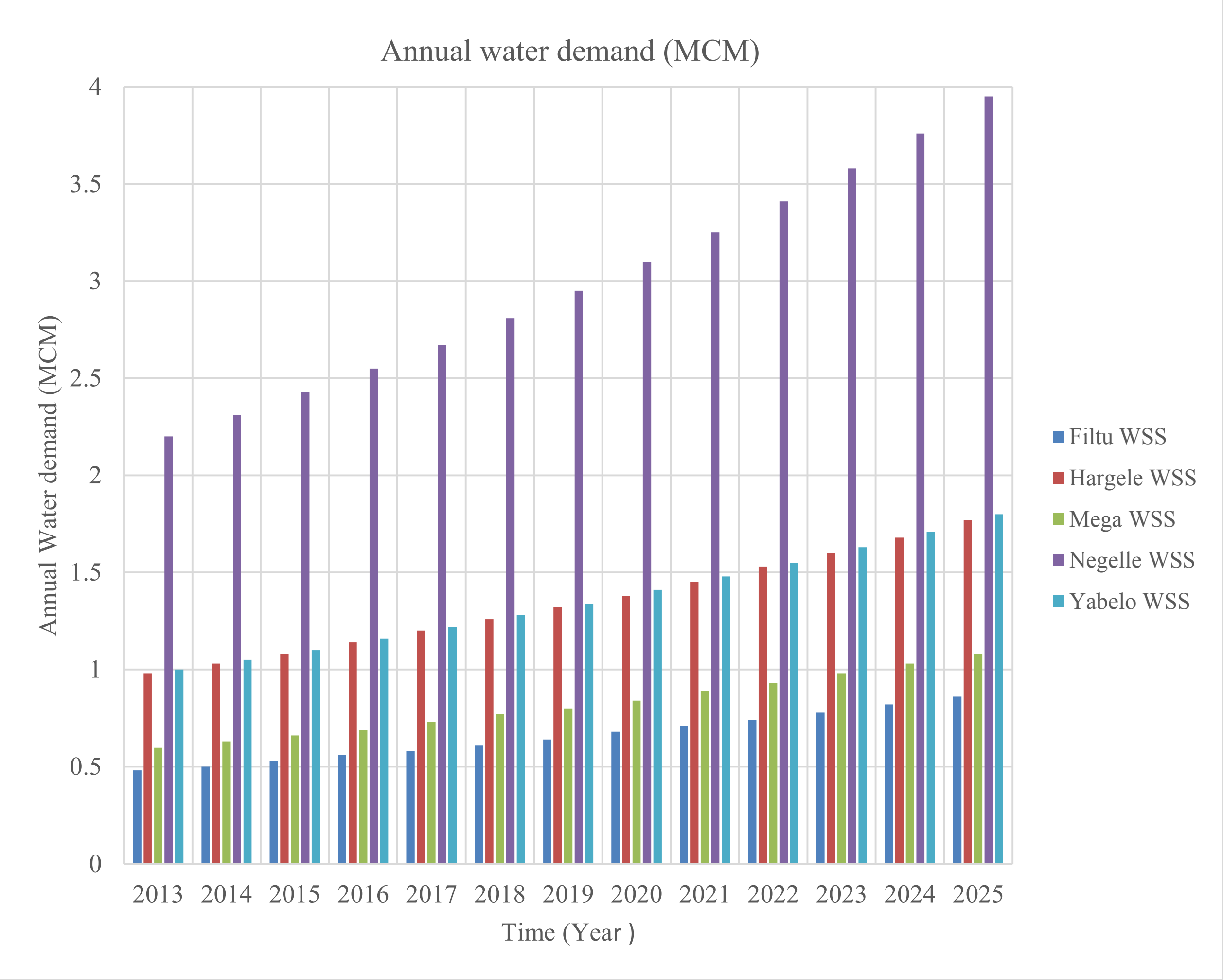

Figure 5.12 Annual Water demand for all demand sites (2013-2025)

Figure 5.12 shows the isolated water supply demand graph excluding irrigation and hydropower demands to clarify the trend of the water supply demand under population increment from year to year. The graph assures that there is an increment in water supply demand as population grows.

Filtu water supply demand site accounts the least share of the total water supply demand 8.27% in the current account year 2013 and 12.64% in the year 2025. While Negelle water supply demand site accounts the largest share from the total water supply demand, that's 41.5% in the current account year 2013 and 58% in the year 2025.

The water supply demand for all the water supply demand sites clearly grows from 5.3 million cubic meters in the current account year 2013 to 6.8 million cubic meters in the year 2025. This shows the demand will grow up by 28.3% in the year 2025 in reference to the current account year 2013.

5.2.4. Scenario Generation

5.2.4.1.Reference Scenario

Reference scenario was developed from the current account year 2013 with future projections without intervention up to the year 2025. In this case, all variables remained constant.

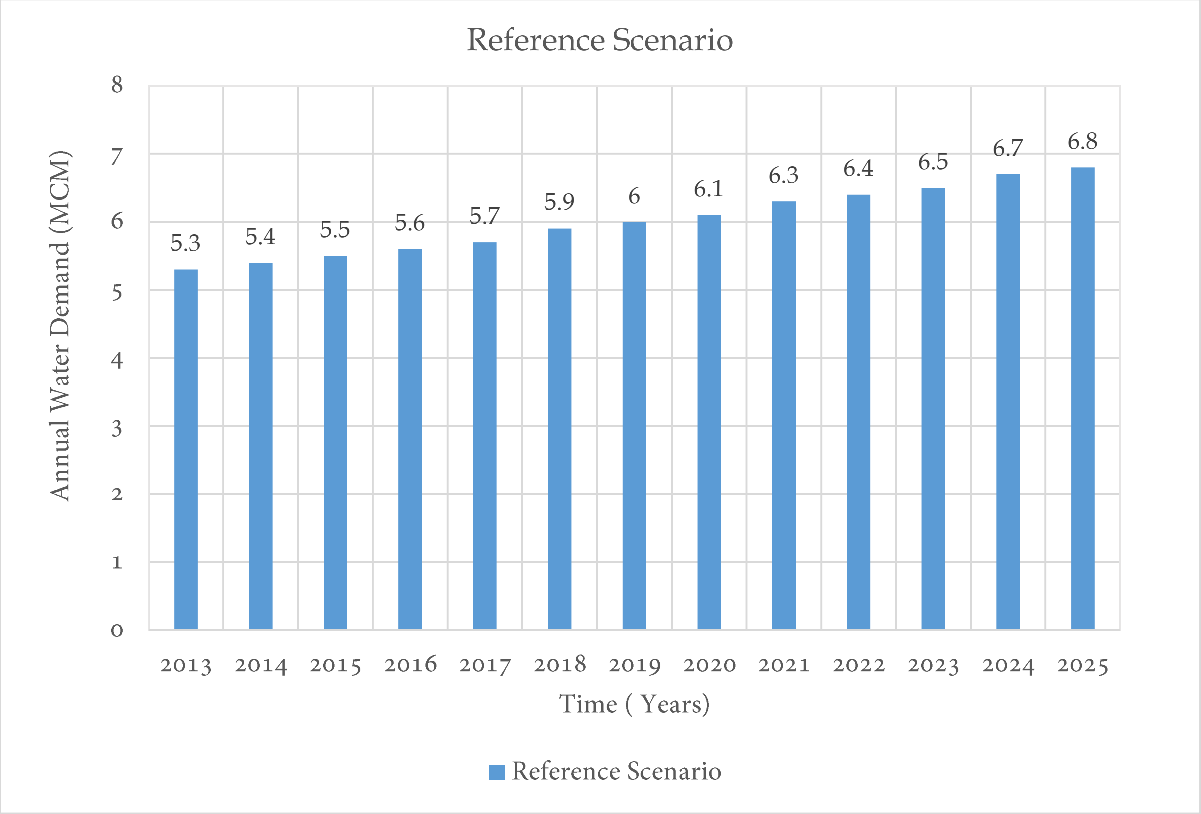

Figure 5.13 Annual water demand for the reference scenario (MCM)

The water supply demand is found to be increasing as population increases in the reference scenario. Figure 5.13 assures the usual trend.

5.2.4.2. High Population Growth Scenario

But what will happen if the population growth rate is set to higher growth rate than the reference scenario population growth rate?

In this case, the population growth rate was raised to 5.54% to simulate the water supply demand in the future.

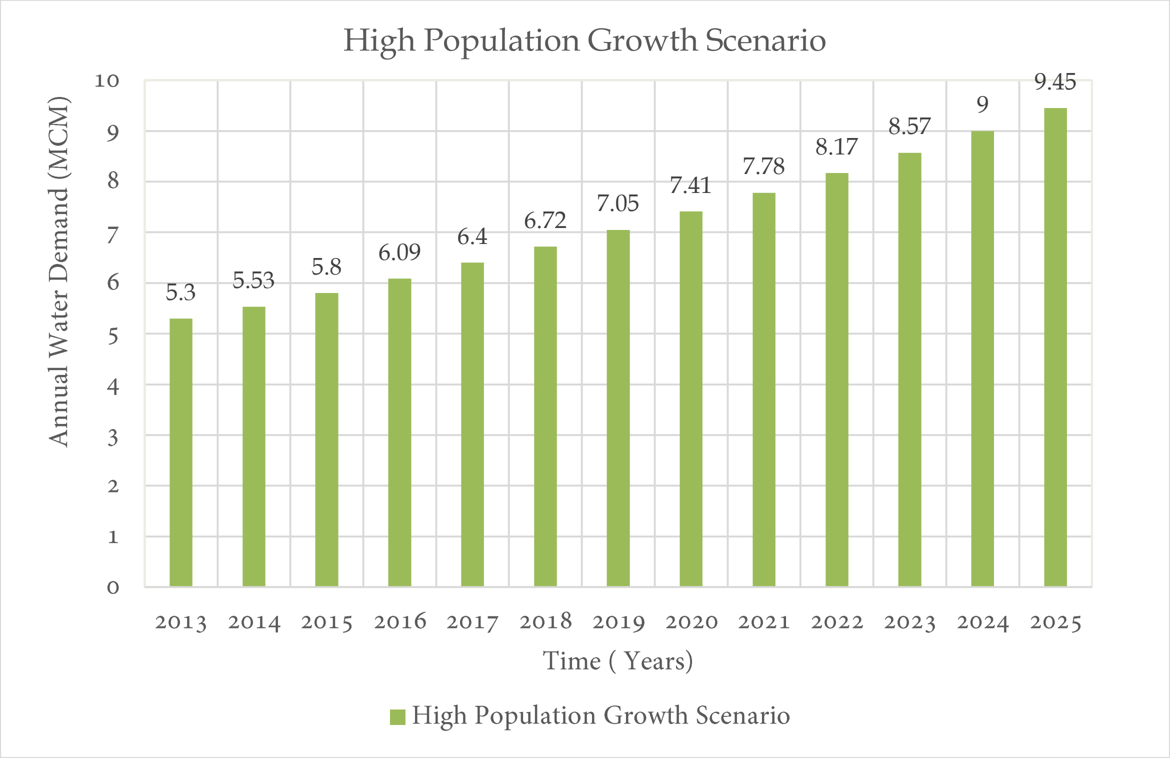

Figure 5.14 Annual water demand for high population growth scenario

As illustrated in Figure 5.14, the water supply demand increased to higher level of increment than the reference scenario water supply demand showed.

The following figure shows the behavior of the water supply demand for the reference and high population growth scenarios in the same graph for comparison.

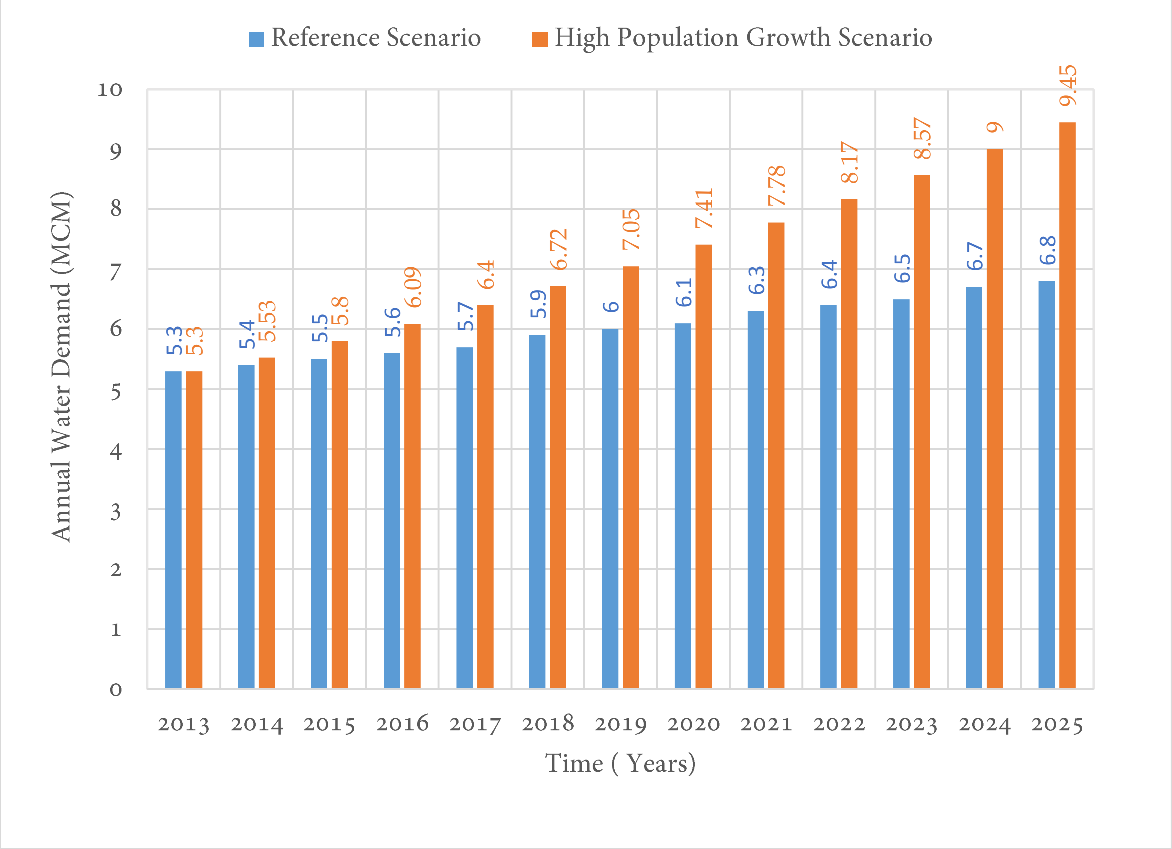

Figure 5.15 Annual water demand for both scenarios

This also shows that the annual water supply demand of the high population growth scenario is increasing in higher level than the reference scenario. There is an increment by 38.97% in the year 2025 in high population growth scenario with respect to the reference scenario.

5.2.4.3.Annual Unmet Water Demands for both Scenarios

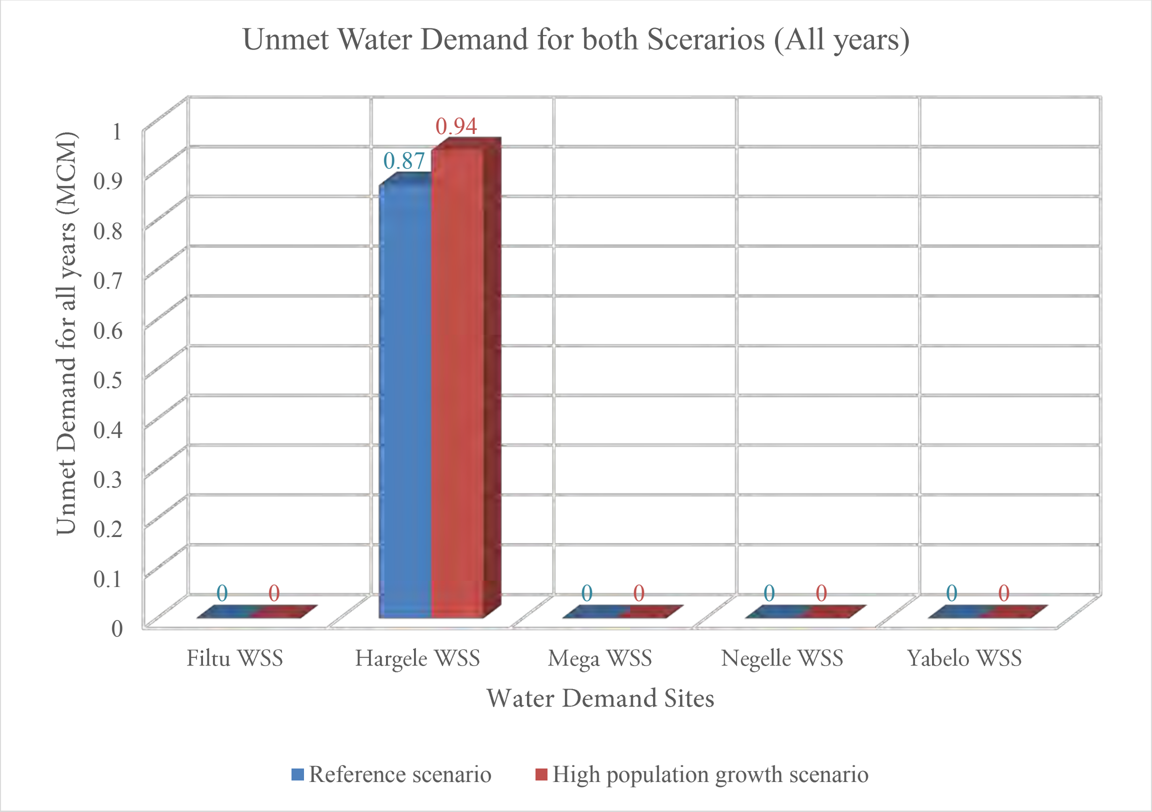

Figure 5.16 Unmet annual water demand for both scenarios

This result shows that the annual unmet demand for high population growth scenario is higher than the annual unmet demand for the reference scenario for all water supply demand sites.

5.2.4.4. Improved Irrigation Techniques and Methods Scenario

In this case, the impact of improved irrigation techniques and/or changing irrigation methods on irrigation water demand is analyzed. As the irrigation techniques are improved and irrigation methods are changed from flooding to either sprinkler or drip irrigation methods, the irrigation water demand decreases. Therefore, irrigation techniques can be improved from year to year by using new technological approaches to decrease the irrigation water demand.

Figure 5.17 shows the irrigation water demand decreases as the irrigation techniques are improved and new technological approaches are involved.

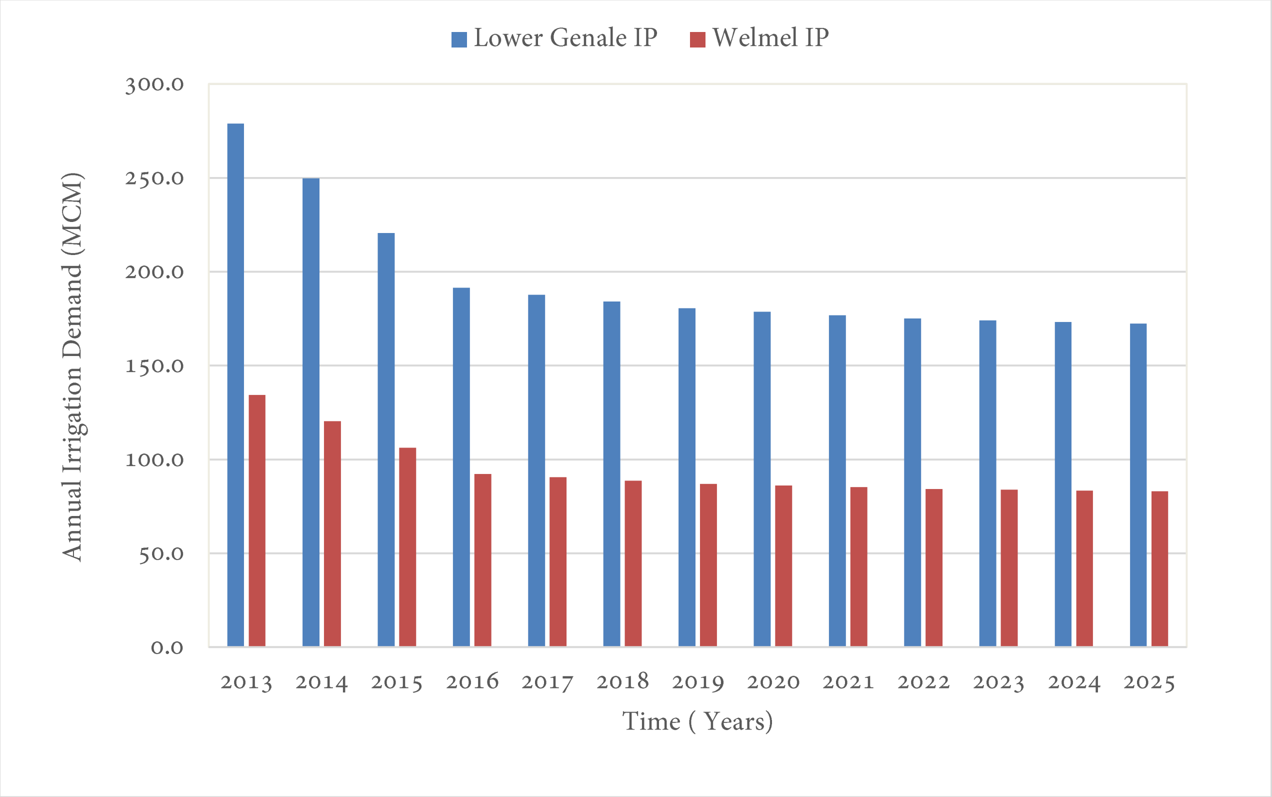

Figure 5.17 Improved irrigation techniques and methods scenario

5.3. Uncertainties on the Model Results

This study on the assessment of surface water potential and water demand in Genale Dawa river basin, involved a series of computer programs, model inputs to the models (SWAT and WEAP) and model outputs, which are based on simplified assumptions. Hence, it is anticipated that the uncertainties presented in each of the computer programs, mode inputs, model assumptions and model outputs kept on existing in cumulating manner while progressing towards the final outputs/results of the models.

The types of uncertainties presented throughout the whole process can be associated with the data quality, DEM resolution and the hydrologic modeling applied (the parameters that I have used for calibration may not represent the actual catchment) with simplified model assumptions.

The uncertainties on model results associated with data quality include poor quality meteorological data availability with missing which need to be filled by extended simplified methods which in turn increase the uncertainties again.

The Digital Elevation Model (DEM) resolution by itself has a significant uncertainty impact on the model output as it may misses some points in the catchment/ground.

The other uncertainty on model result is associated with the spatial data input, soil data, land use/ land cover data and land slope classification. The soil and land use/land cover data cannot be hundred percent clipped or overlaid to the SWAT model. The other fact is that while changing the actual representative catchment land use/land cover data to SWAT code land use/land cover, it needs to change the actual land use/land cover in to similar or nearer SWAT code land use data base in order to communicate with the model. Eventually, this leads to the uncertainties on the model results.

During the model calibration, only few sensitive model parameters were used which may not represent the actual catchment; this in turn leads to uncertainty on the model results.

CHAPTER SEVEN

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

1) The ArcSWAT hydrologic model calibration and validation results evaluated based on coefficient of determination ($R^2 = 0.88$) and Nash – Sutcliff's efficiency ($E_{NS} = 0.86$) during calibration, ($R^2 = 0.85$) and ($E_{NS} = 0.84$) during validation for its performance showed that the model is able to simulate the runoff significantly good in the study area.

2) The study area receives a mean annual precipitation of 810.5 mm and the mean annual runoff leaving the entire basin is estimated as 6.37 billion cubic meters; which corresponds to 37.92mm. This result shows that there is a slight increment in volume of runoff (8.3%) from the previous studies done by National Master Plan Study (WAOCOS, 1990). This might be either due to land use changes/catchment characteristics in general that increase the runoff coefficient, or due to climate change impacts on the river flow.

3) The result of the WEAP model shows that irrigation water demand is extremely large as compared to water supply and hydropower demands in the study area. That's the irrigation demand covers 98.13% of the total annual demand while both water supply and hydropower take the rest (1.87%) in the current account year 2013.

4) The result of WEAP model shows that water supply demand is extremely increasing in the future due to fast growing population. The water supply demand in the current account year 2013 is 5.3 million cubic meters while this demand grows to 6.8 million cubic meters in the year 2025; which corresponds to 28.3% increment.

5) In water demand analysis, 98.28% of the supply requirement is met while only 1.72% is the unmet demand in the study area based on the demand sites considered in the current account year.

6.2. Recommendation

This study was carried out using various models, computer programs and model inputs with poor quality climatic data obtained from National Meteorological Agency each of which possess a certain degree of uncertainty; therefore, these results should be taken with care and should be taken as initial assessment to picture the surface water availability and demand in the study area. This study did not cover all demand sites found in the basin in water demand assessment. Only five water supply demand sites in towns, two large scale irrigation projects and a single hydropower project were involved in the demand assessment.

Hence, researches should be continued considering detail demand sites including small and medium irrigation and hydropower projects; including rural population sharing the surface water.

Similar researches should be extended using higher resolution digital elevation models to see the variation in results of surface water availability in the study area.

As this study is limited to the assessment of surface water potential and water demand of selected large scale irrigation and hydropower projects including water supply schemes using surface water, it will have a profound significance if researches are extended to include groundwater potential and quality analysis in the study area.

There will be a better understanding and information of the basin if researches are extended in subbasin basis as the accuracy of the information increases for small areas.

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Annex

APPENDIX A: Definition of some important words

Forecast/ Projection: When a projection is designated "most likely" it becomes a forecast or prediction. A forecast is often obtained using physically- based models, possibly a set of these, outputs of which can enable some level of confidence to be attached to projections.

Scenario: A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario but scenarios often require additional information (e.g. about the baseline or base year conditions). A set of scenarios is often adopted to reflect, as well as possible, the range of uncertainty in the projection. Other terms that have been used as synonyms for scenario are "characterization", "storyline" and "construction".

Current accounts year: A current accounts year in WEAP model is the selected year with available data which serves as the base year for the model.

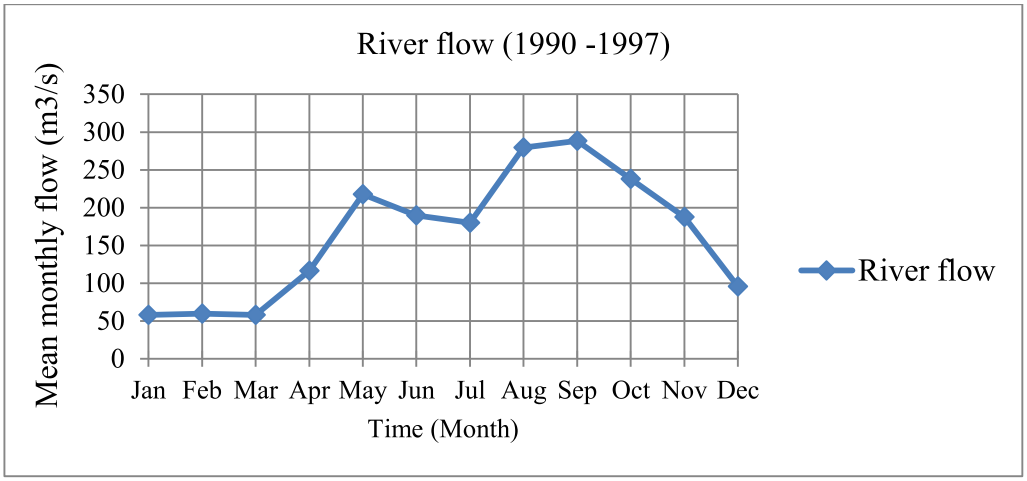
Reference Scenario: is the type of scenario which is created from the current accounts year to show the behavior of the model output without intervention.

PcpSTAT: is a computer program that calculates statistical parameters of daily precipitation data used by the weather generator of the ArcSWAT model.

DewPOINT: is also computer program designed to calculate the average daily dew point temperature per month using daily air temperature and relative humidity data used by the weather generator of the ArcSWAT model.

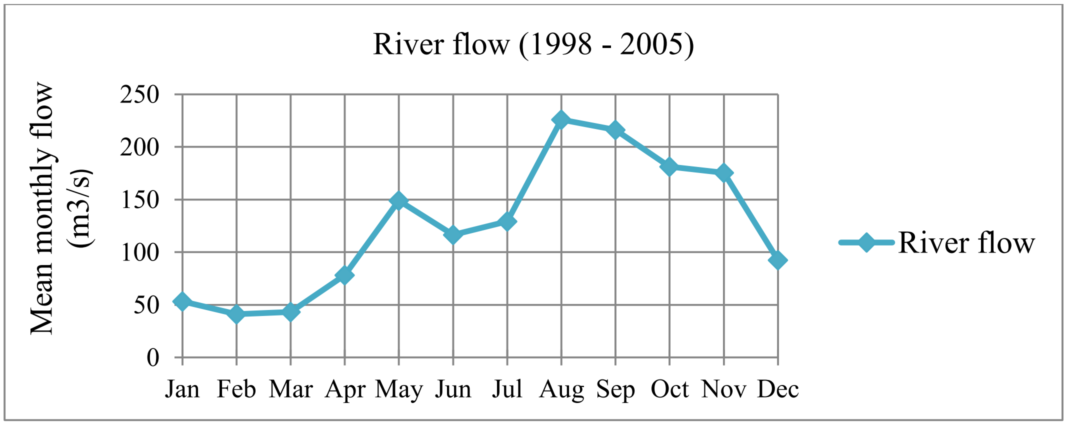
APPENDIX B:

Figure B.1 Mean monthly flow of Halwey River used for calibration (1990 -1997)



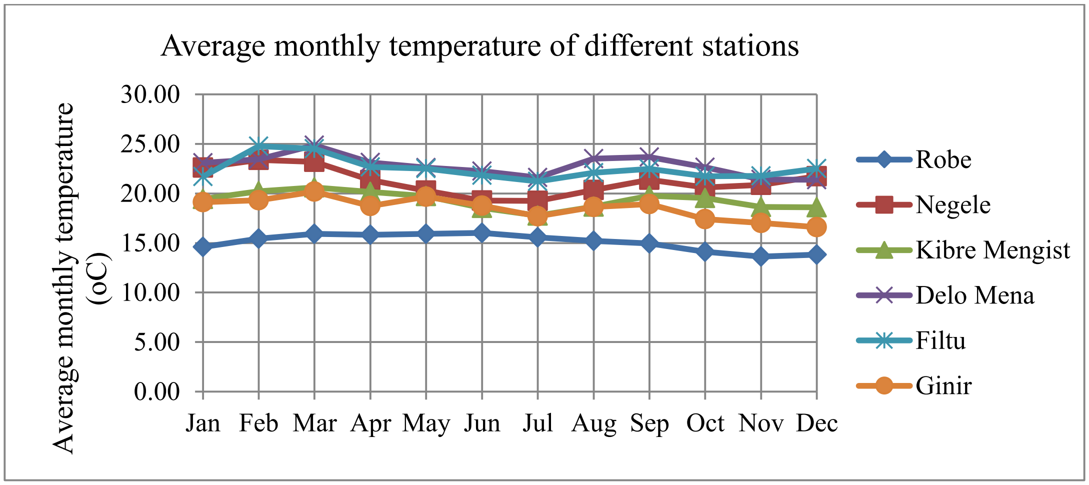
APPENDIX C:

Figure C.1 Mean Monthly flow of Halwey River used for validation (1998 -2005)



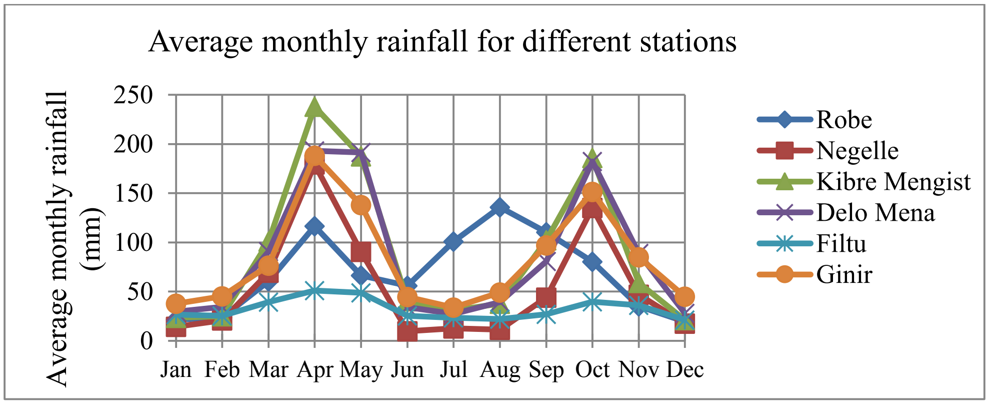
APPENDIX D:

Figure D.1 Average monthly temperature of different stations (1988-2013) used for SWAT model input data



APPENDIX E:

Figure E.1 Average monthly rainfall for different stations (1988-2013) used for SWAT model input



APPENDIX F:

Statistical analysis of daily precipitation data output of PcpSTAT (1988 – 2013) of Robe station used for ArcSWAT Weather generator input

```
Statistical Analysis   of         Daily      Precipitation  Data     (1988   -         2013)
Input       Filename   =          RBpcp.txt

Number      of         Years      =  26
Number      of         Leap       Years      =  5
Number      of         Records    =  6899
Number      of         No Data    values     = 0
            ________________________________________________________________________

            Month      PCP_MM     PCPSTD     PCPSKW         PR_W1    PR_W2   PCPD
            ________________________________________________________________________

            Jan.         21.58    3.0505       6.5291       0.0676   0.5       3.89
            Feb.         23.81    3.1314       5.3257       0.0886   0.5       4.44
            Mar.         60.49    4.674        3.5663       0.2083   0.5909   11
            Apr.        116.57    6.8553       2.8254       0.4108   0.6455   16.61
            May.         66.27    3.9664       3.1779       0.3597   0.6143   15.56
            Jun.         55.96    3.9482       3.3041       0.3123   0.5247   12.39
            Jul.        100.87    6.713        3.9584       0.4355   0.6323   17.22
            Aug.        135.85    9.4662       5.7946       0.4767   0.7123   20.28
            Sep.        110.16    5.5015       2.6299       0.4795   0.7453   20.5
            Oct.         80.2     4.8621       3.4579       0.2509   0.7025   15.5
            Nov.         35.18    3.9214       5.1325       0.0963   0.5385    5.78
            Dec.         19.39    2.8827       7.6014       0.0826   0.4189    4.11
            (written   by         Stefan     Liersch,       Berlin,  August  2003)
```

APPENDIX G:

Table G.1 Weather generator input parameters for Robe Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMPSTDMX	1.44	1.76	1.84	1.71	1.36	1.28	1.56	1.51	1.15	1.36	1.53	1.38
TMPSTDMN	2.12	1.94	1.90	1.38	1.50	1.43	1.25	1.28	1.57	1.91	2.17	2.29
WNDAV	1.63	1.82	1.86	1.62	1.63	1.78	1.71	1.75	1.55	1.30	1.26	1.33
SOLARAV	8.64	17.35	19.81	14.29	9.14	3.09	5.89	12.63	15.75	13.80	10.00	3.42
TMP_MAX	22.83	23.68	23.32	21.84	22.39	22.83	21.84	21.33	20.78	19.8	20.68	21.66
TMP_MIN	6.36	7.23	8.52	9.79	9.49	9.21	9.29	9.1	9.16	8.44	6.57	6.02
DEWPT	7.9	8.27	9.97	11.66	10.45	11.27	11.67	11.62	11.2	10.05	8.91	7.17
PCP_MM	21.58	23.81	60.49	116.57	66.27	55.96	100.87	135.85	110.16	80.2	35.18	19.39
PCPSTD	3.05	3.13	4.67	6.86	3.97	3.95	6.71	9.47	5.50	4.86	3.92	2.88
PCPSKW	6.53	5.33	3.57	2.83	3.18	3.30	3.96	5.79	2.63	3.46	5.13	7.60
PR_W1	0.07	0.09	0.21	0.41	0.36	0.31	0.44	0.48	0.48	0.25	0.10	0.08
PR_W2	0.50	0.50	0.59	0.65	0.61	0.52	0.63	0.71	0.75	0.70	0.54	0.42
PCPD	3.89	4.44	11	16.61	15.56	12.39	17.22	20.28	20.5	15.5	5.78	4.11

APPENDIX H:

Table H.1 Weather generator input parameters for Kibre Mengist Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMPSTDMX	1.78	1.99	2.63	1.96	1.61	1.95	2.71	2.61	1.94	1.90	1.53	1.47
TMPSTDMN	2.81	2.65	2.56	2.33	2.05	1.83	1.34	1.44	1.51	1.58	2.52	2.90
SOLARAV	8.18	15.81	18.77	14.24	13.72	3.09	5.46	12.17	15.55	14.66	10.27	3.81
WNDAV	0.68	0.76	0.77	0.68	0.61	0.72	0.73	0.72	0.65	0.54	0.59	0.64
PCP_MM	23.4	25	100.7	238	187.5	40.2	31	37.7	102.23	185.8	59.03	20.98
PCPSTD	3.73	3.78	7.84	12.22	12.14	5.37	3.49	4.42	6.58	9.84	6.08	3.17
PCPSKW	9.01	5.51	4.09	2.57	3.11	8.76	6.33	5.98	3.10	2.82	4.14	7.33
PR_W1	0.04	0.05	0.16	0.41	0.30	0.16	0.16	0.18	0.30	0.31	0.11	0.06
PR_W1	0.56	0.49	0.63	0.72	0.62	0.36	0.43	0.31	0.62	0.73	0.55	0.43
PCPD	3.00	2.88	9.85	18.65	14.54	6.15	6.96	6.65	13.50	17.88	6.04	3.19
TMP_MAX	28.6	29.4	28.68	26.37	25.18	23.2	22	23.8	25.67	25.25	26	26.94
TMP_MIN	10.2	11	12.54	13.93	14.3	13.9	13.6	13.5	13.86	13.81	11.26	10.3
DEWPT	14.4	14.4	14.37	13.62	12.35	11.6	9.97	11.2	13.53	11.87	13.65	14.06

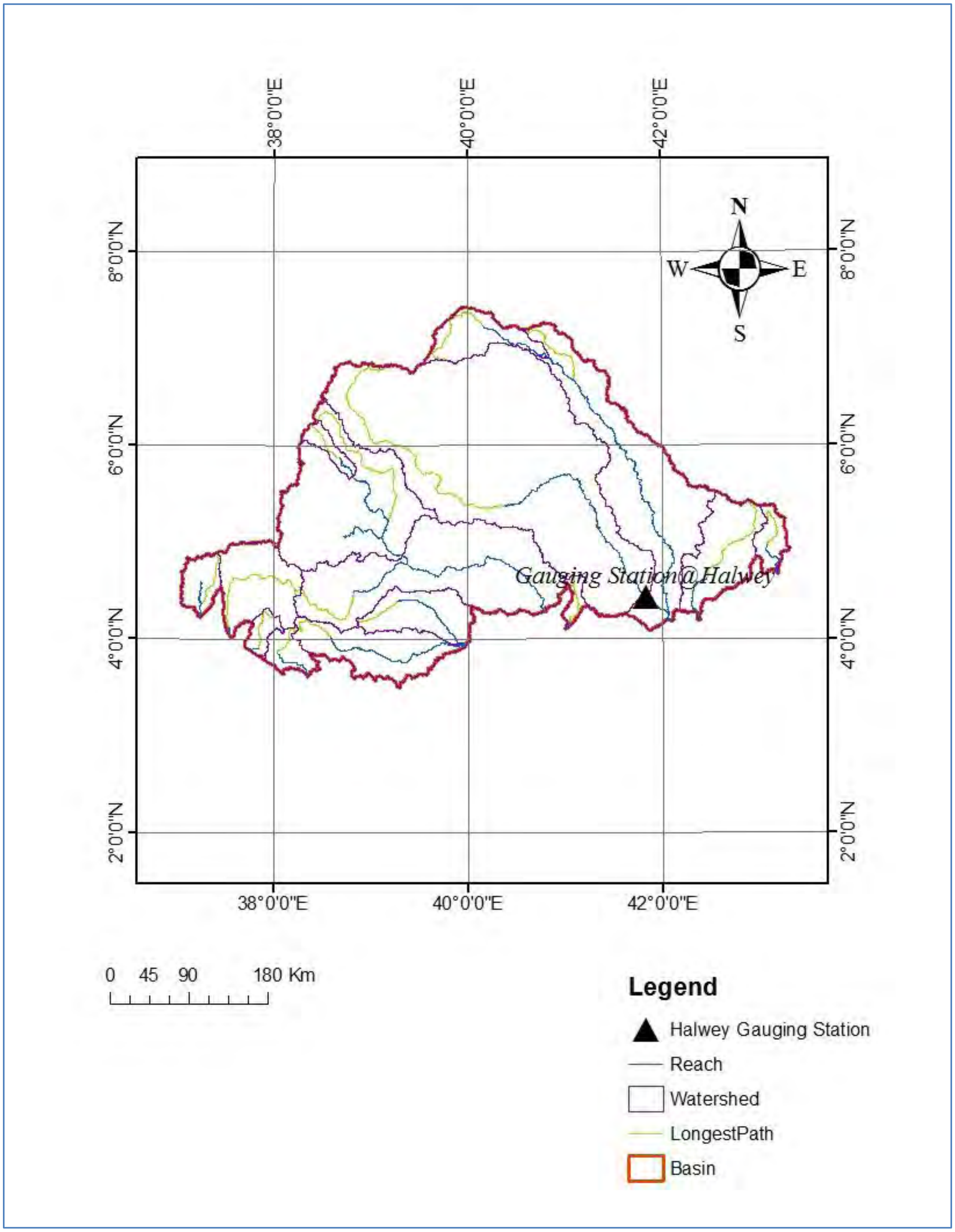
APPENDIX I:

Table I.1 Weather generator input parameters for Negelle Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SOLARAV	8.79	17.81	20.07	14.66	8.70	3.01	5.61	13.63	15.56	13.44	10.10	4.12
WNDAV	2.63	2.67	2.42	2.27	2.40	2.76	3.11	3.07	2.73	2.27	2.36	2.49
TMPSTDMN	2.09	2.18	2.04	1.90	1.30	1.27	1.49	1.60	1.62	1.35	1.43	1.71
TMPSTDMX	1.53	1.58	2.10	2.51	1.51	2.02	2.61	2.29	1.72	1.92	1.63	1.52
PCP_MM	14.25	20.81	69.19	179.50	90.59	9.57	12.56	11.44	43.80	135.07	46.85	17.62
PCPSTD	1.98	3.00	6.40	10.22	7.94	1.51	1.08	0.99	4.22	8.47	6.35	2.61
PCPSKW	10.98	7.83	4.96	2.42	5.50	12.63	6.48	7.32	6.48	3.67	9.78	10.12
PR_W1	0.04	0.05	0.15	0.35	0.24	0.10	0.13	0.05	0.20	0.30	0.12	0.04
PR_W2	0.78	0.75	0.65	0.75	0.62	0.53	0.63	0.75	0.67	0.77	0.65	0.76
PCPD	5.35	5.35	9.81	18.58	13.08	5.38	8.27	6.58	11.42	18.81	8.50	5.35
TMP_MAX	29.15	29.99	29.20	26.10	24.58	23.49	23.67	25.44	26.62	25.24	26.29	27.82
TMP_MIN	16.07	16.78	17.16	16.63	16.00	15.07	14.83	15.24	16.17	15.99	15.42	15.64
DEWPT	13.56	13.77	13.78	12.12	10.60	9.99	9.01	10.19	11.72	11.28	13.31	13.60

APPENDIX J:

Figure J.1 Location Map of Halwey Gauging Station used for calibration and validation



APPENDIX K:

Figure K.1. Location map of gauging stations in Genale Dawa River Basin