



MICRO HYDROPOWER POTENTIAL ASSESSMENT IN OMO- GIBE RIVER BASIN: THE
CASE OF CENTRAL GIBE SUB-BASIN

M.Sc. Thesis

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List of Acronym's and Abbreviations

EEPCo	Ethiopian Electric Power Corporation
EEA	Ethiopian Energy Agency
EMA	Ethiopian mapping agency
ENMSA	Ethiopian National Metrological service Agency
FDC	Flow Duration Curve
GIS	Geographical Information System
GIZ ECO	German International Cooperation Energy Coordination Office
GPS	Geographical Positioning System
GWh	Giga Watt-hour
ICS	Interconnected System
KW	kilo Watt
KWh	kilowatt hour
MHP	Micro Hydropower
MoWR	Ministry of water resource
MoWIE	Ministry of Water, Irrigation and Electricity
NA	National Meteorological Agency
NGO	Non-Governmental Organization
NSE	Nash Sutcliffe Efficiency
REF	Rural Electrification fund
SHP	Small Hydropower
SWAT	Soil and Water Assessment Tool
TWh	Tera watt hour

ABSTRACT

This study assessed the Micro hydropower potential of the Central-Gibe Sub-basin in Omo-Gibe river basin to identify and locate possible potential site. Arc GIS 10.3 and SWAT 2012 Model were used for watershed analysis. The model was calibrated & validated by SWAT-CUP for the period 1993-2006, the performance of the model was evaluated using the Reference measures such as Nash-Sutcliffe Efficiency (NSE) and Coefficient of determination (R^2). The $NSE=0.60$ and $R^2=0.66$ for calibration and $NSE=0.60$ and $R^2=0.66$ for validation results. After the model was calibrated & validated sensitive parameters were used for ungauged sub basins for runoff simulation for the period 1990-2017 meteorological stations data. The potential site was selected & the gross head was determined the discharges of these sites were transferred from the model simulation results. Flow Duration Curves were prepared for each sites. A total of five Micro Hydro Power Potential Sites were identified and the total potential capacity was found to be for Derie-River 484.08Kw, Gogare-River 348.62Kw, Hae-River 481.16Kw, Megecha-Winike-River 480.95Kw and Wunike-River 457.31Kw. In addition to this appropriate type of schemes were proposed & all of them turned to be Run-Off- River plant. Finally, the identified potential sites were ranked considering Energy output, Design discharge, Head, ratio between Waterway length, distance from access road and distance of the site to demand center based on this decision criteria's river Wunike is found to score the first while Gogare is at the bottom with its very low rank.

KEY WORD: Micro hydropower, ARC-GIS, SWAT, SWAT-CUP, Calibration

1. INTRODUCTION

1.1 Background

Energy is vital to achieve the development of economic, environmental and social aims of sustainable human development. Like in many other Sub-Saharan countries, Ethiopia's energy sector depends highly on biomass. Access to modern fuels including electricity is mostly not possible in rural areas and in most cases neither sufficiently reliable nor affordable. The Ethiopian Government has therefore adopted strategy comprising a grid-extension by EEPCO and off-grid electrification by small hydropower and alternative power development systems (EEPCO, 2004).

The global energy demand is skyrocketing; the hunt for cleaner, cheaper and more sustainable energy resources has been a hot issue in the past few decades. Following that, many nations have managed to reduce their dependence on traditional energy systems while others find it unaffordable due to their economic situations and technological incapability (Jhon, 2009).

The theoretical potential of hydropower in Ethiopia is estimated to be 30,000-45,000 MW which would enable an annual energy of 160,000 GWh (GTZ, 2010). The economically exploitable hydropower potential is estimated to be between 15,000 and 30,000 MW. Large hydropower makes up 98% of Ethiopia's power production. The government has large expansion plans for large hydropower plants to reduce energy shortages and to eventually become an energy exporter (GTZ, 2010).

According to United Nations 1.6 billion people live in extreme poverty (Laguna et. al., 2006). Around 2.4 billion people rely on traditional biomass for cooking and heating purposes and roughly a quarter of the world's population with 1.6 billion people does not have access to electricity (Laguna et. al., 2006). Access to modern, safe and affordable energy and energy services is considered as one of the attributes having a great potential to reduce poverty (John, 2009).

In Ethiopia, potentials SHP exist in rural and semi-urban areas, which can change the developmental equation of the rural areas (Leonard, et al. 2005). They could also provide considerable help to the country, by meeting the power deficit in the main interconnected grid system, substituting thermal plants in the main grid or isolated grids, helping reduce fuel imports and electrifying remote rural areas (Leonard, et al. 2005). Rural electrification through

conventional means such as grid connection or diesel generators is very costly (Leonard, et al. 2005).

The SHP has different advantages as compared to larger plants such that it is simple in design, construction and operation. It has very minimal adverse impacts on environment, and it has minimal costs for transmission from generation point to load centers (Smail & Andrew, 2000). Ethiopia is fortunate and blessed with abundant water resources which can be tapped to meet its growing energy needs, despite being landlocked and non-oil producing country. Hydropower is one of the main energy sources that is recognized and given priority for poverty reduction and sustainable development in Ethiopia (Solomon 1998).

Regardless of its great economic advantages, large scale hydropower projects need considerably large amount of investment, face strong opposition of environmental civil organizations, and take relatively longer gestation period than small hydropower schemes (Solomon 1998). Therefore, Small (Scale) Hydropower (SHP) schemes have emerged as an alternative energy sources since they are renewable, easily developed, relatively inexpensive, and it has low impact on the environment. SHP systems can play an important role in the electrification of rural areas and towns in Ethiopia that are far from the national electricity grid, or to contribute to the national grid. It is also desirable not only to meet an ever growing energy demand, but also to reduce biofuels use related health risks like respiratory illnesses, cancer, carbon monoxide poisoning, and the causes for the environmental pollution (Leonard, et al. 2005).

Ethiopia has a huge hydropower potential, which has hardly been exploited. Studies put the gross hydro potential of Ethiopia at 650TWh/year. Although there are substantial hydropower resources, Ethiopia has one of the lowest levels of per capital electrical consumption in the world. The annual consumption of electricity in 1995 was 1670 GWh, equivalent to 30kwh/capital. The installed capacity was about 417.75 MW (377.75 MW + 40MW) of which 90% was provided by hydropower. The present capacity deficit was estimated to be about 300MW (EEPCO, 2004).

1.2 Statement of the Problem

Access to electricity is one of the keys to development because it provides light, heat and power used in residential, commercial and industrial sectors. According to the World Bank, the world's poor people spend more than 12% of their total income on energy and around 1.7 billion people do not have access to electricity (Laguna, 2006).

As a result, the majority of the population in the rural area has to rely on biomass based energy system, which has resulted in massive deforestation and soil erosion in the region. Moreover, in Central Gibe Sub-Basin considerable amounts of effort and time are now exerted for the collection of fuels which divert productive human capital from agriculture and other income generating activities.

But in the Central Gibe Sub-Basin there are perennial rivers combined with good topography, which makes Micro-Hydropower suitable near these villages but the identification and location possible potential site are not investigated with scientific manner Having these facts in mind the potential for micro hydropower for this region should be investigated so that the energy problem will be solved to some degrees, beside that it helps to maintain carbon free environment.

1.3 Objective of the Study

1.3.1 General Objective

The overall objective of this study is to assess Micro-Hydropower Potential in Central Gibe sub-basin in the Omo-Gibe River basin.

1.3.2 Specific objectives

Some of the specific objectives adopted to meet the main objective includes:

- To identify and locate possible potential sites.
- To estimate the potential power and energy output.
- To rank potential sites based on multi decision criteria's.

1.4 Significance of the Study

Ethiopia is endowed with renewable energy resources such as wind, solar, biomass and small hydro power. Demand for electricity is growing; the increase trend is due to the combined effects of expansion in the economy, growing population and higher disposable income, which provides

a strong growth in energy demand therefore one of the alternative to answer the energy demand by providing micro hydro power potentials which is very important for address electric power for rural areas which enhance the rural people and it helps the decision maker by identifying the appropriate potential site for implementation.

2. Literature Review

2.1 Micro-Hydropower in the World

Hydropower is a renewable, non-polluting and environmentally friendly source of energy. Hydropower is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and electricity is produced. Many other components may be in a system, but it all begins with the energy in the moving water. The use of water falling through a height has been utilized as a source of energy since a long time. It is perhaps the oldest renewable energy technique known to the mankind for mechanical energy conversion as well as electricity generation. In the ancient times waterwheels were used extensively, but it was only at the beginning of the 19th Century with the invention of the hydro turbines that the use of hydropower got popularized. India has a century old history of hydropower and the beginning was from small hydro (Canadian Hydropower Association, 2007).

The first hydro power plant was of 130 kW set up in Darjeeling during 1897, marked the development of hydropower in the country. Similarly, by 1924 Switzerland had nearly 7000 small scale hydropower stations in use. Even today, Small hydro is the largest contributor of electricity from renewable energy sources, both at European and world level. With the advancement of technology, and increasing requirement of electricity, the thrust of electricity generation was shifted to large size hydro and thermal power stations. However, it is only during the last two decades that there is a renewed interest in the development of small hydro power (SHP) projects mainly due to its benefits particularly concerning environment and ability to produce power in remote areas. Small hydro projects are economically viable and have relatively short gestation period. The major constraints associated with large hydro projects are usually not encountered in small hydro projects. Renewed interest in the technology of small scale hydropower actually started in China which has more than 85,000 small-scale, electricity producing, hydropower plants ([http://practicalaction.org/.](http://practicalaction.org/))

Hydropower will continue to play important role throughout the 21st Century, in world electricity supply. Hydropower development does have some challenges besides the technical, economic and environmental advantages it shares above other power generation (fossil fuel based) technologies. At the beginning of the new Millennium hydropower provided almost 20% (2600 TWh/year) of the electricity world consumption (12900 TWh/year). It plays a major role in several countries.

According to a study of hydropower resources in 175 countries, more than 150 have hydropower resources. For 65 of them, hydro produces more than 50% of electricity; for 24, more than 90% and 10 countries have almost all their electricity requirements met through hydropower refer Table 2.1 for worldwide installed small hydropower capacity (<http://www.uniseo.org/hydropower.html>).

Table 2.1: Installed SHP capacity in the world region for <10MW (Jhon,2014)

Region	Capacity (MW)	Percentage
Asia	32,641	68.00%
Europe	10,723	22.30%
North America	2,929	6.10%
South America	1,280	2.70%
Africa	228	0.50%
Australia	198	0.40%
TOTAL	47,997	100%

2.2 Hydropower Potentials of Ethiopia

The birth of modern energy in Ethiopia dates back to the late 19th century and the country is endowed with enormous water, solar, wind and geothermal energy potentials. However, more than a century later, only a tiny part of the potentials is utilized and only 48.3% of the population has access to electric energy as of July 2012 (EEPCO, 2015). The power system is reliant on hydropower, which accounts for 94% of generation. Ethiopia is estimated to have the capacity to produce 45,000 MW of hydropower, out of this it is only 4068 MW or less than 9.04% of the total exploitable amount is exploited Existing Power plants & their detail information is given on Table 2.2.

Table 2.2: Existing Power plants & their detail information. (Ethiopian electric power corporation, Online)

No	Power Plant	Installed Capacity	Status	Operational Since	River
1	Aba Samuel	6.6	Operational	1932	Akaki

2	Awash II+III	64	Operational	1966,1971	Awash
3	Fincha	134	Operational	1973	Fincha
4	Fincha/Amerti Nesh	95	Operational	2011	Amerti Nesh
5	Giba I+II	385	Project Implementation		Gibba
6	Genale Dawa III	254	Operational	2017	Genale
7	Genale Dawa V	257	Project Implementation		Genale
8	GERD	(6450)	Under Construction		Blue Nile
9	Tis Abay I+II	84.4	Operational	1953,2001	Blue Nile
10	Tekeze	300	Operational	2010	Tekeze
11	Tana Beles	460	Operational	2010	Beles
12	Melka Wakena	153	Operational	1989	Shebele
13	Koysa	(2160)	Under Construction		Omo
14	Koka(Awash)	43	Operational	1960	Awash
15	Gilgel Gibe III	1870	Operational	2016	Omo
16	Gilgel Gibe II	420	Operational	2010	Gilgel Gibe/Omo
17	Gilgel Gibe I	184	Operational	2004	Gilgel Gibe

However, given the vulnerability of focusing only of hydropower development, the Government is diversifying and developing geothermal and wind power as well. Of the above exploitable potential in the country, about 1500 MW to 3000 MW would be suitable for small scale power generation including Pico and Micro hydropower. (Abebe, 2011).

Generally, there are 12 major basins in the country with 8 of them being river basins, 3 dry basins while the remaining one being lakes basin (MoWR, online). Most of these water basins have very special nature due to the landscape of the country in that in many cases it is possible

to use the water of those basins as a source of Ethiopian Energy Systems: Potentials, opportunities and sustainable utilization hydropower and use the same water for irrigation in the downstream. Another special feature of the Ethiopian rivers is the fact that most of the major rivers are sourced in the central part of the country and stream to all directions with some of the river basins covering very large areas. Wabishebelle River, for instance, covers an approximated area of more than 202,000km² while the Blue Nile basin covers about 200,000km² of land. The hydropower and irrigation potentials of the main river basins of the country are summarized in Table 2.3.

Table 2.3: Hydropower and irrigation potentials of the main river basins of the country (Dawit,2010)

No.	River basin	Hydropower potential (GWh)	Irrigation Potential ('000ha)	Potential hydropower sites
1	Abay (Blue) Nile	55000/78820*	1800	132
2	Omo-Gibe	26026/36560*	90.4	23
3	Baro-Akobo	19826	631	39
4	GenaleDawa	9270	1070	23
5	Tekeze	8384	186.9	15
6	Wabishebelle	7457	209.3	18
7	Awash	5589	206	43
8	Rift Valley Lakes	12240/800*	131	6
9	Mereb	na**	5	na
10	Aysha	na	0	na

11	Denakil	na	na	na
12	Ogaden	na	na	na
	Total	143,792/166,706*	4329.6	299

* Different data from different references: both values are put whenever the difference is considerable

** Data's are not available

2.3 Rural Electrification in Ethiopia

Rural electrification is the process of providing electrical services to rural areas: generally, regions with sparse population where agriculture is the dominant livelihood. The three most important rural energy sources, in their order of importance, are fuel wood, dung and agri-residue; while the three most important end-uses are “mitad” baking, other cooking and lighting. The implication of this is that, if rural households are provided with electricity, even for lighting, the gain in terms of environmental protection of rural areas is significant. In view of the above there is a huge market for investors in the area of rural electrification. And the huge market could be taken as the other opportunity for the development of the energy sector in general and rural electrification in particular (Muluken,2014).

In extending electrical power to low income areas where domestic consumers are poor and the demand of electricity for productive purposes is absent; low levels of demand, low revenues, and high initial costs are obstacle to investment (Aklilu, 2010).

2.4 Overall Sector Outlook

The market for MHP in Ethiopia is not well developed. Despite an estimated potential of over 1000 MW, a long history of micro- and Pico-hydro power practice, and low electrification level, the development and utilization of the MHP technology has gone backwards over the past several decades. Some studies indicate that there were nearly one thousand MHPs distributed throughout the country mainly for grain milling purposes⁹. Now, their number does not exceed a couple of hundred. There were several factors that worked against the development and dissemination of MHPs in Ethiopia in the past. The first factor was the

abandonment of MHP schemes in the early 1970s when land was nationalized by the defunct communist regime. Owners of the schemes, who were also owners of the land on which MHPs were built, were expelled from their lands, which also meant abandonment of the schemes. Secondly, the misconception that MHP technology is of the past and hence, instead of adopting modern and more efficient technologies, diesel motors have been chosen to replace MHP schemes in rural areas. The third factor is the expansion of grid electricity in to MHP operational areas making them less competitive, and hence less attractive for private investment. The root cause for all these problems against MHP is the absence of appropriate energy policies that are conducive for the development and utilization of renewable energy resource. Now, renewables are getting high-level policy attention as supply reliability and resource diversification are critical to power supply security and also the role they play in reaching remote rural areas with modern energy services is crucial. Formation of Rural Electrification Fund (REF) and the drafting of a feed-in tariff law are few indications to mention (Dereje,2013).

However, since the 1980s the interest for MHP development has been reinvigorated by few NGOs. With introduction of modern turbine units and efficient system designs, several abandoned schemes were rehabilitated and new ones were developed primarily for grain milling services. Recently, there is a growing interest among government, NGOs and the private sector for promotion and development of MHPs.

The formation of REF to make financing available and the observed interest to introduce a feed-in tariff law indicate a paradigm shift from the government side. Private sector investment including co-operatives and individuals is increasing. REF has already received and approved five MHP schemes in off-grid location to be developed by cooperatives. There is also interest among potential developers to rehabilitate MHP schemes that were abandoned due to encroachment of the national grid if an attractive feed-in tariff is to be put in place.

Table 2.4: Existing EEPCo hydro plants in the micro range (Keneni,2007)

Name, Location	Head	Type Scheme of	Installed capacity (KW)	Commissioning Year	Current status
Yadot, Bale Zone	23	ROR	350	1991	Operational

Welega, Weliso town	16	ROR	162	1965	Not operational
Sotosomore, Jimma	30	ROR	147	1954	Not operational
Huluka, Ambo town	40	ROR	150	1954	Not operational
Deneba, Bunobedele	14	ROR	123	1967	Not operational
Gelenmite, DenbiDollo	42	ROR	195	1966	Not operational
Chemoga, DebreMarkos	55	ROR	195	1962	Not operational
DerbreBerhan		ROR	130	1955	Not operational
Jibo, Harar Zone		ROR	420		Not operational
Total Capacity		ROR	1872		
Operational			350		
Not operational			1522		

2.5 Definition of Micro-Hydropower

The definitions of small-hydropower, mini-hydropower and micro-hydropower generations vary among different countries and organizations (Zelalem, 1993). Since we don't have a common defined ranges for Micro-Hydropower here in Ethiopia It is necessary to make appropriate definition of Micro-Hydropower before proceeding to the evaluation of existing sites. Micro-Hydropower defined as having generation capacity of less than 100KW (Zelalem, 1993) Micro-Hydropower as having generation capacity less than 500KW (Keneni 2007; Abebe 2015).

2.6 Classification of micro-hydropower by facility type

Hydropower plants are often classified in four main categories according to operation and type of flow. Diversion & canal, Run-of-river (RoR), storage (reservoir) and pumped storage HPPs all vary from the very small to the very large scale, depending on the hydrology and topography of the watershed.

2.6.1 Diversion and Canal

A Diversion & canal HPP draws the energy for electricity production mainly from the available flow of the river. Such a hydropower plant may include some short-term storage (hourly, daily), allowing for some adaptations to the demand profile, but the generation profile will to varying degrees be dictated by local river flow conditions. As a result, generation depends on precipitation and runoff and may have substantial daily, monthly or seasonal variations (Kumar et al 2011).

2.6.2 Run-Off-River

This type of project allows generation of electricity without the impact of damming the water way. A portion of water flow from a river or stream is diverted through channel to forebay tank and then led via penstocks to drive hydraulic turbines after which, the water is redirected back to its original source. There is no water storage and the power fluctuates with the stream flow. run-of-river plants (ROR) are employed where topography, environmental concern, or other factors prohibit reservoir construction and where natural river flows are reliable enough to justify the large capital costs that characterize hydropower. They are often suited to supply electrical needs of an isolated area or industry, if the minimum flow in the river or stream is sufficient to meet the load's peak power requirements. Compared to other storage schemes, ROR have less environmental and social impacts. However, at times flows become too high or too low, for the utilities capacity and this necessitates shutdowns until flows return to within the acceptable range (Kumar et al 2011).

2.6.3 Storage Hydropower

For hydropower plant to provide power on demand, either to meet a fluctuating load or to provide peak power, water must be stored in a reservoir. Providing storage usually requires the construction of a dam and the creation of new lakes. This impacts the local environment in both negative and positive ways, although the scale of development after magnifies the negative impacts. This often presents a conflict as larger hydro projects are attractive because they can provide "stored" power

during peak demand periods. New dams for storage reservoirs for small hydro plants is generally not financially viable except at isolated locations where the value of energy is possibly very high (Jhon 2009).

2.6.4 Pumped storage

Like peaking, pumped storage is a method of keeping water in reserve for peak period power demands. Pumped storage is water pumped to a storage pool above the power plant at a time when customer demand for energy is low, such as during the middle of the night. The water is then allowed to flow back through the turbine-generators at times when demand is high and a heavy load is placed on the system (Kumar et al 2011).

2.7 Model Description

There are two groups of hydrology models which can be distinguished: stochastic and process-based models. The first groups of models are black box systems based on data and using mathematical and statistical concepts to form a functional relationship for example rainfall as an input and runoff as an output of the model. The most commonly technique involved in stochastic hydrologic models is regression, transfer functions, neural networks and system identification. The second groups of hydrologic models are process-based models where they attempt to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be much more complicated. These models are called deterministic hydrology models.

Deterministic hydrology models can be subdivided into single-event models and continuous simulation models. Recent research in hydrologic modeling tries to have a more global approach to the understanding of the behavior of hydrologic systems to make better predictions and to solve the major challenges in water resources management. Among the various types of models, semi-distributed models are the most effective hydrological simulation model as it overcomes the difficulties normally encountered with fully distributed model and lumped model (Jajarmizadeh et al., 2013). Hence, to model such processes based on semi-distributed hydrological model SWAT-2012 for estimating runoff/stream flows in semi ungauged watershed of Gibe Sub-Basin.

3. Materials and Methods

3.1 General

It is very important to collect adequate and quality data to do successful research work on any field of study. The types of data collected from various organizations for this specific study are as follows: The Metrological data, Stream flow data and Topographic maps for the respective study area are collected from Ethiopian Metrological Service Agency, Ministry of water, Irrigation & Energy, Ethiopian Mapping Agency. The Model used in this research is Soil and Water Assessment Tool (SWAT). The detail data used & methodology to develop a Hydrological model in SWAT are discussed in this chapter.

3.2 Description of the study area

The Gibe sub basin is located in Hadiya Zone of South Nations Nationalities Regional State as shown in Fig.3.1 below. It is located at 235km from Hawassa, Capital of the Region accessed through Hawassa–Shasheme-Halaba-Wulbareg-Hosana-Lere-Kose-Gunchire-Welkite. The first 215km is concrete asphalt road and the remaining 80km which branches from Lere town is all weathered road. The Watershed is specifically located in the Gibe river valley, nearly Southeast-Northwest trending valley. Access to the Study Area is from the town of Kose following a partly recently upgraded and newly developed road. It geographically lies between the coordinate of 37°40'0"E to 38°0'0"E and 7°40'0"N to 8°20'0"N.

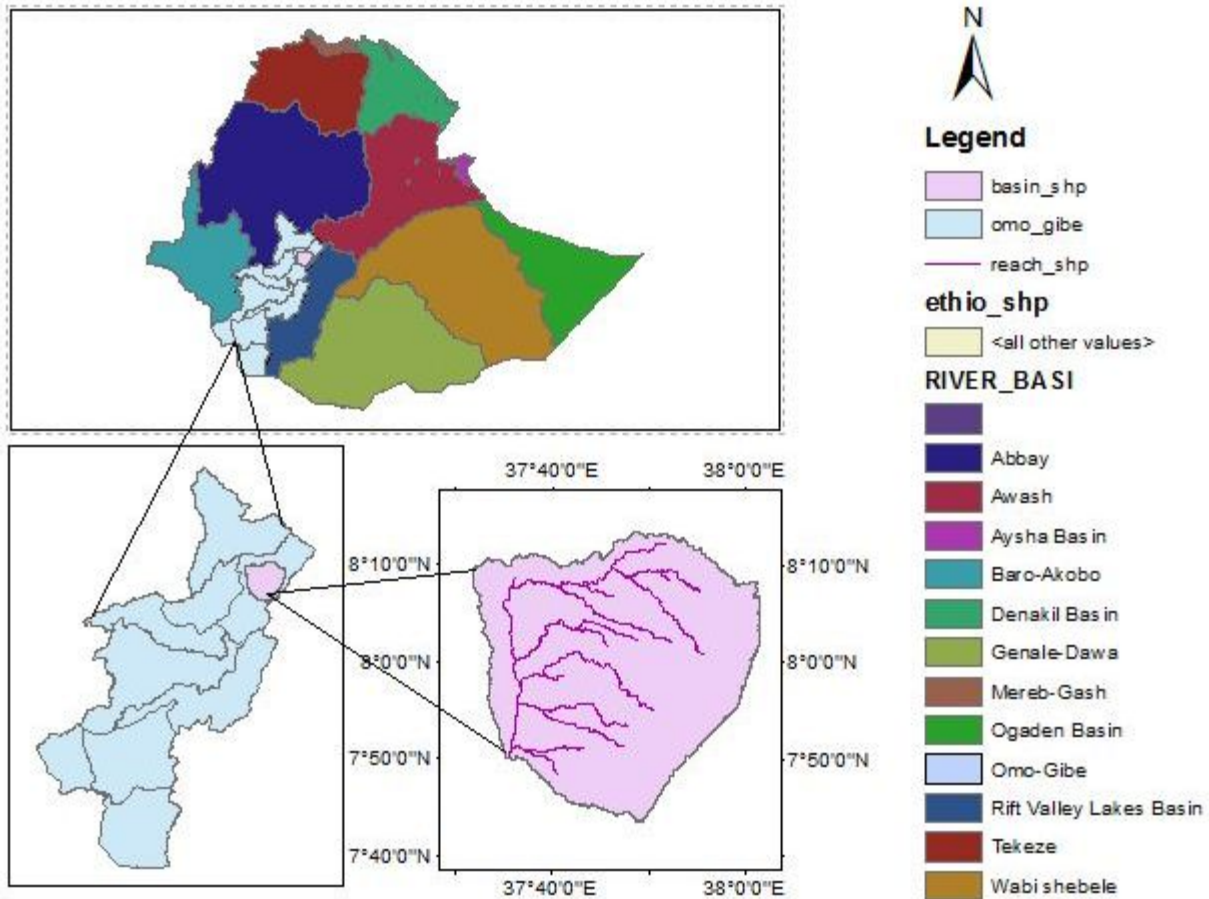


Figure 3.1: Map of Study area

3.3 Geology

The surface geology of the Gibe Sub basin is dominated by residual soils at relatively higher elevations and bed rock geology mainly ignimbrites invading the river bed and river banks (Daniel, 2011). The bedrock geology within the area of is identified to be consisted of two units, ignimbrites underlying the residual/ alluvial soils. The ignimbrites unit is characterized by weathered and fractured which ends to overlying reddish clay residual soils. The ignimbrite which invading the entire river bed at the site is characterized by slightly weathering and some minor local joints/fractures.

3.3.1 Digital Elevation Model

The topography and other important terrain characteristics of any watershed are derived from Digital Elevation Model (DEM) for hydrological simulation. Digital Elevation Model (DEM) describes the elevation of any point in a watershed as a specific spatial resolution.

ArcGIS 10.3 applied a digital elevation model for raster based hydrological analysis. DEMs of the study area with the resolution of 30m* 30m grid DEM has been used. SWAT model calculates all sub basins or reaches topographic parameters for the process of delineation of the watershed. These parameters such as defining of the stream network with its characteristics, channel slope, length, and width were determined by the DEM.

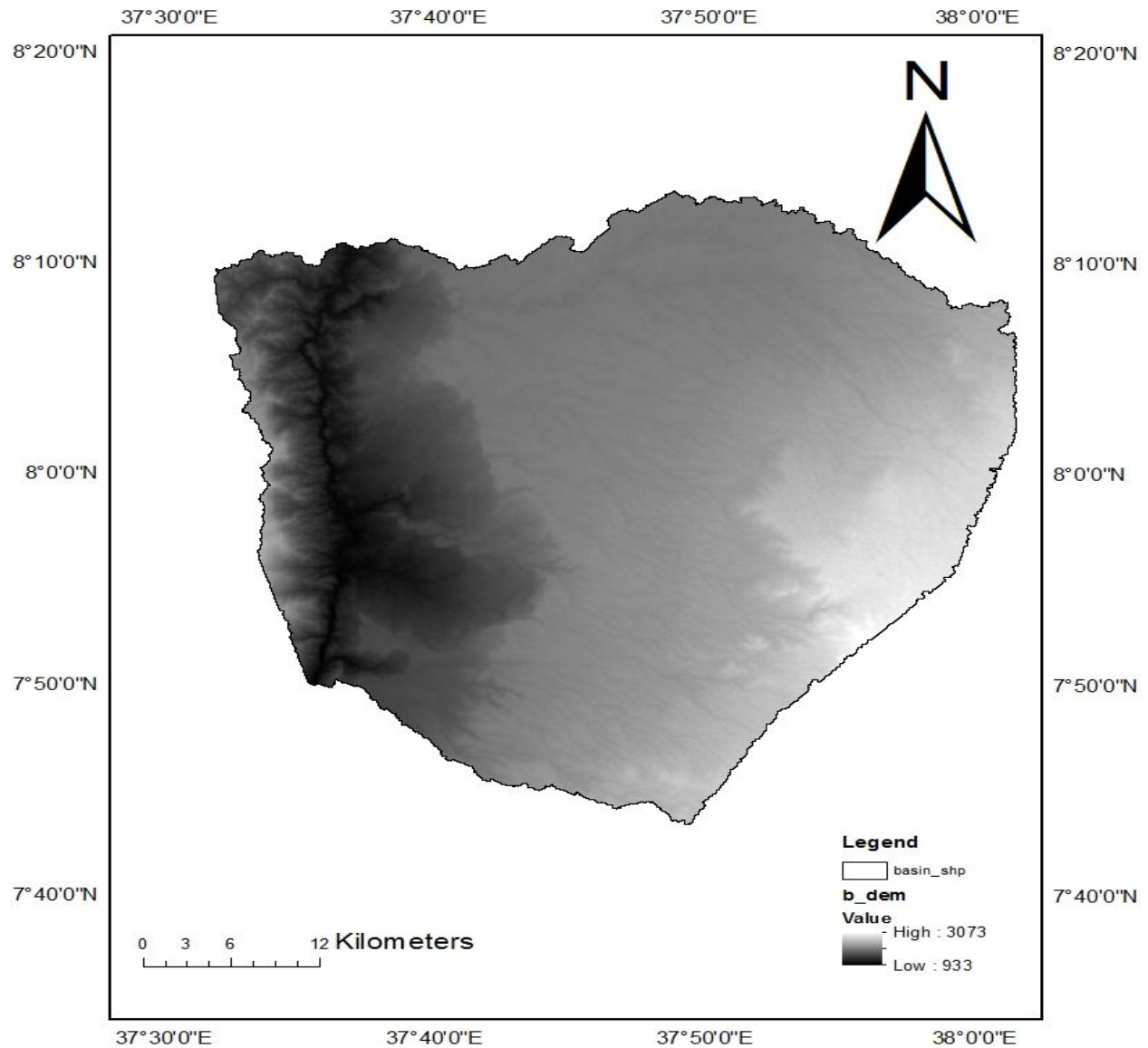


Figure 3.2: DEM of Watershed

3.3.2 Soil

The dominant soil type in the Watershed or the different soil types would enable to obtain information about the hydrologic soil group in the watershed. Based on the soil map developed by FAO, the dominant soil types are eutric Cambisols (22.8%), pellic vertisols (68.83%), Dystric fluvisols (1.27%), Orthic acrisol (0.70%), Leptosols (2.81%), eutric nitsols (3.20%), chromic Luvisol (4.37%), chromic Cambisols (0.26%), Orthic solonchaks (1.02%), Dystric nitsols (0.09%) and calcic xerosols (0.09%) of the watershed area.

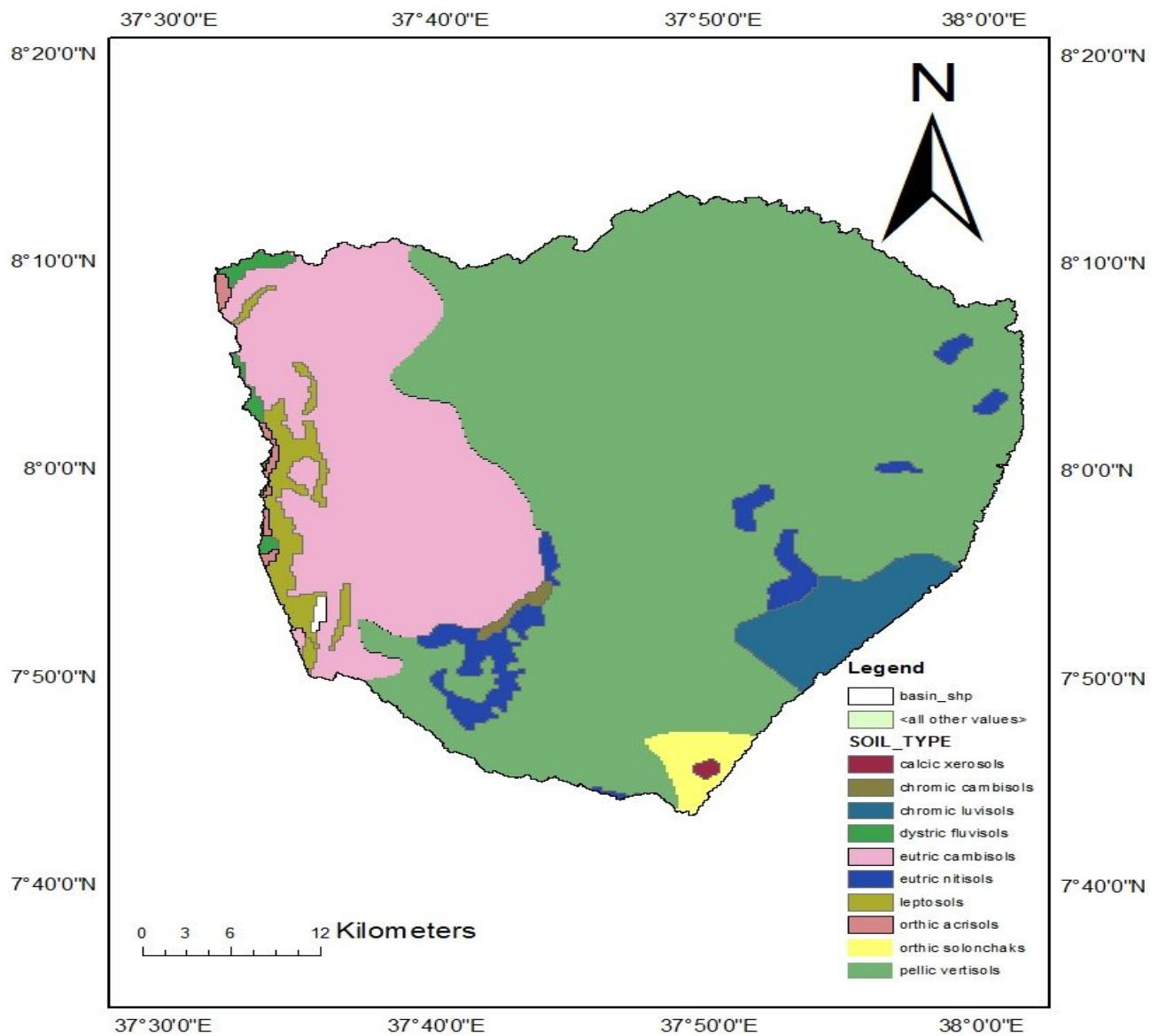


Figure 3.3: Map of Watershed Soil Classification

3.3.3 Land use

The dominant land use in the Watershed is agriculture. In the headwater sub-basin barley and wheat are commonly growing annual crops. Whereas "Enset (false banana) also dominantly cover much of the watershed. Such land use information is vital for the estimation of peak discharge generated in the catchment. Based on the land use map shown in figure 1.4, the agricultural land close grown (AGRC) comprises 65.76% of the total watershed area, forest mixed accounts 6.93% of the total watershed area, range grass accounts 1.87% and bushed shrubbed (range brush) comprises 25.44% of the watershed area.

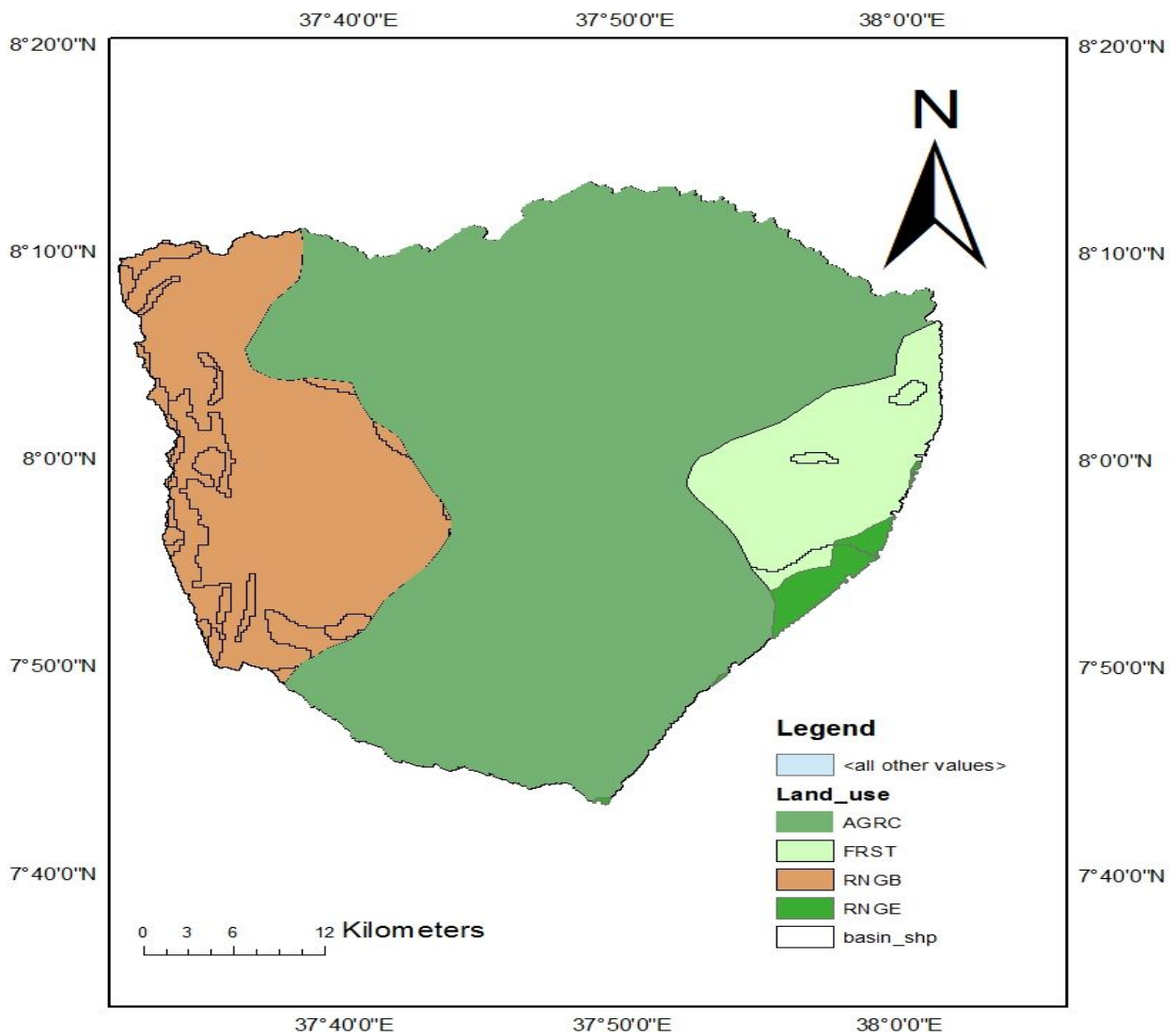


Figure 3.4: Land use Map of Watershed

3.4 Climate and Hydrology of the Study Area

3.4.1 Climate Data

3.4.1.1 Data Availability

The climatic Data availability in the study area is presented in Table 3.1

Table 3.1: Data availability in the study area

Climate Variable	Time Scale	Date Length	Station
Rainfall	Daily	1987-2018	Hosana
	Daily	1988-2017	Gunchire
	Daily	1987-2018	Fonko
	Daily	1985-2017	Welkite
	Daily	1985-2017	Sekoru
Temperature	Daily	1985-2018	Hosana
	Daily	1988-2017	Gunchire
	Daily	2016-2018	Fonko
	Daily	1985-2017	Welkite
	Daily	1985-2017	Sekoru
Humidity	Daily	2013-2018	Hosana
	Daily	2012-2017	Sekoru
Wind speed	Daily	1987-2015	Hosana
	Daily	1987-2016	Sekoru
Solar Radiation	Daily	1987-2018	Hosana
	Daily	2012-2017	Sekoru

3.4.1.2 Data Completion

Data completion is primary step before application of any data for hydrological studies. Most of the aforementioned data is complete. However, some variable exhibit missing records in the time series. Various methods are available to estimate missing rainfall records of gauged stations. The methods used for the analysis of data in this study are the normal-ratio method.

The Normal-Ratio Method (NRM) is used where the mean annual precipitation of any of the adjacent stations exceeds the station in question by more than 10% and it

$$P_x = \frac{Nx}{n} \left(\frac{Pa}{Na} + \frac{Pb}{Nb} + \frac{Pc}{Nc} \dots \frac{Pn}{Nn} \right) \dots \dots \dots \text{Equation (3.1)}$$

Where:

P_x is the precipitation for the station with missing records

$P_a, P_b, P_c, \dots, P_n$ are the adjacent stations precipitation

$N_a, N_b, N_c, \dots, N_n$ are long-term mean annual precipitation values at the respective stations.

3.4.1.3 Checking Homogeneity of Stations

If the probability of occurrence of a storm of a given intensity is the same throughout an area, then the area is said to be homogeneous. If the frequencies as well as the intensities of all the rains are the same at all place in such area. One of the methods to check homogeneity of the selected stations in the watershed is the non-dimensional rainfall records and plotted to compare the stations with each other (Garg, 1976).

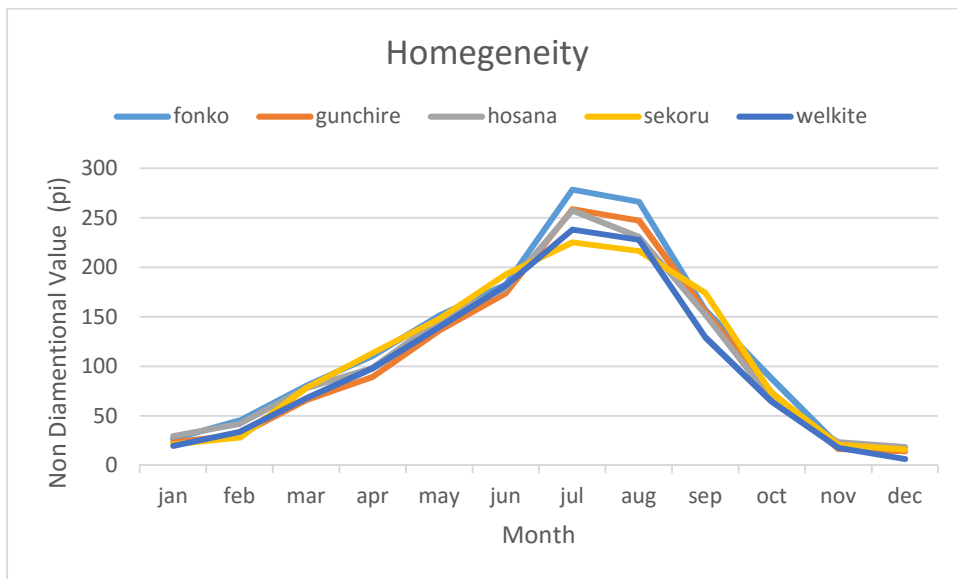


Figure 3.5: Non-dimensional plots of selected stations in the watershed

3.4.1.4 Test for consistency of record

Sometimes a significant change may occur in and around a particular rain gauge station. Such a change occurring in a particular year will start affecting the rain gauge data, being reported from that particular station. After a number of years, it may be felt that the data of that station is not giving consistent rainfall values. In order to detect any such inconsistency, and to correct and adjust the reported rainfall values, a technique, called double mass curve method is generally adopted (Garg, 1976).

a technique, called double mass curve method generally adopted (Garg, 1976).

$$P'_x = P_x \frac{M_c}{M_o} \dots\dots\dots \text{Equation 3.2}$$

Where: P'_x corrected precipitation at station x P_x is original recorded precipitation at station x, M_o is original slope of the double mass curve and M_c is corrected slope of the double mass curve.

The stations used in this study have not undergone a significant change during the study period (1990 – 2017). The lines are fairly smooth with no station displaying a strong or long-lasting break in slope

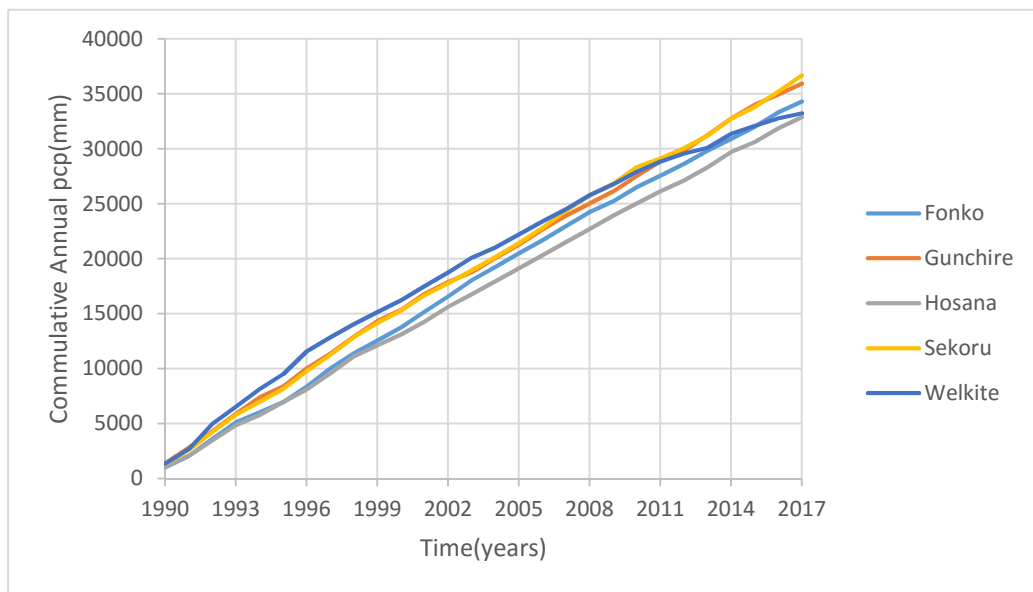


Figure 3.6: Double mass curve of stations of the watershed

3.4.1.5 Rainfall

The Long term mean monthly Rainfall computed at Gunchire and Welkite Climatic Stations base on the National Metrology Agency during the period (1990-2017) is presented in the figure3.4. The peak average Monthly rainfall appears through the months, July-August. The mean annual rainfall estimated at Gunchire station during the same period is 1267 mm/y similarly, the mean annual rainfall estimated at Welkite station during the same period is 1134 mm/y (see APPENDEX: A).

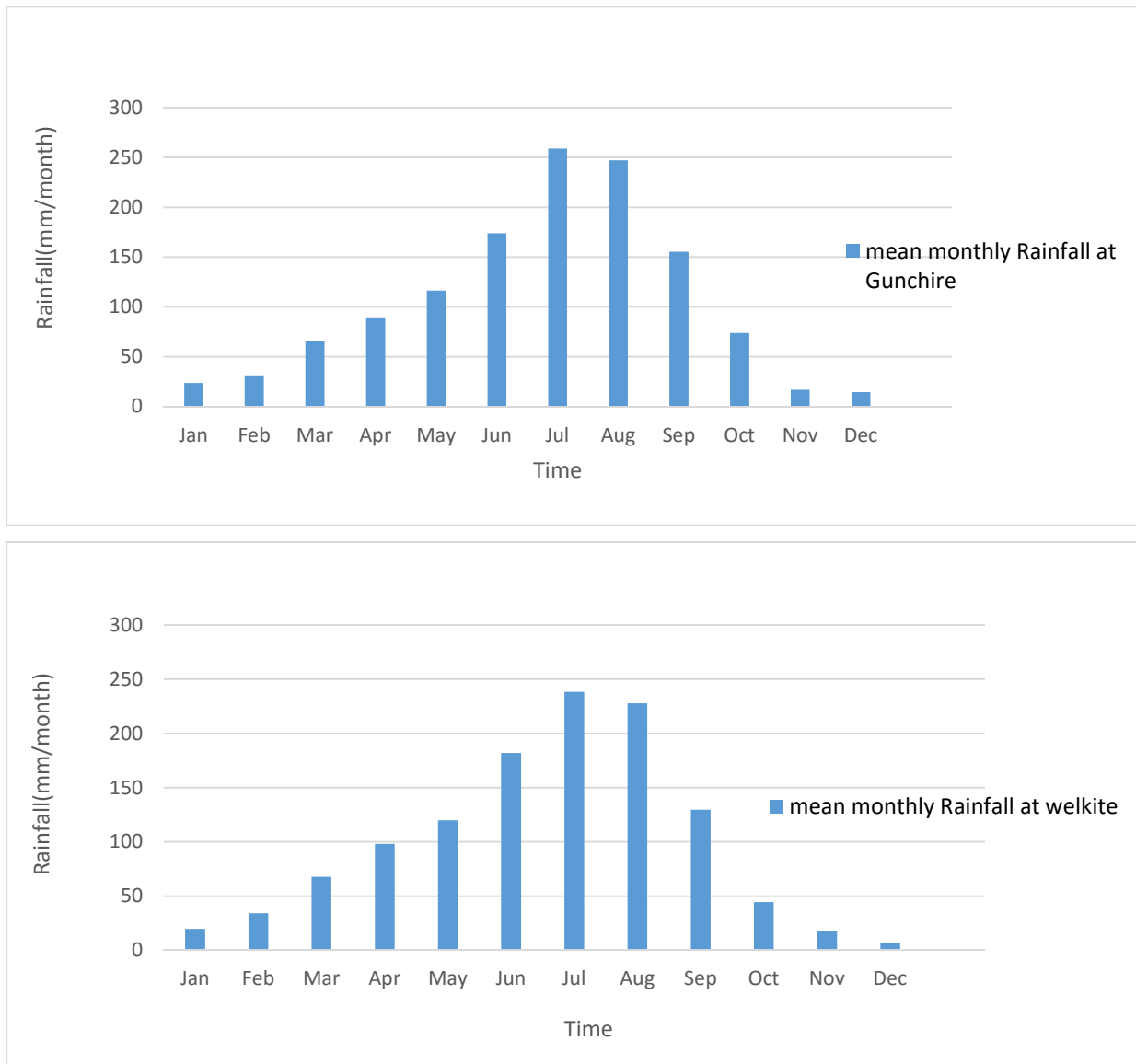


Figure 3.7: Long term mean monthly Rainfall (intra-annual variability) at Gunchire and Welkite Stations.

3.4.1.6 Temperature

The highest mean maximum monthly temperature at Welkite station computed during the period 1987-2017 observed in the months of February (29.3°C) and the lowest mean maximum temperature observed in the month of August (24.07°C). The long-term mean annual maximum temperature for the same period is 26.9°C. Similarly, the highest mean minimum temperature Computed during the same period observed in the month April (14.28°C) and the lowest mean monthly minimum temperature observed in the month of December (11.89°C). The computed long term mean annual mean minimum temperature during the same period is 13.11°C (see APPENDEX: B).

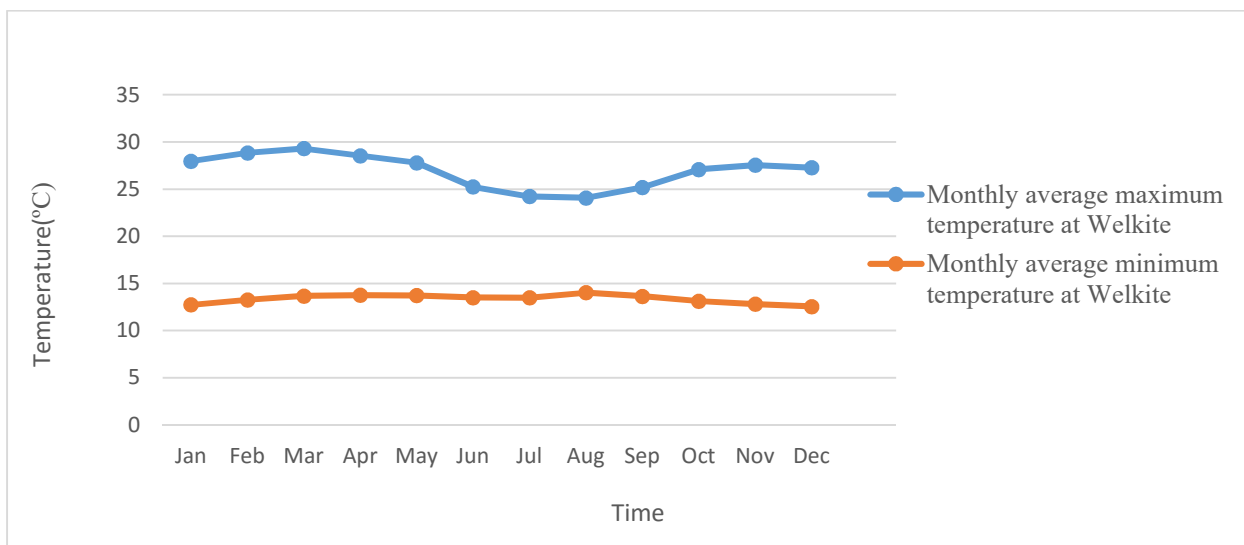


Figure 3.8: Long term mean monthly temperature at Welkite station (1987-2017)

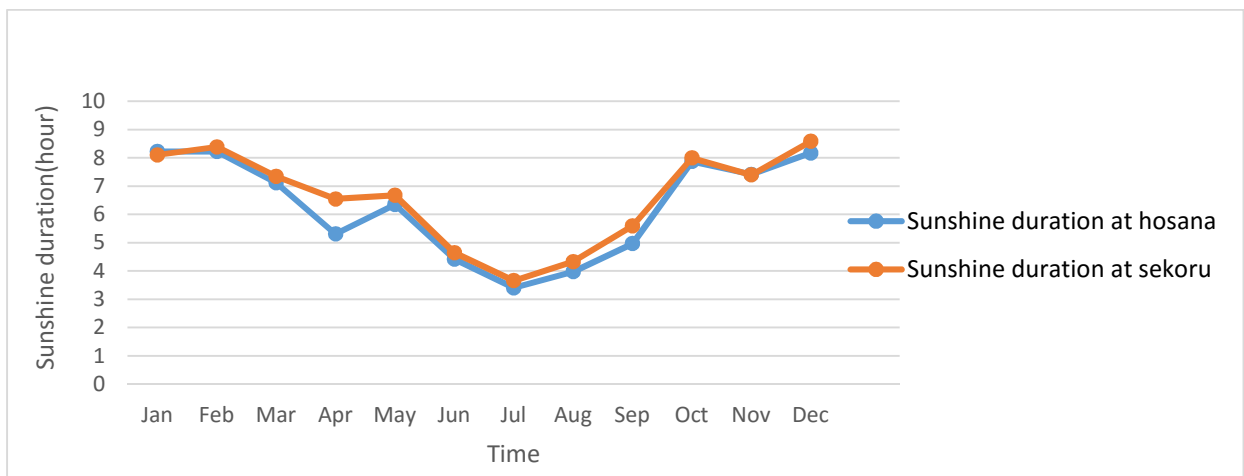


Figure 3.9: Intra annual variability of sunshine duration at hosana and Sekoru station over the period (2012-2018)

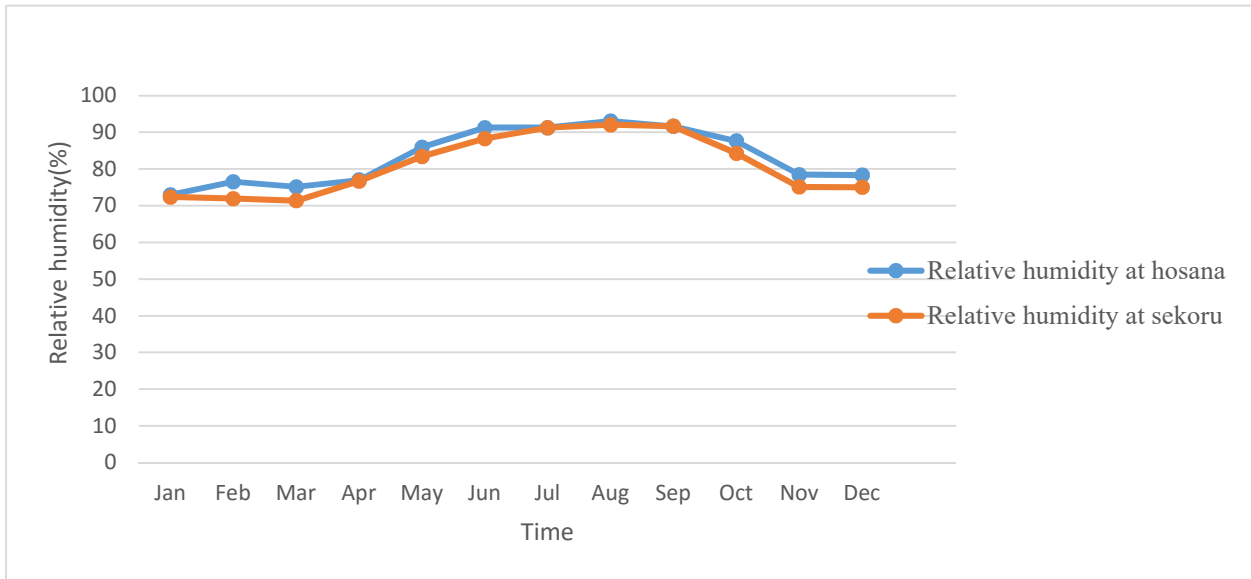


Figure 3.10: Intra annual Variability of Relative humidity at Hosana and Sekoru Stations over the period (1987-2017)

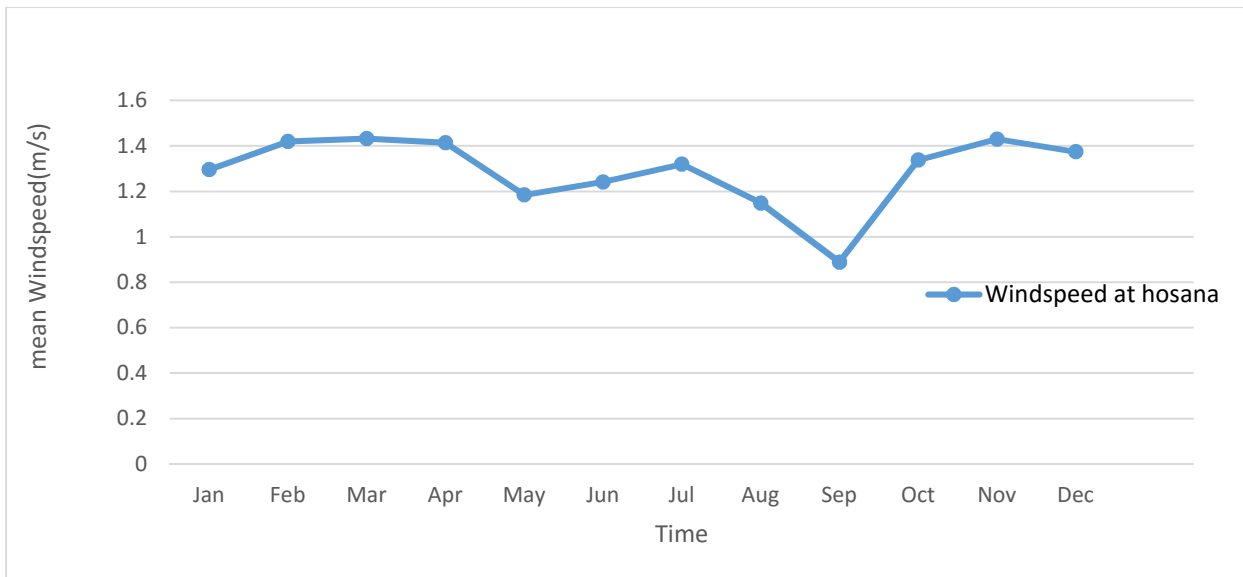


Figure 3.11: Intra annual variability of wind speed at Hosana station over the period (1987-2015)

3.5 Methodology

3.5.1 Model Input of SWAT

The quality and the quantity of data applied for SWAT model determine the performance of the model to account for the physical characteristics of that particular river basin or catchments. Hence, the model required the digital elevation model (DEM), land use/ land cover, soil layers, daily values of precipitation, maximum and minimum air temperature, solar radiation, relative humidity, and wind speed for the simulation of daily stream flow. If these meteorological data are not complete, then WXGEN weather generator of SWAT model generates these values to in-fill gaps in measured records using monthly average data over a number of years.

The model utilizes the DEM to create stream network, sub basin and delineate the watershed boundary of Central Gibe sub-Basin using the elevation or topographic data and also calculate the sub basin parameters for example the longest path distance and the slope of sub basin. Hydrological Response Unit (HRU) which is the smallest unit of the model to route stream flow was established after reclassification of land use and soil maps and then overlaid one upon each other. The threshold value was assigned to sub divide the watershed area into HRU which is an area having unique land use, soil and slope combinations.

Schematic linkage of Data Preparation for SWAT Model Simulation

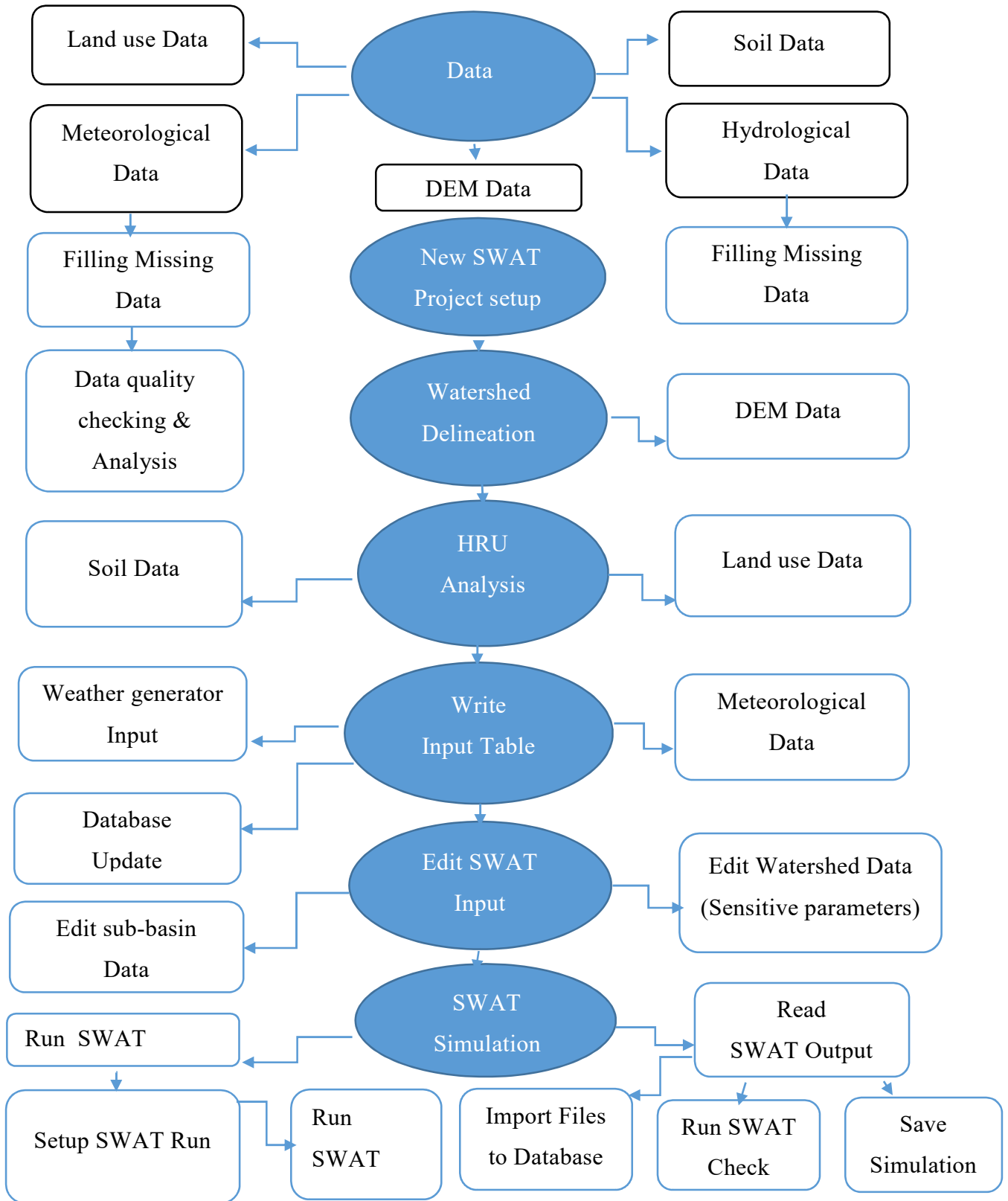


Figure 3.12: Steps in SWAT Model simulation

3.5.2 Soil Properties

The soil properties provide information about the physical characteristics of the land surface in a watershed that is essential to estimate the volume of water storage for each layer of soil profile in order to quantify the daily runoff. The soil data were obtained from the master plan project study of Omo Gibe River Basin which was prepared by EMWE. The classification was made according to the FAO-UNESCO Soil Classification System. All soils data were extracted from this database which is required by the SWAT model. For assimilation of the soil digital map with the SWAT model, a database that contains physical and chemical properties for each soil layers were prepared with it's an attribute table. The major soil classification map of the watershed area was made according to the FAO-UNESCO soil classification system.

3.5.3 Land Use

Land uses and/or land covers affect surface water runoff, groundwater flow, and evapotranspiration in a watershed. The available land use cover map for the study area was collected from the GIS and remote sensing department of MoIWE. This land cover map was reclassified using ArcGIS and the final land use map consists of 4 different classes. SWAT connects these codes with the land cover/plant growth database to simulate the growth of a particular land cover.

3.5.4 Climatic Input Data

Climate variables are the driving force in the hydrological water balance model which include precipitation, air temperature, solar radiation, wind speed and relative humidity. SWAT needs daily weather data which can be supplied either directly from a recorded measured data or generated using a weather generator model. The minimum required daily data in the SWAT model for transformation of the rainfall to runoff are precipitation, maximum and minimum air temperature, and the others climate variables like solar radiation, wind speed and humidity are derived using the weather generator model.

The climate variables utilized for the model were obtained from ENMA for five meteorological stations within the Omo Gibe River Basin. Since the majority of the meteorological stations are second class, the available data are mainly rainfall and temperature.

3.5.5 Hydrological Model SWAT

Hydrologic models are simplified, conceptual representations of a part of the hydrology cycle and they are primarily used to describe the physical processes controlling the transformation of precipitation to runoff. Nowadays, there are various hydrologic models are developed with different structural characteristics. Numerous researchers classified these models based on their views and objectives (Shaw, 1983; Chow et al., 1988; and Gosain et al., 2009).

3.5.6 Hydrological Flow Data

The hydrological flow data are important for routing of stream flows and calibration of the hydrology model for the watershed. Daily flow data of Megecha gauge stations were gathered from the Department of the Hydrology section in Ethiopian Ministry of Water Irrigation and Energy, the hydrological flow data are collected from 1990 to 2006.

3.5.7 HRU Analysis

In SWAT, there are two methods to determine the HRU distribution. The first method is to assign a single HRU to each sub watershed and/or the second one is to assign multiple HRUs to each sub watershed. If a single HRU per sub basin is selected, the HRU is determined by the dominant land use category, soil type, and slope class within each watershed. Whereas if multiple HRUs are selected, the major land use, soil, and slope data can be specified that will be used to determining the number and type of HRUs in each watershed. For this study, multiple HRU was selected and the land use was reclassified into three broad categories depending on the 20% threshold which is the default value of SWAT model which is compatible with the SWAT naming convention. This doesn't mean that there are one land cover types, rather it means that those land cover types which are less than 20% are ignored and the area of the remaining land uses is reapportionment so that 100% of the land area in the sub basin is modeled. Based on the above procedure, the land covers in watershed are agricultural land close grown (AGRC) comprises 65.76% of the total watershed area, forest mixed (FRST) accounts 6.93% of the total watershed area, range grass (RNGE) accounts 1.87% and bushed shrubbed (range brush) (RNGB) comprises 25.44% of the watershed area. Similarly, on the basis of 10% default threshold of soil type in watershed.

The dominant soil type in the Watershed or the different soil types would enable to obtain information about the hydrologic soil group in the watershed. Based on the soil map developed by FAO, the dominant soil types are eutric Cambisols (22.8%), pellic vertisols (68.83%), Dystric fluvisols (1.27%), Orthic acrisol (0.70%), Leptosols (2.81%), eutric nitsols (3.20%), chromic Luvisol (4.37%), chromic Cambisols (0.26%), Orthic solonchaks (1.02%), Dystric nitsols (0.09%) and calcic xerosols (0.09%) of the watershed area.

3.6 SWAT Model Performance and Evaluation

3.6.1 SWAT-CUP

SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be linked to SWAT. A schematic of the linkage between SWAT and SUFI-2 optimization programs is illustrated in the Figure 3.11. Automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The main function of an interface is to provide a link between the input/output of a calibration program and the model. The simplest way of handling the file exchange is through text file formats (Karim C. Abbaspo).

3.6.2 Sensitivity Analysis

Sensitivity analysis is the systematic process of detecting the highest influential model parameters for model calibration and model predictions. This describes the ratio of the change in model output to a change in the model input parameter. It explains how a given specified range of input parameters applied on the model will affect the model output. Depending on some researchers, they pointed out that sensitivity analysis and calibration in SWAT are difficult and time consuming processes owing to estimation of large number of parameters. Hence, the main benefit of sensitivity analysis is reducing the number of parameters that must be estimated during the calibration of the model. In doing so, one can minimize the time required for computation of model calibration as well as efforts required in estimating the various input parameters.

SWAT Model is one of semi distributed watershed model that required a number of physical

and process parameters to describe hydrological, climatic, water quality, land management within a watershed. These made the calibration of the model complex to a specific watershed area due to the number of parameters to be estimated as well as the possible associations' among each other (Vandenberghe et al., 2002). Due to this fact, many researchers have suggested that sensitivity analysis should be conducted prior to model calibration in order to identify the most sensitive parameters that describe the model parameters. Sensitivity analysis and calibration were carried out for Megecha sub-watersheds of Gibe sub-basin, for the calibration step of this study.

Based on sensitivity analysis, the most important model parameters were distinguished with great attention, otherwise an insignificant change in the values of the model will bring large change in the model output for some parameters. Hence, it is indispensable to give more emphasis in selecting the best possible values of the input parameters. Whereas the other model parameters that have low sensitivity can be neglected in the process of calibration because small changes in their values do not cause large changes in model output.

3.6.3 Calibration

SWAT models contain several parameters in which they are grouped into physical and process parameters. A physical parameter contains the physical properties of the watershed that can easily be measured for instance the areas of the catchment, fraction of impervious area, surface area of water bodies, and surface slope. Process parameters contain certain properties of the watershed that cannot be straightforward measured owing to spatial and temporal variability. Such parameters are for example effective depth of surface soil moisture storage, the effective lateral inflow rate, the coefficient of nonlinearity controlling the rate of percolation to the groundwater (Sorooshian and Gupta, 1995). Hence, in order to control the above problem, one needs to use the physical process hydrology model to select the estimated values of the model parameters in order to predict the potential future management of the model to closely represent the real characteristics of the watershed area.

The values of process parameters are selected for simulation during the model calibration process. To achieve this, two important processes have to be accomplished during calibration. The first step is the parameter specification and the other is parameter estimation. In the former process specification of the initial parameters using the information about the watershed properties and behaviors. Subsequently, it was followed by physical parameter estimation based

on the measurements obtained from the fields. The measured parameters will not be adjusted by the model unless it has uncertainty in their values.

Nonetheless, for the process parameters estimates of the range of possible values are established based on the judgment and understanding of the hydrology of the watershed. There are various techniques designed to reduce uncertainty in the estimation of the process parameters during parameter estimation. The typical approach is selecting an initial value of estimating within the specified range. Consecutively followed by adjusting the parameter values till the model behavior closely matches the watershed. This process of adjustment can be done manually or using computer-based automatic methods. As it is mentioned above the objective of a calibration procedure is the estimation of values for those parameters, which cannot be assessed directly from field data. According to Refsgaard and Storm (1996), three types of calibration procedures can be identified Trial-and-error (i.e., manual parameter adjustment); Automatic (numerical parameter optimization); and a combination of manual and automat.

3.6.4 Validation

The model should be tested with independent data without any adjustment on the parametric values of calibration in order to evaluate the efficiency of the model for future predictions of the water management of the watershed. This testing procedure of the model with an independent data set is commonly referred to as model validation. Model calibration identifies the best or at least a reasonable parameter whereas validation proves that the calibrated parameters are reasonably performed well under an independent data.

3.6.5 Model Efficiency

For the evaluation of the calibration (and validation) performance of the model, two statistical parameters namely R^2 = the squared correlation coefficient between the observed and simulated output, which in SWAT is usually the stream flow, and NS = the Nash-Sutcliffe efficiency parameter, are evaluated. Values of $R^2 > 0.6$ and $NS > 0.5$ for the calibration of the daily and monthly simulated stream flow are usually considered as adequate for an acceptable calibration (Santhi et. al., 2001).

1. Coefficient of determination (R^2) is calculated as

The range of values of coefficient of determination between observed discharge (Q_m) and simulation discharge (Q_s) is 1.0 (best) to 0.0 (worst). This coefficient measures the fraction of

the variation in the measured data that is replicated in the simulated model results. A value of 0.0 for R^2 means that none of the variance in the measured data is replicated by the model predictions. On the other hand, a value of 1.0 indicates that all of the variance in the measured data is replicated by the model predictions.

$$R^2 = \frac{\sum(Q_{mi} - Q_m) * (Q_{si} - Q_s)}{\sum(Q_{mi} - Q_s)^2} \dots \dots \dots \text{Equation (3.3)}$$

2. NS: Nash-Sutcliffe (1970) coefficient calculated as

The statistical index of modeling efficiency (NS) values range from 1.0 (best) to negative infinity. NS is a tough test of performance than R^2 and is never larger than R^2 . NS measures how well the simulated (Q_s) results predict the measured data (Q_m) relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison. A value of 0.0 for NS means that the model predictions are just as accurate as using the measured data average (Q_m) to predict the measured data. NS values less than 0.0 indicate the measured data average is a better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average. This measure is highly affected by a few extreme errors and can be biased if a wide range of flow events is experienced.

$$NS = 1 - \frac{\sum(Q_m - Q_s)^2}{\sum(Q_m - Q_m)^2} \dots \dots \dots \text{Equation (3.4)}$$

Source SWAT CUP-4 User's Manual, (Abbaspour, 2011)

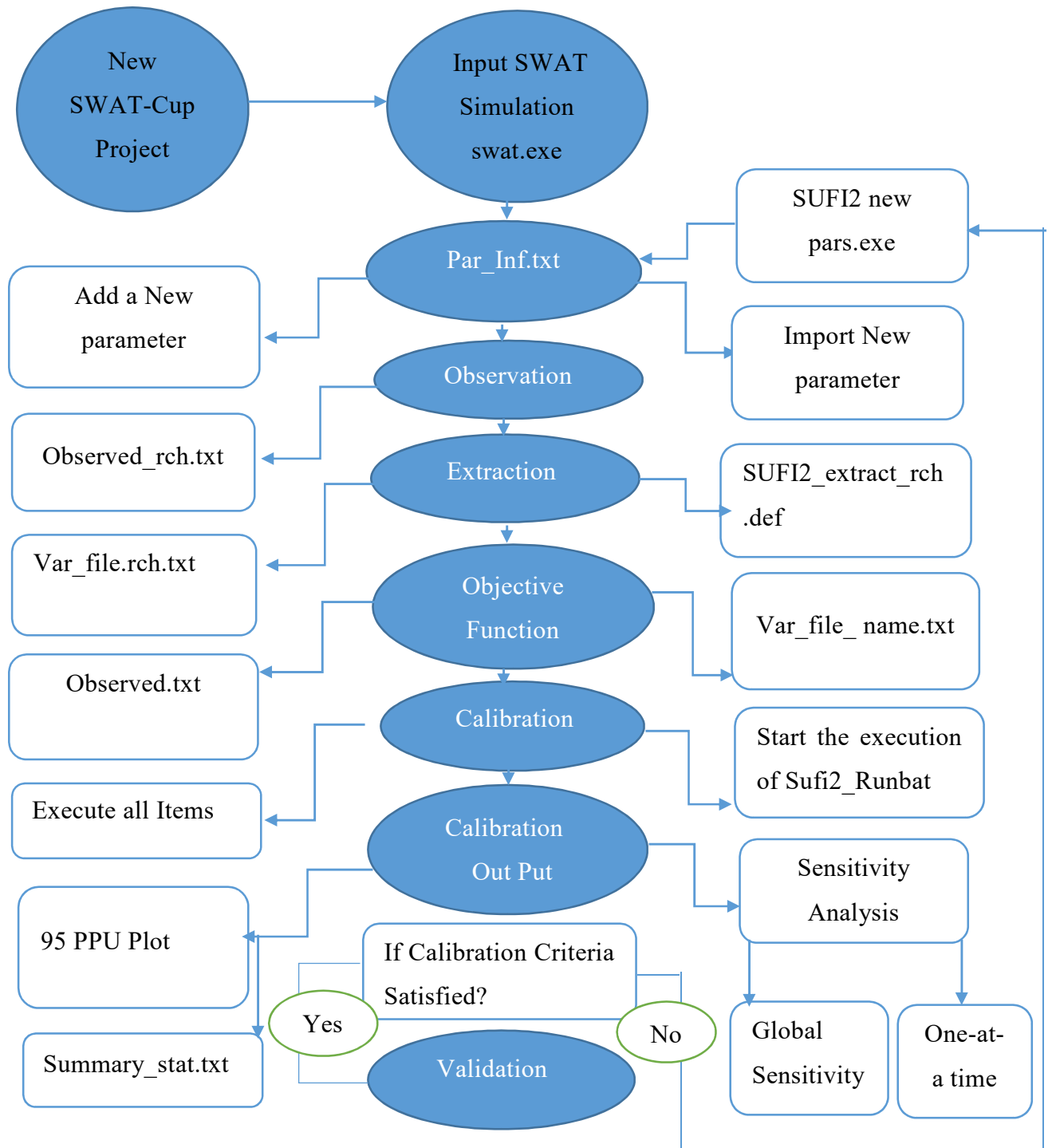


Figure 3.13 Schematic of the linkage between SWAT, SWAT-CUP (SUFI-2) optimization program

3.7 Selection of Potential Development Sites

The potential sites that are suitable for hydropower generation are selected by considering different parameters such as Site identification considering river gradient and catchment area, Identification based on waterway construction conditions, & Identification Based on Local Information In cases where potential sites cannot be interpreted on the topographical map because of the small usable head or the presence of a fall or pool, for this study the two basic parameters that are considered is discussed below.

(1) Level of firm discharge

While it is difficult to judge the suitability for development based on the absolute volume of firm discharge, a potential site with a relatively high level of firm discharge is more favorable site for a micro-hydro plant designed to supply power throughout the year.

(2) L/H [ratio between waterway length (L) and total head (H)]

A site with a smaller L/H value is more advantageous for small-scale hydropower. Figure 3.14 shows the relation of the ratio between the total head (H) and the waterway length (L) (L/H) among existing small-scale hydropower sites where the total head is not less than 10 m (the minimum head which can be interpreted on an existing topographical map). As clearly indicated in the figure, the L/H of micro hydro is generally not higher than 40 or is an average of 25. (DEUMB, 2009).

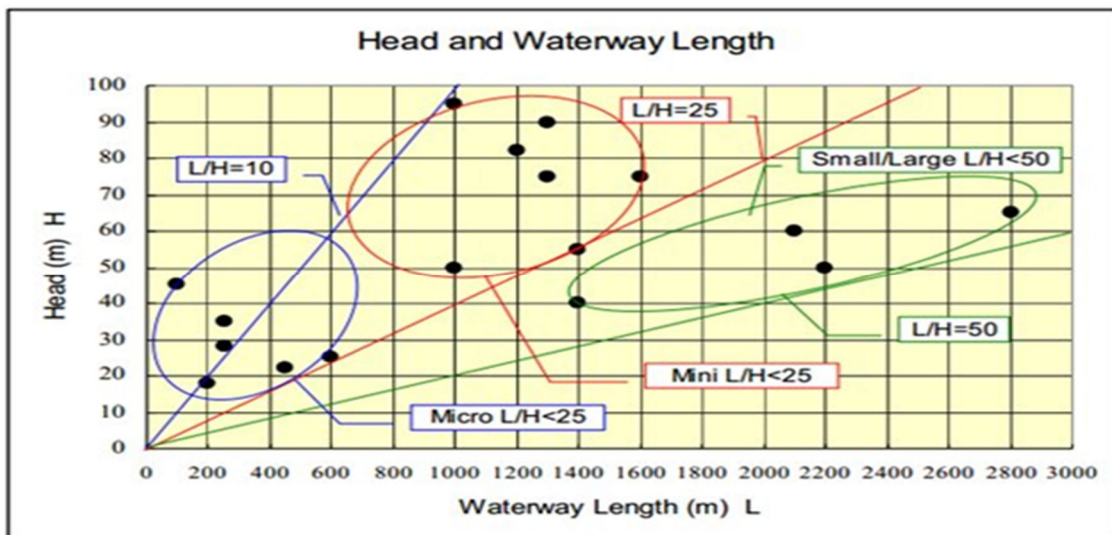


Figure 3.14: Relation between water way length and Head

3.7.1 Calculating theoretical available power

Once the flow duration curve for the sites selected is established, the next step was estimation of potential power and energy. Before any power plant is contemplated it is essential to assess the inherent power available from the discharge of the river and the head available at the site. The theoretical potential power of a river can be expressed as:

$$P = \gamma qgh \dots\dots\dots \text{Equation (3.5)}$$

Where

γ - unit weight of water=1000kg/m³

q -flow or discharge of the river=m³/s

g - gravity=m³/s

h - drop of potential head=m

This expression written in terms of horse power & kilo watt would be

$$P = 1000qh/75 = 13.33(hp)$$

$$P = 0.736 * 13.33Qgh = 9.8QH (KW) \dots\dots\dots \text{Equation (3.6)}$$

The actual use of the above equation is difficult due to the fact that the discharge of any river varies over a wide range. High discharges are available only for short durations in a year. The corresponding available power would be of short duration. Thus the available power obtained from a given river can be classified according to the following types.

(I) Minimum potential power computed from the minimum flow available 100 percent of time, i.e., for all 365 days or 8760 hours, P100

(II) Small potential power computed from the flow available for 95 percent of time, i.e., flow available for 8322 hours, P95.

(III) Average potential power computed from the flow available for 50 percent of time, i.e., flow available for 6 months or 4380 hours, P50.

(IV) Mean potential power computed from the average of mean yearly flows for a period of 10 to 30 years, which is equal to the area of the flow-duration curve corresponding to this mean year. This is known as Gross river power potential, represented as P_m.

(V) Maximum Potential Power computed from the flow available for 25 to 35 percent of time (U.S. Department of Energy, 1983).

It can be seen that the evaluation of the average flow is a complicated problem and will be close to the correct value only when obtained from an average flow duration curve based on a

flow data of a longer period. For this study, a flow data of 28 years' simulation result is used. Technically available power is obtained by including losses due to conveyance, plant losses such as entrance loss, rack loss, generator and turbine loss etc. For MHP, the overall efficiency, η , of 50% is multiplied with the theoretical power to obtain technically available power. The low overall efficiency is as a result of the following losses (Harvey, 1998. as cited in Keneni 2007; John, 2014; Mubarek, 2017).

- Channel loss = 5%
- Penstock losses = 10%
- Turbine losses = 20%
- Generator losses = 15.4%
- Step-up and down transformer losses = 4%
- Transmission losses = 10%

Power output is obtained after all these losses are considered.

Power output = Power input * conversion efficiency

Power output = $0.95 * 0.9 * 0.8 * 0.84 * 0.96 * 0.9$ Power input

Power output = $0.5 * \text{Power input}$

Therefore, overall efficiency, η for MHP = 0.5

Power output = $9.81 \eta Q H$ (Kw)

$P = 4.9 Q H$ (Kw)..... Equation (3.7)

3.7.2 Stream flow and Head of flow

In the assessment of any hydropower plants potential, flow of water and head are essential. It is because the power generated by the HP plant is normally dependent on stream flow and head of flow.

3.7.3 Stream flow

Two methods are widely used for analysis of stream flow data as a primary estimation of power. Potential-flow-duration curve (FDC) and sequential stream flow routing (SSR). The flow duration curve method is better method for all preliminary or screening studies. This method is also the best choice for high-head, run-of-river projects where head is generally fixed or even for low-head projects where head varies with discharge. For multipurpose storage projects, the SSR method is more appropriate and also can be used for examining the feasibility

of including power at new water conservation or flood control projects. For peaking and pumped storage projects, hourly SSR routing is required (Mohammed et al., 2003).

Flow-duration curves (FDC) were used to summarize stream flow characteristics and can be constructed from daily, weekly, or monthly stream flow data. These curves show the percentage of time that flow equals or exceeds various values during the period of record, for example $Q(50, \text{daily})$ is the flow which is reached or exceeded statistically in 50% of the time, meaning in an average year at 50% of 365 days. However, these curves are useful for evaluating the power output of run-of-river projects and for other power projects where head varies directly with flow (EM11110-2-1701, 1985, As cited in Nardos 2011).

There are two computing ordinates for plotting flow duration curve, viz. the rank-ordered technique and the class-interval technique. The rank-ordered technique considers a total time series of flow that represent equal increments of time for each measurement value, such as mean daily, weekly, or monthly flows, and ranks the flows according to magnitude. To develop the flow-duration curve, the observed stream flows should be arranged in descending magnitude. Then the data are ranked, the largest beginning with order 1, from 1 to total number of data. The probability of exceedance is estimated by the following relation The FDC is plotted according to the above procedure (Mohammed et al., 2003) whereas in class-interval technique the time series of flow values are categorized in to class intervals, the classes range from the highest flow value to in the series to the lowest value in the time series.

A tally is made of the number of flow in each, and by summation the number of values greater than a given upper limit of the classes can be determined. The number of flows greater than a given upper limit of the class can be divide by the total number of flow values in the data series to obtain the exceedance percentage. The value of the flow for the particular upper limit of the class interval is then plotted versus the computed exceedance percent (Warnick et al., 1984As cited in Nardos 2011).

Then after plotting FDC a flow value is selected to become a design flow for the generation of Power. The flow rate value ($Q(\% \text{daily})$, $Q(\% \text{weekly})$, & $Q(\% \text{monthly})$), taken for run-off-river scheme varies from literature to literature.

3.7.4 Gross head & net Head

To estimate the hydropower potential of any site hydrological data and physical characteristic of the site should be known. Gross head is one of the physical characteristic of the site

and measuring is carried out using different techniques. For this research work the gross head was read from the topographic map of scale 1:50000. Having established the gross head available, the head losses that include losses due to conveyance, plant losses such as entrance loss, rack loss, generator and turbine loss etc. were considered to get the net head.

3.7.5 Comparison of Flow-duration curves from monthly and daily data

A flow-duration plotted using monthly average flow has a tendency towards a higher design discharge that sometimes produces quite larger errors. This is because the monthly average used will mask within-month variation. Consequently, it is necessary to obtain an average daily flow Series, as far as possible, in order to build a daily flow duration curve (Tong Zheng Wang Haiding-1996 as cited in Tamene 2004).

Considers the determination of the average daily Flows-duration curve as the unquestionably most important hydrological input for the dependent power, energy, and economic studies of hydropower project (Ramsahoye 1982 as cited in Tamene 2004). Especially when it is desired to provide investors and lenders with certainty, conservative estimate of stream flow is considered appropriate. However, the analysis based on monthly data is useful to make preliminary insight in to the design. (Tamene 2004).

4. Results and Discussions

4.1 Modeling of Megecha sub-watershed

The megecha sub-watershed is located at the upper section of the Watershed which encompasses 19 sub basins delineated at the outlet of Megecha gauging station. It has an area of 95.142km². Weather data at the Megecha sub watershed were analyzed from the gauging stations of precipitation and temperature located around and within the sub watershed. These data are from 1990-2017 daily observations of precipitation, maximum and minimum temperature. The corresponding daily stream flow measured over 14 years (1993-2006) hydrological observation data at Megecha gauging station was collected from hydrology department of MoWIE.

4.1.1 HRU Analysis

In SWAT, there are two methods to determine the HRU distribution. The first method is to assign a single HRU to each sub watershed and/or the second one is to assign multiple HRUs to each sub watershed. If a single HRU per sub basin is selected, the HRU is determined by the dominant land use category, soil type, and slope class within each watershed. Whereas if multiple HRUs are selected, the major land use, soil, and slope data can be specified that will be used to determining the number and type of HRUs in each watershed. For this study, multiple HRU was selected and the land use was reclassified into three broad categories depending on the 20% threshold which is the default value of SWAT model which is compatible with the SWAT naming convention. This doesn't mean that there are one land cover types, rather it means that those land cover types which are less than 20% are ignored and the area of the remaining land uses is reapportionment so that 100% of the land area in the sub basin is modeled. Based on the above procedure, the land covers in Megecha sub watershed are agricultural land–close-grown (AGRC). Similarly, on the basis of 10% default threshold of soil type in Megecha sub watershed Chromic Luvisols (LVx).

Further, overlaying of the land cover, soil and slope selected in defining the HRU definition using the default threshold values, the Megecha sub watershed was subdivide into 19 HRU having unique land use and soil combinations that enables the model to reflect differences in evapotranspiration and other hydrology conditions for land cover/crop and soil. Runoff is predicted separately for each HRU and routed to obtain the total runoff at the outlet of the

sub watershed. This increases the accuracy of load predictions and provides a much better physical description of the water balance of the study area.

4.1.2 SWAT Simulation

The first step is to setup is period of simulation After the pre-processing of the data and SWAT model set up, simulation was done for the period 1990 to 2006 and the simulation for 1990-1993 was considered as a warm-up for the model but the rest of the years i.e., from 1993 to 2006 were used for Sensitivity Analysis.

4.1.3 Sensitivity Analysis (SA) of the model at Megecha sub watershed

The sensitivity analysis was conducted to provide roughly estimated values before adjusting sensitive input parameters during the calibration period. SA was procedurally conducted utilizing two steps to select the most sensitive parameters in the model. At the beginning twenty-six parameters were taken into consideration in SA within the SWAT model. From these, the most seven sensitive parameters were found that affect stream flow within the SWAT model and the other remaining parameters were obtained no significant effect on monthly stream flow simulations at Megecha sub-watershed.

As the initial procedure, which is manual calibration is labor intensive and time consuming; automatic SA was conducted in SWAT by means of the SWAT-CUP interface (Abbaspour et al., 2007). SWAT-CUP is an extension of the SWAT model, and parameter sensitivities are determined by calculating the multiple regression system, which regresses the Latin hypercube generated parameters against the objective function values in SUFI-2. The SUFI-2 parameter estimation procedure (Abbaspour et al., 2004) calculates the measurement of sensitivity and uncertainty for each of the calibration parameters during the optimization process. The SWAT-CUP, measure of relative sensitivity and significance of sensitivity are expressed using the values of t-statistics and the corresponding p-values respectively.

The results of the automated SA indicate that there are seven most sensitive parameters in decreasing order; taken into account their p-values of statistical significance (see Table 4.1).

Table 4.1: Relative sensitivities of the optimized parameters for Megecha sub-watershed

No	Parameter	P-value	t-stat	Fitted value

1	V_CN2.mgt	0.000000000	-31.977876978	75.067734
2	V_GWDELAY.gw	0.000000014	-5.718456105	29.310848
3	V__SOL_AWC.sol	0.245095822	1.163032953	0.394440
4	V__ALPHA_BNK.rte	0.278830949	-1.083542576	0.407043
5	V__CH_K2.rte	0.403808734	-0.835195516	12.945768
6	V__SOL_K.sol	0.650683364	0.452950598	0.479564
7	V_ALPHA_BF.gw	0.880819927	0.149968532	0.168101

1. p-value determines the significance of the sensitivity. A value closer to zero denotes more significance.

2. t-stat provides a measure of the sensitivity. A larger absolute values indicates a sensitive parameter

From Table 4.1, some of the most sensitivity parameters namely Base Flow Alpha factor (V_ALPHA_BF.gw), Ground water delay (V_GWDELAY.gw), Saturated hydraulic conductivity (V_SOL_K (1).sol), Available water capacity of the soil layer (V_SOL_AWC (1).sol), Base flow factor (V_ALPHA_BNK.rte), Effective Hydraulic Conductivity in main channel alluvium (V_CH_K2.rte) and Initial SCS runoff Curve No for moisture condition II (V_CN2.mgt).

4.1.4 Calibration of the model at Megecha sub watershed

Subsequently the calibration of the model was performed using only the most significant sensitive model parameters that were distinguished in SWAT-CUP. The main targets of the calibration of the model is continuous daily and monthly stream flow observed at gauging station Megecha between January 1, 1990 and December 31, 2001. Out of the 12-year long calibration period, the first three years from January 1, 1990 to December 1992 were utilized as "warm-up" to allow for the hydrologic processes to reach initial equilibrium. The iteration of calibration processes was continued till satisfactory results obtained from the simulation by observing the model performance indicators which are calculated simultaneously in each steps.

For prediction of the model performance, frequently used statistical model Reference measures, namely R^2 =coefficient of determination and NS=the Nash-Sutcliffe simulation efficiency (Nash and Sutcliffe, 1970) were applied. These Reference measures were utilized between the observed and simulated daily and monthly stream outflows. Depending on Ramanarayanan et al., (1997), for the model to be accepted or satisfactory for model prediction, the model performance statistics should be $R^2 > 0.6$ and $NS > 0.5$ for daily simulated value (Santhi et. al., 2001). These values are considered as adequate statistical values for acceptable model calibration. Hence, the performance of the calibration is based on R^2 and NS between the simulated and measured daily and monthly discharge as well as a visual comparison of the simulated and measured stream flows hydrographs (Figure4.1).

Therefore, the values for R^2 and for NS parameter for the fit of the Monthly stream flows are $R^2 =0.66$ and $NS= 0.60$. (See APPENDIX: E). Based on the performance statistical parameters of the model for prediction, the model is satisfactorily accepted. Nonetheless, the model succeeds the performance criteria, it doesn't capture the continuous simulation time range for instance base flows for the month case. To explain this, further study is required to clarify this disagreement (Seyoum and Koch, 2013).

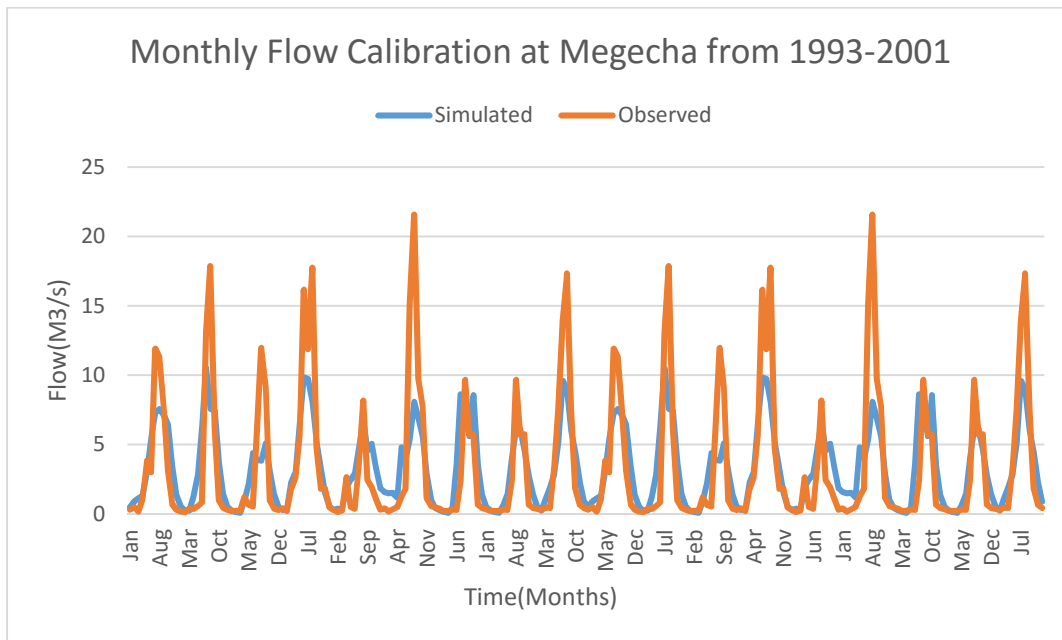


Figure 4.1: Observed and Simulated Monthly Flow Calibration at Megecha River for the period (1993-2001)

4.1.5 Validation of the model at Megecha sub watershed

Flow validation was performed with an independent data with the aim to guarantee the model whether it has the capability to predict a hydrological response variable for future time periods or conditions. In this case, the calibrated parameters are unchanged and an independent data further than previously used were applied during the simulation. Flow data from a period of Five years from January 1, 2002 to December 31, 2006 from Megecha gauging station were utilized in order to validate the model for a different time period. As the analogous values for $R^2=0.66$ and $NS=0.60$ (see APPENDEX: F).

Overall, according to many researchers' performance evaluation criteria, the model is agreeable to take advantage of it to represent the watershed. Hence, the set of optimized parameters during the calibration process for Megecha sub-watershed can be characterized as the representative set of parameters for the watershed. The daily and monthly observed and simulated flows were plotted and inspected in Figure 4.2

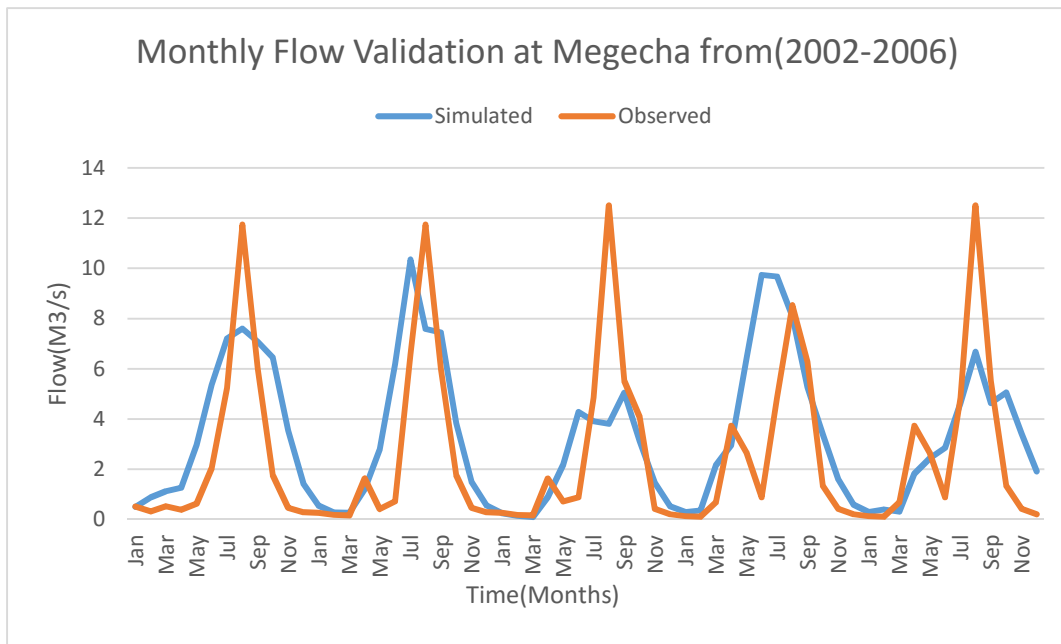


Figure 4.2: Observed and Simulated Monthly Flow Validation at Megecha River for the period (2002-2006)

4.2 Modeling watershed

The watershed is located at the central section of Gibe sub-basin which encompasses Twenty-nine sub basin. It has an area of 2094 km². 28 years' weather data at Fonko, Gunchire, Hosana,

Sekoru and Welkite were analyzed from the gauging stations located around. These data are from 1990-2017 daily observations of precipitation, maximum and minimum temperature collected from National Metrological Agency Further, overlaying of the land cover, soil and slope selected in defining the HRU definition using the default threshold values, the watershed was subdividing into 76 HRU having unique land use and soil combinations that enables the model to reflect differences in evapotranspiration and other hydrology conditions for land cover/crop and soil. Runoff is predicted separately for each HRU and routed to obtain the total runoff at the outlet of the sub watershed. This increases the accuracy of load predictions and provides a much better physical description of the water balance of the study area.

4.2.1 SWAT Simulation

To finalize the setup of input for the SWAT model and RUN SWAT model, by using sensitive parameters result from Megecha sub-watershed. The first step is to setup is period of simulation After the pre-processing of the data and SWAT model set up, simulation was done for the period 1990 to 2017 and the simulation for 1990-1993 was considered as a warm-up period.

4.3 Potential Selected sites

Sites suitable for Micro hydropower development were selected considering different parameters mentioned in the previous section 3.6.1; Table 4.2 specifies their geographic location.

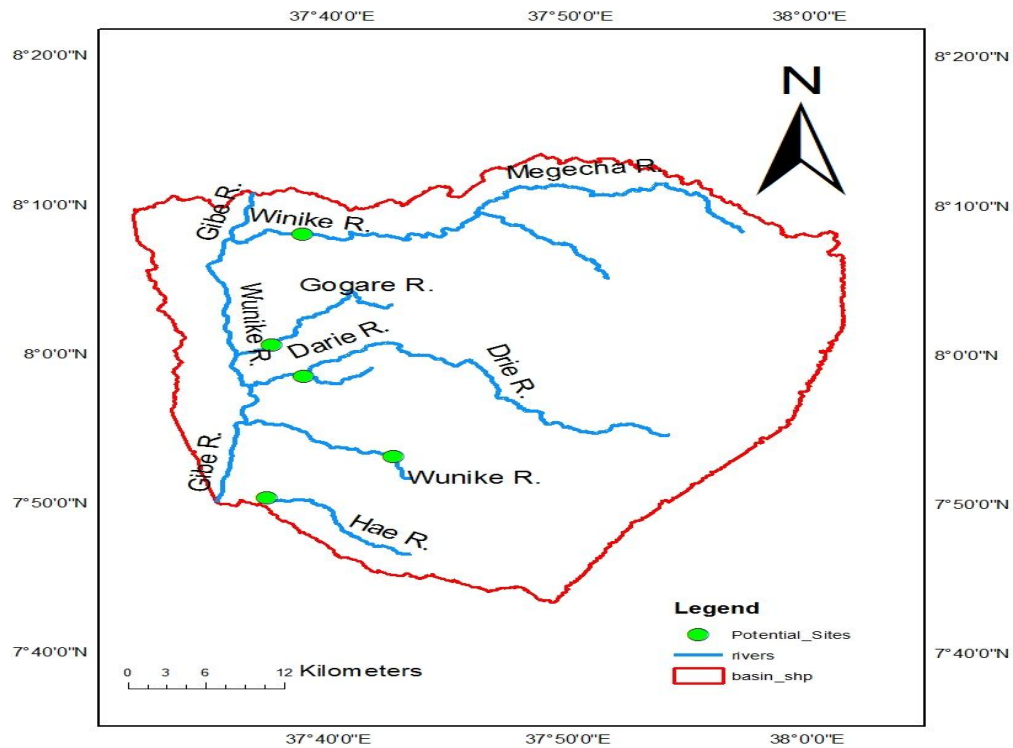


Figure 4.3: GIS based map of the potentially viable sites

Table 4.2: Geographic Location of sites.

	River Name	Latitude	Longitude	Altitude(m.a.s.l)
1	Derie	881838	351069	1190
2	Gogare	885729	348590	1241
3	Hae	866803	348167	1450
4	Megecha-Winike	899414	350922	1460
5	Wunike	871933	357896	1710

4.3.1 Flow head

Gross head is one of the physical characteristic of the site which is used to estimate the hydropower potential at the site, and measuring is usually carried out using different techniques, for this research work the gross head was read from Google Earth image 2019.

Table 4.3: Gross Head for each site.

No	River Name	Facility type	Head(m)
1	Derie	Diversion & Canal	54
2	Gogare	Diversion & Canal	22
3	Hae	Diversion & Canal	98
4	Megecha-Winike	Diversion & Canal	21
5	Wunike	Diversion & Canal	45

4.3.2 Flow duration curve

Flow-duration curves (FDC) are used to summarize stream flow characteristics and can be constructed from daily, weekly, or monthly stream flow data, for this study the FDC is constructed from monthly flow data, the reason has been discussed in the previous section 3.6.3 & Q_{35} is taken as design flow. (see APPENDEX D).

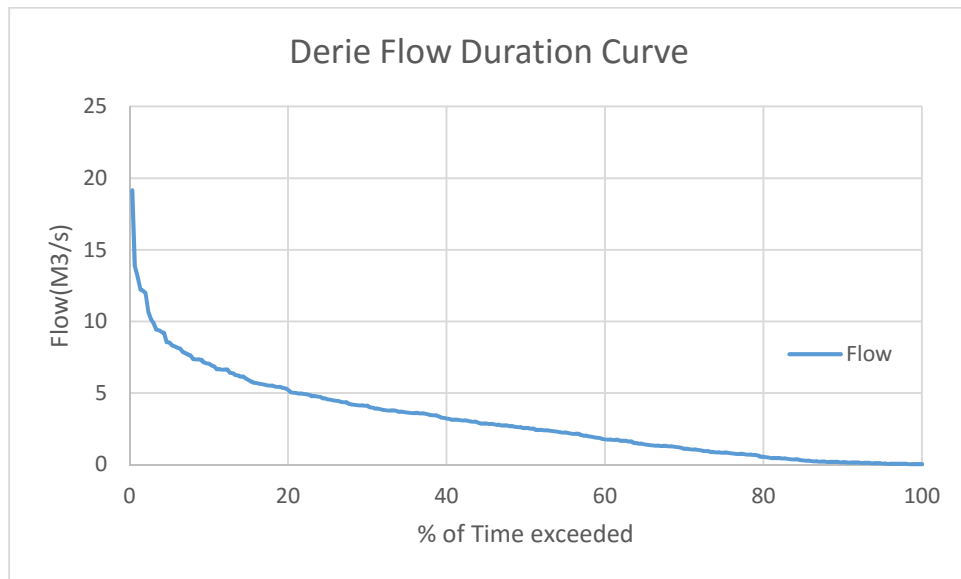


Figure 4.4: Derie-river Flow Duration Curve

This is the technically available power mentioned in the previous section 3.6.2

Table 4.4: Results of flow duration curve that was constructed from monthly flows

No	River Name	Facility type	Q_{35} (M ³ /s)
1	Derie	Diversion & Canal	3.659
2	Gogare	Diversion & Canal	3.234

3	Hae	Diversion & Canal	1.002
4	Megecha-winike	Diversion & Canal	9.348
5	Wunike	Diversion & Canal	2.074

Table 4.5: Technically available power of the sites.

No	River Name	Facility type	Head(m)	Q ₃₅ (M ³ /s)	P(Kw)
1	Derie	Diversion & Canal	54	3.659	968.17
2	Gogare	Diversion & Canal	22	3.234	348.62
3	Hae	Diversion & Canal	98	1.002	481.16
4	Megecha-Winike	Diversion & Canal	21	9.348	961.90
5	Wunike	Diversion & Canal	45	2.074	457.31
				Total	3217.16

The technically available power potential of the rivers Derie and Megecha-Winike is greater than 500KW, but since we are interested in Micro-Hydropower we use cascade power development, by decreasing the available head in to two (Table 4.6).

Table 4.6: Technically available power of the cascade sites

No	River Name	Facility type	Head	Q ₃₅ (M ³ /s)	P(Kw)
1	Derie	Diversion & Canal	27	3.659	484.08
2	Gogare	Diversion & Canal	22	3.234	348.62
3	Hae	Diversion & Canal	98	1.002	481.16
4	Megecha-Winike	Diversion & Canal	10.5	9.348	480.95
5	Wunike	Diversion & Canal	45	2.074	457.31

Maximum potential energy of each site is calculated using equation 3.6

Table 4.7: Technically available potential energy of the sites

No	River Name	$E_{max}(KWh)$
1	Derie	8,481,169.2
2	Gogare	3,053,911.2
3	Hae	4,214,961.6
4	Megecha-Winike	8,426,244
5	Wunike	4,006,035.6

4.4 Ranking of sites

To facilitate a favorable condition for local decision makers to make a reasonable decision as to which sites should be given the top priority for future micro hydropower development project implementation, ranking of the sites is essential. Even though there are so many criteria that govern the ranking of the sites, due to limitations of data only head and discharge, ratio between waterway length (L) and total head (H), the site condition: accessibility, i.e., distance from access road and distance to the demand center, and the energy output have been considered.

4.4.1 Energy Output

The last outcome that is needed from a river site is the energy output. In order to determine the rank a site has with respect to the others, the ratio of the energy output of that site to the highest of the energy of all sites is considered. For example, the energy output of the river Gogare is 3.053GWh/year and the highest energy output from all the rivers is 8.481GWh/year. Therefore, the ratio of energy output of Gogare river to that of highest energy of all sites is $3.053/8.481 = 0.360$. This value is added to the ratios of other parameters to obtain the ranking value of the river Gogare.

4.4.2 Design Discharge

One of the main and, in fact the key parameter determining the potential of a river is the stream flow or the discharge. This parameter is used along with the others to determine the rank of the sites. Like that of the energy output, the ratio of the design discharge of a site to that of the

annual maximum discharge of all sites is obtained and added to the other ratios so that the ranking value is computed. The Design discharge of Gogare is 3.234 m³/s while that of the maximum is 9.348 m³/s. Thus, the discharge ratio is $3.234/9.348 \text{ m}^3/\text{s} = 0.345$.

4.4.3 Head

The potential energy that makes the turbine to rotate while the water strikes it is as a result of the head above the turbine. Especially in Ethiopian condition the head plays a great role in amplifying the power. Therefore, head is taken as one of the parameters to evaluate the rank of the sites. The highest head of the sites under study is found to be about 98m. The head of river Gogare is 22m. This makes the ratio to be about 0.22.

4.4.4 L/H [ratio between waterway length (L) and total head (H)]

The ratio between the total head (H) and the waterway length (L) (L/H) of a site is a key parameter on minimizing the cost of a micro hydropower. A site with a smaller L/H value is more advantageous for small-scale hydropower. Therefore, L/H is taken as one of the parameter to evaluate the rank of the sites. In this case the ratio is obtained taking in to account the smallest L/H, so the inverse ratio of the L/H of the site to that of the minimum of the all site is taken to add up with the rest ratio, for Gogare, $L/H=7.90$ & the minimum L/H of all the site is 2.57, so the ratio is $1/ (7.90/2.57) =0.325$.

4.4.5 Distance from Access Road

Unless there is all weathered road at least in the nearby surrounding, it is obviously difficult to carry out development projects. Thus, it is necessary that accessibility or distance to accessible road have some weight in determining the rank of a site. In our example the distance of site Gogare from the nearby road is about 9.43km. This is the same as step no4. The site which is very near or adjacent to all weathered road is river Wunike having a distance of 0.87km from the road. The inverse ratio of this distance of the river Wunike to the distances of other respective sites is taken in the evaluation of the rank. For river Gogare the ratio is $1/ (9.43/0.81) = 0.092$.

4.4.6 Distance of the Sites to the Demand Center

This factor is also very influential in determining the rank of a site. The effect is similar to the factor described in number 5 above. As much as possible the end users should be nearer

to the hydropower station since expensive transmission lines are not appreciated in MHP installation Wunike is the river which is very near to the demand site with 0.87km. So the inverse ratio becomes $1(0.87/0.87) = 1$. The sum of the above five ratios reveals the rank of the river of Wunike.

$$R = R_e + R_q + R_h + R_{l/h} + R_{dar} + R_{ddc} \dots \dots \dots \text{Equation (4.1)}$$

$$R = 0.360 + 0.345 + 0.22 + 0.325 + 0.092 + 0.043 = 1.385$$

Where

R_e :-ratio of energy output of a site to the maximum of energy output of all sites.

R_q :-ratio of the Design discharge of a site to the maximum Design discharge of all sites.

R_h :-inverse ratio of head of a site to the minimum head of all sites.

$R_{l/h}$:- inverse ratio of the lowest L/H (ratio between waterway length (L) and total head (H)) to that of a site.

R_{dar} :- inverse ratio of the lowest distance of the sites to the road & the average of all (Distance between the site and the nearby road).

R_{ddc} :-inverse ratio of the lowest distance of the sites to the site under consideration (distance between the site & the demand center)

The ranking of all other sites is performed in similar manner. According to the result of the ranking process, the river Wunike is found to score the first while Gogare is at the bottom with its very low rank.

Table 4.8: Ranking parameter

No	River Name	Head	E_{max} (GWh)	Q_{35}	L/H	Distance from access road(Km)	Distance from demand center(Km)
1	Derie	69	8,481,169.2	3.659	3.33	8.31	8.31
2	Gogare	22	3,053,911.2	3.234	7.90	9.43	8.88
3	Hae	98	4,214,961.6	1.002	2.96	2.92	0,94
4	Megecha Winike	28	8,426,244	9.348	13.7	4.49	4.49
5	Wunike	104	4,006,035.6	2.074	2.57	0.87	0.39

Table 4.9: Ranking of the site

No	River Name	R _c	R _q	R _h	RL/H	R _{dar}	R _{dde}	Rank	
1	Wunike	0.473	0.221	0.459	1	1	1	4.153	1
2	Hae	0.496	0.107	1	0.86	0.297	0.414	3.174	2
3	Derie	1	0.391	0.55	0.77	0.104	0.046	2.861	3
4	Megecha-Winike	0.99	1	0.214	0.18	0.193	0.08	2.657	4
5	Gogare	0.360	0.345	0.22	0.325	0.092	0.043	1.385	5

5. Conclusions and Recommendations

5.1 Conclusions

In developing countries like Ethiopia even though naturally endowed with huge surface and ground water resources, only small fractions of these potentials are exploited to achieve the national economic and social development goals.

This study aimed at assess the Potential Micro hydropower of the Central Gibe sub-basin in Omo-Gibe river basin, and thoroughly identify and locate possible potential site in the basin for Micro hydropower energy generation, beyond the main task of the study objective. In addition to these the outputs of this paper will serve as an input to provide a good understanding of Micro hydropower generation systems starting from the preparation of weather data of meteorological stations to the proper simulation, for developers in the Gibe sub-basin.

Hydrology model SWAT was applied to the Omo Gibe River Basin to simulate and/or watershed runoff for the main and its tributaries of sub basin of the rivers. For better decision on the proper utilization and allocation of these resources; hydrological models are necessary for assessment and management of the quantity and quality of water resources both spatially and temporally in the basin. To achieve this, the total watershed has been delineated downstream of Gibe-river and divided into 29 sub-basins, out of this 5 sub-basins have Micro hydropower potential, whereby the upper one is defined by the outlet gauging station megecha. The calibration and validation of the model was performed for the time-period 1993-2006, after calibration and validation of gauged station Megecha used sensitive parameters for ungauged sub-basins to simulate runoff potentials for each sub-basin. Moreover, SWAT hydrologic model has two basic advantages instead of relying only on collected data. In the first place, finding all the information essential for understanding the hydrological process is difficult whether in gauging or un-gauged river basins due to the limited range of measurement techniques in space and time. For such conditions, hydrological models provide an alternative solution.

In this study the Micro hydropower potential of the selected sites of the central Gibe sub-basin were assessed & the following are the summery

- According to this study there are 5 sites which are identified as Micro hydropower potential sites were determined & the total potential capacity was found to be for Derie-

river 484.08Kw, Gogare-river 348.62Kw, Hae-river 481.16Kw, Megecha-Winike-river 480.95Kw and Wunike-river 457.31Kw.

- The type of hydropower schemes which is suitable for all the sites is Run-Off-River plant.
- The result of ranking process, the river Wunike is found to score the first, river Hae score second, river Derie score third, river Megecha-Winike score fourth and river Gogare is at the bottom with its very low rank.
- MHP is a decentralized energy source located close to the consumers, transmission losses can be reduced although electricity can be delivered as far as a mile away to the location for scattered Rural villages of Gibe sub –basin.
- MHP is a clean energy source (it does not produce waste in the rivers, or air pollution) and renewable (the fuel for hydropower is water, which is not consumed in the electricity generation process).

Generally, the cost of generation of Micro hydro power is low compared to other renewable energy sources such as wind, solar, biomass etc. The operation and maintenance cost of Micro hydro project is very low. These important facts, combined with the current Power cut-off, makes small hydro power projects a winning business proposition. Within the context of the objective of the proposed project, investments in Micro hydropower stations are justified bearing in mind the numerous socio economic benefits to be derived by the rural community.

5.2 Recommendations

Based on the current study the following recommendations can be drawn for Micro hydropower generation:

- In order to take advantage of MHP potential in Ethiopia, joint effort of government organizations and individual investors should be considered.
- High initial cost need to be overcome with easier/improved access to finance for project developments. Awareness of small hydropower should be raised among local banking institutions or micro- finance institutions in order to improve risk assessment and provide attractive loan conditions.
- Availability of hydrological and climate data are very crucial for future development of any water resource projects in this sub-basin. Hence, the result of SWAT model will contribute to solving the problem of the study region through simulated stream flows for all sub basins.
- Looking at the enormous benefits of electrifying rural villages by MHP installation, it is recommended that the government of Ethiopia should give attention to promote the development of MHP plants. To fulfill the current Power cut-off, the above before too long, private investors should be encouraged in various ways to pursue MHP development.

Last but not the least, there is the need to do more detailed hydrological, topographical and geological studies at each identified site. A more rigorous analysis of energy consumption and future demand would be useful.

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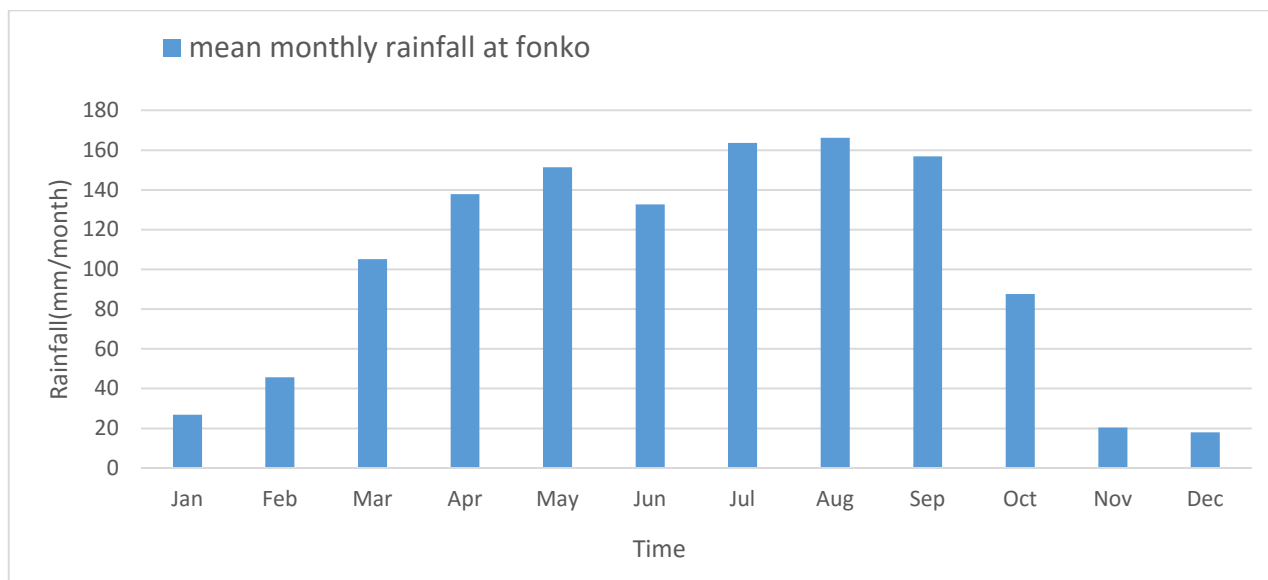
APPENDICES

APPENDEX: A Rainfall

Fonko Rainfall(1990-2017)													
Year	Months												Grand Total
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	
1990	0	124.8	123.6	125.3	119.8	37	110.4	131.7	181.3	79.6	2.9	0	1036.4
1991	9.1	82.3	151.9	46.8	87.7	140	171.1	163.2	106.9	16.6	0	58.9	1034.5
1992	49.5	42.9	132.3	219.4	203	160.4	229.1	231.2	124	122.8	46.3	0	1560.9
1993	61	110.5	0	317.4	253.8	66.3	137.5	183.1	125.8	255.6	0	0	1511
1994	0	0	84	89.7	133.8	125.6	157.7	122.8	169.4	0	7.9	0	890.9
1995	0	23	61.6	217.4	118.6	66.4	128.3	156.5	119.6	0	0	54.7	946.1
1996	95.4	29.6	265.4	210	159.5	140.4	201	175.4	116.8	1.4	11.1	0	1406
1997	53.6	0	71.7	135.7	108.1	235.4	117.1	183.8	175.4	514.8	69.3	0	1664.9
1998	0	189.8	161.6	158.8	121.3	118.9	117.2	224.6	92.5	187	6	0	1377.7
1999	0	0	111.4	38.2	98.1	109.1	259.1	133.9	185.8	217.9	0	0	1153.5
2000	0	0	6.9	209.6	168	145.7	132.6	207	162	70	21.6	56.8	1180.2
2001	7	60.9	270.1	113.4	188.5	171.3	143.9	266.3	136.7	57.8	3.9	1.2	1421
2002	94.7	53.6	130.8	85.2	193.3	124.8	119.2	251.8	190.6	1.8	0	160.3	1406.1
2003	69.9	47	154.8	269	42.8	186.4	262.4	176	206.3	14.6	8.2	55.7	1493.1
2004	89.2	25.8	114.5	173.4	25.7	68.4	214	174.9	179.7	91.8	6	33	1196.4
2005	24.8	0	110.8	169.1	189.9	111.5	165.6	164.4	166.5	76.5	58.8	0	1237.9
2006	9.2	19.9	147.1	174.5	108.8	141.1	210.1	195.3	111.5	60.8	10.8	15	1204.1
2007	58.5	77.9	93.2	112.8	149.1	143.6	199	117.1	298.3	21.2	0	0	1270.7
2008	0	7.8	10.8	104.1	168.2	200.1	236.5	126.6	206.7	108.6	99.1	0	1268.5
2009	52.5	12.8	16.2	39.6	115.5	87.2	197.9	172.9	134.3	127.4	12.8	39.9	1009
2010	13.9	104.5	216.5	126.9	220.6	84.7	201.3	77.8	122.5	10.1	57.6	16.9	1253.3

2011	14.1	6.3	199.8	80	207.9	91.1	155.9	152.3	129.6	0	27.4	0	1064.4
2012	0	0	64.4	108	61.1	221.6	166.5	185.2	244.5	0	19.2	12.3	1082.8
2013	0	54.7	155.3	114.7	143.6	177.7	174.3	171.2	99.6	70.8	7.9	0	1169.8
2014	14.6	63.2	56.2	111.9	265.7	28.2	119.1	221.8	120	60.6	16.4	0	1077.7
2015	0	0	32.9	63	206	239.6	90	175.5	100.3	163.5	30	0	1100.8
2016	37.1	17.4	93	309	162	164.9	86.8	111.5	174.2	104.1	67.6	0	1327.6
2017	0	127.2	49.6	0	219.2	128.8	77.8	151.9	212.7	15.6	10.5	0	993.3

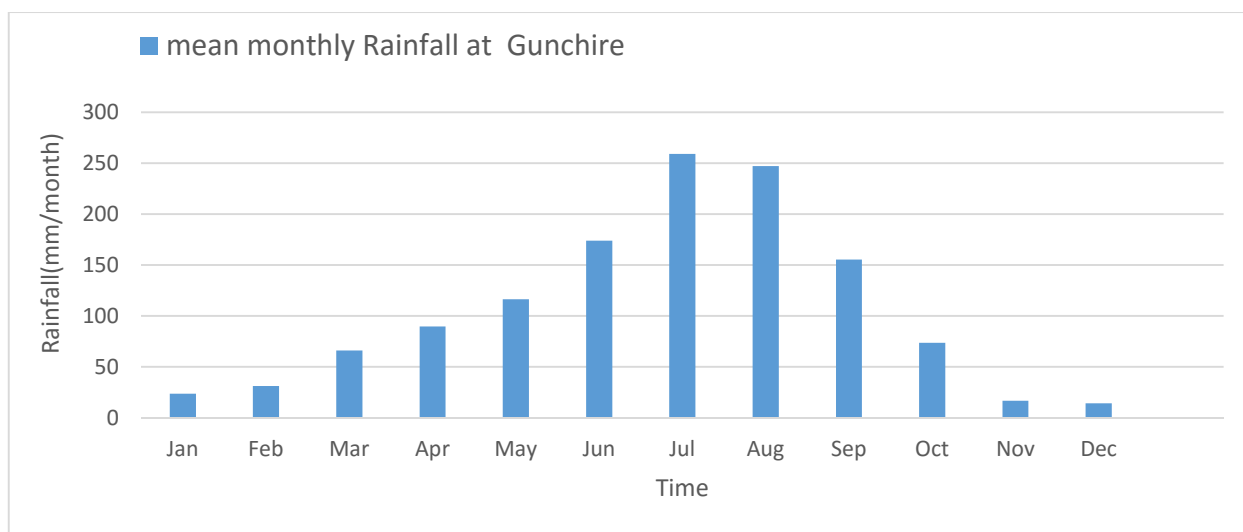
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean monthly rainfall at fonko	26.93	45.78	105.14	137.85	151.41	132.72	163.62	166.21	156.91	87.53	20.40	18.03



Gunchire rainfall(1990-2017)													
	Months												
Year	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
1990	15.0	207.3	80.7	132.0	93.3	168.4	244.1	227.3	226.0	29.0	3.2	3.2	1429.5
1991	3.5	86.3	127.9	48.3	81.2	259.6	275.4	267.1	171.9	35.9	0.0	66.2	1423.3
1992	19.2	35.8	59.4	63.2	111.3	163.6	305.8	333.0	163.8	155.2	36.0	10.0	1456.3
1993	28.9	106.7	8.6	159.5	169.1	225.8	265.9	224.9	258.7	173.7	3.8	0.2	1625.8
1994	3.3	3.2	112.0	126.7	112.7	286.6	379.6	230.7	187.1	7.9	14.1	0.0	1463.9
1995	5.6	15.4	33.5	188.8	111.6	203.3	71.7	170.3	138.2	32.1	4.2	31.3	1006.0
1996	36.8	7.3	212.6	134.3	272.7	322.6	311.6	228.7	96.9	24.5	6.0	0.0	1654.0
1997	61.6	20.9	82.1	148.4	87.6	112.8	235.1	214.1	73.9	186.4	71.6	39.4	1333.9
1998	70.9	62.0	59.9	119.0	261.4	111.0	247.2	266.1	209.4	120.5	11.7	0.0	1539.1
1999	35.9	0.0	24.1	52.8	103.2	216.9	314.4	261.4	120.6	285.4	0.0	0.1	1414.8
2000	0.0	0.0	8.1	86.4	75.2	114.5	180.1	235.4	201.1	70.2	43.6	1.3	1015.9
2001	1.6	7.2	178.5	49.0	154.2	232.6	344.6	267.4	144.0	62.7	6.1	3.9	1451.8
2002	68.6	14.1	110.1	40.3	52.6	168.4	297.6	138.2	143.0	7.2	0.1	49.8	1090.0
2003	11.2	9.7	87.6	117.2	0.0	0.0	199.9	266.7	137.5	13.4	10.2	42.2	895.6
2004	43.0	16.6	49.2	154.0	66.6	205.0	217.8	269.6	203.7	47.9	2.0	16.2	1291.6
2005	108.5	3.4	139.8	59.1	119.5	221.5	236.4	111.7	129.8	49.0	28.6	0.0	1207.3
2006	16.0	34.0	97.7	63.0	151.1	150.4	254.5	366.3	130.7	48.3	31.0	16.1	1359.1
2007	53.5	42.1	74.7	91.0	103.0	228.6	220.4	213.2	222.4	48.6	4.0	0.0	1301.5
2008	0.0	0.0	0.0	57.5	209.5	67.6	260.6	210.9	127.9	42.2	104.2	0.2	1080.6
2009	39.8	3.5	22.0	90.9	33.0	78.4	240.2	285.1	123.6	117.3	8.1	65.0	1106.9
2010	0.0	80.0	60.3	70.4	198.1	212.3	254.9	258.7	139.4	35.4	22.9	36.1	1368.5

2011	11.8	3.4	30.9	73.7	178.8	129.0	356.9	335.3	199.5	11.0	23.0	0.0	1353.3
2012	0.0	1.3	50.5	64.0	58.9	226.5	256.5	189.7	122.0	12.4	0.0	7.3	989.1
2013	11.5	5.8	35.4	78.5	138.7	272.8	318.1	289.0	114.2	158.3	0.0	5.2	1427.5
2014	18.9	79.6	77.5	127.7	198.4	108.0	286.1	313.3	187.6	75.5	9.3	8.6	1490.5
2015	0.0	20.1	106.6	11.5	130.4	204.6	201.3	197.0	203.3	166.2	25.1	0.0	1266.1
2016	0.0	11.5	0.0	100.9	239.8	115.0	222.3	229.2	0.0	0.0	0.0	0.0	918.7
2017	0.0	0.0	0.0	0.0	0.0	195.5	254.5	319.5	175.2	48.8	1.8	0.0	995.3

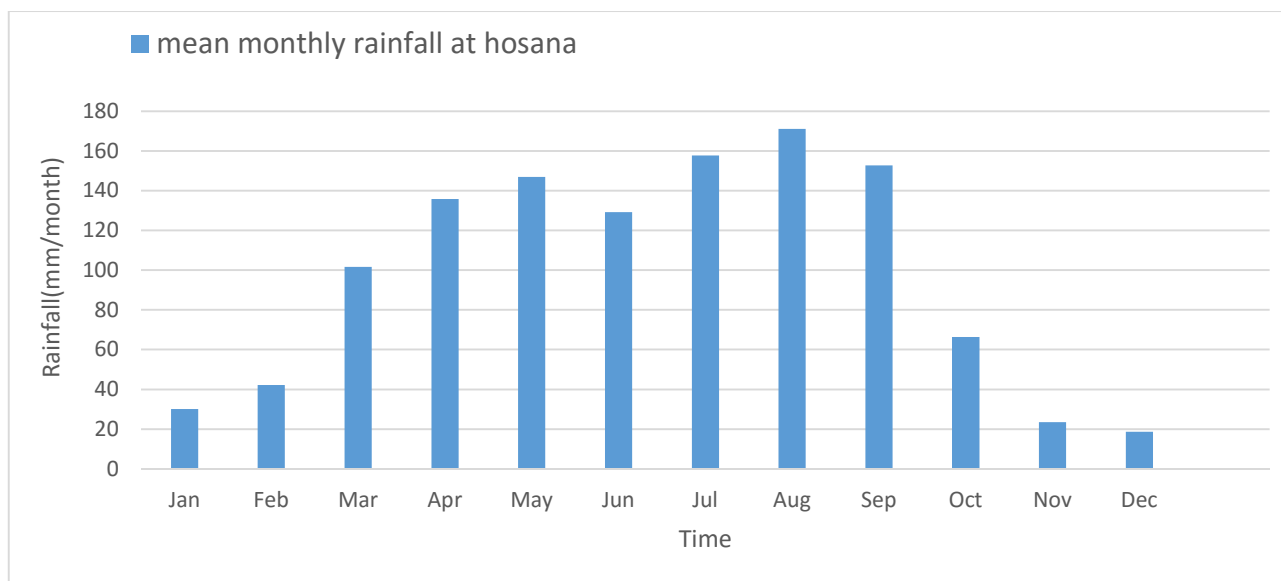
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean monthly Rainfall at Gunchire	23.75	31.33	66.15	89.58	116.24	174.01	259.05	247.14	155.41	73.75	16.81	14.37



Hosana Rainfall (1990-2017)													
Year	Months												Grand Total
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	
1990	0	144.8	153.1	95.9	114.9	107.2	133.8	125.6	135.3	40.5	6.8	1	1058.9
1991	7.1	45.7	94	31.6	128.7	138.6	210.5	185.9	110.2	9.7	0	66.3	1028.3
1992	58.9	88.1	119.6	174.5	106.2	171.7	121.4	280.1	104.3	106.2	52.9	3.7	1387.6
1993	78.1	107	20.6	255.2	285.7	75.1	122.8	199	92.7	177.2	0	0.1	1413.5
1994	0	0	146.7	83.9	128.9	80.8	148.3	128.7	192.8	0.2	10.1	0	920.4
1995	0.5	62.7	70	219.6	109.3	82.4	196	156.5	160.6	4.2	0	98.9	1160.7
1996	90.7	17.8	153	170.4	162.7	108.8	186.7	129.6	125.6	6.6	16.3	0	1168.2
1997	28.7	0	80.7	177.6	140.1	171.7	113.1	186.4	140.2	318.7	85.3	0	1442.5
1998	73.8	63.2	107.7	203.6	143	159.9	205.3	188.5	235.3	158.5	17.6	0	1556.4
1999	1	0	56.5	77	122.5	143.5	181.7	107.8	127.7	193.6	0	0	1011.3
2000	0	0	15.4	205.8	105.2	145.5	86.2	124.5	177.9	64.9	21	45.5	991.9
2001	4.8	70.1	184	109.6	172.1	91	151.9	188	101.8	62	4.7	5.5	1145.5

2002	83.3	47.2	150.7	111.7	135.5	90	103.6	314.7	154.7	2.8	0.4	151.8	1346.4
2003	35.8	58.9	118.7	194.4	78.7	108.3	135.9	213.3	182.9	11.7	14.3	0	1152.9
2004	96.8	19.4	90.6	176.2	104.6	123.4	133.6	152.3	181.8	75.1	17.3	14	1185.1
2005	31.5	18.8	177.8	162.1	197.2	64.6	160.1	98.9	162.6	37.7	67.7	0	1179
2006	28.9	53.9	135.5	160	75.8	169.8	183.9	222.2	88.2	50.3	6	27.2	1201.7
2007	31.8	50.7	119.4	152.1	121.3	163.1	179.9	127.3	210.3	19.4	0	0	1175.3
2008	0	1.2	43	64.3	238.9	144.6	192.5	136.2	139	126.1	116.5	0.5	1202.8
2009	43.1	4.8	73.4	85.5	120.1	122.7	188.5	181.1	156.7	169.4	5.1	55.8	1206.2
2010	11.8	110	139.9	111.3	182.8	94.4	116	145	138.5	18.8	19.3	33.7	1121.5
2011	15.5	11.2	101.7	115.9	232.8	126	158.8	182.5	119.3	0	49.2	0	1112.9
2012	0	0	67.4	138.3	68.3	150.3	233.1	155.9	163.5	1.4	2.4	7.7	988.3
2013	1	17.4	143.6	67.9	131.6	182.2	200.8	211	173	46.4	0.4	0	1175.3
2014	25	117.8	76.6	134.9	251.8	76.2	188.3	270.9	193	74.4	0	0	1408.9
2015	0	3	45.1	19.2	136.9	213	142.6	161.2	142.2	0	31.3	11.5	906
2016	92.8	0	81.2	258.6	135.9	122.8	96.1	123.8	138	68.8	111.2	0	1229.2
2017	0.6	69.5	77.9	44.6	183.9	189.3	143	90.8	225.5	12.4	1.2		1038.7

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean monthly rainfall at hosana	30.05	42.26	101.56	135.78	146.98	129.18	157.66	170.99	152.63	66.32	23.46	18.69

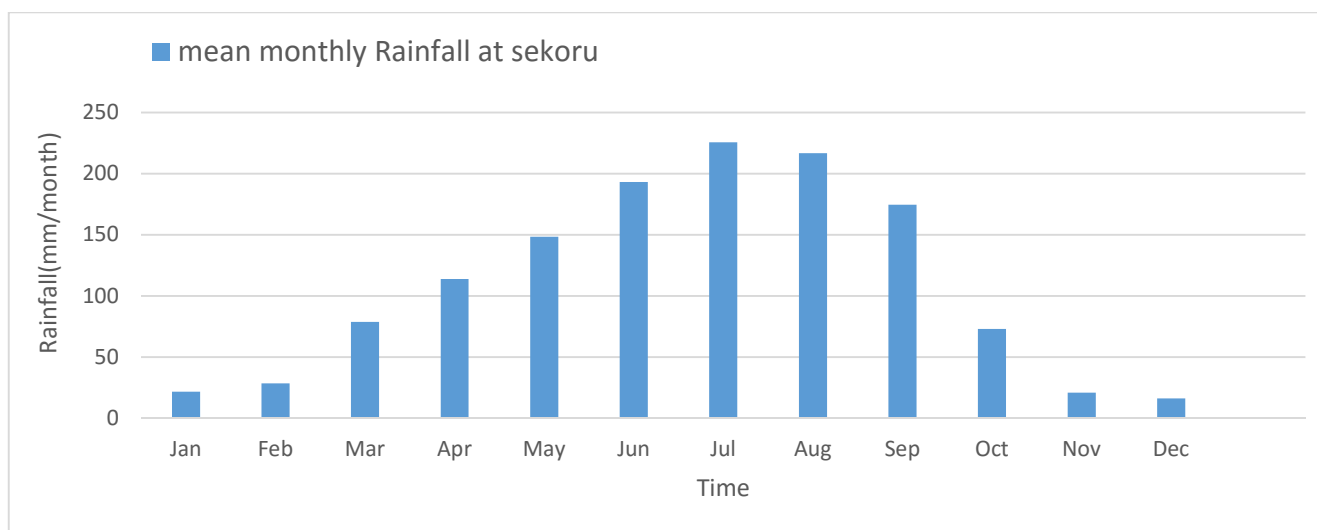


Sekoru Rainfall (1990-2017)													
	Months												
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Grand Total
1990	1.4	106	68.1	103	105.1	273.1	255.3	232.4	167.5	12.2	5.2	3	1332.3
1991	21	70.5	133.9	63.5	114.8	227.7	289.8	232.8	93.5	18	2.3	27.5	1295.3
1992	77.7	89.3	49.5	94.2	157.2	264.7	258	312.9	141.1	90.4	54	13.8	1602.8
1993	13.8	116.2	56.8	195	180.4	191.5	157.7	309.7	183.5	185.8	1.4	0	1591.8

1994	0	0	71.1	143.7	189.5	222.6	243.4	166	150.4	0	0	0	1186.7
1995	5.8	12.9	62.2	165.1	182.5	122.3	155.3	167.1	183.4	39.9	0	66.2	1162.7
1996	61.9	4.9	194.2	172.3	213.2	244.6	314.4	209	150.8	37.8	12	2.4	1617.5
1997	50.3	1.3	62	177.1	158.8	122.6	181.9	211.2	131.6	275	96	14.3	1482.1
1998	46.6	62.1	61.9	111.6	187	285	299	207.9	197.1	111.5	28	0.2	1597.9
1999	9.1	0	38.2	65.9	179.3	276.4	264.6	156.8	182.1	135.4	0	0	1307.8
2000	0	0	18.6	149.6	123.7	132.4	150.2	187.6	165.9	162.4	34.4	12.5	1137.3
2001	24.8	1.8	117.1	75.8	195.7	222	217	194.8	218	102.7	0.9	0.3	1370.9
2002	89.9	6.7	43.1	54.2	59	153.7	268.6	205.8	152.3	8.9	0	48.3	1090.5
2003	37.9	51	63.3	124.3	28	232.1	238.9	147.5	151.3	12.5	61.9	48.8	1197.5
2004	49	26.2	37.3	149.6	63.1	130.3	181.8	279	152.4	82.1	17.2	23	1191
2005	39.9	1.4	118.6	96.6	229.6	175.6	237.1	116.2	124.1	102.2	33.9	0	1275.2
2006	12	26	132.2	81.5	121.5	191.9	239.2	230.3	165.4	114.7	43.6	45.6	1403.9
2007	0	26.7	119.6	105.9	135.5	283.6	343.2	209.5	273.3	46.3	0	0	1543.6
2008	0	2.2	23.8	103.6	263.6	169.3	249.6	239.4	184	102.6	23.1	0	1361.2
2009	0	0	24.4	85.8	52.6	179.7	181.3	255	195.5	70.9	11.7	55.9	1112.8
2010	0	78.3	182.9	148.4	230.2	242.4	262	194.3	135	40.5	0	0	1514
2011	0	0	77.5	75	77.5	75	77.5	77.5	75	77.5	75	77.5	765
2012	0	0	67.3	78.6	64	135	145.7	170.4	261.5	1.5	9.6	0	933.6

2013	0	0	80.6	78	80.6	167	264.4	225	211.8	46.5	0	0.2	1154.1
2014	33.5	50.6	77.5	169.7	189.1	183	290.5	301.2	121.5	67.7	56.2	1.2	1541.7
2015	0	0	43.4	95	133.3	198.8	224	247.3	120	0	0	0	1061.8
2016	32.3	9.5	105.3	137	238.6	170.8	132.1	340	190.1	28.8	14.1	11.8	1410.4
2017	0	52.5	73.9	88.7	199.2	135.1	190.9	238.5	407.9	66.2	6.4		1459.3

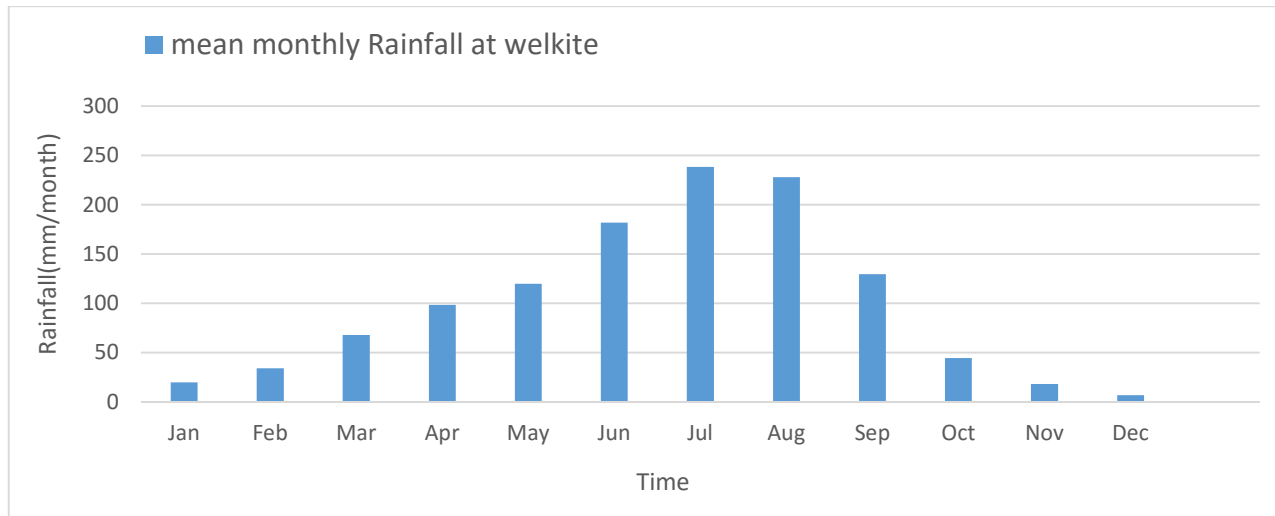
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean monthly Rainfall at sekoru	21.68	28.43	78.73	113.88	148.31	193.15	225.48	216.61	174.50	72.86	20.96	16.16



Welkite Rainfall (1990-2017)													
	Months												
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Grand Total
1990	13.9	143.8	64.9	73.9	79.9	161.4	255.3	300.7	216	25.2	11.7	1.2	1347.9
1991	0	109.2	97.7	13.6	156.3	309.8	275	222.1	122.1	7	0	36.7	1349.5
1992	16.8	129.8	29.9	247.3	195.3	358.2	326.9	717.1	109.2	55.9	115.6	4.1	2306.1
1993	31.9	136.3	85	248.7	203.4	132	309.7	265.9	155.5	4.1	0	0	1572.5
1994	0	8.7	227.9	181.9	207.3	184.8	362.9	146.2	230.9	3.4	25	0	1579
1995	0	27.1	40.3	319.9	75.9	128.1	252	394.5	28.1	18.3	0	55.6	1339.8
1996	105.4	12.1	233	174.9	243.8	332	386.5	396.8	163.9	31.8	25.3	4.1	2109.6
1997	74.5	0	99.6	206	116.8	48.8	250.6	152.8	136.5	134.2	53.2	0	1273
1998	22.3	20.7	121.9	32.1	97.6	193.7	351.5	238.3	79.3	15.8	0	0	1173.2
1999	4.2	0	0	21.6	72.5	224.7	267.2	124.8	201.1	198.4	0	0	1114.5
2000	0	0	0	38.4	98.7	169.2	310.1	229.4	138.6	54.1	26.8	4.2	1069.5
2001	6.2	11.1	67.1	37.4	105.4	154.6	400.8	273.2	116.8	97.8	3.4	5.5	1279.3
2002	47	6	76.8	58.3	168	278.1	254.4	232.2	90.1	0	0	37.8	1248.7
2003	17.6	63.5	76.4	122.9	34.8	196.9	369.4	218.1	202.7	25.3	10.1	9.3	1347
2004	46.3	9.9	30.1	97.7	88.5	207.5	76.8	204.3	160	3.3	6.3	10.3	941

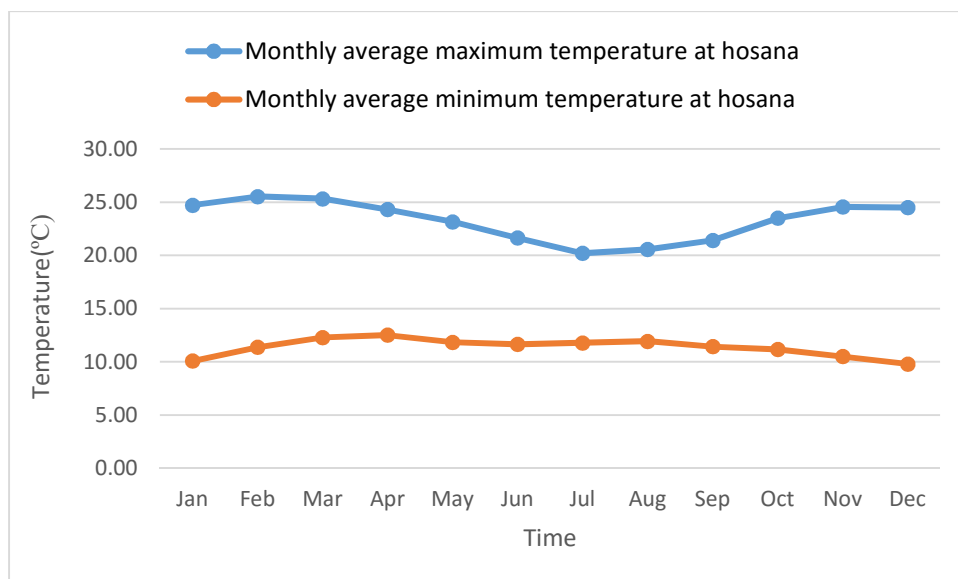
2005	44.7	4.4	93.9	97.4	10.3	173.9	240.5	211.6	239.1	38.6	34.2	0	1188.6
2006	4.4	25.4	83.2	99	100.3	120	255.7	234.7	174	52.3	35.5	4.7	1189.2
2007	42.3	58.3	34.9	52.8	122.5	189.3	220.1	216.6	137.2	27.2	0	0	1101.2
2008	0	8.4	7.9	95.4	248.8	189.9	287.8	239.9	83.5	52	67.5	0	1281.1
2009	25.8	37.1	7.2	30.1	57.6	157	240.1	187.8	108.6	108.1	1.4	18.5	979.3
2010	37.7	76.1	40.8	103.8	157.8	266.5	138	135.5	117.5	44	18	0	1135.7
2011	11.8	0	55.2	25.4	130.5	165.6	138	229	117.5	44	18	0	935
2012	0	0	44	92	40.3	135	139.5	139.5	135	0	0	0	725.3
2013	0	0	62	60	70	105.1	55.8	84	54	18	19	0	527.9
2014	0	55.5	57	37	167.5	115	210.8	332.5	181.8	120.5	0	0	1277.6
2015	0	0	51	20.5	165	159.5	129.5	117.5	39.5	2.5	36.5	0	721.5
2016	4	4.5	64.5	115.5	70	109.5	131	97.5	46	17	0	0	659.5
2017	0	8.5	49.6	48	69.4	128.5	37.2	40.3	48	49.6	0	0	479.1

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean monthly Rainfall at welkite	19.89	34.16	67.92	98.27	119.79	181.95	238.33	227.96	129.73	44.59	18.13	6.86

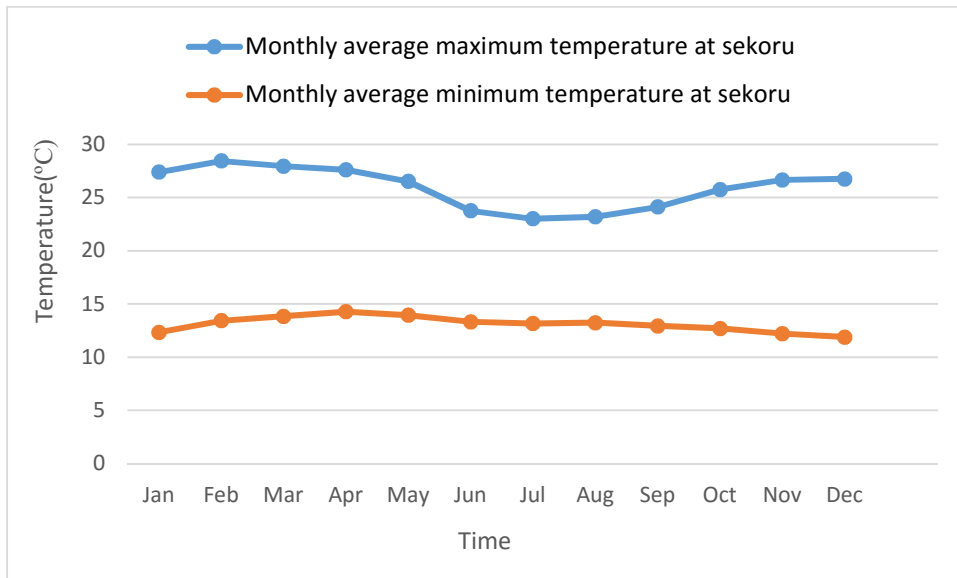


APPENDEX: B Temperature

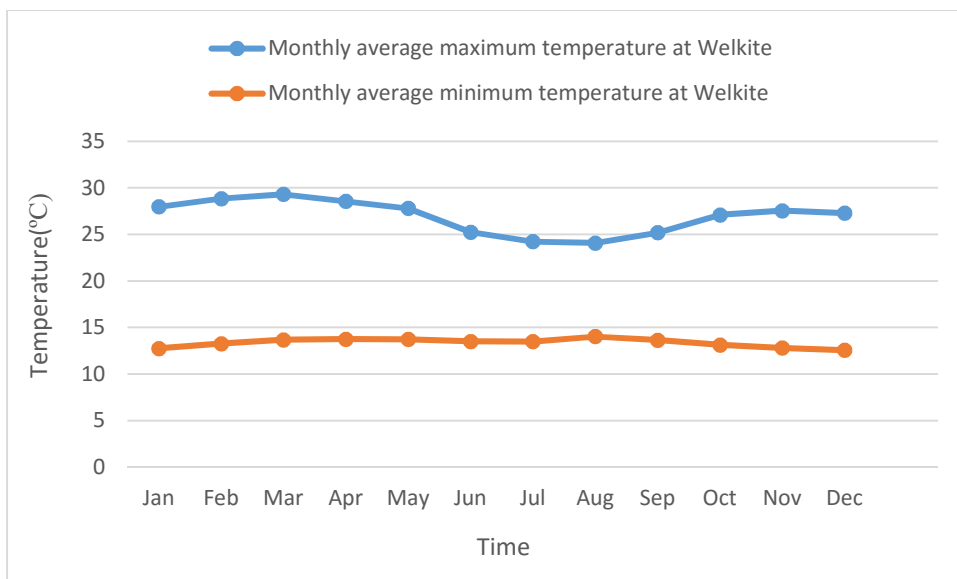
Hosana Temperature (1987-2017)												
Temperature	Months											
	Ja n	Fe b	M ar	Ap r	M ay	Ju n	Jul	Au g	Se p	Oc t	No v	De c
Monthly average maximum temperature at hosana	24.72	25.53	25.33	24.32	23.15	21.65	20.21	20.56	21.42	23.50	24.56	24.49
Monthly average minimum temperature at hosana	10.08	11.37	12.30	12.52	11.84	11.64	11.79	11.94	11.44	11.17	10.51	9.80



Sekoru Temperature (1987-2017)												
Temperature	Months											
	Ja n	Fe b	M ar	Ap r	M ay	Ju n	Jul	Au g	Se p	Oc t	No v	De c
Monthly average maximum temperature at sekoru	27.39	28.45	27.95	27.60	26.53	23.76	23.02	23.20	24.13	25.76	26.67	26.75
Monthly average minimum temperature at sekoru	12.35	13.43	13.84	14.28	13.95	13.34	13.17	13.24	12.95	12.71	12.22	11.90



Welkite Temperature (1987-2017)												
Temperature	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly average maximum temperature at Welkite	27.98	28.85	29.31	28.56	27.81	25.25	24.23	24.08	25.19	27.10	27.54	27.28
Monthly average minimum temperature at Welkite	12.74	13.26	13.68	13.75	13.72	13.50	13.49	14.04	13.64	13.13	12.81	12.56



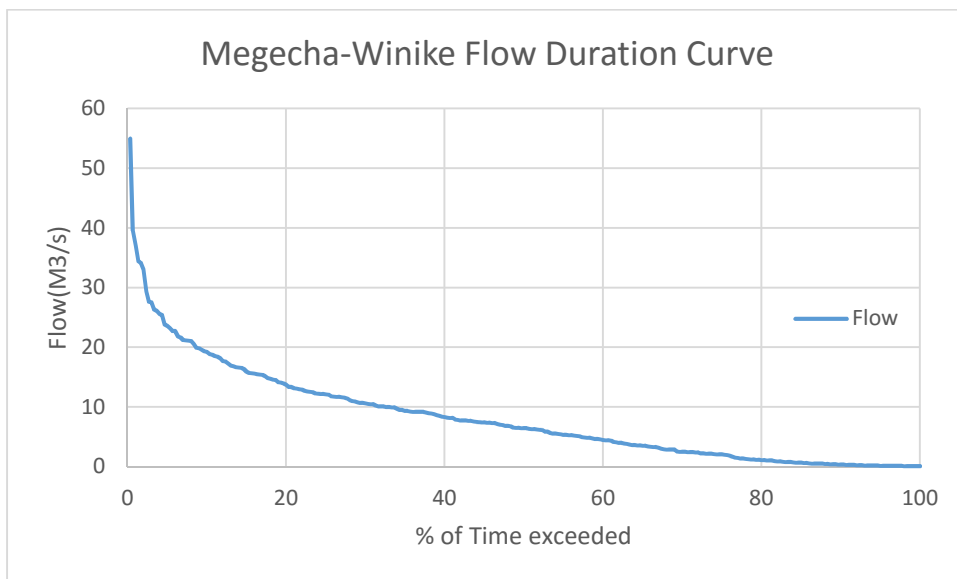
APPENDEX: C Observed Stream Flow

Observed Mean monthly stream flow of Megecha river (1993-2006)												
	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	0.28	0.35	2.23	2.99	6.54	9.84	9.75	8.05	5.17	3.31	1.54	0.55
1994	0.28	0.39	0.31	1.88	2.46	2.87	4.76	6.71	4.57	5.07	3.36	1.86
1995	1.57	1.49	1.50	1.18	4.80	3.99	5.40	8.08	6.87	5.59	2.84	0.99
1996	0.44	0.27	0.14	0.09	0.42	3.65	8.63	7.92	5.61	8.57	3.52	1.35
1997	0.48	0.23	0.13	0.09	0.63	1.40	4.08	6.13	6.12	4.60	2.74	1.41
1998	0.49	0.23	1.11	1.88	2.88	5.16	9.61	8.95	5.98	4.47	2.34	0.89
1999	0.47	0.89	1.12	1.29	3.02	5.45	7.29	7.58	7.12	6.40	3.46	1.34
2000	0.51	0.25	0.24	1.24	2.82	6.30	10.50	7.59	7.45	3.73	1.41	0.51
2001	0.23	0.13	0.09	0.93	2.20	4.39	3.89	3.83	5.08	3.07	1.41	0.49
2002	0.28	0.35	2.23	2.99	6.54	9.84	9.75	8.05	5.17	3.31	1.54	0.55
2003	0.28	0.39	0.31	1.88	2.46	2.87	4.76	6.71	4.57	5.07	3.36	1.86
2004	1.57	1.49	1.50	1.18	4.80	3.99	5.40	8.08	6.87	5.59	2.84	0.99
2005	0.44	0.27	0.14	0.09	0.42	3.65	8.63	7.92	5.61	8.57	3.52	1.35
2006	0.48	0.23	0.13	0.09	0.63	1.40	4.08	6.13	6.12	4.60	2.74	1.41

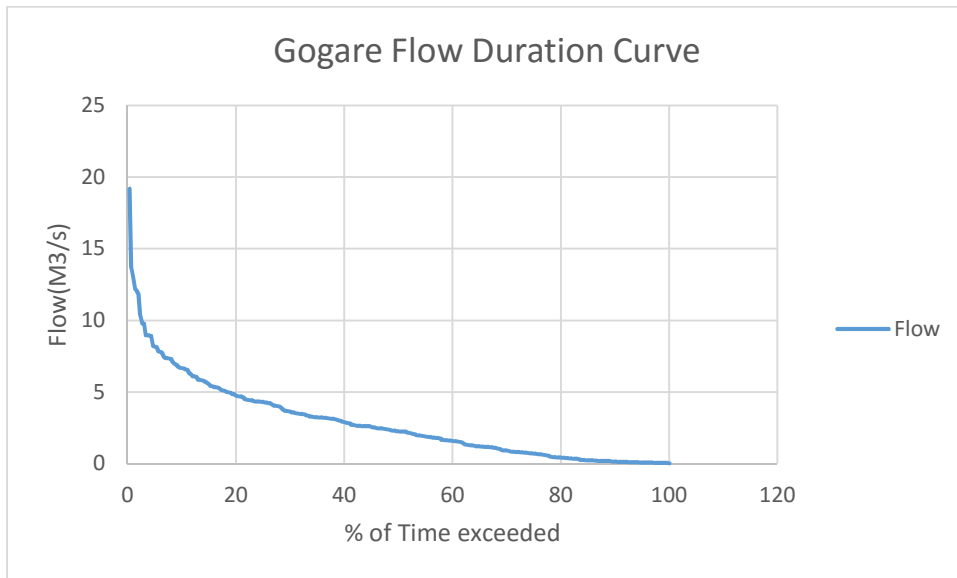
APPENDEX: D SWAT Result Simulated stream flow and Flow Duration Curve

Simulated mean monthly stream flow (M³/s) at Megecha-Winike river(1993-2017)												
	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	3.52	10.00	2.18	10.96	33.08	5.53	6.82	18.19	9.92	23.58	6.11	2.20
1994	0.42	0.14	2.40	0.12	1.05	1.06	3.86	3.54	16.66	5.48	3.27	0.27
1995	0.07	5.42	0.11	2.87	1.84	2.05	11.67	13.13	21.06	6.81	3.32	9.50
1996	8.19	1.54	7.66	11.71	8.32	6.43	21.18	12.28	14.76	6.57	1.93	0.36
1997	0.42	0.08	2.52	10.70	5.33	12.12	8.63	21.25	19.54	54.95	15.70	7.30
1998	6.46	4.72	7.40	12.06	10.53	13.34	21.13	27.53	37.03	34.11	15.67	6.76

1999	1.21	0.40	1.24	0.18	0.57	4.65	9.34	9.18	12.59	22.75	9.18	4.58
2000	0.64	0.19	0.10	2.47	3.96	10.07	3.51	5.64	15.90	9.96	5.33	3.20
2001	0.22	3.74	10.49	7.12	5.89	4.34	11.59	19.27	12.98	9.95	2.07	0.34
2002	5.12	2.24	11.18	9.71	0.76	1.37	2.36	39.53	21.83	8.54	4.41	16.92
2003	4.42	7.46	9.16	13.11	9.21	4.13	9.35	20.58	23.87	9.17	5.85	0.89
2004	5.16	0.67	3.61	10.10	5.28	5.22	7.85	9.09	19.35	14.12	6.98	2.48
2005	0.48	0.26	15.15	4.62	16.62	3.37	12.18	7.38	17.33	6.33	8.80	1.12
2006	0.75	2.44	7.74	12.23	1.22	15.47	11.73	27.63	14.59	9.19	2.84	2.17
2007	0.33	1.18	7.67	7.90	1.67	12.56	18.54	14.16	22.75	10.47	6.31	1.17
2008	0.23	0.13	0.14	0.21	4.86	9.50	19.95	12.51	13.35	18.77	25.39	6.16
2009	2.19	0.31	0.75	2.90	0.54	2.43	12.73	17.64	17.68	26.10	7.05	2.49
2010	0.43	4.11	10.70	2.86	11.44	3.03	6.23	10.99	10.08	4.96	0.61	0.12
2011	0.12	0.06	3.57	0.09	8.15	0.65	13.73	19.85	14.88	7.30	3.60	0.50
2012	0.17	0.09	2.08	1.31	1.49	3.40	21.67	13.92	18.88	7.73	3.81	0.47
2013	0.15	0.53	6.29	0.52	2.87	10.77	16.58	23.22	25.64	12.92	6.49	1.10
2014	0.70	10.64	3.97	5.28	16.33	4.89	15.40	34.43	29.38	12.16	6.53	0.96
2015	0.28	0.18	0.31	0.06	1.07	14.56	10.26	4.85	15.63	8.40	5.54	0.67
2016	7.75	0.19	2.01	18.44	11.72	7.57	2.13	7.40	11.79	8.21	15.51	2.42
2017	0.84	1.34	0.88	0.12	6.45	16.85	8.95	8.91	26.37	7.38	4.47	7.50

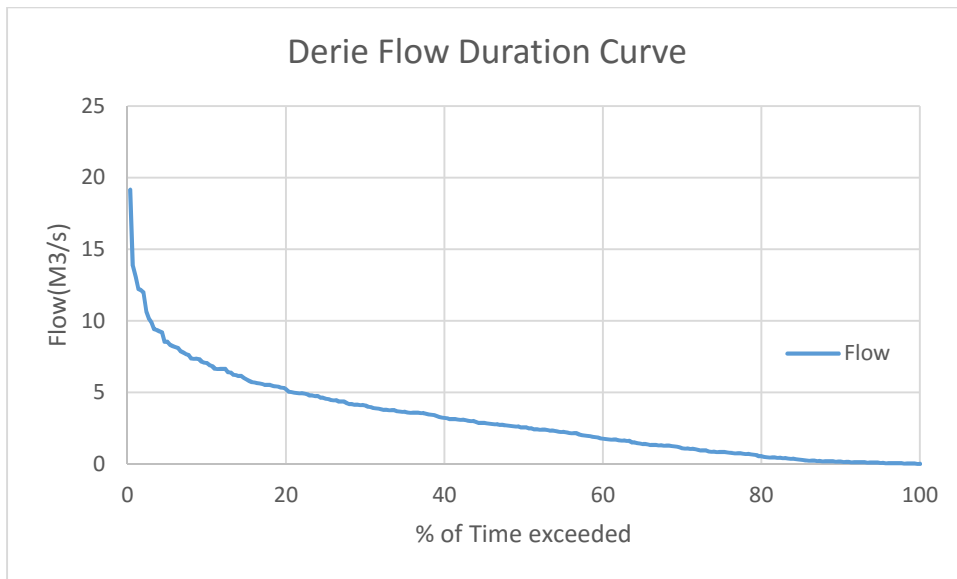


Simulated mean monthly stream flow (M³/s) at Gogare river(1993-2017)												
	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	1.15	3.48	0.81	4.14	11.80	2.17	2.30	6.10	3.35	8.14	2.32	0.94
1994	0.19	0.08	0.83	0.09	0.41	0.36	1.21	1.21	5.79	2.07	1.20	0.13
1995	0.06	1.79	0.07	1.27	0.64	0.73	4.01	4.70	7.35	2.43	1.17	3.01
1996	2.90	0.57	2.62	4.23	3.15	2.46	7.37	4.31	5.06	2.23	0.70	0.15
1997	0.16	0.06	0.79	3.69	1.94	4.36	3.22	7.32	6.77	19.20	5.65	2.63
1998	2.26	1.65	2.63	4.51	4.04	4.71	7.45	9.79	13.02	12.20	5.54	2.40
1999	0.47	0.18	0.42	0.10	0.22	1.64	3.18	3.28	4.33	7.85	3.24	1.66
2000	0.25	0.10	0.07	0.91	1.51	3.38	1.33	1.86	5.33	3.44	1.81	1.03
2001	0.10	1.17	3.48	2.65	2.26	1.67	4.02	6.67	4.45	3.22	0.74	0.14
2002	1.60	0.72	3.78	3.52	0.45	0.58	0.82	13.70	7.75	2.99	1.53	5.34
2003	1.56	2.47	3.21	4.77	3.54	1.57	3.11	7.07	8.21	3.24	2.08	0.35
2004	1.61	0.24	1.19	3.59	1.98	1.90	2.61	3.12	6.66	4.85	2.38	0.85
2005	0.18	0.11	4.99	1.79	6.11	1.42	4.22	2.46	5.86	2.14	2.82	0.36
2006	0.24	0.78	2.65	4.35	0.67	5.44	4.05	9.80	5.14	3.07	0.97	0.70
2007	0.13	0.40	2.58	2.84	0.77	4.44	6.58	5.01	7.81	3.69	2.15	0.46
2008	0.11	0.08	0.07	0.10	1.78	3.22	6.97	4.43	4.63	6.32	8.92	2.25
2009	0.78	0.15	0.23	1.11	0.23	0.82	4.28	6.26	6.09	8.96	2.49	0.93
2010	0.18	1.29	3.67	1.17	4.28	1.28	2.00	3.57	3.28	1.62	0.23	0.07
2011	0.07	0.04	1.14	0.06	2.93	0.42	4.72	6.90	5.11	2.53	1.21	0.21
2012	0.09	0.06	0.67	0.50	0.61	1.10	7.37	4.95	6.57	2.69	1.35	0.19
2013	0.08	0.19	1.97	0.19	1.05	3.65	5.71	8.17	8.96	4.48	2.23	0.43
2014	0.26	3.30	1.29	1.88	5.86	1.95	5.32	12.08	10.37	4.31	2.25	0.38
2015	0.13	0.10	0.13	0.05	0.37	4.86	3.47	1.81	5.41	2.88	1.86	0.25
2016	2.54	0.10	0.67	6.70	4.34	2.72	0.83	2.32	3.90	2.72	5.23	0.93
2017	0.35	0.43	0.33	0.08	2.41	5.83	3.20	3.13	8.99	2.62	1.56	2.63



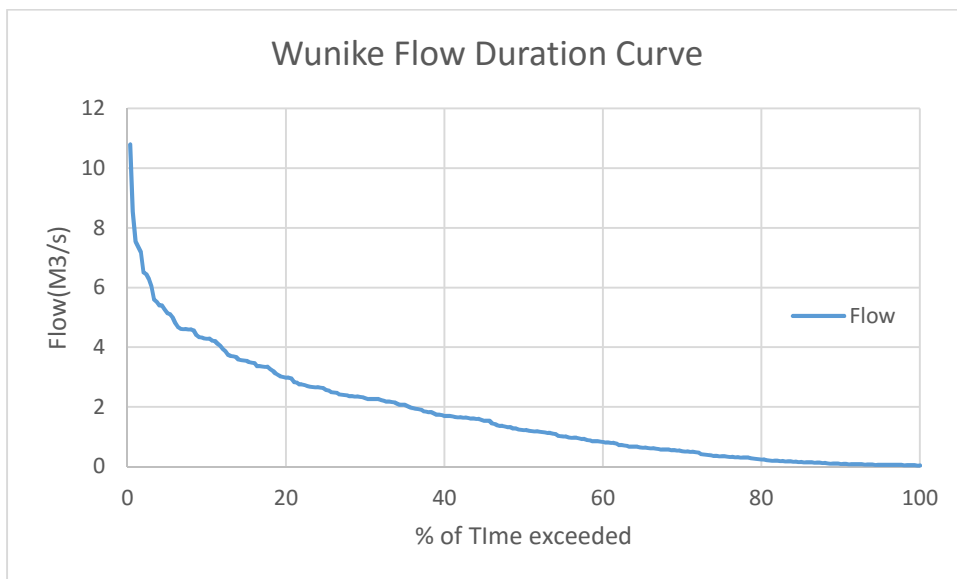
Simulated mean monthly stream flow (M³/s) at Derie river(1993-2017)												
	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	1.22	3.60	0.96	4.63	12.00	2.82	2.79	6.65	3.99	8.26	2.63	0.88
1994	0.18	0.05	0.97	0.23	0.75	0.64	1.63	1.63	6.26	2.40	1.33	0.12
1995	0.03	1.66	0.14	1.67	1.11	1.09	4.58	5.21	7.81	3.01	1.40	3.10
1996	3.23	0.77	2.69	4.19	3.38	2.84	7.39	4.63	5.33	2.51	0.72	0.14
1997	0.16	0.04	0.84	4.14	2.43	4.76	3.80	7.62	7.16	19.15	6.23	3.09
1998	2.40	1.66	2.75	4.55	4.20	4.96	7.71	9.91	13.06	12.24	5.92	2.44
1999	0.45	0.14	0.46	0.11	0.43	2.03	3.76	3.80	4.75	8.18	3.57	1.72
2000	0.25	0.07	0.04	1.31	1.92	3.78	1.79	2.35	5.71	3.91	2.07	1.10
2001	0.11	1.29	3.84	2.88	2.57	2.02	4.27	6.86	4.98	3.66	0.82	0.16
2002	1.77	0.85	4.01	3.60	0.68	0.80	1.05	13.85	8.34	3.52	1.73	5.66
2003	1.97	2.66	3.26	4.88	3.58	1.73	3.48	7.37	8.54	3.78	2.25	0.36
2004	1.75	0.38	1.30	3.88	2.16	2.16	3.02	3.67	7.07	5.45	2.73	0.87
2005	0.20	0.11	5.36	2.27	6.43	1.80	4.46	2.88	6.15	2.63	3.07	0.56
2006	0.28	0.84	2.85	4.37	0.89	5.54	4.49	10.16	5.64	3.44	1.07	0.73
2007	0.13	0.46	2.78	3.22	1.01	4.79	6.93	5.53	8.12	4.15	2.34	0.45
2008	0.09	0.05	0.06	0.20	2.24	3.69	7.34	5.00	5.07	6.64	9.21	2.56

2009	0.86	0.17	0.31	1.38	0.52	1.26	4.95	6.67	6.64	9.44	3.03	1.07
2010	0.20	1.46	3.71	1.35	4.38	1.52	2.26	4.11	3.92	1.98	0.28	0.08
2011	0.07	0.04	1.32	0.22	3.60	0.95	5.04	7.35	5.59	2.87	1.30	0.21
2012	0.06	0.03	0.71	0.68	0.75	1.41	7.89	5.46	7.08	3.15	1.48	0.19
2013	0.06	0.19	2.16	0.34	1.33	4.16	6.15	8.55	9.28	4.93	2.42	0.40
2014	0.25	3.45	1.51	2.19	6.02	2.32	5.73	12.16	10.65	4.80	2.38	0.37
2015	0.10	0.07	0.14	0.06	0.55	5.43	4.13	2.56	5.83	3.14	1.90	0.25
2016	2.51	0.18	0.75	6.66	4.47	3.12	1.19	2.70	4.37	3.14	5.54	1.24
2017	0.46	0.50	0.42	0.13	2.74	6.41	3.62	3.59	9.37	3.30	1.87	2.95



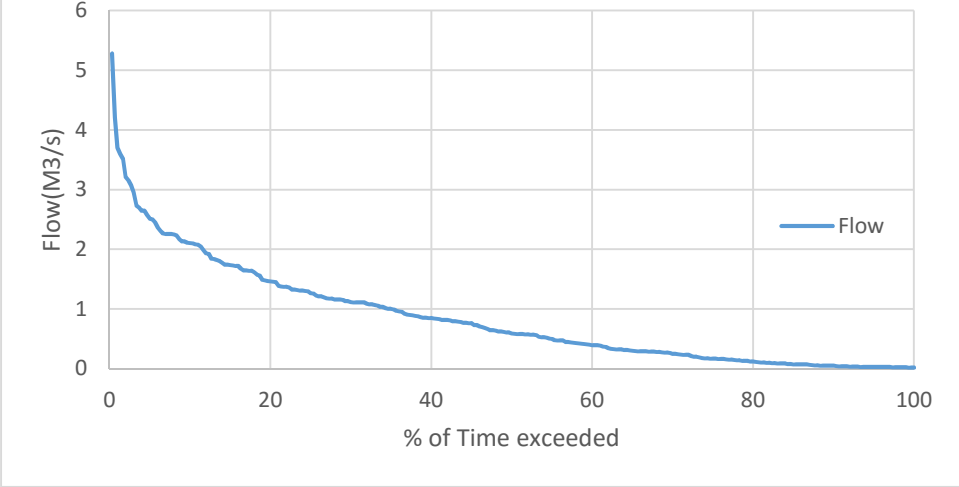
Simulated mean monthly stream flow (M ³ /s) at Wunike river (1993-2017)												
	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	0.81	2.27	0.36	2.21	6.51	1.54	1.32	4.21	2.18	4.61	1.24	0.40
1994	0.10	0.06	0.58	0.06	0.27	0.27	0.89	0.85	4.13	1.25	0.34	0.08
1995	0.05	1.15	0.06	0.63	0.41	0.49	2.55	3.49	4.60	1.13	0.35	2.08
1996	1.94	0.20	1.61	2.35	1.82	1.68	4.34	2.70	3.00	0.97	0.31	0.09
1997	0.12	0.05	0.59	2.27	1.13	2.50	2.33	4.56	4.05	10.80	3.36	0.95
1998	1.36	0.98	1.66	2.26	2.17	2.74	4.82	6.04	7.36	7.18	2.07	0.67

1999	0.22	0.11	0.31	0.06	0.13	1.01	1.99	2.49	2.68	5.01	1.54	0.50
2000	0.14	0.07	0.05	0.55	0.85	2.18	0.79	1.54	3.56	2.30	0.72	0.67
2001	0.06	0.88	2.35	1.57	1.21	1.11	2.64	4.33	2.82	1.63	0.30	0.08
2002	1.19	0.54	2.48	1.97	0.19	0.32	0.55	8.55	5.11	1.35	0.42	3.75
2003	1.28	1.22	1.91	2.66	1.85	0.78	2.26	4.68	5.14	1.70	0.67	0.18
2004	1.19	0.16	0.84	2.23	1.17	1.16	1.70	2.43	4.42	3.06	0.92	0.35
2005	0.12	0.08	3.37	0.97	3.59	0.58	2.67	1.86	3.68	1.36	1.79	0.24
2006	0.18	0.61	1.73	2.57	0.28	3.21	2.65	6.45	2.98	1.28	0.31	0.51
2007	0.09	0.31	1.74	1.74	0.39	2.66	4.22	3.34	4.62	2.11	0.70	0.21
2008	0.07	0.05	0.05	0.08	1.01	2.03	4.29	2.98	2.97	3.55	5.28	0.81
2009	0.47	0.09	0.17	0.71	0.14	0.57	2.76	4.30	3.94	5.40	1.04	0.34
2010	0.10	0.97	2.26	0.57	2.34	0.63	1.43	2.76	2.42	0.83	0.15	0.06
2011	0.06	0.04	0.85	0.04	1.70	0.20	3.37	4.61	3.02	1.03	0.55	0.13
2012	0.06	0.05	0.51	0.33	0.36	0.80	4.60	3.51	4.29	1.22	0.38	0.11
2013	0.06	0.15	1.45	0.14	0.67	2.40	3.87	5.40	5.52	2.08	0.65	0.20
2014	0.18	2.39	0.92	1.18	3.35	1.09	3.57	7.53	6.29	1.83	0.62	0.19
2015	0.08	0.07	0.10	0.04	0.25	3.12	2.16	1.67	3.71	1.32	0.72	0.15
2016	1.66	0.08	0.48	3.70	2.36	1.60	0.61	1.64	2.83	1.64	3.27	0.64
2017	0.16	0.31	0.24	0.07	1.38	3.48	1.93	2.37	5.60	1.60	0.52	1.61



Simulated mean monthly stream flow (M ³ /s) at Hae river (1993-2017)												
	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	0.39	1.11	0.17	1.08	3.21	0.73	0.65	2.08	1.07	2.25	0.58	0.19
1994	0.05	0.03	0.28	0.03	0.13	0.13	0.45	0.41	2.05	0.59	0.16	0.04
1995	0.02	0.56	0.03	0.31	0.21	0.23	1.27	1.72	2.25	0.53	0.17	1.04
1996	0.92	0.10	0.79	1.16	0.88	0.83	2.13	1.33	1.47	0.45	0.15	0.04
1997	0.06	0.02	0.29	1.11	0.57	1.21	1.16	2.24	1.99	5.28	1.64	0.44
1998	0.66	0.48	0.81	1.11	1.06	1.36	2.37	2.96	3.60	3.52	1.00	0.31
1999	0.11	0.05	0.15	0.03	0.07	0.50	0.97	1.23	1.31	2.46	0.73	0.23
2000	0.07	0.03	0.03	0.28	0.41	1.09	0.37	0.77	1.74	1.11	0.34	0.33
2001	0.03	0.43	1.15	0.76	0.61	0.54	1.30	2.13	1.38	0.76	0.15	0.04
2002	0.58	0.26	1.21	0.96	0.09	0.16	0.27	4.21	2.50	0.64	0.20	1.85
2003	0.62	0.62	0.91	1.30	0.90	0.39	1.11	2.31	2.51	0.82	0.31	0.09
2004	0.58	0.08	0.42	1.08	0.57	0.57	0.85	1.20	2.17	1.49	0.43	0.17
2005	0.06	0.04	1.64	0.51	1.73	0.28	1.33	0.90	1.81	0.64	0.87	0.12
2006	0.10	0.29	0.84	1.26	0.13	1.57	1.32	3.16	1.46	0.61	0.14	0.25
2007	0.05	0.14	0.85	0.85	0.20	1.31	2.08	1.64	2.27	1.02	0.32	0.10
2008	0.03	0.03	0.03	0.03	0.52	0.99	2.10	1.46	1.46	1.74	2.58	0.37
2009	0.23	0.04	0.10	0.32	0.07	0.28	1.37	2.11	1.94	2.65	0.48	0.17
2010	0.05	0.47	1.11	0.29	1.13	0.30	0.70	1.37	1.18	0.39	0.07	0.03
2011	0.03	0.02	0.42	0.02	0.85	0.09	1.68	2.26	1.48	0.47	0.27	0.06
2012	0.03	0.02	0.25	0.16	0.18	0.39	2.26	1.74	2.11	0.57	0.18	0.05
2013	0.03	0.07	0.71	0.07	0.33	1.18	1.93	2.65	2.70	1.00	0.30	0.10
2014	0.09	1.18	0.44	0.58	1.65	0.53	1.78	3.69	3.07	0.88	0.29	0.09
2015	0.04	0.03	0.05	0.02	0.12	1.56	1.03	0.84	1.82	0.62	0.35	0.07
2016	0.82	0.03	0.24	1.84	1.13	0.79	0.29	0.81	1.39	0.79	1.61	0.29
2017	0.08	0.17	0.11	0.02	0.68	1.72	0.96	1.16	2.73	0.77	0.24	0.79

Hae Flow Duration Curve



APPENDIX: E SWAT-CUP Calibration Results

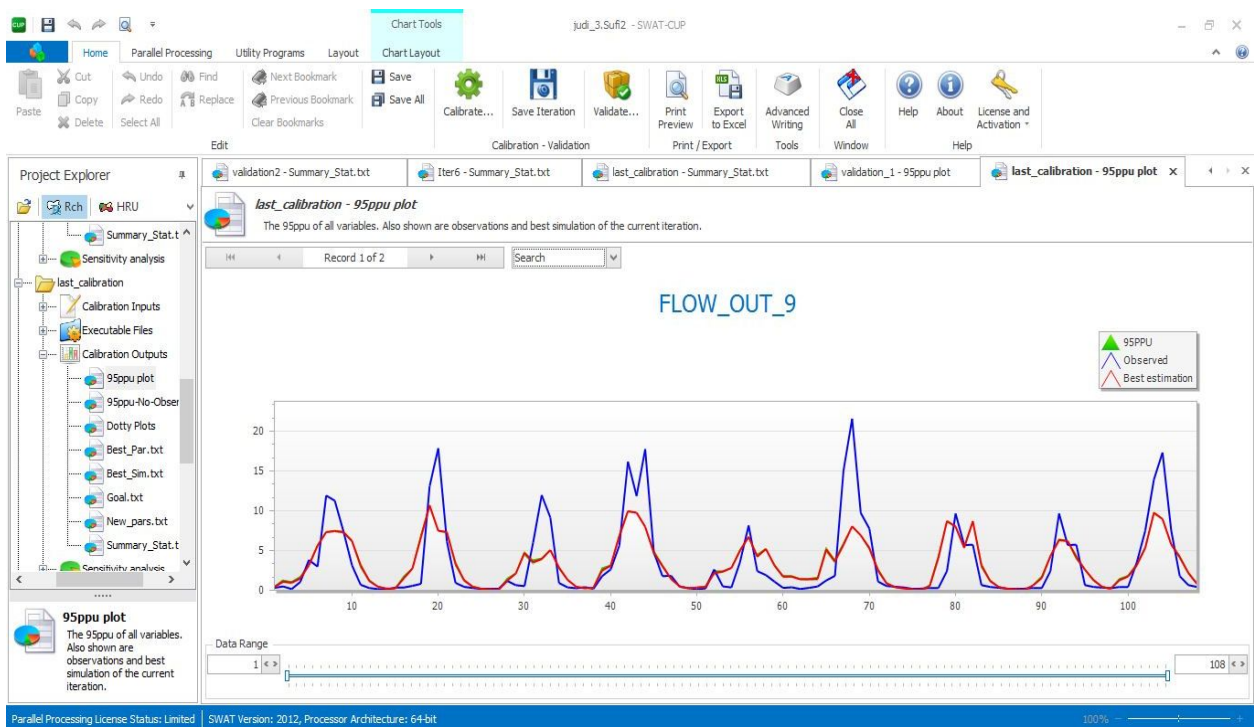
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Goal_type= Nash_Sutcliff ··· No_sims= 1000 ··· Best_sim_no= 727 ··· Best_goal = 6.021653e-001

Variable ····· p-factor · r-factor · R2 ··· NS ··· bR2 ··· MSE ··· SSQR ····· PBIAS · KGE · RSR · MNS · VOL_FR ···
FLOW_OUT_9 ····· 0.06 · 0.01 ··· 0.66 · 0.60 · 0.3080 · 9.5e+000 · 6.2e+000 · 4.2 · 0.54 · 0.63 · 0.49 · 1.04 ···

---- Results for behavioral parameters ----
Behavioral threshold= 0.500000
Number of behavioral simulations = 1000

Variable ····· p-factor · r-factor · R2 ··· NS ··· bR2 ··· MSE ··· SSQR ····· PBIAS · KGE · RSR · MNS · VOL_FR ···
FLOW_OUT_9 ····· 0.06 · 0.01 ··· 0.66 · 0.60 · 0.3080 · 9.5e+000 · 6.2e+000 · 4.2 · 0.54 · 0.63 · 0.00 · 1.04 ···
    
```



APPENDEX: F SWAT-CUP Validation Results

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Goal_type= Nash_Sutcliffe ··· No_sims= 1000 ··· Best_sim_no= 727 ··· Best_goal = 6.021653e-001

Variable ········ p-factor ··· r-factor ··· R2 ··· NS ··· bR2 ··· MSE ····· SSQR ····· PBIAS ··· KGE ··· RSR ··· MNS ··· VOL_FR ···
FLOW_OUT_9 ······ 0.06 ····· 0.01 ····· 0.66 0.60 ··· 0.3080 ··· 9.5e+000 ··· 6.2e+000 ··· 4.2 ··· 0.54 ··· 0.63 ··· 0.49 ··· 1.04 ···

---- Results for behavioral parameters ----
Behavioral threshold= 0.500000
Number of behavioral simulations = 1000

Variable ········ p-factor ··· r-factor ··· R2 ··· NS ··· bR2 ··· MSE ····· SSQR ····· PBIAS ··· KGE ··· RSR ··· MNS ··· VOL_FR ···
FLOW_OUT_9 ······ 0.06 ····· 0.01 ····· 0.66 0.60 ··· 0.3080 ··· 9.5e+000 ··· 6.2e+000 ··· 4.2 ··· 0.54 ··· 0.63 ··· 0.00 ··· 1.04 ···
    
```

