# Small Hydro Power (SHP) Potential Sites Selection and Engineering Geological appraisal – A study in Ziway Lake Sub-Basin, Central Ethiopia

**Wegene Talelign**

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# Signature Page

**Addis Ababa University**
**School of Graduate Studies**

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# Abstract

## Small Hydro Power (SHP) Potential Sites Selection and Engineering Geological appraisal – A study in Ziway Lake Sub-Basin, Central Ethiopia

**Wegene Talelign**

Addis Ababa University, 2016

The present study area is located in Rift Valley drainage basin, in the central part of the country. Meki and Kater drainage Sub-basins of Lake Zeway have been identified for the present study. The main objective of the present study was to identify potential Small Hydropower sites in the study area and to carry out ground verification with engineering geological appraisal, at pre-feasibility level, for selected sites.

In total 49 potential SHP sites has been identified during the present study. Out of these, 19 sites fall within Meki sub-basin and 30 in Kater sub-basin. Most of these identified sites are concentrated along the margin of the sub-basins. For the potential sites the 10 daily observed discharge data has been projected from adjacent gauged stations by percent area ratio method for those which demonstrate similar catchment characteristic, based on statistical regression analysis. Initial estimation of the power potential of 49 SHP sites has been computed for 75% dependable discharge and taking turbine efficiency to be 90% and efficiency of the generator as 95%. The head losses caused by the frictions and bends in the penstock have been taken equal to 10% of the gross hydraulic head. Thus, the total power potential, as estimated for 49 identified sites for which discharge data was available, comes out to be around 17 MW. Thus, these 49 potential SHP sites can be ground verified and be taken up for detailed Engineering Geological Appraisal. However, for the present study, with the limitation of resources, time and financial constraints it was not possible to undertake ground verification and detailed engineering geological appraisal of all 49 SHP sites. Therefore, a sincere effort has been made to select 3 potential SHP site namely; Rufael, Weldia and Lebu to undertake ground verification and engineering geological appraisal, at prefeasibility level. These sites were ground verified for the availability of the head, discharge, the possible layout and turbine selection. Further, engineering geological appraisal of these sites has also been carried out at prefeasibility level. Finally based on the results and finding of the present study, certain recommendations has been made.

**Key words**: Small Hydropower (SHP), Site Identification, Power potential Engineering Geological Appraisal

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# Chapter 1 Introduction

## 1.1 Background

In today's time, undoubtedly, electrical energy is becoming an essential commodity for the modern life. Every sector, like industry, technology, transportation, public utilities or the domestic life is now totally dependent on electrical power. The dependence on electrical power is becoming more and more, which has resulted into increasing demand for it. Electricity, in the present times, is not only an essential commodity for urban areas but gradually becoming equally essential for rural areas also (Nehimia Solomon, 2005; AAU, 2014).

According to EMWIE (2012) access to energy is among the key elements for the economic and social development of Ethiopia. The energy sector in Ethiopia can be generally categorized in to two major components: traditional and modern (traditional biomass usage and modern fuels i.e. electricity and petroleum). As more than 80% of the country's population is engaged in the small-scale agricultural sector and live in rural areas, traditional energy sources represent the principal sources of Energy in Ethiopia.

According to EMWIE (2012) report, rural households utilized the greatest proportion of energy (>80%) out of which 99% is of biomass origin and comprises mainly of firewood, charcoal, crop residues, and dung cakes. This biomass energy is most often utilized without being processed, which has many disadvantages to the users including loss of energy due to poor efficiency of utilization and also it may result into health problems. The vast majority of Ethiopian households (93%) depend on open fire stoves with a very poor fuel efficiency of 10-12%. The household sector, being the major consumer of energy in the country, is putting pressure on the natural ecosystem by devastating the forest resources and compromising food self-sufficiency by taking most of the residues from farms and fields.

The use of renewable source is the most valuable solution to reduce the environmental problems associated with unprocessed bio-mass based energy generation and achieves clean and sustainable energy development. Hydro, wind, biomass, solar and geothermal energy are among the most important renewable sources for energy generation (Ferreira et al., 2016).

The sustainable development of hydropower is becoming increasingly important in legislative agenda of the country. The overall objective of the National Hydropower policy is to enhance

efficient and sustainable development of the water resources and meet the national energy demands as well as supply for external markets to earn foreign exchange (EMWIE, 2012).
The present study was carried out in Zeway Sub-basin. The study area is about 100 km from Addis Ababa, the capital city and falls in Oromia and partly in SNNP region defined by geographical coordinates between latitude $7^o$20’54” to $8^o$25’56” and longitude of $38^o$13’02” to $39^o$24’01”.

## 1.2 Problem Statement

In Ethiopia most of the people (around 80% of the population) lives in rural areas where modern energy access is almost negligible (EMWIE, 2012). To satisfy their energy needs, these people are utilize the greatest portion of energy out of biomass origin and comprises mainly of firewood, charcoal, crop residues, and dung cakes. This biomass energy is most often utilized without being processed, which has many disadvantages to the users including loss of energy due to poor efficiency of utilization and health problems. The household sector is putting pressure on the natural ecosystem by devastating the forest resources and compromising food self-sufficiency by taking most of the residues from farms and fields. To solve these problems electrification of the rural communities is very essential. However, most of the villages and towns are remotely located and interconnected grid system if has to transmit electricity to these villages and towns may not be that much techno-economic viable (AAU, 2014).

These two contradictory factors, need of power and effect of traditional power systems, necessitates for a new method of electrification of the rural areas. This new method can be use of potential of renewable energies such as hydro, wind, solar or a combination of the three. Further, the topography of the study area especially in the high lands, and natural drainage system provides suitable conditions for local power generation. Therefore, small hydropower (SHP)schemes are the appropriate solution to power demand as these require small capital investment and can be completed in a very short period of time, with minimum adverse environmental impacts(Raguvanshi et al., 2008).

In general, SHP schemes have relatively low lifecycle investment costs per kW of installed power and through their modular nature, it is possible to size the system to meet specific power demand according to potential of the site and the available finance. As the system can be designed and installed using local resources: materials and labor, this also creates job opportunities and ability to use technology to advance standard of living in the area.

## 1.3 Objectives

### 1.3.1 General Objective

The main objective of the present research is to identify the potential small hydropower sites and to carry out engineering geological appraisal of the identified small hydro power sites in the study area.

### 1.3.2 Specific Objective

To accomplish the present research, the following specific objectives were designed:

(i) Development of flow-duration curves for different exceedance levels based on available hydrologic data of the study area which will be used for estimation of discharge for un-gauged rivers.
(ii) Topographical study for identification of SHP sites based of formulated selection criteria
(iii) To work out general layout of the proposed scheme; selection of diversion weir and intake site, forebay site, penstock alignment and power house site.
(iv) Ground verification of general layout and to carry out engineering geological appraisal for selected sites (for selected sites).
(v) General design of various components and selection of turbine.
(vi) Compare the selected (ground verified) site from, suitability point of view in the context of engineering geological study along various components of the small hydropower scheme and to propose suitable recommendations.
(vii) To suggest possible future sustainable utilization of the power.

## 1.4 Research Methods

To accomplish the above objectives of the research the following systematic methodology will be adopted;

- Literature review and analysis of previous data on meteorology, hydrology and geology.
- Preparation of base map at a scale of 1: 50,000 from topographic maps and previous works.
- Identification of potential SHP sites in the study area through topographical maps.
- Delineation of potential catchments from topographical maps.

- Ground verification of potential SHP sites and finalization of general layout of the projects (for selected site).

- Collection of data on geology, topography, and hydrology of the area in the field.

- Slope stability studies along the water conductor system of the SHP sites, for present and possible worst conditions.

- The hydrological, meteorological, topographical, geological and geotechnical data were interpreted in accordance with the field observation, literature review to reach at conclusions and to suggest possible recommendations.

- Digitization of maps and generation of various themes, preparation of database file to be attached as attribute data to the various themes, preparation of data/information attachment files including various information on the SHP sites and preparation of GIS Database on SHP sites in the study area.

- Counterchecking of conclusions and validation of result

## 1.5 Significance of the Study

The study may contribute to meet out a part of power needs within the study area, particularly for those areas which are remotely located and cannot be easily connected to the grid. The study also will be significant to make aware people, private company, government organization and non-governmental organization and community of the study area, the small hydropower potential of the study area and use of the resource properly. The present study may also serve as a guide to develop and extend similar type of hydrologic study for other regions in the country, which will help in the speedy development of small hydropower sector. It will be used as input for advanced scientific research works.

## 1.6 Scope and Limitations of the Study

Though the study area covers the Lake Ziway sub basin (Meki and Kater Catchments), its scope is limited to certain accessible areas and proximity to cluster of village during ground verification stage because of limitations of time, resources and financial constraints. However, all efforts are made to perform the present study systematically with adequate scientific inputs and realistic facts under such limitations.

## 1.7 Organization of the Study

The present research study is presented in seven Chapters comprising the following;

| | |
|---|---|
| Chapter I | Deals with General Background, Problem Statement, Objectives, Research Methods, Significance of the Study, Scope and Limitations of the Study and Organization of the study. |
| Chapter II | Describes about an Introduction to Hydropower, General Description of Hydropower, General layout of ROR type Small Hydropower, Importance of Small Hydropower, Advantages of hydropower, Energy sector in Ethiopia and Small Hydropower in Ethiopia |
| Chapter III | Deals with an overview to the present study area, Location and Accessibility, climatic condition, Topography and Drainage, Regional Geologic Setting, Local geology, Soils, Land Use and Land Cover of the study area. |
| Chapter IV | Deal with hydrology analysis. It includes River Gauging Stations in Study Area, Flow Duration Curve Analysis for Gauged Sites, Delineation of Drainage Area for Gauged Stations, Regression Analysis of Available Hydrologic Data of the study area, Transfer of Flow-Duration Curves and Mean Annual Flow at an Ungauged Sites. |
| Chapter V | Describes about Potential SHP sites in the study area. Introduction, Potential Catchment Delineation, Determination of Head, Estimation of Dependable Discharge, Characteristics of Flow-Duration Curves, Estimation of Discharge for Power Generation, Preliminary Estimation of Power Potential of Identified Sites and Annual Power Generation. |
| Chapter VI | In this chapter Engineering Geological Appraisal of selected SHP sites has been presented. This chapter includes Ground Verification for General Layout of Schemes, Geomorphology in and around the Selected SHP Sites Engineering Geological Appraisal of SHP Sites, Geological Investigation of the Selected Site Slope Stability Studies of the Selected SHP Sites, Hydrological Investigation and Selection of Turbine for the selected sites. |
| Chapter VII | Finally Conclusion and Recommendations. |

# Chapter 2 Literature review

## 2.1 Introduction

Energy is considered to be a key factor in the generation of wealth, social development and improved quality of life in all developed and developing countries in the world. Therefore, produced and consumed energy resources and especially renewable energy sources have a very important value (Capik et al., 2012). The use of renewable source is the most valuable solution to reduce the environmental problems associated with fossil fuels based energy generation and achieves clean and sustainable energy development. Hydro, wind, biomass, solar and geothermal are among the most important renewable sources for energy generation (Nautiyal et al., 2011).

## 2.2 General Description of Hydropower

Hydropower, hydraulic power or water power is power that is derived from the force or energy of moving water, which may be harnessed for useful purposes. Hydropower is available in a broad range of project scales and types. Projects can be designed to suit particular needs and specific site conditions. As hydropower does not consume or pollute the water it uses to generate power, it leaves this vital resource available for other uses. At the same time, the revenues generated through electricity sales finance other infrastructure essential for human welfare. This can include drinking water supply systems, irrigation schemes for food production, infrastructures enhancing navigation, recreational facilities and ecotourism (Yuksel, 2008).

### 2.2.1 Classifications of Hydropower

Hydropower is a general term that covers a broad range of installations. Depending on the type, the services provided vary (Gaudard and Romerio, 2014). There are some classifications: into water head, storage capacity or size and facility type: run-of-river (RoR), storage and pumped-storage hydropower (Kumar, et.al, 2011).

#### 2.2.1.1 Power potential

There is no international agreement on the limit of “small”, but most European and other countries accept 10 MW as the upper limit. Within the SHP category, the systems are further categorized into pico, micro, mini, and small systems. Most of the countries and organizations recognize pico as a system that generates less than 10 kW, micro (more than 10 kW but less than 100 kW), mini (more than 100 kW but less than 1 MW), and small (above 1 MW but less than 10 MW) (ESHA, 2004).

#### 2.2.1.2 Mode of head concentration

The objective of a hydropower scheme is to convert the potential energy of a mass of water, flowing in a stream with a certain fall to the turbine (termed the "head"), into electric energy at the lower end of the scheme, where the powerhouse is located (ESHA, 2004). The power output from the scheme is proportional to the flow and to the head. Schemes are generally classified according to the “Head”:

(i) High head: 100m and above
(ii) Medium head: 30 - 100 m
(iii) Low head: 2 - 30 m

#### 2.2.1.3 Mode of discharge regulation

Hydropower plants are often classified in three main categories according to operation and type of flow. Run-of-river (RoR), storage (reservoir) and pumped storage hydro power plants (HPPs) all vary from the very small to the very large scale, depending on the hydrology and topography of the watershed. In addition, there is a fourth category called in-stream technology, which is a young and less-developed technology (Kumar, et.al, 2011).

**Run-of-River**

A RoR 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. When even short-term storage is not included, RoR HPPs will have generation profiles that are more variable, especially when situated in small rivers or streams that experience widely varying flows.

In a RoR HPP, a portion of the river water might be diverted to a channel or pipeline (penstock) to convey the water to a hydraulic turbine, which is connected to an electricity generator (Fig 2.1).RoR projects may form cascades along a river valley, often with a reservoir-type HPP in the upper reaches of the valley that allows both to benefit from the cumulative capacity of the various power stations. Installation of RoR PPs is relatively inexpensive and such facilities have, in general, lower environmental impacts than similar-sized storage hydropower plants (Kumar, et.al, 2011).

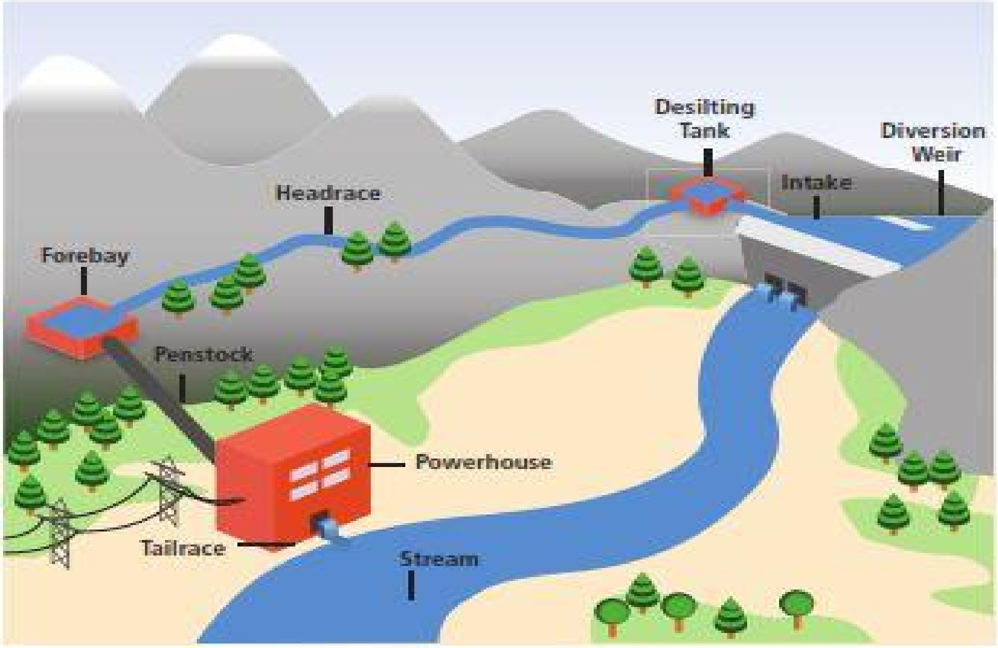

**Fig 2.1 Typical ROR hydropower plant** *(Source: Kumar, et al., 2011)*

## Storage Hydropower

Hydropower projects with a reservoir are also called storage hydropower since they store water for later consumption. The reservoir reduces the dependence on the variability of inflow. The generating stations are located at the dam toe or further downstream, connected to the reservoir through tunnels or pipelines (Fig 2.2). The type and design of reservoirs are decided by the landscape and in many parts of the world are inundated river valleys where the reservoir is an artificial lake.

In geographies with mountain plateaus, high-altitude lakes make up another kind of reservoir that often will retain many of the properties of the original lake. In these types of settings, the generating station is often connected to the lake serving as reservoir via tunnels coming up beneath the lake (lake tapping). One power plant may have tunnels coming from several reservoirs and may also, where opportunities exist, be connected to neighboring watersheds or rivers. The design of the HPP and type of reservoir that can be built is very much dependent on opportunities offered by the topography (Kumar, et.al, 2011).

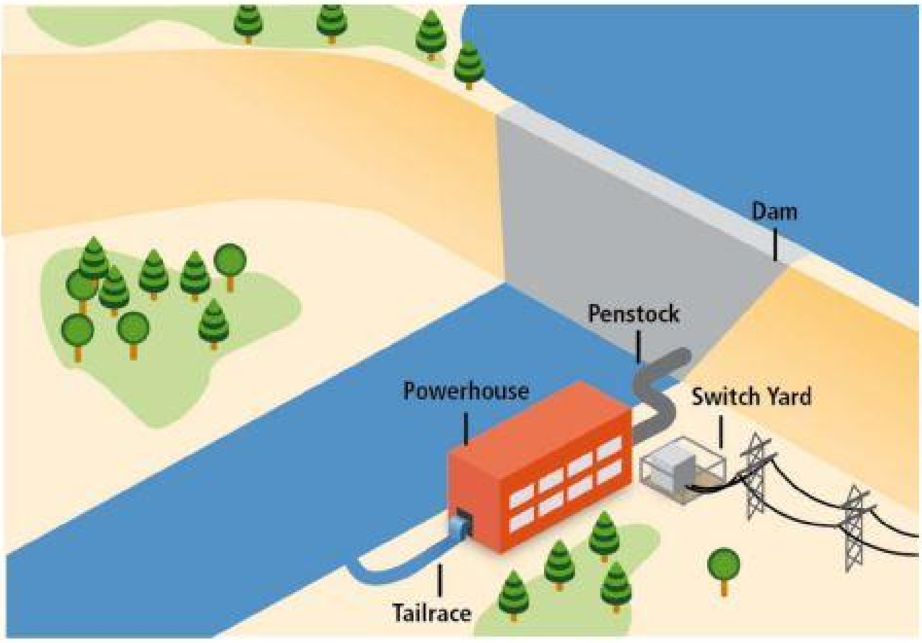

**Fig. 2.2 Typical hydropower plant with reservoir** *(Source: Kumar, et al., 2011)*

### Pumped storage

Powerhouse Tailrace Penstock Pumped storage plants are not energy sources, but are instead storage devices. In such a system, water is pumped from a lower reservoir into an upper reservoir (Fig 2.3), usually during off-peak hours, while flow is reversed to generate electricity during the daily peak load period or at other times of need.

### In-stream technology using existing facilities

To optimize existing facilities like weirs, barrages, canals or falls, small turbines or hydrokinetic turbines can be installed for electricity generation. These basically function like a run-of-river scheme, as shown in Figure 2.4.

## 2.3 General layout of ROR type Small Hydropower

A typical run-of-river SHP system for electricity generation is composed of the following basic components: water intake structure (e.g., weir and settling tank), penstock, turbine, mechanical power transmission system to generator, generator, and electricity transmission system to load centers, and control system (Kaunda et al., 2012) (Fig.2.1).

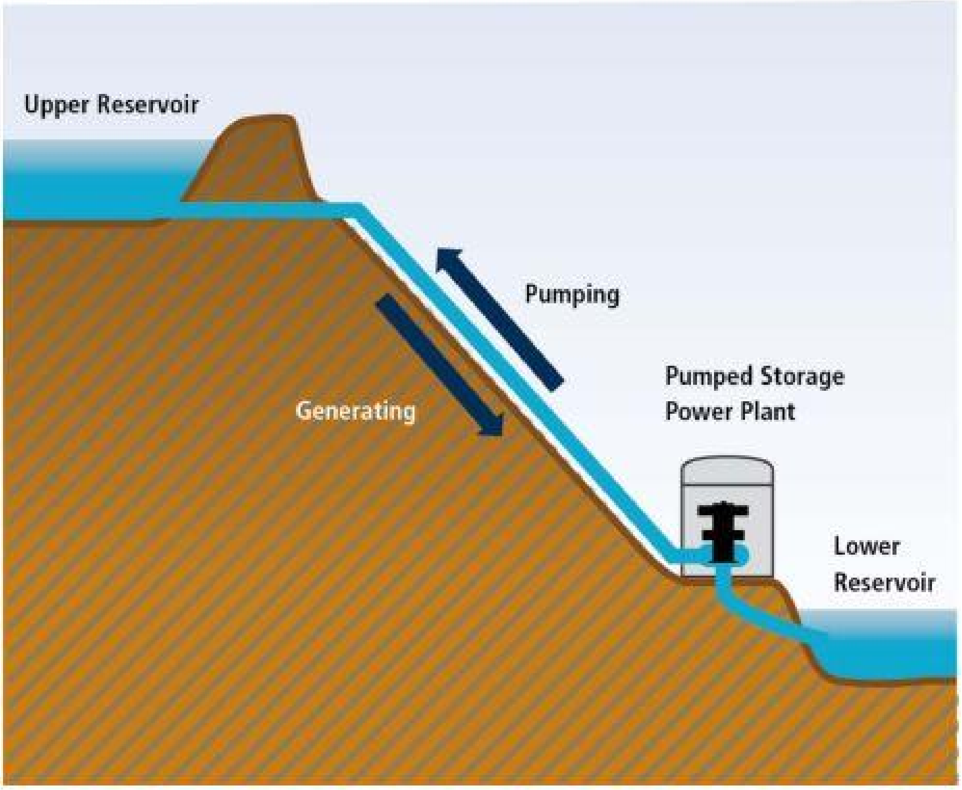

**Fig. 2.3 Typical pumped storage project***(Source: Kumar, et al., 2011)*

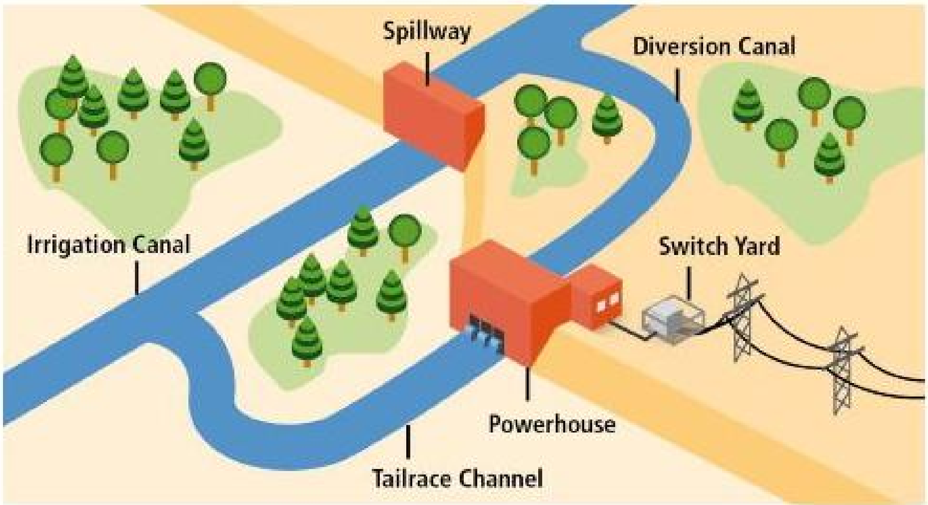

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**Fig. 2.4 Typical in-stream hydropower plant using existing facilities** *(Source: Kumar, et al., 2011)*

In RoR type only part of the river flow is diverted to a forebay through channels or pipes, from which it falls down a penstock to enter an electricity-generating turbine. After this process the water is returned to the river via a tailrace. These plants depend directly on natural water cycles, since their water supply is variable and cannot be controlled. The water head is practically constant, so that the power generated by the power plant will depend on the mass of water flowing along the river or stream. SHP is a site-specific technology and as such not all locations on the river flow course are ideal for SHP development except those that have considerable sizes of head such as sloping sections of the river and natural falls. This shows that most of the potential sites for SHP are found in mountainous areas with perennial rivers (Kaunda et al., 2012).

### 2.4 Importance of Small Hydropower

As an electricity generation technology, SHP is a very efficient energy technology because electricity is generated directly from the shaft power. SHP system for power supply is a well-matured technology as the case with solar PV and wind energy systems (Kaunda et al., 2012).As discussed above SHP schemes have relatively low life cycle investment costs per kW of installed power and through their modular nature it is possible to size the system to meet specific power demand according to potential of the site and the available finance. As the system can be designed and installed using local resources: materials and labor, this also creates job opportunities and ability to use technology to advance standard of living in the area.

In Ethiopia, most of the villages/towns are remotely located and interconnected grid system if has to transmit electricity to these villages/ towns may not be that much techno-economic viable. Presently efforts are being made by Ethiopian Electric Power Corporation (EEPCo) through Universal Electric Access Program to electrify vast areas in Northern, Central & Southern, Western and Eastern parts of the country. Although expansion of the national grid for rural electrification is progressing fast, still there is a vast possibility to develop micro hydro schemes, particularly in those areas which are remotely located and are not covered presently under Universal Electric Access Program (AAU, 2014).

### 2.5 Advantages of hydropower

Small and large hydropower can have different effects. Small hydro generation have no environmental effects to speak of as there are no large dams or reservoirs involved. Large hydro systems with sizable dams and reservoirs may cause one or more of the following in addition to large financial investments (Fritz, 1984);

- Relocation of an existing settlement;
- Reduction of farmland and grazing land;
- Disruption of the normal migration pattern of fish or the flow of traffic;

- The presence of a dam will probably cause the accumulation of silt which will, not only adversely affect power generation but also cause the level of reservoir water to rise, resulting in further inundation of the surrounding lands;
- Increased possibility for water-borne diseases;
- Disappearance of bird and animal sanctuary because of inundation, although other birds and animals can find sanctuary at the boundary of the reservoir.

A few general statements can be made about the environmental aspects of hydro energy generation systems:

- They are generally environment friendly; i.e., no air or thermal pollution;
- The energy source, i.e. water, is not, in the final analysis, consumed like fossil-fuel.

## 2.6 Energy sector in Ethiopia

According to Dawit Hialu (2010) the country is endowed with enormous energy potentials with its hydropower potential leveled the second largest in Africa with a total capacity of over 45 GW. Similarly, its wind, solar and geothermal potentials are approximated to be some 10 GW, 10 GW and 5 GW, respectively.

Although Ethiopia is endowed with a variety of renewable energy resources including hydro, wind, geothermal, solar and bio-energy, access to modern energy is mostly not possible in rural areas and in most cases neither sufficiently reliable nor affordable (Abebe Tilahun, 2011). Like in many other Sub-Saharan countries, Ethiopia’s energy sector depends highly on biomass. Rural household have to rely on burning wood, crop residues and animal dung for their energy needs (Getachew Bekele and Abebe Tilahun, 2011).

Annual per capita consumption of electricity is 100 kWh. The same figure for the Sub-Saharan Africa is 510 kWh. This reveals that most of the energy usage is still from traditional energy sources such as wood and animal waste. Moreover, it also informs the fact that with the country’s economic development and improvement of the per-capita income, there will be huge potential for consumption of electricity within the country.

## 2.7 Hydropower Resource of Ethiopia

Ethiopia is a country with a very high hydropower potential with only a fraction of this potential having been harnessed (EEPCO, 2013).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. The economically exploitable hydropower potential is estimated to be between 15,000 and 30,000 MW. Large hydro power 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 (http://www.smallhydroworld.org/fileadmin/user_upload/pdf/WSHPDR_2013_Executive_Summary.pdf).So far only 3% of it is exploited (MWIE (a), 2013).

GIZ (2009) reported that potential for small and micro-hydropower development is estimated to be 1,500-3,000 MW (10 % of the total hydropower potential in Ethiopia). It is limited by the seasonality of rainfall and reduced availability of water. Increased levels of small-scale irrigation farming, as a result of population growth, lead to increases in water needs.

EMWIE (2013) reported that the installed hydropower capacity in 2013 is around 1.8 GW with twelve existing plants, three plants under construction and one plant under refurbishment. When the committed projects are commissioned, the installed capacity will exceed 10GW. The total interconnected existing hydropower generation installed capacity accounts to 1939.6 MW. Besides, the total installed hydro plants capacity under construction accounts for 8,370 MW (Table 2.1) (EMWIE, 2013).

**Table 2.1Main characteristics of the existing and committed hydro** *(Source: EEPCO, 2013)*

| S.No. | Name | Status | Commissioning year | Capacity(MW) |
|---|---|---|---|---|
| 1 | Awash II | Existing | 1966 | 32 |
| 2 | Awash III I | Existing | 1971 | 32 |
| 3 | Beles | Existing | 2010 | 460 |
| 4 | Fincha | Existing | 1973 | 128 |
| 5 | Genale 3 | Under construction | 2015 | 254 |
| 6 | Gibe I | Existing | 2004 | 184 |
| 7 | Gibe II | Existing | 2010 | 420 |
| 8 | Gibe III | Under construction | 2014/2015 | 1870 |
| 9 | Koka | Existing | 1960 | 42.9 |
| 10 | MelkaWakena | Refurbished | 1988/2014 | 153 |
| 11 | Neshe | Existing | 2013 | 98 |
| 12 | Renaissance | Under construction | 2015/18 | 6000 |
| 13 | Sor | Existing | 2014 | 5 |
| 14 | Tekeze I | Existing | 2009 | 300 |
| 15 | Tis Abay I | Existing | 1964/2000 | 11.4 |
| 16 | Tis Abay II | Existing | 2001 | 68 |

In addition, projects under preparation for construction accounts for 1980 MW installed potential capacity (Table 2.2).

**Table 2.2 Hydropower plants under preparation for construction** *(Source: AAU, 2014)*

| S.No. | Name of Plant | Installed Capacity(MW) | |
|---|---|---|---|
| 1 | Aysha | 300 | Feasibility Completed |
| 2 | Chemoga _ Yeda I&II | 280 | Feasibility Completed |
| 3 | Gilgel Gibe IV | 1400 | Feasibility Completed |
| Total | | 1900 | |

In addition, Candidate Power Plants for Investment to be constructed are also under feasibility or reconnaissance stage (Table 2.3)

**Table 2.3 Candidate Power Plants for Investment** *(Source: AAU, 2014)*

| S. No | Name | Installed Capacity | Project Status |
|---|---|---|---|
| 1 | Baro I&II, Genji | 900 | Feasibility Completed |
| 2 | Beko-Abo | 935 | Under Feasibility |
| 3 | Birbir R | 467 | Reconnaissance |
| 4 | Dabas | 425 | Reconnaissance |
| 5 | Derbu I &II | 250+325 | Feasibility Completed |
| 6 | Geba I & I&II | 366 | Feasibility Completed |
| 7 | Genale V | 100 | Reconnaissance |
| 8 | Gibe V | 660 | Under Feasibility |
| 9 | Gojeb | 153 | Feasibility Completed |
| 10 | LowereDideessa | 613 | Reconnaissance |
| 11 | Mandaya | 2000 | Under Feasibility |
| 12 | Tamas | 1060 | Reconnaissance |
| 13 | Tekeze II | 450 | Under Feasibility |
| 14 | Wabishebele | 87 | Feasibility completed |
| **Total** | | **8791** | |

## 2.8 Small Hydropower in Ethiopia

Ethiopia is endowed with considerable hydropower resources. As discussed above the potential for small- and micro-hydropower development is estimated to be 1,500-3,000 MW (10%of the total hydropower potential in Ethiopia).Small, mini and micro hydro power plants have been in operation in Ethiopia starting since 1939. The first hydropower plant is the Aba Samuel hydropower plant with an installed capacity of 6 MW. The power plant served Addis Ababa in conjunction with other thermal plants until the power demand out stripped the capacity and a bigger power plant the Koka and Awash power plants had to be built. This plant was decommissioned in 1960 (ECA, 2002).

Other mini hydro plant were also built and operated by EEPCO and some are decommissioned when the grid extension reached the supply centers. To date a few plants are in service and these plants were constructed and operated by missionaries and EEPCO. SHP development is currently supported by international development agencies, most of which are not research-based institutions, as a result, information on SHP in Ethiopia is limited in academic arena.

There are a number of hydro power plants sites that have been identified and awaiting implementation. According to Ministry of Water, Irrigation and Energy (MWIE, 2012) data on about 232 small-scale hydropower potential sites have been collected with capacities ranging from 26 kW to 9,840 kW. The total installed capacity of the entire 232 small scale hydropower plants is estimated to be about 500 MW. Only a small fraction of these small scale hydropower plants has been developed to date.

**Table 2.4 Main characteristics of Small Hydropower in Ethiopia** *(Source: EEPCO, 2013)*

| S.No | Name, Location | Head (m) | Type of Scheme | Installed capacity (kW) | Commissioning year | Current status |
|---|---|---|---|---|---|---|
| 1 | Huluka, Ambo | 40 | ROR | 140 | 1954 | Not operational |
| 2 | Sotosomere, Jima | 30 | ROR | 140 | 1954 | Not operational |
| 3 | DebreBrhan | 55 | ROR | 100 | 1955 | Not operational |
| 4 | Welega,Welisotwon | 16 | ROR | 162 | 1965 | Not operational |
| 5 | Gelenmeti,DenbiDolo | 42 | ROR | 195 | 1966 | Not operational |
| 6 | Deneba,BonuBedele | 14 | ROR | 123 | 1967 | Not operational |
| 7 | Yadot, Bale Zone | 23 | ROR | 350 | 1991 | Operational |
| 8 | Dembi | 184 | ROR | 750 | | Operational |
| 9 | Soro, | 120 | ROR | 5000 | 2014 | Operational |
| 10 | DebreMarkos | 42 | ROR | 185 | 1962 | Not operational |
| 11 | Jilbo | 14 | ROR | 420 | | Not operational |
| 12 | Abasamuel | | ROR | 6000 | | Not operational |

Currently, there are three small hydro power plants operated by Ethiopian Electric Power Corporation (EEPCO) and have a total installed capacity of 6.1 MW serving three separate mini-grids (Table 2.4).

The largest one is Sor (5 MW). The first phase of this plant was constructed in 1992, and since then it has been serving a separate 66 kV mini-grid some 650 km southwest of Addis Ababa. It was built as a run-of-river plant with two units of 2.5 MW.

In addition, Ministry of Water, Irrigation and Energy, Rural Electrification Fund is also investigating for five micro hydro projects. These are Tum, Zey, Yabus, Dilla and Teski MHP projects. Out of these projects the estimated power generation by Tiski and Yabus projects would be 8 MW and 1.4 MW, respectively.

Further, a wide spread surface irrigation system with canal network is under investigation/ design or construction. These canal systems may also be utilized for low head power generation.

A joint team of EREDPC, EECMY, and a team of experts from Peoples Republic of China in 1980s have identified over 70 MHP potential sites (GTZ, 2009).

Nehimia Solomon (2005) has identified potential small and micro hydro sites in Muger, Jemma and Waleka sub-basins of Abay basin. In this research study a total of 18 potential sites were identified. The total estimated potential for all 18 sites collectively accounts for 5.33 MW (Potential ranging from 50 to 1000 kW for various sites). Similarly, Ashenafi Gazahgen (2007) investigated Anger and Guder sub-basins of Abay basin and he also identified 18 potential small and micro hydro sites. The total estimated potential for these sites accounts for 19.6 MW.

At present many organizations; government, NGOs and community groups are engaged in the development of Micro Hydro Projects. In recent past and presently rehabilitation and modernization of the old abandoned mills" and/or construction of new ones for mechanical shaft power and electric power generations is taken up by these organizations and community groups. The Rural Electrification Fund (REF), which was established with grants from Global Environment Facility (GEF) and contribution from the government, is available for development of MHP and other energy technologies through the participation of the private sector. Among NGOs, the Ethiopian Evangelical Church Mekane Yesus (EECMY), Ethiopian Rural Self-help Association (ERSHA), Lay Volunteers Association (LVIA) and recently, GTZ Programme "Access to Modern Energy Services" are involved in development of MHPs (GTZ, 2009). Further, GIZ –ECO hydro section has suggested upgrading of existing water mill sites as an attempt to harness MHP potential.

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# Chapter 3 Overview of the Study Area

## 3.1 Location and Accessibility

The study area is the northern part of Central Ethiopian Rift Valley Basin; located partly in Oromia and partly in Southern Nations and Nationality People states. It extends from Gurage Mountain in the west via main Ethiopian rift valley to Mount Chilalo, Galema and Kakka of Arsi in its eastern side. The area is about 6820 km$^2$and bounded between latitude of $7^0$20’54” to $8^0$25’56” and longitude of $38^0$13’02” to $39^0$24’01”.

The study area is accessed by Addis Ababa-Mojo-Ziway, Addis Ababa-Alem Gena- Butajira or Addis Ababa-Asela asphalt roads. Intra catchment areas are accessed by numerous gravel and dry weather roads. The access to these sub-basins is through all types of roads.

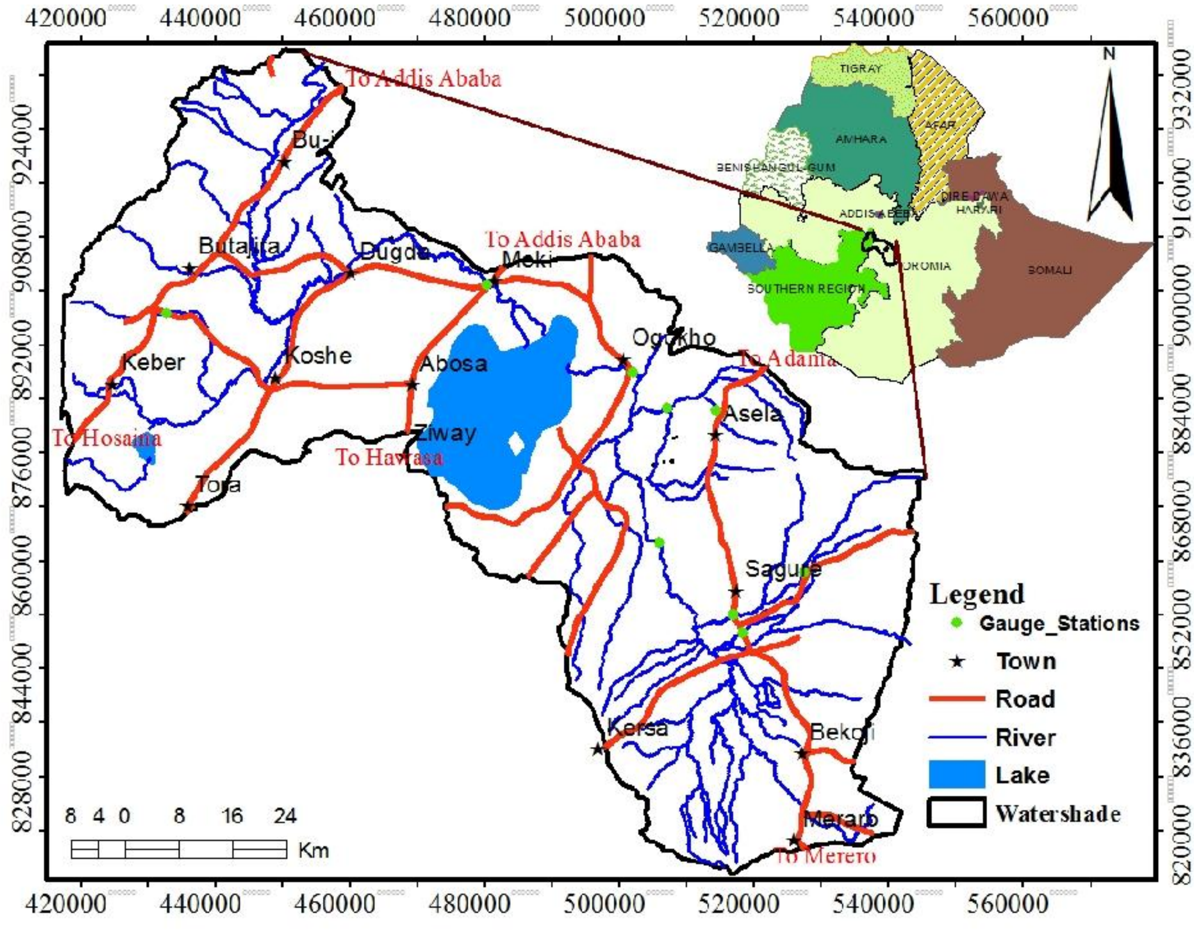


Fig. 3.1 Location map of Lake Ziway Catchment

## 3.2 Climate of the Study Area

The climate of Ethiopia ranges from equatorial desert to hot and cool steppe, and from tropical savannah and rain forest to warm temperate, from hot lowland to cool high lands. The altitude ranges from around 120m below sea level in the Dalol depression up to 4,620 m a.s.l on the Ras Dashen on the Semien Mountains Massifs. The Main Ethiopian rift valley and the Afar is semi-arid to hyperarid (Tamiru Alemayehu, 2006). Based on altitude, the climate can be classified in to five groups (Table 3.1).

***Table 3.1 Ethiopia Climate Classification System***

| Altitude (m.a.s.l) | Mean annual temperature ($^0$C) | Description | Local Name |
|---|---|---|---|
| 3,300 and above | 10 or Less | Cool | Kur |
| 2,300 - 3,300 | 10-15 | Cool Temperate | Dega |
| 1,500 - 2,300 | 15-20 | Temperate | Weyina Dega |
| 500 - 1,500 | 20-25 | Warm Temperate | Kola |
| below 500 | 25 and above | hot | Bereha |

(Source: Tamiru Alemayehu, 2006)

In Ethiopia, rainfall has an uneven distribution both in time and in space (Tamiru Alemayehu, 2006).The spatial and temporal variation of rainfall in Ethiopia is strongly controlled by the inter-annual movement of the position of the Inter Tropical Convergence Zone (ITCZ).This is partly due to the presence of one major and one small rainy season, in large part of the country. The central, eastern and northeastern areas of the country experience a nearly bimodal rainfall distribution. These are the Belg rains (February to May) and Kiremt rains (June to September). A subsidiary effect is that a large amount of rainfall on the highlands is concentrated as runoff in river valleys, which drain into the low-lying areas where annual rainfall is low. In almost all river basins in Ethiopia, some 80% of the runoff results from annual precipitation falling in four months from June to October. Two groups of factors mainly determine the extent of flow in streams: climatic and physical characteristics of the drainage basins (Tamiru Alemayehu, 2006; Alemu Dribssa 2006).

The temperature, wind speed and humidity are also highly variable with altitude and latitude. Away from the peripheries, the land begins to rise gradually and considerably, culminating in peaks in various parts of the country. The temperature decreases generally towards the interior. Mean annual temperature varies from over 30$^0$C in the tropical lowlands to less than 10 $^0$C in very high altitudes.

According to Ethiopian climate classification (Tamiru Alemayehu, 2006) the study area is classified in to three climate zone (Fig 3.2). These are Temperate (Weyinadega), Cool Temperate (Dega) and Cool (Kur).The positions of Inter Tropical Convergence Zone (ITCZ) and topography have great influence on temporal and spatial distribution of precipitation in the Study Area (Tenalem Ayenew, 1998; Dagnachew Legesse, 2002, Alemu Dribssa, 2006). Bi modal annual precipitation is more apparent in western half of the study area than the eastern side due to Guraghe Mountains that act as barrier to spring rain.

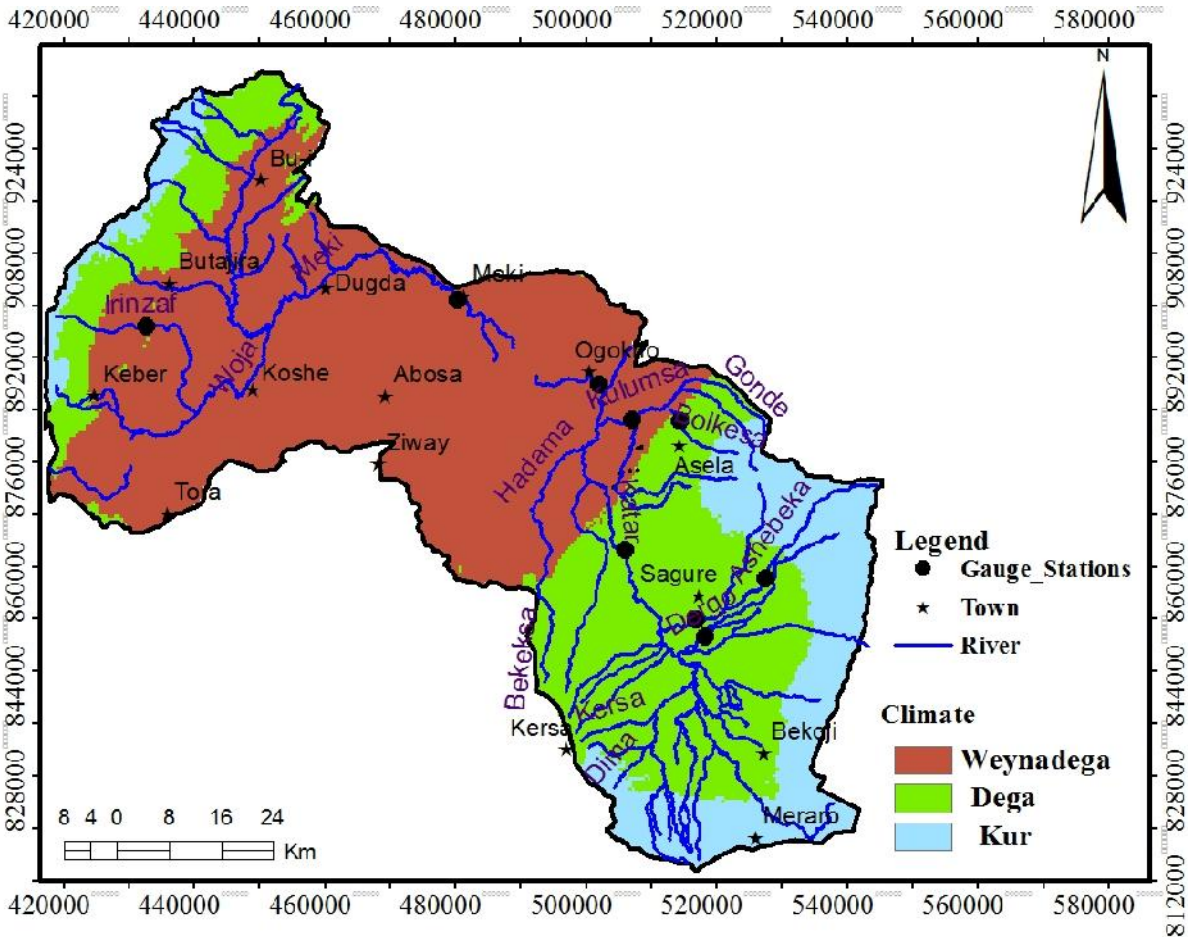


Fig 3.2 Climate Map of the Study Area based on Altitude difference

The average annual rainfall of the area varies spatially from about 620mm in lowland to over 1200mm at extreme highland areas. The mean daily temperature also varies between 13.5$^0$C and 21.8$^0$C in different physiographic areas (Alemu Dribssa, 2006).

## 3.3 Topography and Drainage

### 3.3.1 Topography

The present land forms of the study area are the result of volcanic, tectonic activities such as faulting, fracturing of the rocks and external processes including weathering and erosion by surface water (Giday Woldegebrieletal., 1990; Tenalem Ayenew, 2008). From field observation, Google Earth and DEM data analysis, three physiographic features are identified: the high plateau on either side of the rift, the transitional escarpment and the rift floor. There is a topographic difference of about 2600m between the rift floor and highlands.

The upper reaches of the basin are steep and mountainous while the lower basin is flat with a broad valley. The floor of the rift valley is not uniformly flat, but it is occupied by some reliefs of volcanoes, rising for about 500 m or more, such as it occurs on the plateau, especially along the escarpments limiting the rift, where some reliefs, more than 1000m high. (Fig.3.2).

### 3.3.2 Drainage

The study area is the part of Rift Valley Basin. The Meki, the Katar Rivers and their tributaries drains towards Lake Ziway from its western and eastern sides, respectively (Fig. 3.3). Meki River originates from the highlands of Guraghe Mountains; and travels a distance of about 100km from the highlands at an altitude of 3600m a.s.l to about 1630m a.s.l before draining in to Ziway Lake. It has drainage area of 2078 km$^2$. Kater River originating from the highlands of Arsi and it has drainage area of 3302km$^2$.

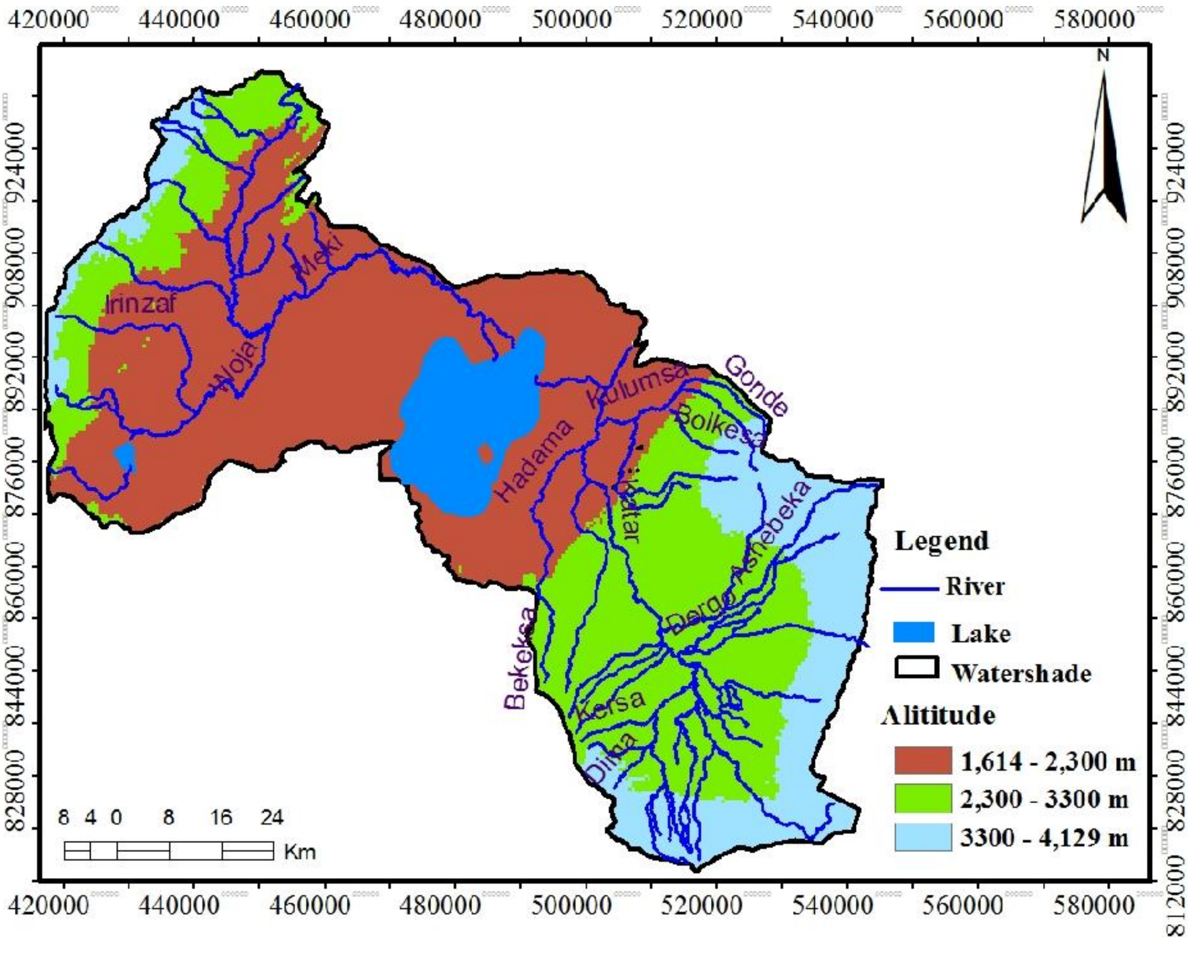


Fig. 3.3 Physiography of the Study Area derived from digital elevation model

Most parts of plateau area have perennial sources of these rivers while the tributaries in the escarpments and rift floor have almost intermittent sources. In addition, the highland is characterized by higher drainage density than the escarpment due to differences in rock permeability, climate and slope (Tenalem Ayenew, 2008).

The highland is characterized by higher drainage density than the escarpment and flat areas of lacustrine deposits in the southern part of the study area, which lack drainage due to differences in rock permeability, climate and slope (Tesfaye Chernet, 1982).

Rift faults have affected the drainage of the area both by determining the river courses and by impounding river water and causing some marshy areas, in the southern part of the study area. Generally, drainage density of the area is controlled by geology, geologic structure, topography, vegetation, rain fall amount and intensity (Tenalem Ayenew, 1998; 2008).

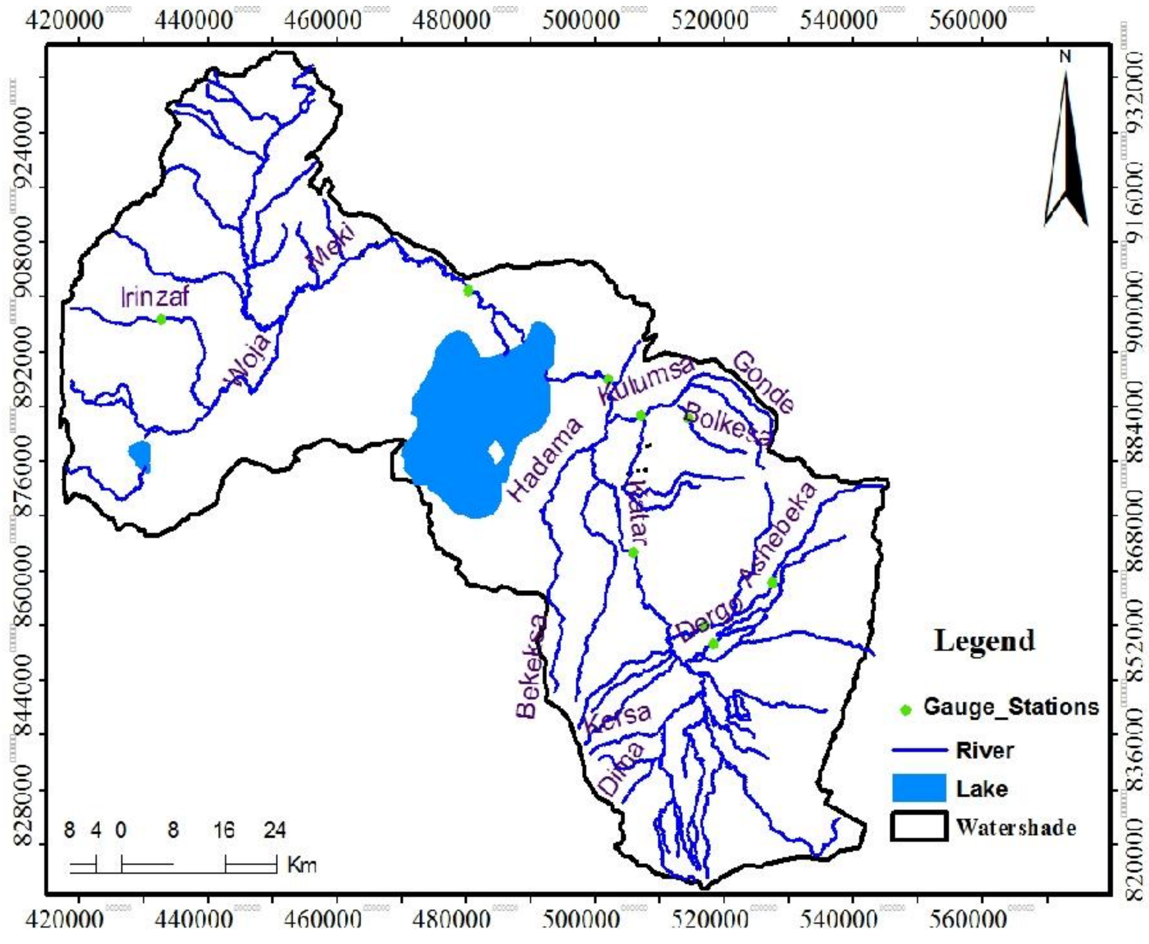


**Fig. 3.4 Drainage Pattern of the Study Area**

## 3.4 Regional Geologic Setting

As the study area is situated in the central part of the Main Ethiopian Rift (MER), in order to understand the general geological condition the general geology and tectonics of the MER is summarized below based on review of different works.

The Main Ethiopia Rift tectonic setting is the north most part of East Africa Rift System (EARS). The Main Ethiopia Rift marks the emerging plate boundary between Nubia and Somalia, formed along after the flood basaltic magmatism (Wolfenden et al., 2004).

The Main Ethiopian Rift (MER) is a roughly NE-oriented segment of the East African Rift system, which extends from the Afar to the Kenya rift. The MER is composed of northern, central and southern segments. It has commonly been suggested that rift propagation in the MER progressed northwards (Wolfenden et al., 2004; Mackenzie et al., 2005; Keir et al., 2006).

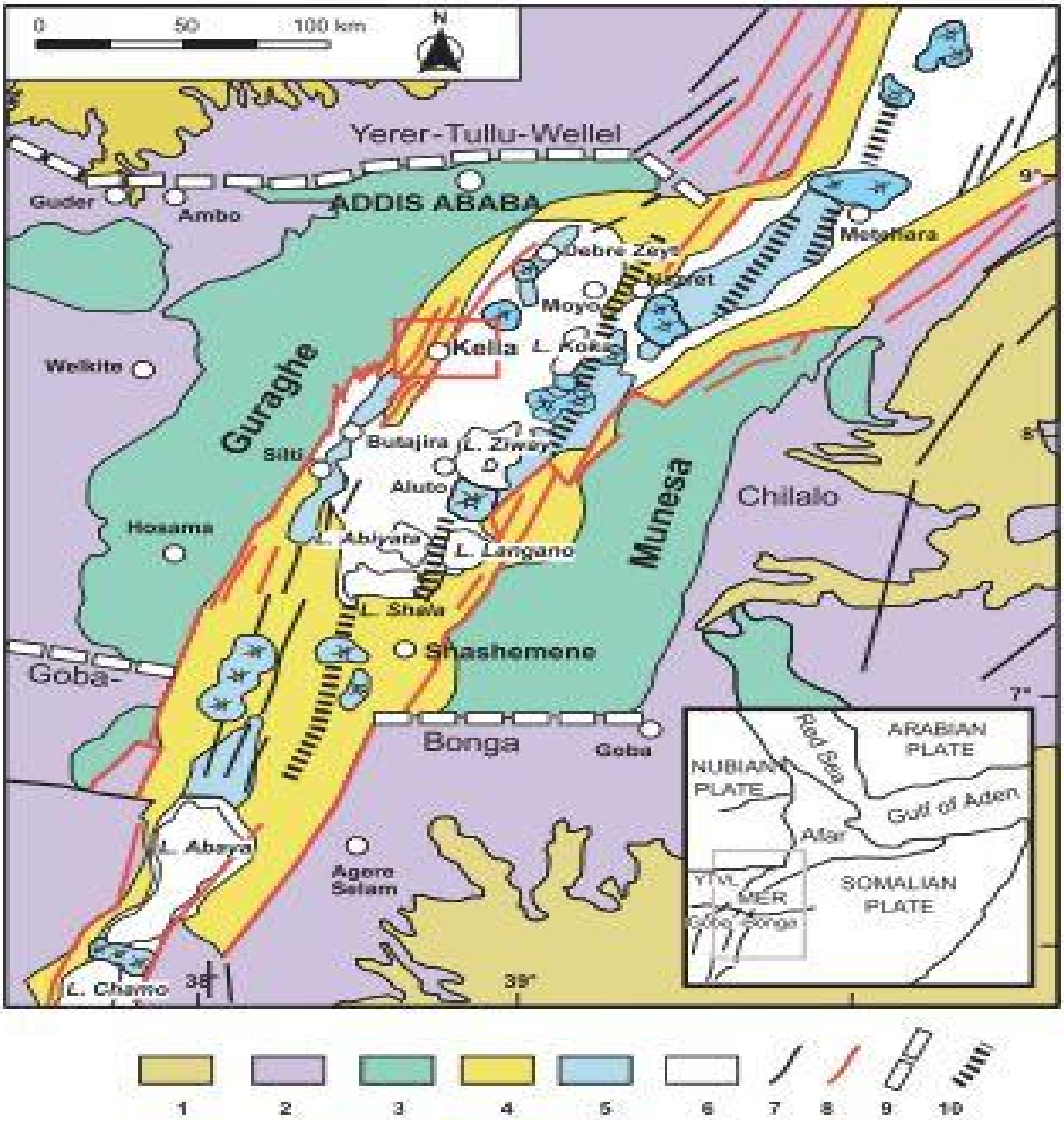
The Central MER is bounded by the Yerer-Tullu-Wellel volcano tectonic lineament to the north and the Goba–Bonga lineament to the south (Tsegaye Abebe et al., 2010). It is also bounded to the east and west by fault escarpments (some of them with an offset of more than 1500 m) such as the Munesa and Guraghe rift margins.

Tertiary to Quaternary volcanics are the only rocks exposed in the MER, apart from minor fluvio-lacustrine sediments, mostly of Quaternary age, that were deposited on the rift floor. One exception is an outcrop of Precambrian crystalline rocks covered by Mesozoic sediments at the base of the Guraghe escarpment, near the village of Kella. (Dipola, 1972; Giday Woldegabriel et al., 1990; Tsegaye Abebe et al., 2010).

## 3.5 Local geology

Geology of the study area is made of volcanites and pyroclastic rocks, whereas large areas of the rift floor are covered by volcano-lacustrine and fluvio-lacustrine deposits. Limited outcrops of Precambrian biotite gneiss, covered by Early Mesozoic fluvial sandstones, marine shales and limestones, occur in a complex horst structure on the western margin (Giday Woldegabriel et al., 1990).

Dipola (1972) reported his observation of out crops of Mesozoic sediments in the rift valley. These Mesozoic sediments crop out at western rift margin, east of Guraghe Mountains. It is underlain by Biotitic gneiss, which also exposed at the same location. The overlaying upper sandstone was probably subjected to a long period of uplift and erosion, that 200 m thick cretaceous upper sand stone, which uncomfortably underlies the trap basalt at Ambo 100km to the north is absent in Guraghe area (Giday Woldegabriel et al., 1990, Tsegaye Abebe et al.,2010).



*(Source: Tsegaye Abebe et al. (2010), Tera Nova)*

*(1) Pre-Tertiary sediments and crystalline basement, (2) Oligocene (32–29 Ma) and lower Miocene (12–8 Ma) plateau volcanics, (3) Miocene–Pliocene rift-shoulder trachytic–rhyolitic volcanics and pyroclastic layers, (4) Plio-Pleistocene rift floor, (5) Quaternary central volcanics and basaltic lava flows, associated scoria cones and phreato-magmatic deposits, (6) Quaternary lacustrine sediments and interbedded pyroclastics, (7) faults, (8) major rift border faults, (9) major transversal tectonic lineaments in the basement, (10) Wonji Fault Belt segments. Red square: area shown in Fig. 2. In the inset: YTVL, Yerer-Tullu-Wellel volcanotectonic lineament, MER, Main Ethiopian Rift.*

**Fig. 3.5 Simplified geological map of central Ethiopia, modified after Jepsen and Athearn (1997).**

Trap series basaltic units occur on the western and eastern margins of the study area (Tsegaye Abebe et al., 2005; Bonini et al., 2005) Several layers of pyroclastic rocks associated with trachytic and rhyolitic lava domes and flows together with some important central volcanoes is cover the study area rift shoulders and rift floor. The products of this episode consist of uncompacted pumiceous fall and flow deposits, rhyolitic–trachytic lava flows forming central volcanic edifices, fissural basaltic lava flows with associated scoria and phreatomagmatic cones, and interbedded lacustrine deposits (Di Paola, 1976; Kazmin et al., 1980).

## 3.6 Soils

Soil in the study area is closely related to parent material and degree of weathering (Makin et al., 1976). Basalt, ignimbrite, acidic lava, volcanic ash and pumice, and riverine and lacustrine alluvium are the main parent materials (Di Paola, 1972). Lacustrine sediments are quite important formation, which cover an area of 4,000km in the Main Ethiopian Rift. The thickness of sediments on the floor of lakes basin is not accurately known. Variable sediment thickness occurs, ranging from about 40m in 030'-40 202. Alluvial deposits composed of silt, sands and gravel occur along the foot of the rift escarpments and the lower reach of rivers such as Meki, Bulbula, Ketar, Weja, Irinzaf, Irisho and Dobena. Residual soils are over trachytic, ignimbritic, rhyolitic and unconsolidated sediments. They are silty clay and reddish in color (Tenalem Ayenew, 1998).

**Table 3.2 Summaries geology of the Study Area**

| Formation symbol | Description |
|---|---|
| Q2us | Lacustrine sediments |
| Qal | Quaternary alluvial deposit:Marsh to bogy,clay- silty soil |
| Quc | Scoria cones and Fallout deposits |
| Ncp | Chefedonsa pyroclastic deposits |
| Qdi | Ignimbrites, tuffs, water lainpyroclastics and occasional lacustrine deposits |
| Nrd | Rhyolitic and Trachaytic lava domes |
| Nwp | Welded pyroclastic Flows |
| Npp | Welded to partially welded pyroclastic Flows |
| Ngr | Gash Megal Rhyolites |
| Ega | Guraghe Anchar Basalts |
| Tv$_7$ | Plliocen trachayte ,it contains layers of trachayte Flows which is light grey, and fine grained to porphyritic trachayte |
| Tv$_6$ | Plliocen Basalt :this is Fresh compact, massive and usually it is grey to dark grey in color |
| Tv$_5$ | Gobersa trachyte: light gray, Fine grained, massive and show flow layering. |
| Tv$_4$ | High land basalt: this contains medium to coarse grained dark, olivine plagioclase phyric basalt. Massive, fine grained basalt layer of basaltic breccia, medium grained dark grey basalts vesicular plagioclase phyric basalts. It also contain air Fall tuff and basaltic pyroclastic. |
| Tv$_{3\ (2)}$ | Upper pyroclasts: contains mainly layers of massive to welded ignimbrite, base surge deposit, volcanic Breccias, loose volcanic ash, tuff and lapilli tuff. |
| Tj | Triassic to Jurassic continental sandstone and Jurassic marine limestone |
| Pe | Gneisses and Granite |

## 3.6 Land Use and Land Cover

The land cover of the catchment is controlled with topographical, climatic and ecological conditions. The land cover has made dramatic change with the past two decade in association with the population growth of the rift valley basin (Alemu Dirbissa, 2006).

**Table 3.3 Arial distributions of land cover units**

| Class | Major cover | Area% | Area(km)2 |
|---|---|---|---|
| 1 | Wood land | 0.049 | 3.3547 |
| 2 | Intensively Cultivated | 54.994 | 3754.0420 |
| 3 | Moderately Cultivated | 21.527 | 1469.5284 |
| 4 | Exposed surface | 0.197 | 13.4714 |
| 5 | Marshland | 2.362 | 161.2195 |
| 6 | Forest | 3.025 | 206.5160 |
| 7 | Water body | 6.540 | 446.4377 |
| 8 | Shrub land | 4.310 | 294.1999 |
| 9 | Grass land | 1.695 | 115.6902 |
| 10 | Afro_Alipen | 5.300 | 361.8269 |
| Total | | 100.00 | 6826.2867 |

The major land use and cover is categorized as forest, grassland, intensively cultivated, marshland, moderately cultivated, shrub land, and water body.

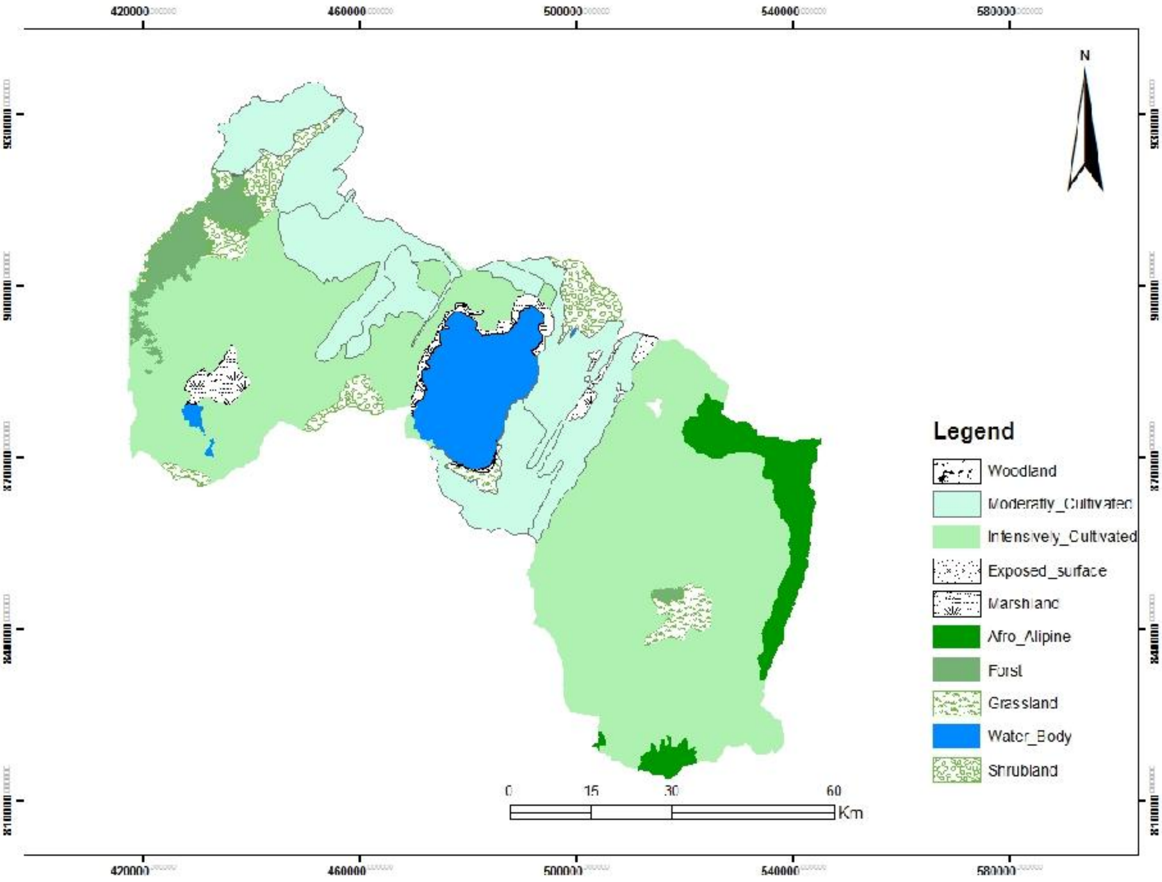


**Fig. 3.6 Land Use/ Land Cover Map of the Study Area**

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# 4 Hydrologic Analysis

## 4.1 Introduction

According to Kumar et al. (2002) for the development of any small hydropower scheme an essential first step is to determine whether there is sufficient and reliable amount of water is available to make the scheme economically viable. Niguse Abebe. (2014) states that to estimate water resources as well as hydropower potentials at the sites, hydrologic study needs to be carried out using existing discharge and rainfall data recorded at the gauging stations available for the sub-basin in or nearby the proposed study area. European Small Hydropower Association (ESHA, 2004) also states that for an ungauged watercourse, where observations of discharge over a long period are not available, it involves the science of hydrology, the study of rainfall and stream flow, the measurement of drainage basins, catchment areas, evapotranspiration and surface geology for the estimation of discharge.

The hydrological study is the basis for the design of the project, determination of capacity to be installed (design of civil structures and electromechanical equipment), calculation of yearly energy production and statement about the profitability of the plant. Ultimately the economic and overall viability of the project depend on the hydrological analysis.

## 4.2 River Gauging Stations in the Study Area

The collection of hydrologic and meteorological data for the flow-duration analysis is a part of the hydropower systems development phase. There are 9 gauging stations on different streams in these two sub-basins of which two are located in Meki sub-basin and the remaining seven in Kater sub-basin. The 10 daily discharge data for all 9 gauging stations was procured from the Ministry of Water, Irrigation and Energy, Addis Ababa, Ethiopia. These gauging stations were used for data projection for the hydropower sites identified within the two sub-basins, and flow duration analysis is under taken with a view to establish a regional flow duration curve. The location of gauging stations in the study area is shown in Fig. 4.1.

## 4.3 Flow Duration Curve Analysis for Gauged Sites

The flow-duration curve is a cumulative frequency curve that shows the percent of time during which specified discharges were equaled or exceeded in a given period (Searcy, 1969; Vogel and Fennessey, 1994). It can be obtained from the hydrograph by organizing the data by magnitude instead of chronologically.

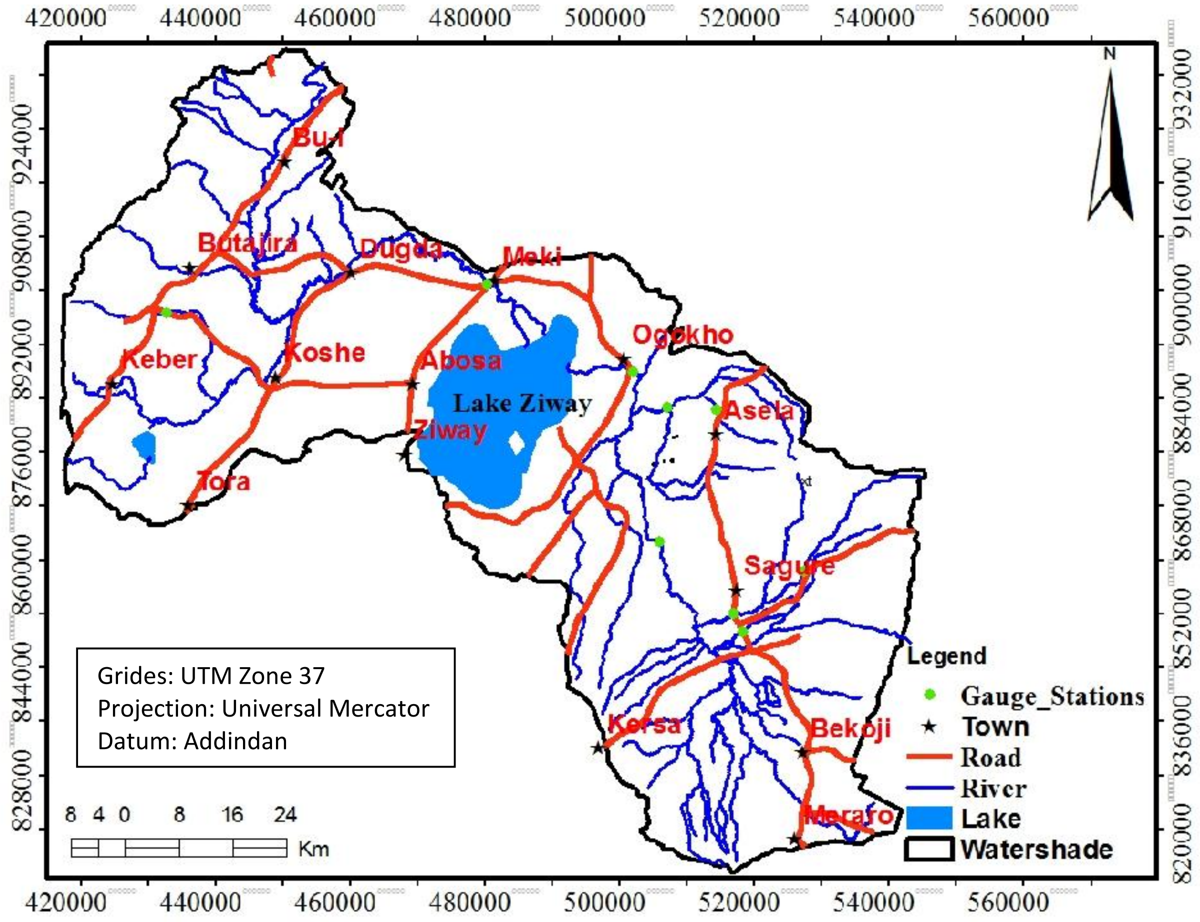

**Fig. 4.1 Location of gauging stations in the study area**

The flow duration curve is very useful in hydrologic analysis in general and especially, useful in hydropower studies. Its compact form makes in very easy to estimate magnitudes of high and low flows and the time availability of flows between these two flow levels. In the hydropower analysis the flow duration curve (FDC) can be used to determine estimated power from a proposed hydropower installation (Fritz, 1984).

Temporal water availability at the proposed project site is essential to estimate the power potential and annual energy generation. In run of the river small hydro projects the flow duration curve (FDC) is drawn to know the time variability of flow (AHEC-IITR, 2013). It shows a discharge which has equaled or exceeded certain percentage of time out of the total time period which is generally taken as one year.

Flow duration curve can be constructed on-parametrically using stream flow records corresponding to different time scales (e.g., daily, weekly, monthly). The basic time unit used in preparing a flow-duration curve greatly affects its appearance (AHEC-IITR, 2013). When mean daily discharges are used, a steep curve is obtained as the flow duration curve. When the mean flow over a longer period is used (such as ten-daily flows or mean monthly flows), the resulting curve will be flatter due to averaging of short-term peaks with intervening smaller flows during a month. Extreme values are averaged out more and more, as the time period gets larger.

According to AHEC-IITR (2013) the steps to draw flow duration curve from available daily average discharge data are given below:

(i) Arranging the flow values (data points) in descending order of their magnitude,

(ii) Sort (rank) average daily discharges for period of record from the largest value to the smallest value, involving a total of n values.

(iii) Assigning plotting position (exceedance probability) to each data point using Weilbul's formula and

$$P = \frac{M}{n+1} * 100 \qquad \text{……….eq. 4.1}$$

Where,
P = Probability that a given flow will be equaled or exceeded (% of time)
M = Ranked position on the listing (dimensionless)
n = Number of events for period of record (dimensionless)

(iv) Plotting data in a two-dimensional space of flow magnitude versus exceedance probability and joining the resulting points to form a smooth curve.

For the present study dependable flow for potential power calculation is based on the analysis of 10 - daily discharge data acquired from the Ministry of Water, Irrigation and Electricity for 9 gauging stations.

## 4.4 Delineation of Drainage Area for Gauged Stations

The catchments area at gauging stations is delineated from the Ethiopian Mapping Authority (EMA) top sheets at a scale of 1:50,000 by using ArcGIS and AutoCAD software by overlaying different layers, SRTM River, hydrometric locations. Fig. 4.2shows delineated catchments for nine gauging stations using ArcGIS software. The catchments delineation includes catchments boundary, perennial stream, drainage network and roads or footpaths, within the catchments boundary.

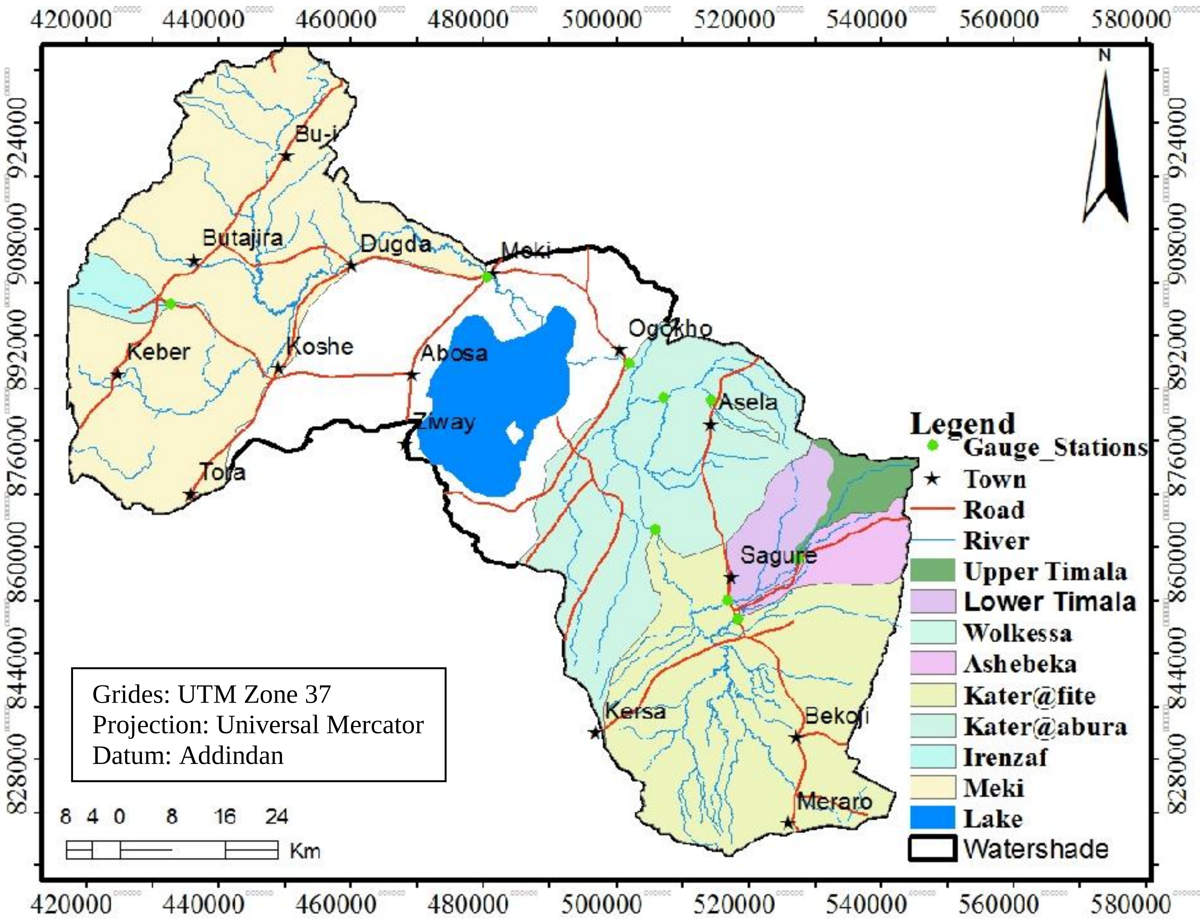

**Fig. 4.2 Delineated catchments for nine gauging stations**

After delineating the watershed boundary of the gauged stations on a topographic map, the drainage area was determined using GIS. The drainage area for each gauged station is shown in Table 4.1.

**Table 4.1 Summary Statistics of Collected Stream Hydrological Data**

| Station Number | Station Name | Period of Record | | | Drainage Area(km$^2$) | Mean Annual Discharge (MCM) |
|---|---|---|---|---|---|---|
| | | From | To | No. of years | | |
| 081018 | Meki | 1969 | 2010 | 42 | 2078.0 | 169.53 |
| 082032 | Irinzaf | 1982 | 2010 | 26 | 49.0 | 80.18 |
| 081019 | Ketar at Abura | **1970** | 2010 | 40 | 3150 | 408.14 |
| 081011 | Katar nr Fite | 1982 | 2010 | 28 | 1975 | 443.66 |
| 081010 | Ashebeka | **1982** | 2010 | 11 | 236.9 | 48.45 |
| 081009 | Wolkesa | **1981** | 2010 | 9 | 23.9 | 8.08 |
| 081008 | Lower Timala | 1981 | 2007 | 26 | 184.4 | 28.84 |
| 081007 | Upper Timala | 1997 | 2004 | 7 | 98.8 | 5.35 |
| 081025 | Chiufa nr. Arata | 1985 | 2007 | 22 | 216.0 | 76 |

These delineated catchments were used for the calculation of drainage area, correlation of hydrologic data for regional flow duration curve, and setting of identification criteria for SHP sites.

## 4.5 Regression Analysis of Available Hydrologic Data of the Study Area

Regression analysis is used to predict the value of a dependent variable based on the value of at least one independent variable and to explain the impact of changes in an independent variable on the dependent variable.

In the present study, for the validation of the discharge data simple linear regression analysis of 9 gauge station of mean annual discharge from recording period from 7 to 42 years and catchment area of the gauge station was done.

A perusal of Fig. 4.3indicates that the data points (mean annual flow versus catchments area) show a very good correlation for Kater sub-basins independently with correlation coefficient reasonably close to 0.89.

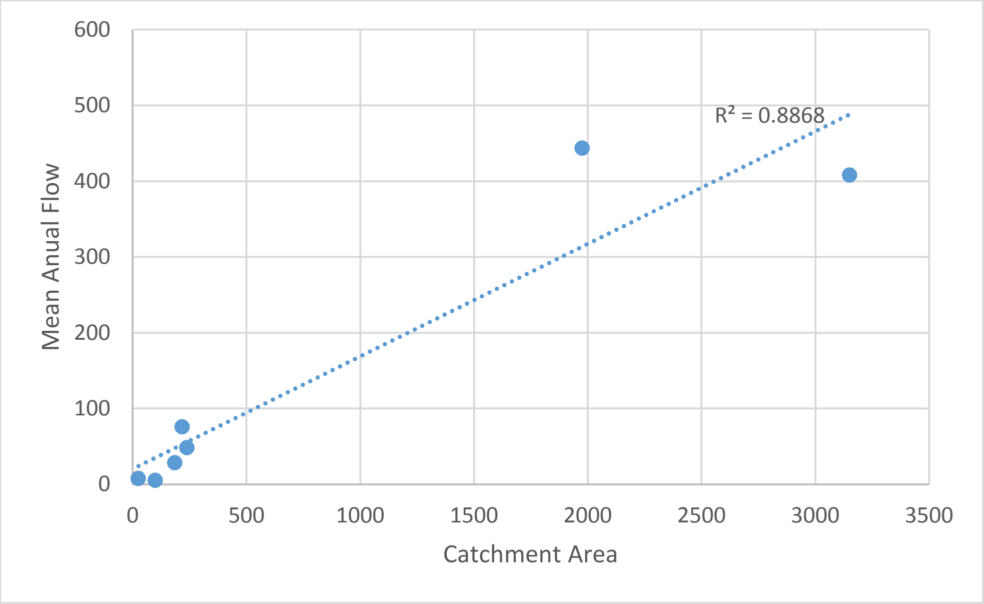

**Fig. 4.3 Plot of mean annual runoff verses catchment area for all 7 gauges in Kater sub-basin**

Fig. 4.4 shows similar relationship for all gauges in Lake Ziway sub–basins. It is apparent that the drainage area correlates well with the annual runoff with a correlation coefficient close to 0.79. This is reasonably sufficient to transfer the flow–duration data for rivers in either Kataer or Meki sub-basins. Thus, both sub-basins may be equally good to project discharge using the correlations for Kater and Meki sub-basins for ungauged streams in the area.

This is mainly done to improve the reliability of the correlation curve for estimation of discharge by increasing the data set points as only 7 and 2 discharge measuring gauges are available in Kater and Meki sub-basins, respectively.

## 4.6 Transfer of Flow-Duration Curves

Any hydropower project requires an ample availability of stream flow data. Unfortunately, most of the hydropower projects especially small hydropower projects are conducted on ungauged river and consequently hydrologists have for a longtime used stream flow estimation methods using the mean annual flows to gauge rivers (Kasamba et al., 2015). It is unusual for one of these gauges to be located precisely at the hydro power site of interest. There may however, be a gauging station located on the same river or a downstream river with a drainage area containing the site's watershed.

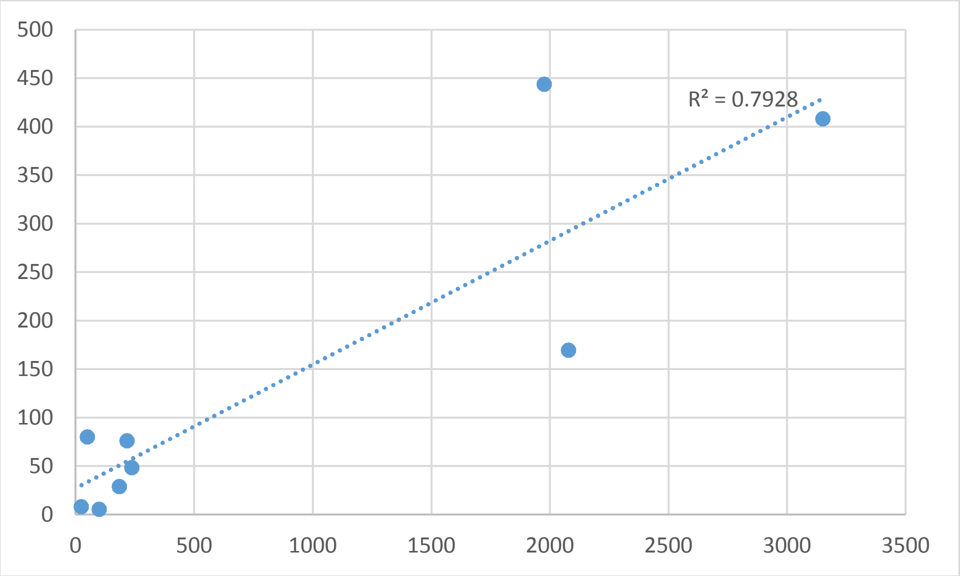

**Fig.4.4 Plot of mean annual runoff verses catchment area for 9 gauges in Lake Ziway sub-basin.**

By flow estimation methods which include the runoff data method, area ratio method and the correlation flow methods approximation for a flow–duration at the un-gauged site can be obtained (Inversin, 1986).Area ratio method is conventionally used to transfer stream flow related information from gauged sites to ungauged sites. The method is useful in obtaining estimates of water availability for hydropower at ungauged sites (especially for small hydropower plants, for run-of-river plants) within the study area (Fritz,1984).

In general, the drainage area and the mean annual flows at the gauging site and the discharge estimated at site are the basis by which data transfer is made. The former is established from topographic and aerial maps of the basin. The estimation of the mean annual flow for the un-gauged station is discussed under this topic. Equation 4.2 is the common type of relation that is used to estimate flow–duration at an un-gauged site.

$$Qsite = \frac{DAsite}{DAgauge}^{v} Q\ gauge \qquad \text{………}eq.\ 4.2$$

Where;

$v$ - typically varies between 0.6 and 1.2

*DAsite* - drainage area of the power plant site (Km$^2$)

*DA gauge*- drainage area of the gauge (Km$^2$)

*Qsite*- discharge at the diversion site (m$^3$/s)

*Qgauge*- discharge at the gauge (m$^3$/s)

Usually, the proximately of the site to the gauge is used as basis for the choice of the value of v. Three different cases are considered depending on the proximity of the hydropower site of interest to the gauging station. The following three sub–sections elaborate the guidelines for data transfer (Gulliver & Roger, 1991, as cited in Zelalem, 2001; Ashenafi Gezahagn 2007; Abebe Tilahun., 2010).

### 4.6.1 Site in Close Proximately to Gauge

If the drainage area (DA) of the site is within 20% of the drainage area of the gauge site gauge $0.8 \leq \frac{DAsite}{DAgauge} \leq 1.2$, use v=1. The estimated discharge at the site will probably be within 10% of the actual discharge, which is normally sufficient.

### 4.6.2 Site in Close Proximity to Upstream and Downstream Gauges

If the DA site is within 50% of the DA gauge, consider whether the data of the two gauges (upstream and downstream gauges, if any) can be combined. In addition, when a weighted average between upstream and downstream gauges is possible, the following linear interpolation (Equation 4.2) may be applied for a site lying between upstream and downstream gauges.

$$\boldsymbol{Qsite} = \frac{\boldsymbol{DAgauge1 - DAsite\ Qgauge1 + (DAsite - DAgauge2)Qgauge2}}{\boldsymbol{DAgauge1 - DAgauge2}} \text{………………...4.3}$$

### 4.6.3 Site and Gauge not in Close Proximity

If the area of the site is more than 50% of the area of the gauge, it is better to estimate the value of ‘v’ from the ratio of the average annual flow data in the basin. The ratio of the average annual discharge at the site (estimated) and at the gauge (recorded) can be used to transform the flow duration curve form the gauge to site. This method could also be applied even when the first two cases hold true.

## 4.7 Mean Annual Flow at an Ungauged Sites

From the discussion in the previous sections, it is clear that the evaluation of mean annual flow is necessary for transfer of flow duration curves. When interest focuses to estimate the flow of one site only, then the proportion of mean annual flow at gauge and site (using techniques discussed in section 4.6) can provide the ratio for the data transfer (Inversion, 1986). However, when estimate has to be made at many ungauged sites, the preparation of a regional flow-duration curve is recommended. This can be done by correlating the actually recorded data, i.e. the mean annual runoff and the discharge at specified exceedance levels for gauged sites as discussed above in 4.3.

Once the regional flow–duration curve is properly constructed, the remaining task is estimating the discharges at ungauged sites of the required exceedance values from the mean annual flow.

There are a number of possibilities for estimating the mean annual runoff at a site. One method is to use runoff maps of the region if such are available (Inversion, 1986). Often such map provides information on the value of runoff coefficient corresponding to the various land use forms. Alternatively, mean annual runoff can be estimated from the hydrological data of the region.

For the present study, the second technique is adopted for the estimation of 75% dependable discharge data in the region. The next section discusses the approaches applied to the Meki and Kater sub-basins using easily available meteorological data and drainage parameter (Area) for correlation purpose.

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# Chapter 5 Small Hydropower Potential Assessment

## 5.1 Introduction

Before an SHP system is installed on a site, it is important to determine the power that will be harnessed from the site. The information on flow rate and head at the site as well as other site conditions are important in the design of the whole SHP system (Kaunda et al., 2012). It is important to first undertake an initial study for hydropower resource assessment using hydrological and topographical graphs/maps as well as geographic information system (GIS) and flow duration curve before undertaking a comprehensive feasibility study of the site.

This section presents the findings of a small/mini hydropower study aimed at estimating preliminary hydropower potential distribution within the study area, which obviously has physical resource in terms of large rivers with significant annual flows together with topographical conditions suitable for power generation.

## 5.2 Potential Catchment Area Delineation

The catchment area (also referred to as drainage basin or watershed) is the surface of the earth that is occupied by a drainage system, consisting of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water. The catchment area is an important parameter to identify the available discharge at a specific location and topographic information of the area (FMC AG, 2014).

From topographic information it is possible to identify points of high gradient for hydropower development. Topography, in general is the landscape of the area. It defines the general ruggedness of the area, general elevation difference within the valley and steepness or gentleness of the valley slopes. Topography of the area is an important factor and is the key component for the identification of a suitable site (http://tkraghu.tripod.com)

In the present study, potential catchments were delineated from the Ethiopian Mapping Authority (EMA) topo-sheets at a scale of 1:50,000 and also by using ArcGIS software using SRTM layer showing digital elevation data. The Catchment delineation includes catchment boundary, perennial stream, drainage network, roads or foot paths and towns. These delineated catchments were used for the calculation of catchments area. A total of 16 topo-sheets from Ethiopian Mapping Authority (EMA) on 1:50,000 scale and satellite image were examined to delineate potential catchment area around different potential diversion structure locations. During the present study a total of 49 potential SHP sites have been identified (Table5.1 (a), (b)). Outofthese19 sites falls within the Meki sub-basin and the rest 30 sites form a part within the Ketar sub-basin. The identified SHP sites are named after the respective river names on which the small hydro power schemes were identified. Figure 5.1 shows the distribution of identified potential SHP sites and the location of gauging stations on various streams in the study area.

**Table5.1 (a) identified potential SHP sites in Ketar sub basin of the study area**

| S. No. | Name of SHP site | Diversion weir elevation | Location of Diversion weir (UTM) | | Gross Head (m) | Net Head (m) | Catchment Area(km2) | Nearest Town |
|---|---|---|---|---|---|---|---|---|
| | | | Northing | Easting | | | | |
| 1. | Kulumsa1 | 2020 | 888441.81 | 515194.49 | 110 | 99 | 48.42 | Kulumsa |
| 2. | Kulumsa2 | 2100 | 888888.66 | 516911.51 | 60 | 54 | 43.14 | Kulumsa |
| 3. | Kulumsa2 | 2100 | 887049.37 | 516149.51 | 120 | 114 | 54.29 | Kulumsa |
| 4. | Bolkesa | 2080 | 883934.60 | 512975.60 | 240 | 216 | 27.27 | Assela |
| 5. | Anko | 2100 | 881623.00 | 510749.07 | 280 | 252 | 18.02 | Assela |
| 6. | Kombolcha(A11) | 2090 | 878394.35 | 508465.58 | 280 | 252 | 33.92 | Assela |
| 7. | A10 | 1900 | 874518.48 | 505357.34 | 40 | 36 | 120.34 | Golja |
| 8. | A9 | 1990 | 872083.49 | 504114.21 | 50 | 45 | 118.32 | Golja |
| 9 | A8(Ketar) | 1850 | 872412.27 | 502326.75 | 70 | 63 | 2062.26 | Golja |
| 10. | A7 | 1900 | 872412.27 | 503003.82 | 50 | 45 | 2056.39 | Golja |
| 11. | A6 | 1940 | 871282.61 | 502879.27 | 40 | 36 | 2055.84 | Golja |
| 12. | A5 | 2060 | 868899.34 | 503340.55 | 40 | 36 | 2051.58 | Golja |
| 13. | A4 | 2100 | 867406.48 | 503520.67 | 100 | 90 | 2048.76 | Golja |
| 14. | A3 | 2230 | 865261.19 | 503988.93 | 50 | 45 | 1935.42 | Golja |
| 15. | Ashebeka4 | 2600 | 856444.87 | 525896.37 | 70 | 63 | 111.56 | Digelu |
| 16 | Bishole2 | 2600 | 856555.5 | 528405 | 70 | 63 | 93 | Digelu |
| 17 | Ashebeka5 | 2700 | 8607.2154 | 528214.72 | 70 | 63 | 105.01 | Digelu |
| 18 | Bishole | 2700 | 858272.50 | 530980 | 60 | 54 | 28.41 | Digelu |
| 19 | Ashebeka1 | 2840 | 863081.19 | 530124.74 | 50 | 45 | 102.89 | Digelu |
| 20 | Ashebeka2 | 3000 | 865530.45 | 532571.13 | 50 | 45 | 81.40 | Digelu |
| 21 | Dinsa | 2760 | 860739.66 | 529315.43 | 60 | 54 | 25.01 | Digelu |
| 22 | TilkuGusha | 2620 | 850936.55 | 530247.80 | 40 | 36 | 57.97 | Tijo |
| 23 | TinishuKechema | 2780 | 825915.83 | 515412.48 | 40 | 36 | 15.3 | Merero |
| 24 | TilikuKechema | 2900 | 823703.72 | 516413.42 | 100 | 90 | 12.27 | Merero |
| 25 | Kela | 2760 | 826239.66 | 512150.53 | 100 | 90 | 20.50 | Merero |
| 26 | Dima | 2760 | 826464.95 | 511661.04 | 80 | 72 | 60.29 | Merero |
| 27 | Berole | 2760 | 827085.20 | 510583.01 | 120 | 108 | 30.28 | Merero |
| 28 | MelkaBedi | 1880 | 866798.10 | 492851.69 | 80 | 72 | 144.49 | Golja |
| 29 | Melka Bedi2 | 2050 | 863265.60 | 494212.59 | 100 | 90 | 119.04 | Golja |
| 30 | Melka Bedi3 | 2340 | 854642.49 | 493882.11 | 60 | 54 | 58.44 | Golja |

## 5.3 Determination of Head

The power potential is directly proportional to the discharge and the available Head. For a given site, discharge is mainly controlled by the hydrology and catchment characteristics whereas, head is a function of topography of the area. The term 'Head' is the altitude difference between the forebay and the powerhouse site. In other words head is the vertical height from where the water is dropped on the turbine to generate hydropower (Fig.5.2).

**Table 5.1(b) Identified potential SHP sites in Meki sub basin of the study area**

| **S. No.** | **Name of SHP site** | **Diversion weir elevation** | **Location of Diversion weir(UTM)** | | **Gross Head (m)** | **Net Head (m)** | **Catchment Area(km2)** | **Nearest Town** |
|---|---|---|---|---|---|---|---|---|
| | | | **Northing** | **Easting** | | | | |
| 1. | Lenkaro | 2080 | 887739 | 427171 | 40 | 36 | 66.90 | Kibet |
| 2. | Akamuja | 2000 | 902761.5 | 436080 | 40 | 36 | 70.58 | Butajira |
| 3. | Wizar | 2040 | 903600.52 | 434044.45 | 40 | 36 | 33.22 | Butajira |
| 4. | Lebu | 2020 | 912711.60 | 440611.66 | 80 | 72 | 63.42 | Kela |
| 5. | Weldia5 | 2220 | 923134.15 | 442561.83 | 140 | 126 | 53.22 | Bui |
| 6. | Weldia2 | 2340 | 923133.83 | 442561.53 | 100 | 90 | 51.50 | Bui |
| 7. | Weldia3 | 2480 | 923971.21 | 442036.26 | 140 | 126 | 18.92 | Bui |
| 8. | Weldia4 | 2600 | 923557.09 | 441179.35 | 160 | 144 | 10.66 | Bui |
| 9 | Weldia | 2110 | 921447.48 | 445447.48 | 90 | 81 | 55.85 | Bui |
| 10. | Rufael4 | 2650 | 927717.72 | 445376.13 | 40 | 36 | 32.96 | Bui |
| 11. | Rufael2 | 2410 | 926192.88 | 447566.07 | 130 | 117 | 51.75 | Bui |
| 12. | Rufael3 | 2250 | 926796.19 | 448625.10 | 100 | 90 | 54.08 | Bui |
| 13. | Rufael | 2130 | 926300.02 | 450075.18 | 70 | 63 | 71.88 | Bui |
| 14. | Gerjele | 2480 | 927818.52 | 449227.93 | 320 | 238 | 13.40 | Bui |
| 15. | Gulo | 2310 | 930670.94 | 455797.77 | 120 | 108 | 23.33 | Bui |
| 16 | Gulo_alel | 1950 | 929080.87 | 455178.27 | 80 | 72 | 49.44 | Bui |
| 17 | Garore | 1890 | 883793.08 | 427901.43 | 50 | 45 | 114.70 | Kibet |
| 18 | Garora2 | 1940 | 884251.86 | 427078.97 | 160 | 144 | 35.50 | Kibet |
| 19 | Teladu | 1770 | 906301.45 | 463616.78 | 50 | 45 | 1963.95 | EjersaLele |

Practically, the total available head is not actually available for the power generation as some of the hydraulic losses occur due to friction in pipe and local constrictions. Therefore, actual head available after head losses is known as 'Net Head' and the head available before the head losses is known as 'Gross head'. The net available head (H) can be estimated as the difference between available geometric head and total head losses from forebay to the powerhouse site, equation (eq.5.1), resulting from simplification of energy equation (Wali,. 2013).

$H = Hg - \sum h$……….*eq.5.1*

Where, 'H' is net head, $H_g$ is geometrical head and $\sum h$ is total head loss.

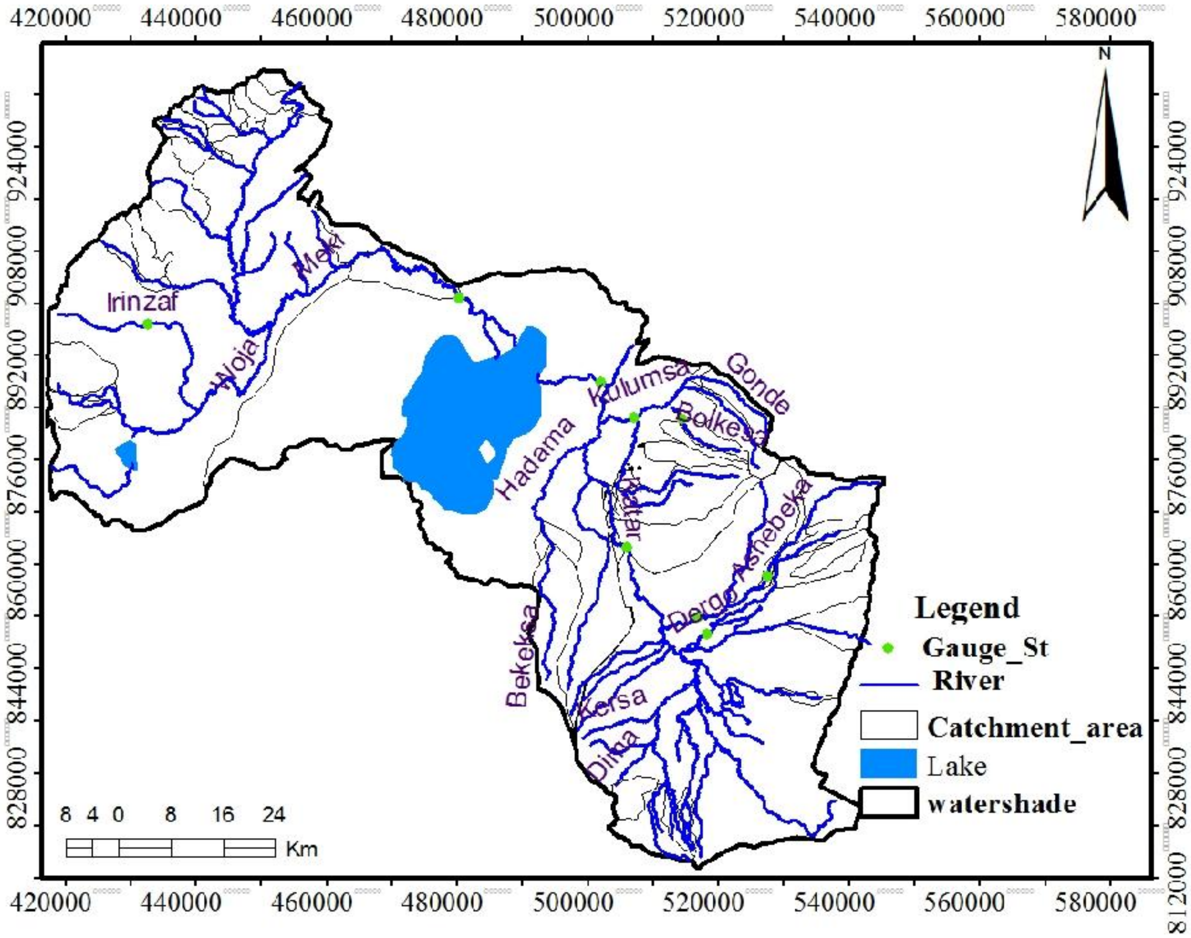

**Fig. 5.1 Distribution of identified potential SHP sites and the location of gauging stations on various streams in the study area**

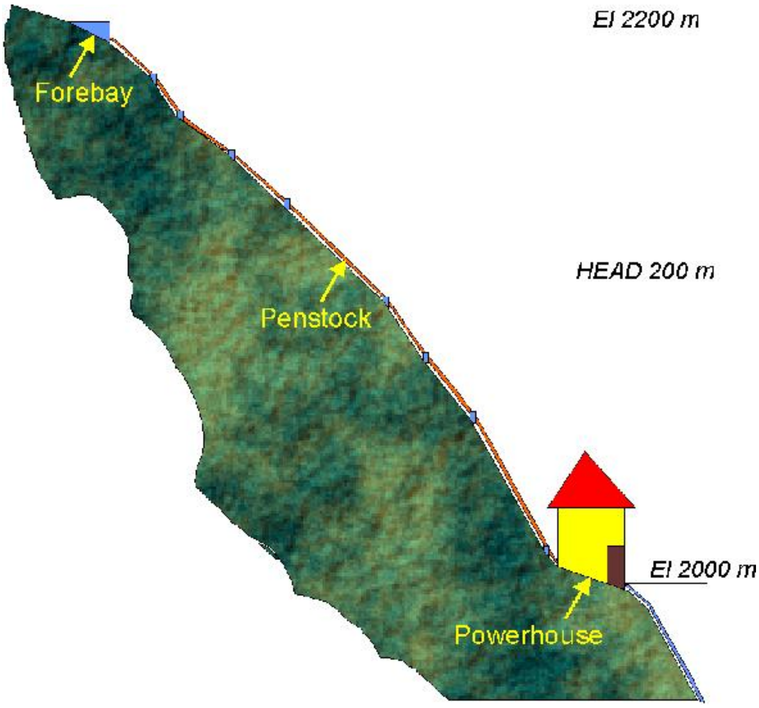

**Fig. 5.2 Determination of Head**

The total head losses ∑h (equation 5.2) from forebay to the powerhouse site, that could include head losses due to pipe friction $h_f$ (determine with equation 5.3) and local constrictions $h_L$, (losses from trash racks, bends, valves, etc. determine with equation 5.4) (Ransal, 2005).

$$\sum h = \sum h_f + \sum h_L \text{……….} \textit{eq. 5.2}$$

Friction losses occur due to friction along water conveyance structures such as pipes or canals; the degree of loss varies according to pipe or canal length and roughness and flow velocity. Lower head losses occur under conditions of smoother shorter conveyance structures, and lower velocity flows. It is determined with equation 5.3.This is known as Darcy-Weisbach energy loss equation (general form).

$$\sum h_f = f\frac{LV^2}{D2g} \text{……….} \textit{eq. 5.3}$$

Where, *f*-Darcy-Weisbach friction factor (no unit), L length of the pipe (m), V-mean velocity of flow (m/s), D diameter of the penstock (m), and gravitational acceleration ($ms^{-2}$).

The equation (5.3) applies to systems with incompressible fluids exhibiting a steady flow rate through a closed circular pipe of any cross-section and it is valid for both turbulent and laminar flows (Otuagoma et al., 2016).

In addition to friction losses, water flowing through a pipe systems experience head losses due to geometric changes at entrances, bends, elbows, joints, racks, valves and at sudden contractions or enlargements of the pipe section. This loss also depends on the velocity and is expressed by an experimental coefficient K multiplied by the kinetic energy $v^2/2g$. It is determined with equation (eq. 5.4) (ESHA, 2004).

$$\sum h_L = K\frac{V^2}{2g} \text{……….} \textit{eq. 5.4}$$

Where: K- resistance coefficient based on the type of local constriction (no unit), V-mean velocity of flow (m/s) and gravitational acceleration ($ms^{-2}$).

For small hydro plants, head losses can be of huge importance to the feasibility of the project and should be thus minimized as much as possible (Ashenafi Gezahagn, 2007). Accounting for the head losses caused by frictions, entrance, bends, trash rack, exit losses and valve losses should be considered in the computation of design head. A good profile will achieve a uniform acceleration of the flow, minimizing head losses. A proper designed pipeline will have a net head of 85 to 90 % of the gross head measured (FMC AG, 2014).

In the present study, for power potential assessment Gross head has been determined from the topo-sheet on 1:50,000. The net head is considered as 90 % of the gross head which is a common practice for power potential assessment at desk study level (Prajapati, 2015).In the absence of design layout in the initial stages the total head losses can be safely estimated as10% of the gross head (AHEC, 2001).

## 5.4 Estimation of Dependable Discharge

As discussed in the previous chapter flow duration curve (FDC) is used to describe the time availability of flow at a certain point in a river. For the present study dependable flow for potential power calculation is based on the analysis of daily discharge data acquired from the Ministry of Water Resources for 9 gauging stations. These gauging stations have recorded daily discharge data from 7 to 40 years. For water availability studies for SHP, the FDC were drawn from 1997 to 2006 for 10 years for all gauge stations except Irinzaf at Butajira (1986 to 1995). For working out the FDC for 75% dependable flow, the 10 daily discharge series of that year was considered. These 36 discharge values were arranged in descending order and percentage of time each has exceeded or equaled was worked out using Weilbul’s formula (see Eq. 4.1). This FDC is plotted between percentage of time and average 10-daily discharge. From FDCs, discharges of various dependability such as Q90, Q75, Q50, etc. may be obtained.

A design limited to 90% exceedance, for instance, leaves a greater portion of the power potential estimation. In contrast, design for higher flows, say 75% exceedance, would result power potential estimation in as shown in the flow-duration curve (Fig.5.2). However, the later requires substantial back up power potential source than the former (Zelalem Hailu and Horlacher, H.B, 2008)

In the present study 49 potential SHP sites has been identified. For these potential streams, gauged data is available in the upstream or downstream or adjoining catchments to the proposed diversion sites. For initial estimate of the power potential the observed discharge data from nearby locations have been projected at the proposed sites to work out the dependable flows (Nehimia Solomon, 2005; Ashenafi Gezahagn, 2007). Depending on the distance of a particular site to a neighboring gauge, area ratio method is used to transfer stream flow related information from gauged sites to un-gauged sites as discussed in Chapter 4, section 4.6. The regression analysis of mean annual flow versus catchments area also showed a very good correlation for Kater sub-basins with correlation coefficient reasonably close to 0.86.Thus, the projection of discharge data from nearby gauge stations on the proposed identified diversion sites by area proportion method is very well justified.

For the present study 75% of dependable flow was considered for potential power estimation of identified sites. This may ensure a full capacity generation for at least 9 months and a partial generation for remaining three months in a year. Thus, the total estimated potential for a given SHP site may be tapped by installation of two units of turbines of same installed capacity. Both turbines can be run simultaneously for 9 months and during lean flow only one unit can be operated.

### 5.5 Characteristics of Flow-Duration Curves

A flow duration curve characterizes the ability of the basin to provide flows of various magnitudes. The shape of a flow-duration curve in its upper and lower regions is particularly significant in evaluating the stream and basin characteristics. The shape of the curve in the high-flow region indicates the type of flood regime the basin is likely to have, whereas, the shape of the low-flow region characterizes the ability of the basin to sustain low flows during dry seasons. A very steep curve (high flows for short periods) would be expected for rain-caused floods on small watersheds. Regulation of floods with reservoir storage will generally result in a much flatter curve near the upper limit. In the low-flow region, an intermittent stream would exhibit periods of no flow, whereas, a very flat curve indicates that moderate flows are sustained throughout the year due to natural or artificial stream flow regulation, or due to a large groundwater capacity which sustains the base flow to the stream.

All the flow-duration curves show similar characteristic of steep drop at the tail. This implies that the reliable flow decreases sharply with increase in the demanded degree of dependability. This affects the choice of appropriate installation capacity of the power plant (FMC AG, 2014).

If design has to be made for a highly reliable flow, the installation capacity of the power plant will be very low and vice–versa. This is one of the major problems facing small hydropower development in semi-arid regions. The available water is concentrated within few wet months of the year. Guarantee of power supply is possible only during excess flow months unless measures are taken to cope up with the shortage (Zelalem Hailu and Horlacher, H.B, 2008).

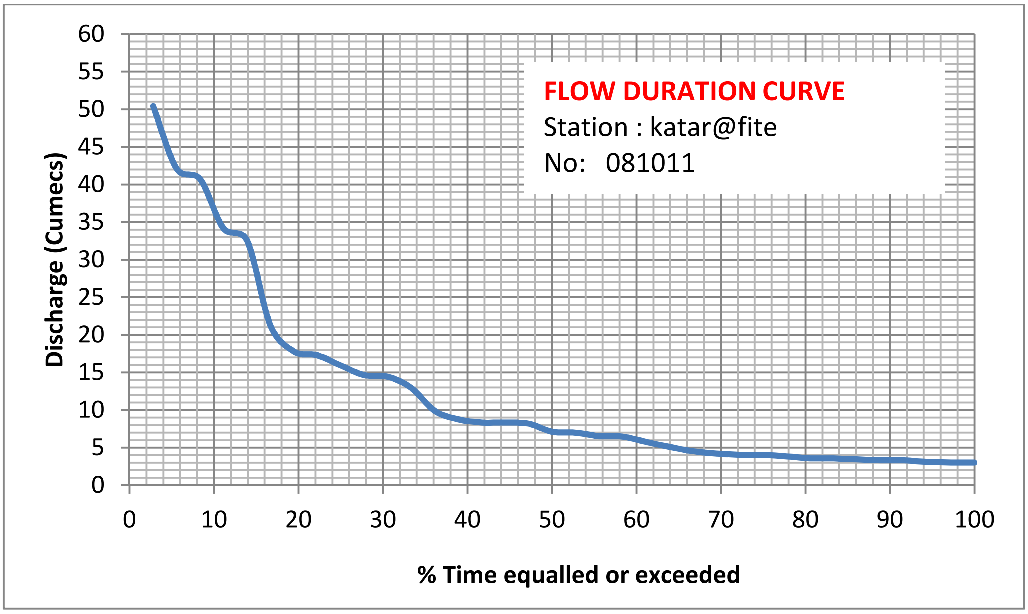

**Fig. 5.3 (a) Flow Duration Curve for Kater River at Fite**
***(Based on observed daily discharge from 1997 to 2006)***

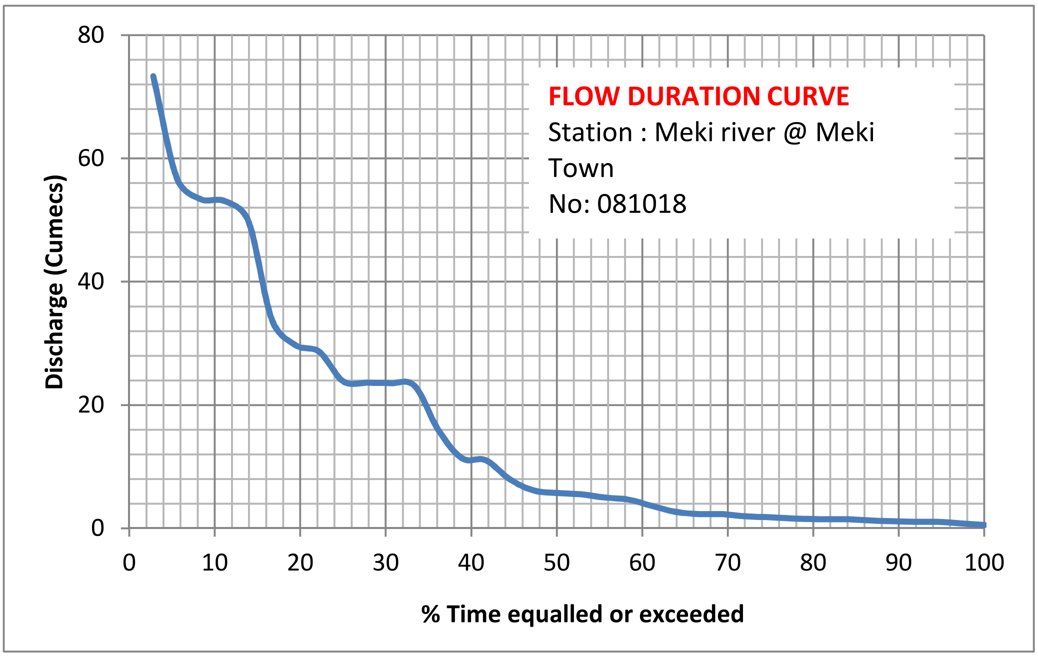

**Fig. 5.3 (b) Flow Duration Curve for Meki River at Meki Twon**
**(Based on observed daily discharge from 1997 to 2006)**

To select the most appropriate hydraulic equipment and estimate the sites potential with calculations of the annual energy output, a flow-duration curve is most useful.

## 5.6 Estimation of Discharge for Power Generation

The FDC were used for the selection of design flows. In hydropower design practices the design flow is selected based on the potential power generation classified as minimum, small, median or mean potential power with the exceedence probability corresponding to 100%, 95%, 50% on the FDC and the arithmetic mean of the mean annual discharges of the site for a period of 10 to 30 years for the mean potential power generation respectively (ESHA, 2004).

Design discharge is the discharge, based on which the installed capacity of a given SHP scheme is worked out. Discharge, for which the maximum power, for a maximum period in a year may be generated efficiently, is the design discharge for power generation. The design discharge may depend on the economics and the requirement for power. For instance, if a scheme has to be constructed in isolated mode the design discharge will be taken at higher dependability (80–90%) as the power has to be generated and distributed to local area throughout the year, or to a maximum period in a year. On the other hand if the scheme is grid connected in that case the design discharge may be taken at lower dependability (say 60-70%), provided it is economically feasible (ESHA, 2004).

The design discharges for the present study is considered as 90% of 75% dependable flow and 10 % of 75 % dependable flow has been left for environmental reasons.

## 5.7 Preliminary Estimation of Power Potential of the Identified Sites

The potential energy generation depends mainly on available flow and hydraulic head provided by topography. The amount and characteristics of water discharge at a potential SHP site has been evaluated through hydrological analysis. Results from the hydrological analysis, topographical data, and efficiencies of various SHP structures were used to quantify the power potential generation. Basically, the power exploited from hydropower at a particular site is proportional to the product of flow rate and head as given in the following equation (eq. 5.5).

$$P = \frac{\eta \rho g Q H}{1000} \text{………...} eq.5.5$$

Where;

η is the overall energy conversion efficiency (hydraulic to shaft power).

ρ is the density of water,

g (m/s) is the acceleration due to gravity,

Q (m/s) is the discharge taken equal to75% dependable flows, and

H (m) is Net head

**Table 5.2(a) Discharge data projection for identified potential SHP sites in Meki sub-basin from surrounding gauging stations**

| Potential SHP site | | | Gauging station | | | Drainage Area($km^2$) | | Dependable Discharge($m^3/s$) | |
|---|---|---|---|---|---|---|---|---|---|
| Name of SHP Site | Location of DW site (UTM) | | Name of gauging station | Location of gauging station (UTM) | | | | | |
| | Northing | Easting | | Northing | Easting | Gauge | Site | Q75 recorded at gauge | Q75 recorded at site |
| Lenkaro | 887739 | 427171 | Irinzaf | | | 49 | 66.90 | 0.35 | 0.48 |
| Akamuja | 902761.5 | 436080 | | | | 49 | 70.58 | 0.35 | 0.50 |
| Wizar | 903600.52 | 434044.45 | | | | 49 | 33.22 | 0.35 | 0.24 |
| Lebu | 912711.60 | 440611.66 | | | | 49 | 63.42 | 0.35 | 0.45 |
| Weldia | 923134.15 | 442561.83 | | | | 49 | 53.22 | 0.35 | 0.38 |
| Weldia2 | 923133.83 | 442561.53 | | | | 49 | 51.50 | 0.35 | 0.37 |
| Weldia3 | 923971.21 | 442036.26 | | | | 49 | 18.92 | 0.35 | 0.14 |
| Weldia4 | 923557.09 | 441179.35 | | | | 49 | 10.66 | 0.35 | 0.07 |
| Weldia5 | 921447.48 | 445447.48 | | | | 49 | 55.85 | 0.35 | 0.40 |
| Rufael | 927717.72 | 445376.13 | | | | 49 | 32.96 | 0.35 | 0.24 |
| Rufael2 | 926192.88 | 447566.07 | | | | 49 | 51.75 | 0.35 | 0.37 |
| Rufael3 | 926796.19 | 448625.10 | | | | 49 | 54.08 | 0.35 | 0.39 |
| Rufael4 | 926300.02 | 450075.18 | | | | 49 | 71.88 | 0.35 | 0.51 |
| Gerjele | 927818.52 | 449227.93 | | | | 49 | 13.40 | 0.35 | 0.10 |
| Gulo | 930670.94 | 455797.77 | | | | 49 | 23.33 | 0.35 | 0.17 |
| Guloalel | 929080.87 | 455178.27 | | | | 49 | 49.44 | 0.35 | 0.35 |
| Garore | 883793.08 | 427901.43 | | | | 49 | 114.70 | 0.35 | 0.82 |
| Garora2 | 884251.86 | 427078.97 | | | | 49 | 35.50 | 0.35 | 0.25 |
| Teladu | 906301.45 | 463616.78 | Meki | | | 2078 | 1963.95 | 2.39 | 2.15 |

For determining the power potential, the following criteria were considered:

(a) The net head is considered as 90 % of the gross head which is a common practice for power potential assessment for desk study level.

(b) The efficiency considered for turbines and generators are 90% and 95%, respectively which combined accounts to the overall efficiency of 85.5%.

**Table 5.2(b) Discharge data projection for identified potential SHP sites in Kater sub-basin from surrounding gauging stations**

| Potential SHP site | | | Gauging station | | | Drainage Area(km$^2$) | | Dependable Discharge(m$^3$/s) | |
|---|---|---|---|---|---|---|---|---|---|
| Name of SHP Site | Location of DW site (UTM) | | Name of gauging station | Location of gauging station (UTM) | | | | | |
| | Northing | Easting | | Northing | Easting | Gauge | Site | Q75 recorded at gauge | Q75 recorded at site |
| Kulumsa1 | 888441.81 | 515194.49 | Wolkesa | | | 23.12 | 48.42 | 0.06 | 0.13 |
| Kulumsa2 | 888888.66 | 516911.51 | | | | | 43.14 | | 0.11 |
| Kulumsa2 | 887049.37 | 516149.51 | | | | | 54.29 | | 0.14 |
| Bolkesa | 883934.60 | 512975.60 | | | | | 27.27 | | 0.07 |
| Anko | 881623.00 | 510749.07 | | | | | 18.02 | | 0.05 |
| Kombolcha (A11) | 878394.35 | 508465.58 | | | | | 33.92 | | 0.09 |
| A10 | 874518.48 | 505357.34 | | | | | 120.34 | | 0.31 |
| A9 | 872083.49 | 504114.21 | | | | | 118.32 | | 0.31 |
| A8(Ketar) | 872412.27 | 502326.75 | Kater@fite | | | 1932.22 | 2062.26 | 4.08 | 4.35 |
| A7 | 872412.27 | 503003.82 | | | | | 2056.39 | | 4.34 |
| A6 | 871282.61 | 502879.27 | | | | | 2055.84 | | 4.34 |
| A5 | 868899.34 | 503340.55 | | | | | 2051.58 | | 4.33 |
| A4 | 867406.48 | 503520.67 | | | | | 2048.76 | | 4.33 |
| A3 | 865261.19 | 503988.93 | | | | | 1935.42 | | 4.09 |
| Ashebeka 4 | 856444.87 | 525896.37 | Upper Timala | | | 108.57 | 111.56 | 0.48 | 0.49 |
| Bishole2 | | | | | | | 93 | | 0.41 |
| Ashebeka 5 | 8607.2154 | 528214.72 | | | | | 105.01 | | 0.46 |
| Bishole | 858272.50 | 530980 | | | | | 28.41 | | 0.13 |
| Ashebeka 1 | 863081.19 | 530124.74 | | | | | 102.89 | | 0.45 |
| Ashebeka 2 | 865530.45 | 532571.13 | | | | | 81.40 | | 0.36 |
| Dinsa | 860739.66 | 529315.43 | | | | | 25.01 | | 0.11 |
| TilkuGusha | 850936.55 | 530247.80 | | | | | 57.97 | | 0.26 |
| TinishuKechema | 825915.83 | 515412.48 | | | | | 15.3 | | 0.07 |
| TilikuKechema | 823703.72 | 516413.42 | | | | | 12.27 | | 0.05 |
| Kela | 826239.66 | 512150.53 | | | | | 20.50 | | 0.04 |
| Dima | 826464.95 | 511661.04 | | | | | 60.29 | | 0.27 |
| Berole | 827085.20 | 510583.01 | | | | | 30.28 | | 0.13 |
| MelkaBedi | 866798.10 | 492851.69 | Kater@fite | | | 1932.22 | 144.49 | 4.08 | 0.30 |
| Melka Bedi2 | 863265.60 | 494212.59 | | | | | 119.04 | | 0.25 |
| Melka Bedi3 | 854642.49 | 493882.11 | | | | | 58.44 | | 0.12 |

(c) The downstream release of 10 % at diversion weir site is considered for environmental consideration. Thus, 90% of available discharge was considered for power potential estimation.

To estimate the preliminary un-regulated power potential of each identified hydropower site equation 5.5 was used.

Installed capacity is among the most important figures to characterize a hydropower plant; it is defined as the designed power output of the installed turbine units (FMC AG, 2014). Installed capacity depends primarily on available head (Section 5.3), and on design discharge (Section 5.4); it is calculated according to the equation shown above using design discharge, Q and net head and the overall efficiency at design discharge.

**Table 5.3 (a) Estimated small/mini/micro hydropower potential for identified sites inMeki sub-basins**

| S.No | Name of SHP | Gross Head(m) | Net Head(m) | Flow Q75 | Discharge Available for Power Generation ($m^3/s$) | Power potential (KW) |
|---|---|---|---|---|---|---|
| 1 | Lenkaro | 40 | 36 | 0.48 | 0.43 | 129.67 |
| 2 | Akamuja | 40 | 36 | 0.50 | 0.45 | 135.88 |
| 3 | Wizar | 40 | 36 | 0.24 | 0.22 | 65 |
| 4 | Lebu | 80 | 72 | 0.45 | 0.41 | 244.88 |
| 5 | Weldia5 | 140 | 126 | 0.38 | 0.34 | 361.45 |
| 6 | Weldia2 | 100 | 90 | 0.37 | 0.33 | 251.37 |
| 7 | Weldia3 | 140 | 126 | 0.14 | 0.13 | 133.16 |
| 8 | Weldia4 | 160 | 144 | 0.07 | 0.06 | 72.46 |
| 9 | Weldia | 90 | 81 | 0.40 | 0.36 | 244.58 |
| 10 | Rufael4 | 40 | 36 | 0.24 | 0.22 | 65.22 |
| 11 | Rufael2 | 130 | 117 | 0.37 | 0.33 | 326.79 |
| 12 | Rufael3 | 100 | 90 | 0.39 | 0.35 | 264.96 |
| 13 | Rufael | 70 | 63 | 0.51 | 0.46 | 242.54 |
| 14 | Gerjele | 320 | 238 | 0.10 | 0.09 | 179.66 |
| 15 | Gulo | 120 | 108 | 0.17 | 0.15 | 138.60 |
| 16 | Gulo_alel | 80 | 72 | 0.35 | 0.32 | 190.22 |
| 17 | Garore | 50 | 45 | 0.82 | 0.74 | 278.55 |
| 18 | Garora2 | 160 | 144 | 0.25 | 0.23 | 271.76 |
| 19 | Teladu | 50 | 45 | 2.39 | 2.15 | 811.43 |
|  |  |  |  |  | **Total** | **4408.18** |

Perusal of Table 5.3 (a) and (b) clearly indicates that the total power potential for 19 potential sites in Meki sub-basin is 4408.18 KW whereas, for 30 potential sites in Kater sub- basin is 13059.53 KW. Thus, the total potential in the present study area for the 49 identified sites is 17,467.71 KW. In Maki sub-basin 16 sites fall under Mini Hydro power (more than 100 KW but less than 1 MW) with total potential of 4205.5 KW and 3 sites under micro Hydro power (more than 10 kW but less than 100 kW) with a total potential of 202.68 KW. Similarly, in Kater sub-basin 6 sites fall into small Hydro power category (more than 1 MW) with total potential of 10402.36 KW, 14 sites fall under Mini Hydro power (more than 100 KW but less than 1 MW) with total potential of 2123.35 KW and 10sites under micro Hydro power (more than 10 kW but less than 100 kW) with total potential of 534.22 KW.

**Table 5.3 (b) Estimated small/mini/micro hydropower potential for identified sites in Kater sub-basins**

| S.No | Name of SHP | Gross Head(m) | Net Head(m) | Flow Q75 ($m^3/s$) | Discharge Available for Power Generation ($m^3/s$) | Power potential (KW) |
|---|---|---|---|---|---|---|
| 1 | Kulumsa1 | 110 | 99 | 0.13 | 0.12 | 99.64 |
| 2 | Kulumsa2 | 60 | 54 | 0.11 | 0.10 | 45.29 |
| 3 | Kulumsa2 | 120 | 114 | 0.14 | 0.13 | 124.30 |
| 4 | Bolkesa | 240 | 216 | 0.07 | 0.06 | 108.70 |
| 5 | Anko | 280 | 252 | 0.05 | 0.05 | 105.68 |
| 6 | Kombolcha(A11) | 280 | 252 | 0.09 | 0.08 | 169.09 |
| 7 | A10 | 40 | 36 | 0.31 | 0.28 | 84.54 |
| 8 | A9 | 50 | 45 | 0.31 | 0.28 | 105.68 |
| 9 | A8(Ketar) | 70 | 63 | 4.35 | 3.92 | 2071.39 |
| 10 | A7 | 50 | 45 | 4.34 | 3.91 | 1475.79 |
| 11 | A6 | 40 | 36 | 4.34 | 3.91 | 1180.63 |
| 12 | A5 | 40 | 36 | 4.33 | 3.90 | 1177.61 |
| 13 | A4 | 100 | 90 | 4.33 | 3.90 | 3107.58 |
| 14 | A3 | 50 | 45 | 4.09 | 3.68 | 1389.36 |
| 15 | Ashebeka4 | 70 | 63 | 0.49 | 0.44 | 232.50 |
| 16 | Bishole2 | 70 | 63 | 0.41 | 0.37 | 195.51 |
| 17 | Ashebeka5 | 70 | 63 | 0.46 | 0.41 | 216.65 |
| 18 | Bishole | 60 | 54 | 0.13 | 0.12 | 54.35 |
| 19 | Ashebeka1 | 50 | 45 | 0.45 | 0.41 | 154.75 |
| 20 | Ashebeka2 | 50 | 45 | 0.36 | 0.32 | 120.78 |
| 21 | Dinsa | 60 | 54 | 0.11 | 0.10 | 45.29 |
| 22 | TilkuGusha | 40 | 36 | 0.26 | 0.23 | 69.38 |
| 23 | TinishuKechema | 40 | 36 | 0.07 | 0.06 | 18.1 |
| 24 | TilikuKechema | 100 | 90 | 0.05 | 0.05 | 37.7 |
| 25 | Kela | 100 | 90 | 0.04 | 0.04 | 30.16 |
| 26 | Dima | 80 | 72 | 0.27 | 0.24 | 144.78 |
| 27 | Berole | 120 | 108 | 0.13 | 0.12 | 108.59 |
| 28 | MelkaBedi | 80 | 72 | 0.30 | 0.27 | 162.89 |
| 29 | Melka Bedi2 | 100 | 90 | 0.25 | 0.23 | 173.45 |
| 30 | Melka Bedi3 | 60 | 54 | 0.12 | 0.11 | 49.77 |
|  |  |  |  |  | **Total** | **13059.53** |

## 5.7 Annual Power Generation

Annual generation has been worked out for various schemes by using eq. 5.6 and the results are presented in Table 5.4.

The annual power is calculated for 90% of the operational time in a year, 10% time is left for breakdowns, maintenance and nonoperational periods.

Annual Power generation = Pp * 24 hours * 365 days………*eq. 5.6*

**Table 5.4 (a) Annual power generation small/mini/micro hydropower potential for identified sites in Meki sub-basins**

| S.No | Name of SHP | Net Head(m) | Discharge Available for Power Generation ($m^3/s$) | Power Potential(KW) | Annual Power Generation (MWh) |
|---|---|---|---|---|---|
| 1 | Lenkaro | 36 | 0.43 | 129.67 | 1022.32 |
| 2 | Akamuja | 36 | 0.45 | 135.88 | 1071.28 |
| 3 | Wizar | 36 | 0.22 | 65 | 512.46 |
| 4 | Lebu | 72 | 0.41 | 244.88 | 1930.63 |
| 5 | Weldia | 126 | 0.34 | 361.45 | 2849.67 |
| 6 | Weldia2 | 90 | 0.33 | 251.37 | 1981.80 |
| 7 | Weldia3 | 126 | 0.13 | 133.16 | 1049.83 |
| 8 | Weldia4 | 144 | 0.06 | 72.46 | 571.27 |
| 9 | Weldia5 | 81 | 0.36 | 244.58 | 1928.27 |
| 10 | Rufael | 36 | 0.22 | 65.22 | 514.194 |
| 11 | Rufael2 | 117 | 0.33 | 326.79 | 2576.41 |
| 12 | Rufael3 | 90 | 0.35 | 264.96 | 2088.944 |
| 13 | Rufael4 | 63 | 0.46 | 242.54 | 1912.19 |
| 14 | Gerjele | 238 | 0.09 | 179.66 | 1416.44 |
| 15 | Gulo | 108 | 0.15 | 138.60 | 1092.72 |
| 16 | Gulo_alel | 72 | 0.32 | 190.22 | 1499.69 |
| 17 | Garore | 45 | 0.74 | 278.55 | 2196.09 |
| 18 | Garora2 | 144 | 0.23 | 271.76 | 1740 |
| 19 | Teladu | 45 | 2.15 | 811.43 | 6397.31 |
|  |  |  | **Total** | **4408.18** | **34351.52** |

**Table 5.4 (b) Annual power generation small/mini/micro hydropower potential for identified sites in Kater sub-basins**

| S.No | Name of SHP | Net Head (m) | Discharge Available for Power Generation ($m^3/s$) | Power potential (KW) | Annual Power Generation (MWh) |
|---|---|---|---|---|---|
| 1 | Kulumsa1 | 99 | 0.12 | 99.64 | 785.56 |
| 2 | Kulumsa2 | 54 | 0.10 | 45.29 | 357.06 |
| 3 | Kulumsa2 | 114 | 0.13 | 124.30 | 979.98 |
| 4 | Bolkesa | 216 | 0.06 | 108.70 | 856.99 |
| 5 | Anko | 252 | 0.05 | 105.68 | 833.18 |
| 6 | Kombolcha(A11) | 252 | 0.08 | 169.09 | 1333.11 |
| 7 | A10 | 36 | 0.28 | 84.54 | 666.51 |
| 8 | A9 | 45 | 0.28 | 105.68 | 833.18 |
| 9 | A8(Ketar) | 63 | 3.92 | 2071.39 | 16330.84 |
| 10 | A7 | 45 | 3.91 | 1475.79 | 11635.13 |
| 11 | A6 | 36 | 3.91 | 1180.63 | 9308.09 |
| 12 | A5 | 36 | 3.90 | 1177.61 | 9284.28 |
| 13 | A4 | 90 | 3.90 | 3107.58 | 24500.16 |
| 14 | A3 | 45 | 3.68 | 1389.36 | 10953.71 |
| 15 | Ashebeka4 | 63 | 0.44 | 232.50 | 1833.03 |
| 16 | Bishole2 | 63 | 0.37 | 195.51 | 1541.40 |
| 17 | Ashebeka5 | 63 | 0.41 | 216.65 | 1708.07 |
| 18 | Bishole | 54 | 0.12 | 54.35 | 428.49 |
| 19 | Ashebeka1 | 45 | 0.41 | 154.75 | 1220.06 |
| 20 | Ashebeka2 | 45 | 0.32 | 120.78 | 940.15 |
| 21 | Dinsa | 54 | 0.10 | 45.29 | 357.07 |
| 22 | Tilku Gusha | 36 | 0.23 | 69.38 | 546.99 |
| 23 | Tinishu Kechema | 36 | 0.06 | 18.1 | 142.7 |

| | | | | | |
|---|---|---|---|---|---|
| 24 | Tiliku Kechema | 90 | 0.05 | 37.7 | 297.23 |
| 25 | Kela | 90 | 0.04 | 30.16 | 237.78 |
| 26 | Dima | 72 | 0.24 | 144.78 | 1141.45 |
| 27 | Berole | 108 | 0.12 | 108.59 | 856.12 |
| 28 | Melka Bedi | 72 | 0.27 | 162.89 | 1284.22 |
| 39 | Melka Bedi2 | 90 | 0.23 | 173.45 | 1367.48 |
| 30 | Melka Bedi3 | 54 | 0.11 | 49.77 | 392.39 |
| | | | | Total | 102952.4 |

Perusal of results in Table 5.4 (a) and (b) indicates that total annual power generation from 19 potential sites in Maki sub-basin will be 34351.52 MWh, whereas in Kater sub-basin 30 potential sites will generate 102952.4 MWh. Thus, the total generation from the 49 potential sites in the study area would be 137,303.92 MWh.

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# Chapter 6 Engineering Geological Appraisal of the Identified SHP Sites

## 6.1 Introduction

In general, site selection must consider potential energy generation (water power capacity), which depends on the head and the usable discharge, and potential constraints related to construction costs, plant operation and the environmental and social risks and impacts of the location (FMC AG, 2014). The following constraints must be considered: water resources, topography, geotechnical characteristics, site access, energy demand, interaction with other hydropower projects (HPP), construction constraints, grid connection, environmental issues, social issues, and financial incentives. Though, among all these factors, topography and geology of the area are the two main technical factors which significantly affect the site selection, design, construction and performance of SHP project.

Ideally, no site is assumed to be suitable from topographical or geological point of view, as there may always be some problems associated to topography or the geological setup of the area. However, identification of possible adverse and unfavorable conditions in the project area, during initial stages of site selection, helps in adopting proper remedial measures so that the project do not pose any problems during the construction or performance stage (http://tkraghu.tripod.com).

In the present study, the potential SHP sites were identified from Ethiopian Mapping Agency topographic maps at 1:50,000 scale at a preliminary stage of the study. Detailed topographical survey has been carried out for the identified sites. The survey included delineation of possible alignment and locations of various SHP components, which were later considered for power potential estimation for each site. From the present study a total of 49 potential sites have been identified. In addition, the suitability of the selected sites for hydropower development such as; actual head measurement, accessibility details and engineering geological suitability of the sites has been ascertained through field investigation.

Preliminary field survey is to be carried out for the identified alignment and location, covering sufficient area to examine all possible shifts in locations to arrive at an optimum alignment and positioning of structures. Thus, the 49 potential SHP sites can be taken up for detailed engineering geological appraisal. However, with the limitation of resources, time, and financial constraints, it was not possible to undertake field investigation for ground verification and detailed engineering appraisal of all 49 SHP sites. Thus, a sincere effort has been made to cover 3 potential SHP sites to undertake ground verification and engineering geological appraisal. The selection of these 3 sites, as first priority, is based on the following criteria;

(i) The selected site should not be very remote. Sites close to Addis Ababa are taken up for engineering geological assessment though there are sites which are very far form Addis Ababa.
(ii) There should be an access to all the components, diversion weir, water conductor and powerhouse.
(iii) The estimated power potential is greater than 200 kW.
(iv) The site must be located near a cluster of un-electrified villages; this is to ensure proper power utilization.

The sites which satisfy the above criteria were finally taken up for ground verification and detailed engineering appraisal. These sites are listed in Table 6.1 and shown in Fig.6.1.

**Table6.1 Selected sites for engineering geological Appraisal**

| **Name of SHP Site** | **Name of Stream** | **Location of Diversion Weir (UTM)** | | **Nearest Town** |
|---|---|---|---|---|
| Rufael | Rufael | 450367mE | 926349mN | Bui |
| Weldia | Weldia | 445503mE | 921738mN | Bui |
| Lebu | Lebu | 441245mE | 911955mN | Kela |

Following section will focus on ground verification and the engineering geological appraisal for the selected small hydropower projects in the study area.

## 6.2 Ground Verification for General Layout of Schemes

Through topographical survey conducted as a part of the field work, necessary information was gathered for general layout of the different components of the identified SHP sites. With the help of EMA topomaps (1:50,000) and Google earth, it is possible to locate with reasonable precision the intake, headrace alignment, penstock alignment and the powerhouse sites at the feasibility studies. Thus, the tentative location of the various components of the SHP scheme has been selected based on certain parameters.

Hydraulic structures, such as diversion weir should be founded on level foundations, with adequate side slopes and minimum width, not subject to stability problems. Along the proposed open channel many geomorphologic features can adversely affect its selected line, which together with a steep slope of the terrain may lead to potential instability. Thus, the water conductor alignment has been decided on either bank of the stream, provided the alignment has minimum length, minimum cross drainages and the slopes on which the water conductor is planned are relatively gentle.

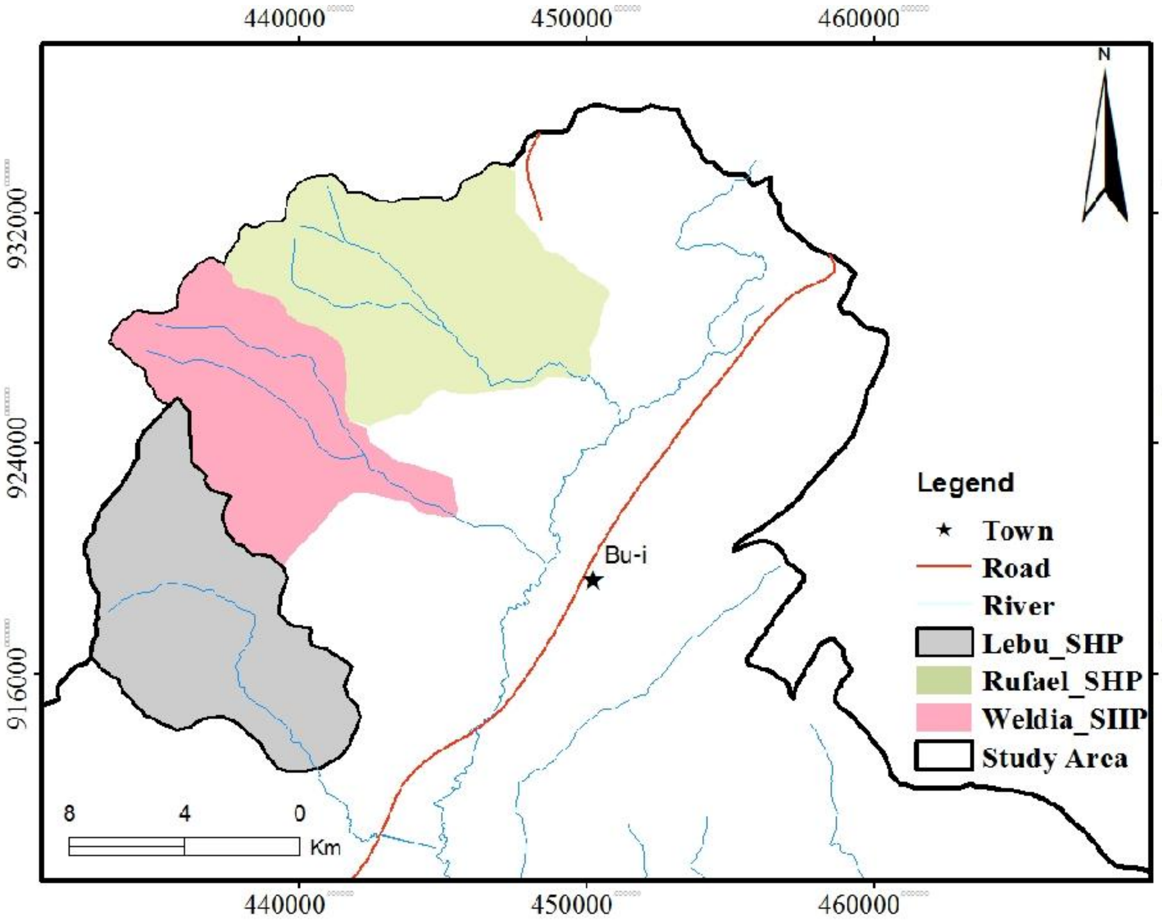

**Fig.6.1 Selected sites for ground verification and engineering geological appraisal**

For each major components desilting tank, forebay tank there must be a flat land or relatively gentle slope available, this may be identified on topographical map by examining the contour pattern. The layout of the penstock, usually placed on a steep slope may pose problem both for its anchoring blocks and slope instability. Therefore, the proposed penstock alignment is selected in such a way that it has a minimum length with least number of bends. This has to ensure that there are minimum frictional losses in hydraulic head. Moreover, the alignment must follow the ridge line, so that the anchor blocks are not subjected to scouring due to flowing water during rainy season. Deep in the valley, frequently built on an old river terrace, the proposed powerhouse site must have adequate flat land or a very gentle slope to accommodate the powerhouse; this may be identified on topo sheet by examining the contour pattern. The tailrace channel must meet the main stream downstream of the powerhouse site, if it meets up stream of powerhouse site it may cause toe erosion at the base of the powerhouse (ESHA, 2004).

Based on the above-mentioned criteria, general layout for various SHP schemes, have been planned on EMA topo-sheets (1:50,000). Further, each general layout of SHP schemes has been visited and the following field verification has been made;

(i) Accessibility of various components, diversion weir site, desilting tank, forebay and powerhouse site. Each component site has been physically visited and observation were made and recorded.

(ii) Physical verification of each of the component of SHP site and the gross head is estimated, by using a GPS (Global positioning system). With the aid of the engineering hydraulic principals outlined in chapter 5 the net head is also determined.

(iii) Personal interviews were conducted with the local people to qualitatively assess the flow variations in respective streams.

(iv) Engineering geological appraisal of the sites at pre-feasibility level has been done to permit initial estimates, for the safety of the powerhouse foundations, the stability of slopes and the overall conditions and strength of rocks and soils present at various components. Stability condition of slopes on which the penstock alignment is proposed has been studied. The detailed engineering geological appraisal of small hydropower sites are discussed later in this chapter.

The present layout of each individual SHP sites is based on 1:50,000 topographic sheets and Google Earth. The site selection for the different components of the scheme is such that the access is feasible and discussed here under;

### 6.2.1 Rufael SHP Site

This site is located on side of Western escarpment of Central Main Ethiopia Rift near Bui town. This site is situated at Rufael River which is a tributary of Meki River in Rift valley Basin. The river Rufael, the sources of which is near the high lands is located north eastern located at an elevation of 2130m, defined by coordinates part of the Meki sub-basin. The main alignment of Rufael SHP site is proposed on the left bank of the Rufael River (Fig.6.2a). The proposed diversion weir will be located at an elevation of 2130m having coordinates 926349mN; 450367mE. The forebay structure may be 926119mN, 4502985mE about 300m downstream of the diversion weir along the ridge. The proposed power house may be located at an elevation of 2080m, defined by coordinates 925937mN, 450526mE about 290m downstream of the forebay along the cultivated land.

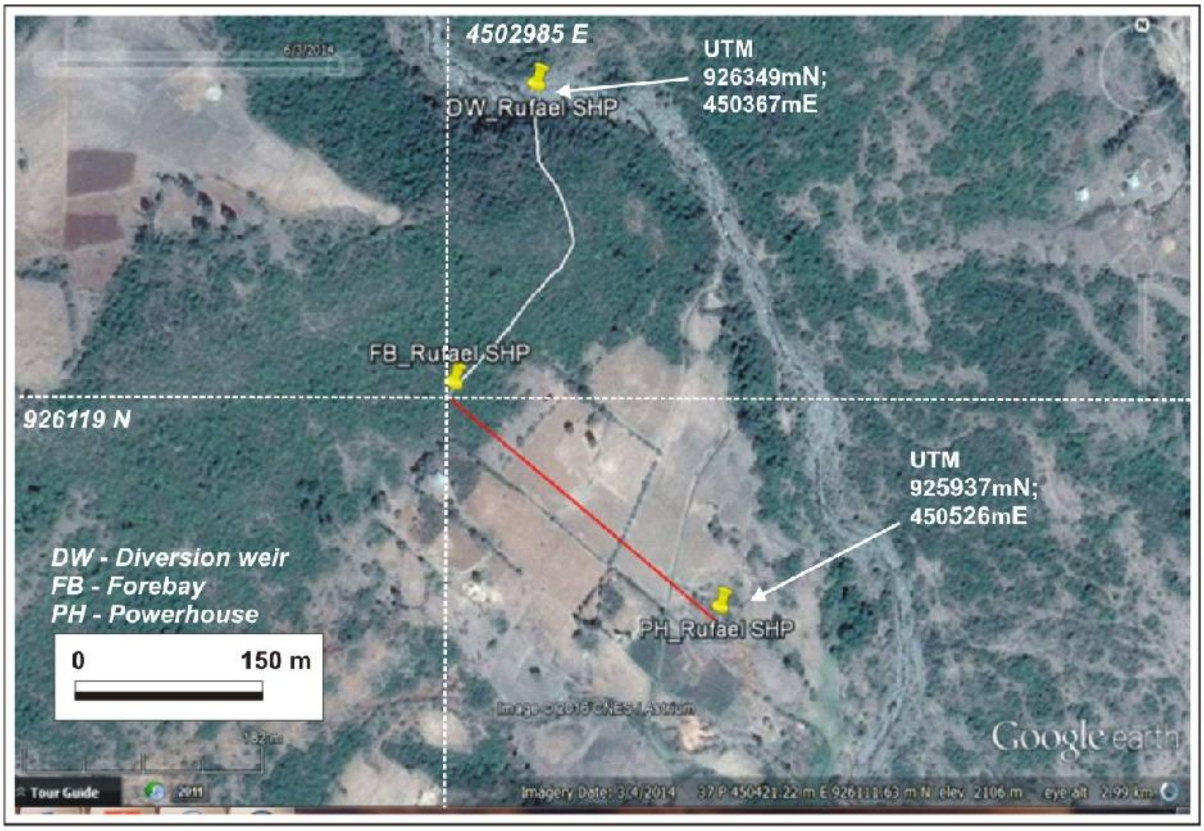

Fig. 6.2a Proposed general alignment of Rufael River small hydro power site

The site is accessible by vehicle on the main asphalt road from Addis Ababa- Alemgena-Butajira 5km before reaching Bui town. This site is well accessible up to powerhouse site (3km from Anati Village) by a footpath along the side of the river on agricultural land starting from the main asphalt road. The water conductor system is accessible through a foot path along the ridge side from the diversion weir site.

### 6.2.2 Weldia SHP Site

This site is located on side of Western escarpment of Central Main Ethiopia Rift near Bui town. This site is situated at Weldia River which is a tributary of Meki River Rift valley Basin. The river Weldia, the sources of which is near the high lands is located in the northern part of Meki sub-basin. The main alignment of Weldia SHP is to be set up on the right bank of the Weldia River. The proposed diversion weir will be located at an elevation of 2122m having coordinates 921738mN; 445503mE.The forebay will be located at an elevation of 2120m, defined by coordinates 921729mN, 446395mE about 930 m downstream of the diversion weir along the ridge. The power house will be located at an elevation of 2065m, defined by coordinates 921486mN, 446398mE about 240 m downstream of the diversion weir along the river course.

**Fig. 6.2b Proposed general alignment of Weldia small hydro power site**

The site is accessible by vehicle on the main asphalt road from Addis Ababa- Alemgena- Butajira 5km after reaching Bui town. This sites are well accessible up to powerhouse site by a gravel road which starts form the main asphalt road. A footpath is present along the side of the river on agricultural land and across the ridge to the diversion weir site. The water conductor system is assessed through a foot path along the ridge side from the diversion weir site.

### 6.2.3 Lebu SHP Site

This site is located on side of Western escarpment of Central Main Ethiopia Rift near Kela town. This site is situated at Lebu River which is a tributary of Meki River in Rift valley Basin. The river Lebu, the sources of which is near the high lands is located in the northern part of the Meki sub-basin. The main alignment of Lebu SHP site is to be set up on the right bank of the Lebu River. The proposed diversion weir will be located at an elevation of 2006 m having UTM coordinates 911955mN; 441245mE. The forebay will be located at an elevation of 2006 m, defined by coordinates 911908mN, 441808mE about 640 m downstream of the diversion weir along the ridge. The power house will be located at an elevation of 1940m, defined by coordinates 911598mN, 441953mE about 340m downstream of the diversion weir.

**Fig. 6.2c Proposed general alignment of Lebu small hydro power site**

The site is accessible by vehicle on the main asphalt road from Addis Ababa- Alemgena-Butajira 3km after reaching Kela town. This site is well accessible up to powerhouse site (4km from main road) by a gravel road which starts form the main asphalt road. A footpath is present along the side of the river and across the ridge to the diversion weir site. The water conductor system is accessed through a foot path along the right bank of the river from the diversion weir site.

## 6.3 Geomorphology in and around the Selected SHP Sites

The proposed sites are located in the Western Margins of Main Ethiopia Rift Valley mountain range in central Ethiopia, namely the Guraghe Highland. It shows consequently a great diversity of geomorphologic features within a comparatively small area. Escarpments, steep slopes and narrow valleys are in fact a major landform in the mountain range, often reaching several small waterfalls flowing over them. The elevation difference between the low land and the high land of the area is very high. Therefore the river of the basin runs from higher elevation to lower elevation by developing several falls (forming beautiful landscape) and steep slope toward the lowland which provides significant head for power generation at several locations (Plate. 6.1).

**Table 6.2 Characteristics of the selected small hydropower (SHP)**

| S. N | Name of SHP | Diversion Weir Location | | | Water Canal Length(Km) | Forebay Location | | | Penstock Length(Km) | Power house Location | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | UTM(m) | | Elevation(m) | | UTM(m) | | Elevation(m) | | UTM(m) | | Elevation (m) |
| | | E | N | | | E | N | | | E | N | |
| 1 | Rufael | 450367 | 926349 | 2130 | 0.30 | 450298 | 926119 | 2130 | 0.29 | 450526 | 925937 | 2080 |
| 2 | Weldia | 445503 | 921738 | 2122 | 0.93 | 446395 | 921729 | 2120 | 0.24 | 446398 | 921486 | 2065 |
| 3 | Lebu | 441245 | 911955 | 2006 | 0.64 | 441808 | 911908 | 2006 | 0.34 | 441953 | 911598 | 1940 |

The location at which diversion weir is proposed to construct, the stream flows in a relatively wide valley with U- strike shaped cross section having rather shallow river bottom. Some perennial tributaries can be observed upstream and downstream side of the proposed weir site. The left and right bank of the river at the proposed weir site shows a gentle slope.

## 6.4 Engineering Geological Appraisal of SHP Sites

In general, the complexity of a site investigation depends upon the nature of the ground conditions and the type of engineering structure (Bell, 2007). Most of the small projects comprise small diversion structures like trench weirs, short water conductor systems comprising open power channels and forebays, and surface powerhouses founded mostly on overburden. SHP schemes involve small size structure as compared to large Hydropower schemes.

For small hydro schemes much of the appraisal of site geologic conditions will be based on visual inspection of site features. According to the specific geological conditions of the site, the scope of site investigations may vary considerably. A wise and careful geological assessment with limited geological exploration is essential for selecting appropriate alignment and sitting the various structures of the scheme of small hydropower. Detailed field survey is to be carried out for the identified alignment and location, covering sufficient area to examine all possible shifts in locations to arrive at an optimum alignment and positioning of structures (AHEC-IITR, 2013).

*(a) Shows the land scape of Weldia SHP site, (b) shows the general over view of Rufael SHP site,*
*(c) Shows the river section of the proposed diversion weir site of Weldia SHP site,*
*(d) Shows the river section of Rufael SHP the propose diversion weir site,*
*(e) Shows the general land forms of Lebu SHP site and (f) shows water fall at Lebu SHP site).*

**Plate 6.1 Geomorphological Land forms in and around the selected sites**

### 6.4.1 Geological Investigation of the Selected Small Hydropower Site

The main objective of a geological investigation is to assess the suitability of a site for small hydropower project, to enable adequate and economical design and to foresee and provide solution against difficulties that may arise due to ground and other local conditions (AHEC-IITR, 2013).

Geological investigation helps to identify existing surface and sub-surface geological conditions of selected locations for the main structures of the project, to describe stability condition of soil overburden and the bed rock, to analyze geological hazard situation of the area and to recommend appropriate precautionary measures to mitigate anticipated environmental impacts due to unfavorable geological conditions (Balasooriya, 2010).

An assessment of the regional geology by means of geological maps and review of existing reports should be made to assess the potential location and scheme arrangement. In particular consideration should be given to ground conditions, landslides, regional seismic activity and river sedimentation loads. These features may directly influence the design of penstocks and tunnels; the design of the intake structure to be able to cope with high sediment loads or the height of weirs associated with intake structures (Balasooriya, 2010).

For the present study, the basic geologic analysis was carried out to obtain the overall geologic information in and around the respective selected identified sites. In general, the area is occupied by high-grade Biotitic Gneiss, Adigrat Sandstone, Tertiary and Quaternary volcanic rocks, which belongs to western margins of Main Ethiopia rift (Dipola, 1970; Giday Weldegebraile, 1990, Abebe et al., 2010) (Fig.3.5, Chapter 3). Further, 1:250,000 scale Geological map (Akaki sheet) published by Geological Survey of Ethiopia was used for the interpretation of Geological setup in and around the project area. In general, orientation of rocks is aligned in NE-SW direction. However, general Geological data were collected during the field visit for the respective sites.

#### 6.4.1.1 Geology of Rufael SHP Site

The geology of the site is considered based on geological field surveys during the present study. The area is mainly composed of rocks of the volcanic products, alluvial deposit and residual soils. At the proposed diversion weir site light to dark color, fine to medium grained welded to poorly welded pyroclastic rock is exposed on the left bank and it is slightly weathered. The right bank at the weir site is gentle slope and is covered with vegetation. The rock exposed at the left bank has two major joint sets with preferred orientation of N25$^0$E and N 32$^0$ E and it is slightly weathered. Transported fine to boulder sized rocks were observed in the right bank of the diversion weir site. The headrace channel alignment is along the ridge on relatively gentle slope of the left bank. The proposed headrace channel will be mostly crossing through these slightly weathered deposits of welded pyroclastic rocks over gentle slope of the ridge. The proposed forebaye site situated on weleded pyroclastic rocks. The proposed penstock will be mostly crossing through poorly welded pyroclastic deposits under gentle slope of the ridge. The geology along proposed penstock alignment is also overlain by a considerable thickness of residual soils. The proposed power house site is situated on poorly welded pyroclastic rocks.

*(a) shows out crop of welded pyroclastic rocks at Rufael SHP diversion weir site the left bank of the river, (b) shows rock exposure at the right bank of the river the proposed diversion weir of Rufael SHP site (c) rock sample of the out crop of slightly weathered welded pyroclastic rocks at Rufael SHP diversion weir site and (d) shows the bolder rocks at the site of proposed diversion weir of Rufael SHP.*

**Plate 6.2Lithology of Rufael Small Hydro Power (SHP) Site**

### 6.4.1.2 Geology of Weldia SHP Site

The geology of the site is considered based on geological field surveys during the present study. The area is mainly composed of rocks of the volcanic products, alluvial deposit and residual soils. At the proposed diversion weir site dark color, fine grained fractured basalt is exposed on the right bank and it is slightly weathered. The exposed basalt rock at the right bank has one joint sets with preferred orientation of N $24^0$ E are observed. The left bank at the weir site is gentle slope and covered with vegetation. The rock boulders were observed on both side of the left and right banks of the diversion weir site. The water conductor alignment is along the right bank across relatively gentle slope ridge. The proposed penstock will be mostly crossing through welded to poorly welded pyroclastic rocks and residual soil deposits under gentle slope of the ridge. The geology along proposed penstock alignment is also overlain by a considerable thickness of residual soils. The proposed power house site is situated on residual soils.

*(a) shows the river sectionat the proposed diversion weir site of Weldia SHP,*
*(b) shows the out croup of basalt rock at the proposed diversion weir site of Weldia SHP site,*
*(c) shows transported material deposit at the right bank of the river downstream of the proposed diversion weir site of Weldia SHP site and*
*(d) shows joints on outcrop of basalt rock at the proposed diversion weir site of Weldia SHP site,*

**Plate 6.3 Lithology of Weldia Small Hydro Power (SHP) Site**

### 6.4.1.3 Geology of Lebu SHP Site

The proposed diversion weir is situated on reddish brown color, fine to medium grained sandstone and has high strength (Plate 6. 4). The sandstone formed a cliff in both sides of the river banks. The head race canal alignment is along the ridge on relatively gentle slope formed by sandstone rocks which are covered with thin residual soils. The proposed forebay site is situated on slightly weathered sandstone. The geology along proposed penstock alignment is also overlain by sandstone and a considerable thickness of residual soils. The proposed power house site is situated on residual soils.

*(a) the land forms of the sandstone rocks and the surrounding landscapes of Lebu SHP site (b) exposure of sand stone rock outcrop downstream of the proposed diversion weir site (c) Rock sample from the outcrop of the exposed sand stone rock at the propose diversion weir site.*

**Plate 6.4Lithology of Lebu Small Hydro Power (SHP) Site**

### 6.4.2 Slope Stability Studies of the Selected SHP Sites

The stability of slopes is important considerations for siting different structures. Unstable slopes are to be ignored and sites which are away from slip zones, easily accessible site for personnel and transporting the construction materials should be given more weightage (AHEC-IITR, 2013).

In an attempt to reduce the project cost, the layouts of small hydropower projects lean more towards surface structures and, hence, major anticipated geotechnical problems during construction or post construction stages are related to slope instability along power channels, penstock alignments, back slopes of powerhouses, etc.

Identification of slope stability problems and associated hazards generally do not involve detailed, cost driven or time consuming investigations. The required stabilization measures also can be easily planned if detailed geological and geomorphological mapping of the project area is carried out on suitable scale (ESHA, 2004).

### 6.4.2.1 Rufael Small Hydro Power Site

Very old landslide or landslide prone areas were not observed at the trace of the channel, weir site and power house. Moreover, there is no landslide or slope failure occurred recently around the project area according to the information gathered from the people who are living around the area, transported boulders of rocks were observed close to the proposed weir site (Plate).

*(a) Shows bolder of rocks at the left bank of the proposed site of diversion weir of Rufael SHP and*
*(b) shows fine to boulder size transported material at the right bank of the proposed diversion weir site*

**Plate 6.5 Transported material at diversion weir site**

### 6.4.2.2 Weldia Small Hydro Power Site

Very old landslide or landslide prone areas were not observed along the headrace channel alignment, weir site and power house site. However, transported boulders were observed close to the proposed weir site. Moreover, there is no landslide or slope failure occurred recently around the project area according to the information gathered from the people who are living around the area. This fact was also verified during the walkover survey, as no field manifestations of instability were observed along any of the components of the proposed site.

#### 6.4.2.3 Lebu Small Hydro Power Site

Very old landslide or landslide prone areas were not observed at the weir site, water conductor, and power house. However, small failures were observed close to the diversion weir and along the water conductor on both bank of the river (Plate 6.6).However, there is no landslide occurred recently around the project area according to the information gathered from the people who are living around the area. Also, this fact was further verified during the walkover survey, as no field manifestations of instability were observed along any of the components of the proposed site.

*(a) and (b) show surface manifestation of rock fall at the river bank*

**Plate 6.6 Rock falls around proposed diversion weir site at Lebu small hydropower**

### 6.4.3 Hydrological Investigation

Acquiring reliable hydrological data for a reasonable length of time for assessing the pattern of stream flow at different times in representative years wet as well as dry, is the most essential requirement for a dependable formulation of hydro project. Besides the pattern of stream flows, other hydrologic inputs required for the design of project components are design flood, water quality and sediment transportation. The hydrological data cannot be acquired by just visiting the site and carrying out discharge measurements for a short while. It is necessary to acquire the long duration data (Nehimia Solomon, 2005; Ashenafi Gezahagn, 2007). However, personal interviews were conducted with the local people to qualitatively assess the flow variations in respective streams. The information provided by local respondents is in accordance to the long duration observed 10 daily discharge data procured from the Ministry of water, Irrigation and Energy, as presented in Chapter 5.

## 6.6 Selection of Turbine

The turbine is a mechanical device that converts hydraulic power in the water into mechanical power—known as shaft power and is usually placed in the powerhouse. This shaft power is converted into electricity by the generator; thus, the turbine determines the electricity capacity of the SHP installation. The most common types of turbines for SHP application are Francis, Kaplan, Pelton Wheel, Cross flow, and Centrifugal pumps operated in turbine mode (Kaunda et al, 2012).

Type of turbine is selected from techno-economic consideration of generating equipment, powerhouse cost and relative advantage of power generation. Most of the manufacturers have developed standardized turbine designs which may be efficiently employed. Standard design may lead to cheaper and quicker construction. There are different factors, which determine the type of turbine for the given site. The factors may be head, head and load variation, efficiency and specific speed (Nehimia Solomon, 2005).

In the present study the turbine type is selected by utilizing the standard chart, which utilizes the head and power generation in determining the turbine type (Indian Standard 12800, Part 3, 1991). Thus, the type of turbines as determined are presented in table 6.3and is shown through plot in Fig. 6.3.

**Table 6.3 Turbine selection for various SHP sites**

| ***Name of the Scheme*** | ***Design Discharge (cumec)*** | ***Net Head (m)*** | ***Power Potential (kW)*** | ***Installed Capacity (kW)*** | ***Type of Turbine*** |
|---|---|---|---|---|---|
| Rufael SHP Scheme | 0.46 | 45 | 173.45 | 3x50 | Pleton |
| Weldia SHP Scheme | 0.36 | 49.5 | 149.47 | 2x50 | Pleton |
| Lebu SHP Scheme | 0.41 | 60 | 206.33 | 2x100 | Pleton |

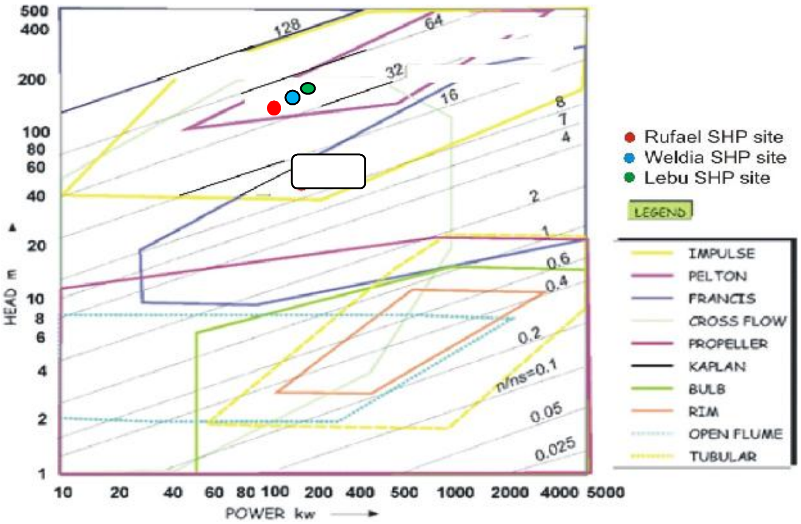

**Fig 6.3 Turbine Selection**

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# Chapter 7 Conclusion and Recommendation

## 7.1 Conclusion

The present study area is located in Ziway drainage basin, in the central part of the country. Meki and Kater drainage Sub-basins of Rift Valley Basin have been identified for the present study. These basins are partly in SNNP and in Oromia region. The main objective of the present study was to identify potential Small Hydropower sites in the study area and to carry out ground verification with engineering geological appraisal for the selected sites, at pre-feasibility level.

During the present study a total of 49 potential SHP sites have been identified. Out of these, 19 sites fall within Meki sub-basin and 30 in Kater sub-basin. Most of these identified sites are concentrated along the margin of the sub-basins. For none of these potential sites, gauged data was available at or near the proposed diversion sites. However, observed discharge data was available either, in the upstream or downstream locations on the same stream or in the adjoining catchments. Thus, for the potential sites the daily observed discharge data has been projected from adjacent gauged stations by percent area ratio method for those which demonstrate similar catchment characteristic.

Initial estimation of the power potential of 49 SHP sites has been computed for 75% dependable discharge and taking turbine efficiency to be 90% and efficiency of the generator as 95%. The head losses caused by the frictions and bends in the penstock have been taken equal to 10% of the gross hydraulic head. Thus, the total power potential, as estimated for 49 identified sites for which discharge data was available, comes out to be around 17MW.

Thus, these 49 potential SHP sites can be ground verified and be taken up for detailed Engineering Geological Appraisal. However, for the present study, with the limitation of resources, time and financial constraints it was not possible to undertake ground verification and detailed engineering geological appraisal of all 49 SHP sites. Therefore, a sincere effort has been made to cover 3 potential SHP site to undertake ground verification and detailed engineering geological appraisal, at pre-feasibility level. The selection of these 3 sites, as first priority, has been done based on certain minimum criteria. Thus finally, 3 identified small hydro power sites satisfies the criteria, these sites are, Rufael, Weldia and Lebu small hydropower sites. Thus, these three sites were ground verified for the availability of the head, discharge and the possible layout. Further, engineering geological appraisal of these sites has been carried out. For this geological mapping were carried out along the water conductor and the powerhouse site in the context of high lightening possible problems that could be caused from the earth materials present around each ground verified SHP sites.

Further, since all structures for SHP schemes are generally located on or at the slope, slope instability becomes the main engineering geological concern in the construction and performance of small hydro power plants. If the slopes are not stable the various structures may fail and entire scheme may become non-functional. Therefore, the slopes along the different components were studied for their stability conditions. Finally, based on the engineering geological appraisal at pre-feasibility study it may be concluded that the proposed slopes only demonstrates moderate level of geological hazards and no major landslide risk exists. In general, the elevation difference between the low land and the high land of the area is very high. Therefore, the river runs from higher elevation to lower elevation passing over different falls (forming beautiful landscape) and steep slope toward the lowland creating head for power generation.

The research indicates that there are 49 small hydropower potential sites in the study area. However, additional possibilities of generating electricity at the level of Ultra, Micro, Mini and Small Hydropower also exist in the study area. Therefore, the present study may serve as a guide to develop and extend similar type of hydrologic study for other regions in the country, which will help in the speedy development of small hydropower sector.

## 7.2 Recommendation

Based on the result of the present study and the problems faced during the present investigations, following systematic recommendations are made;

During the present study, for initial estimate of the power potential the observed discharge data from nearby locations have been projected at the proposed sites to work out the dependable flows. However, it is strongly recommended to observe the actual discharge, at least covering two lean seasons, before finalizing these sites for development.

There is a need to develop a regional flow duration curve/ model for different areas which may be utilized for the estimation of dependable flows of un-gauged streams, to be utilized for the small hydropower investigations at pre-feasibility level.

For the present study the Engineering Geological appraisal carried out for small hydropower sites was an effort made under the limitations of resources, time and financial constraints, therefore the results/ findings should be considered as indicative only. Before the final development of SHP sites it is strongly recommended to conduct detailed Engineering Geological appraisal with actual laboratory testing of rock and soil material.

On an appraisal of the analysis of data collected in the field and conclusion made based on the field observations, the proposed sites showed moderate level of geological hazards and no major landslide risk exists. Further, studies are recommended to assess the slope stability conditions, particularly in those areas where slopes showed manifestations of such hazards.

The topogrhapic survey and the general layout have been prepared on the available topo map at 1: 50,000 scale. Therefore, it is recommended to carry out the detailed topographical survey of the water conductor and powerhouse site on 1: 500 or 200 scales to work out the actual design of various components.

Further study it is recommended; to ground verify the remaining potential SHP sites identified during the present study and to undertake similar studies in the other parts of the country.

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