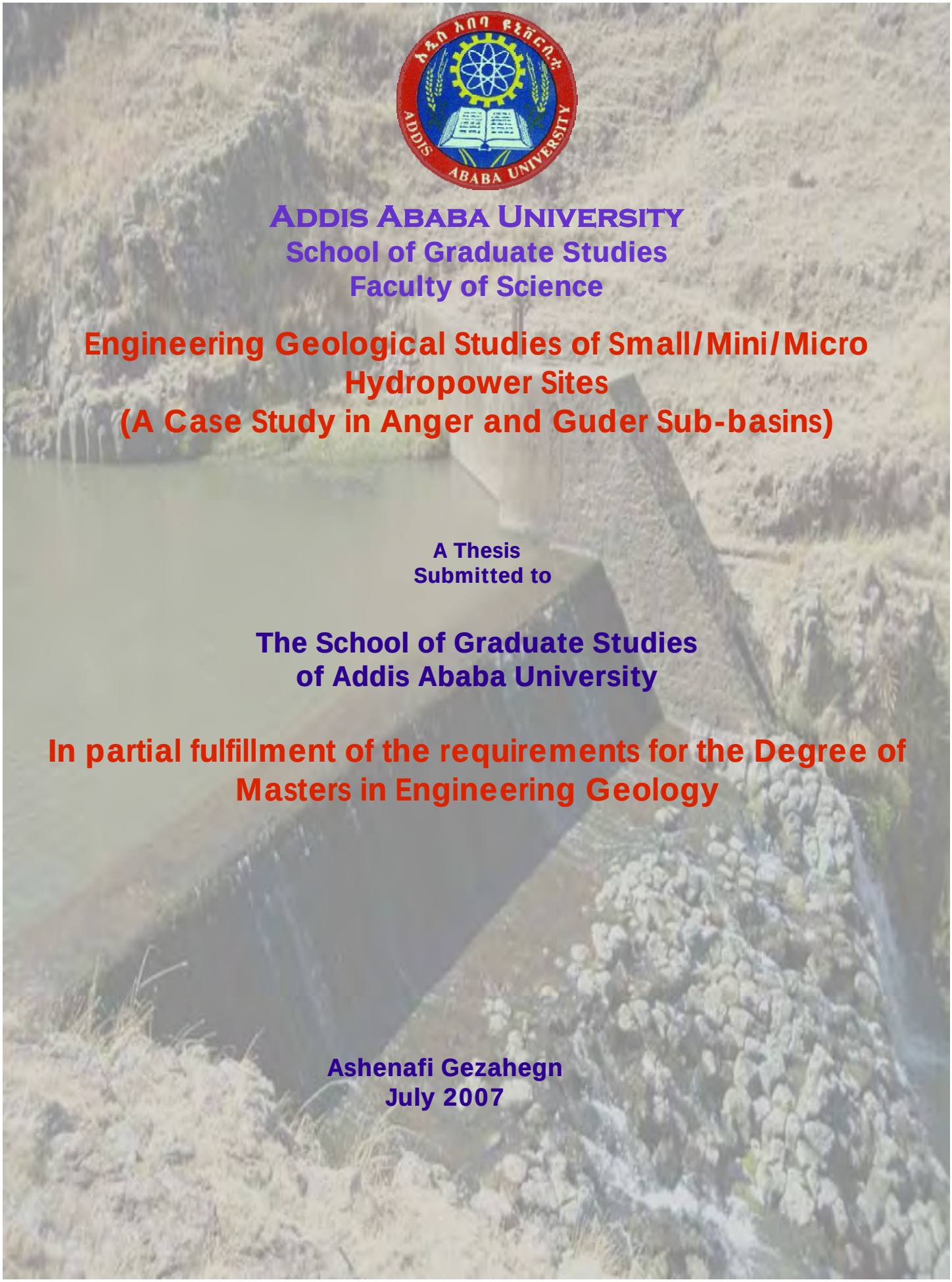


ADDIS ABABA UNIVERSITY
School of Graduate Studies
Faculty of Science

Engineering Geological Studies of Small/Mini/Micro Hydropower Sites (A Case Study in Anger and Guder Sub-basins)

A Thesis
Submitted to

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Ashenafi Gezahegn

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List of Acronyms

AHEC	Alternate Hydro Energy Centre
ASTM	American Society for Testing Materials
EELPA	Ethiopian Electric Light and Power Authority(former name of EEPCO)
EMA	Ethiopian Mapping Authority
ERED	Ethiopian Rural Energy Development and Expansion Centre
ESHA	European Small Hydropower Association
FAO	Food and Agriculture Organization for United Nations
GPS	Global Positioning System
GSI	Geologic Strength Index
GTZ	Deutche Gesellschaft fur Technische Zusammenarbeit (German Technical Cooperation)
IBC	Institute of Biodiversity Conservation
ICS	Inter Connected Systems
LUPARD	Land Use Planning and Regulatory Department
MHPG	Micro-Hydropower Group
MME	Ministry of Mines and Energy
NMSA	National Meteorological Service Agency
NRECA	National Electric Cooperative Association
RE	Rural Electrification
RMR	Rock Mass Rating
ROR	Runoff the River
RQD	Rock Quality Designation
SCS	Self Contained Systems
SHP	Small Hydro Power
SMR	Slope Mass Rating
SRTM	Shuttle Radar Topography Mission
TIN	Triangular Irregular Network
UCS	Unconfined Compressive Strength
UNDP	United Nations Development Program
USCS	Unified Soil Classification System
USD	United States Dollar
UTM	Universal Transverse Mercator
WBISPP	Woody Biomass Inventory and Strategic Planning Project

Abstract

Ethiopia is endowed with huge amount of renewable energy resources such as small-hydro that is identified to be suitable for rural electrification. This study takes the case of potential small hydropower assessment in Anger and Guder sub-basins of Abbay Basin. The study indicates that there are many small hydropower potential sites in the study area. Various researchers identified potential small hydropower sites in the different regions of the country. Unfortunately, random selection of sites as considered by other researchers may end up identifying a site which will not give reliable amount of discharge for power generation through out the year. In this study, a new attempt is tried to produce initial site identification criteria by considering various parameters which will affect the power out put of a site. The initial identification criteria set up specifically suitable for the study area is found to be a minimum of 110 km^2 catchment area and 80 m head. A total of 18 potential sites are identified in the present study by considering this criterion with a total power potential of 19564 kw. In addition an attempt is also made to develop regionalized flow-duration curves for prediction of discharge at ungauged streams. To do this, methods have been involved in developing a set of parametric flow-duration curves based on flow values at gauged points. This data set includes the correlation of drainage area versus average annual run off for all gauges in the region and values of Q for a particular exceedance values. This method allows prediction of only certain exceedance values of discharge for potential sites.

For the present study, engineering geological mapping was carried out along the different components of the sites in the context of high lightening possible problems that could be caused from the earth materials present around each ground verified SHP sites. In an effort to

incorporate these factors, the strength and weathering characteristics of rocks, swelling potential of soils and the stability conditions of rock and soil slopes exposed along the different components of the SHP schemes were evaluated by utilizing various empirical and index properties of soils. Therefore, further research is recommended for the assessment small hydropower sites which consider a combination of more elaborate hydrologic and geotechnical aspects.

CHAPTER ONE INTRODUCTION

1.1 General

Historically, energy has been the pivot of economic development of most of the countries all over the world and this trend persists. It has brought great economic prosperity to nations and has been the centre for social and over all human development. Unfortunately, due to the way energy is sourced, produced and used a major draw back have evolved, major local and global environment and social problems have been associated with the energy system. The combustion, transport and disposal of energy sources as they go through the different conversion processes result in adverse emissions leading to local, regional and global environmental problems.

Energy production and use have been growing through out human history, and all signs indicate that they will continue to do so. However, this growth has gone through some great transitions that were largely dependent on needs and source availability. The oil crises of the 1970 also deeply affected the energy system as it led to re-examination of two major aspects: the need to improve the efficiency of energy production and its use become clear, and the search for alternative to non-renewable source of energy like fossils fuel become a major concern globally. As a result energy efficiency and renewable energy as substitutes for fossil fuels become prominent energy debate leading to the concept of sustainable energy. Sustainable energy can be defined as energy providing affordable, accessible and reliable energy services that meet economic, social and environmental needs with in the over all development context of the society for which the services are intended while recognizing equitable distribution meeting those needs (Davidson 2002).

In present times, small hydro is one of the most valuable answers to the question, how to offer isolated rural communities the benefits of electrification and the progress associated with it, as well as to improve the quality of life. The hydro electric power plant utilizes a natural or artificial

fall of a river. The hydraulic conveyance circuit can be integrated in other components for multiple purposes (e.g. irrigation or water supply systems). This has been considered as one of the most important renewable energy sources.

At present, the economic utilization of renewable energy is based on new techniques and on environmental protection techniques, low-cost and reliable form of energy is in the fore front of many developing countries to achieve energy self sufficiency, which is equally true for Ethiopia also. It represents an important environmental benefit to aid sustainable development due to non-emission of carbon dioxide that contributes to ozone depletion and global warming. Summing up, the small hydropower schemes have an important role to play in the economic development of remote rural areas and can fill the gap of decentralized production, for private or municipal activity production, for sale to national electric grid or for supply industries rural or isolated zones, improving their development, especially the mountainous terrains like in Ethiopia, where this energy (perineal streams) is available abundantly.

1.2 Problem Statement

The livelihood of 85% of the Ethiopian population is dependent on natural resources (particularly non-renewable natural resources). For instance 85% of the total energy is estimated to be derived from biomass (fuel wood and tree residue 70%, dung 8%, agricultural residue 9%). In recent times due to this, the non renewable and exhaustible sources of energy are getting depleted at a very fast rate, (forests, wood lands and generally biomass) is shrinking rapidly, so much so, that out of which now remaining 2.4 % of high forests (IBC & GTZ, 2004), which has focused attention to the non-exhaustible and renewable sources of energy.

Hydropower is one of the most common renewable sources of energy and abundantly available in the hilly region. However, large hydro power plants are not being taken up for execution in sufficient number as these involve huge funds and also the planning and construction period is very long.

Therefore, with the increasing demand for power, the activities on small hydropower projects have accelerated in the recent times all over the world. The small hydro-power schemes are the appropriate solution to power demand as these require small amount of capital investment and can be completed in a very short period of time. Small hydropower offers a wide range of benefits especially for rural areas, particularly in developing countries like Ethiopia. This resource is environmentally responsible and has substantial economic advantages.

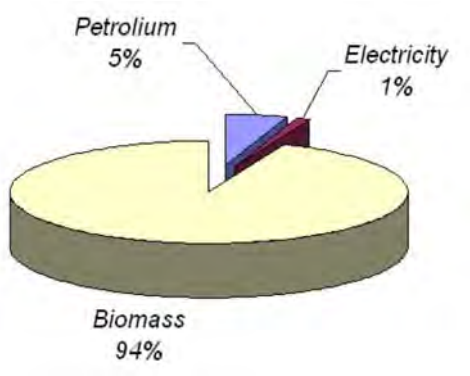


Fig. 1.1 Sources of energy supply Ethiopia (in Trudy 2002)

1.3 General Lay Out of Small Hydro Power Scheme

The basic principle of hydropower is that if water can be piped from a certain level to a lower level, then the resulting water pressure can be used to generate power. If the water pressure is allowed to move a mechanical component then that movement involves the conservation of the potential energy of the water in to mechanical energy. Hydro turbines convert water pressure in to mechanical shaft power, which can be used to drive an electricity generator. A typical small hydropower system, shown in Fig. 1.2, incorporates five major components, the civil work, the water turbine, AC or DC generator, electrical and mechanical control system and transmission system. The civil works consists of desilting tank (to allow sedimentation of stones and silt to avoid turbine damage), headrace channel, diversion weir (to divert part of river or stream), penstock (to guide the water from the forebay tank directly to the turbine) and, the power house (containing the turbine, shaft drive system, electric generator, and control unit).

1.4 Classifications

Based on installed capacity, many countries have their own classification system for small hydropower schemes. These are classified as micro-hydro

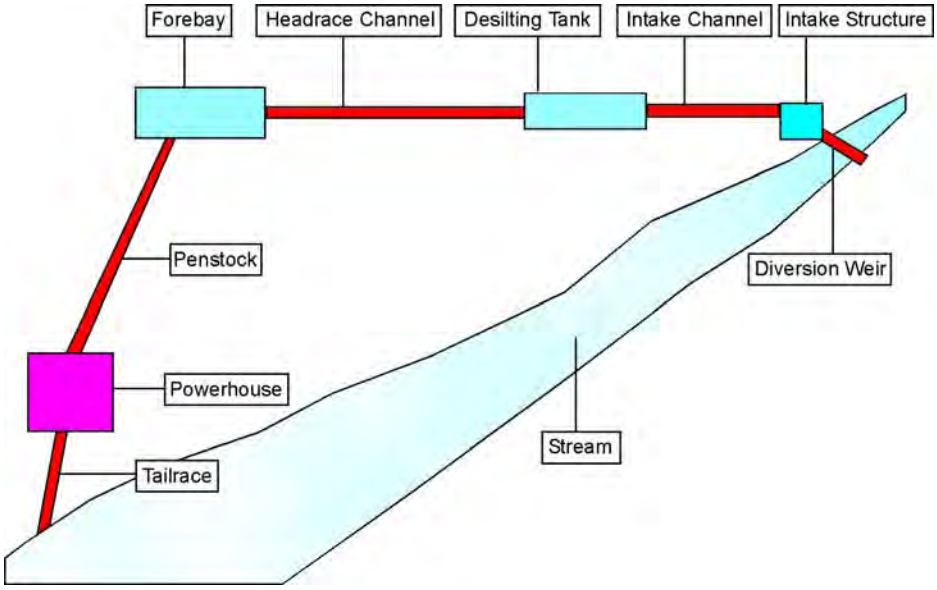


Fig. 1.2 A typical small hydropower system

(less than 0.3 MW), mini-hydro (0.3-1MW) and, small hydro (1-10 MW) installed capacity levels (AAU, Faculty of Technology, 2001).

In addition, the scheme of small hydropower can be classified according to,

(i) General layout
(ii) Mode of discharge regulation
(iii) Mode of head concentration

According to its general layout small hydropower scheme can be classified as

(i) Runoff the river small hydropower
(ii) Canal fall small hydropower (Fig.1.3)
(iii) Dam toe small hydropower

According to the mode of head concentration, the schemes can be classified as

(i) Dam scheme (ii) Diversion scheme (iii) Mixed scheme

In dam scheme, the head is mainly concentrated by the dam which raises the upstream water level where as, in diversion scheme the requirement is

fulfilled by the water diversion structure. The mixed scheme uses both dam and diversion structures.

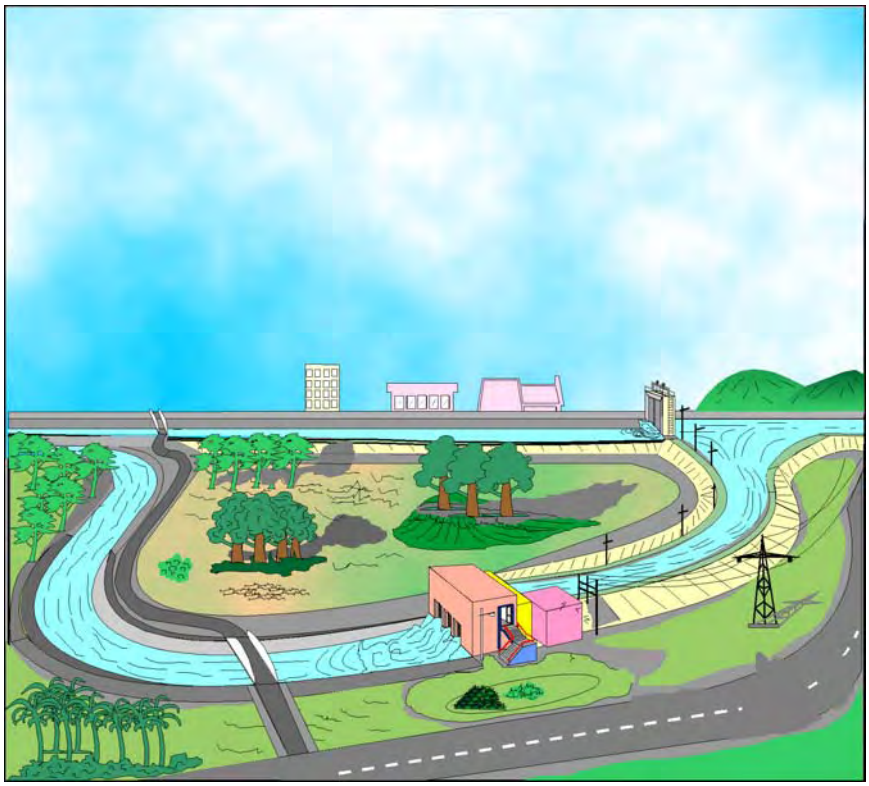


Fig. 1.3 Canal fall small hydro power scheme (AHEC, 2003)

According to the mode of discharge regulation, the schemes can be classified as:

(i) Runoff the river scheme (ii) Daily regulation schemes and
(ii) Seasonal regulation schemes

In runoff the river scheme, power as generated by natural runoff with out no regulation. Firm power is graduated by a natural base flow with high reliability.

Many hydropower plants belong to this scheme due to low costs. However, in the daily regulation scheme, power is generated by the natural daily flow but with daily regulating pond operating in accordance with the fluctuation of the daily load that is, storing water at off-peak hours and discharging it from the pond during peak hours. In the seasonal regulation scheme, a

reservoir is built at the intake of the power station to store water in the rainy season and discharging it in the dry season, thus enhancing the firm power out put the whole year around. Most of these kinds of plants use dam scheme and mixed scheme to concentrate the water (AHEC, 2003).

1.5 Objectives

The over all objective of this study is:

(i) Identification of potential small hydropower sites in the study area.
(ii) To estimate power potential for small hydro project sites.
(iii) Engineering geological appraisal of the identified small hydropower project sites (for selected sites)

To fulfill the research, the following specific objectives are:

(i) Development of regionalized 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 ungauged rivers.
(ii) Development of initial identification criteria for potential small hydropower sites possibly suitable in the study area.
(iii) To work out general layout of the proposed scheme selection of diversion weir and intake site, power house site fore bay site, penstock alignment and power house site.
(iv) Ground verification of general layout and to carry out the geotechnical studies of the diversion site. Power channel, fore bay site, penstock alignment and the power house site
(v) Compare the selected (ground verified) site from, suitability point of view in the context of geotechnical stability along the various components of the small hydropower scheme and to propose suitable recommendations.
(vi) Suggest possible future sustainable utilization of the power.

1.6 Research Methods

This part deals with supporting materials and analytical tools which describes an overall methodology applied to carry out this research and will be compiled as follows:

(i) Review of literatures from different sources both published and un published reports which will be used to get some priority information about the study area and techniques that have been used in related researches.
(ii) Preparation of working map at scale of 1:50,000.
(iii) Daily discharge data processing of gauged streams.
(iv) Delineation of different catchments areas corresponding to the different diversion weir, fore bay and power house site for power potential calculation at varying hydraulic heads and discharge to decide the minimum head and catchments area requirements to be used in the criteria in identification of small hydropower sites.
(v) Identification of potential SHP sites in the study area through topographical maps and SRTM satellite image layer using the developed criteria.
(vi) Ground verification of potential SHP sites from the study area and finalization of general layout projects.
(vii) Collection of data on geology topography and hydrology of the area in the field. In situ tests such as unconfined compressive strength (UCS) using Schmidt hammer on rock materials, litho logical description sampling of rock and soil.
(viii) Laboratory analysis of earth materials which are collected from field for classification
(ix) Slope stability studies along the water conductor system of SHP sites for present and possible worst conditions.
(x) The hydrological, metrological, topographical, geological and geotechnical data will be interpreted in accordance with field observation, literature review and laboratory result to reach at conclusions and to suggest possible recommendations.

(xi) Counter checking of conclusions and validation of results.

1.7 Analytical Tools and Supporting Materials

For present study various analytical tools will be utilized to fulfill the research objectives

(i) Topo sheets (scale of 1:50,000) and satellite image have been used to identify SHP potential sites in the study area. The topo sheets have also been used for the delineation of potential SHP sites.
(ii) Geological map clipped from the Abbay River basin master plan project 1999, have been used to extract the geology of the study area.
(iii) Rating schemes and empirical methods has been utilized to work out the quality and strength characteristics of the rock mass. Bieniawskis Rock mass rating system and Hoek and Brown failure criteria has been used for this purpose.
(iv) Limit equilibrium method has been used to work out the stability conditions of the rock and soil slopes. For these purpose analytical techniques of Hoek and Bray has been utilized besides, computer soft ware for slope stability studies have also been used.

1.8 Importance of the Study

As discussed in section 1.2, majority of population in Ethiopia is dependent on traditional resources to fulfill the energy needs of their subsistence style of life because of poor energy supply situation for scattered rural community. As a result, these people not only have to put up with an unattractive living environment because of lack of electricity, but also have to suffer the consequences of climatic changes caused by the associated environmental impacts. As per the objective of the present study, the research indicates that there are many small hydropower potential sites in the study area and that selection of reasonable sites can be under taken with the development of initial site identification criteria. The study shows that there is a possibility of generating electricity at a level of Micro, Mini and Small Hydropower in the study area. Therefore, the generation of the electric power from the selected potential sites may contribute to meet out a

part of power needs within the study area, particularly for those areas, which are remotely located and can not be easily connected to the grid.

1.9 Scope and Limitations of the Study

Though the study area covers the two sub-basins of Abbay River (Anger and Guder sub basins), its scope is limited to certain accessible and near sites to Addis Ababa 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.

*****

CHAPTER TWO LITERATURE REVIEW

2.1 General

In order to provide a conceptual frame work of the problem of equitable distribution of energy in Ethiopia a systematic literature review has been carried out. An attempt was made to understand, the power scenario and current energy problem in Ethiopia and what are the findings, by previous researchers. Thus, literature review relevant to the present study is presented in the following paragraphs.

Table2.1 Small/Mini/Micro Hydropower Plants Operated by EELPA

No.	Hydropower plant	Head(m)	Type	Installed capacity(kw)	Status
1	Walga	16	ROR	148	Not operational
2	Huluka	40	ROR	140	Not operational
3	Setesemoro	30	ROR	140	Not operational
4	Gelanomite	42	ROR	184	Not operational
5	Dabena	14	ROR	116	0perational
6	Debre Birhan	55	ROR	100	Not operational
7	Debre Markos	42	ROR	185	Not operational
8	Jilbo	14	ROR	420	Not operational
9	Abasamuel	-	ROR	-	Not operational
10	Sor	120	ROR	5000	0perational
11	Yadot	23	ROR	500	0perational
12	Dembi	184	ROR	710	0perational

Source: Ministry of Mines and Energy, 1994, ROR: run-of-the-river

2.2 History of Small Hydro Power (SHP) in Ethiopia

The first SHP site was identified, as early as in 1950 by an Italian soldier near Debre Birhan town at Beresa stream (Plate 1.1). According to the previous studies (EESRC and CESEN-ANSALDO, 1986) this power station was generating a power of about 100kw by utilizing a head of 50m. This power station is functional till 1977 and the operation was then stopped as the town of Debre Birhan was connected to the national grid. Presently, the country has 12 SHP schemes namely, Walga, Huluka, Setesemoro Gelanomite, Dabena, Debre Markos, Jilbo, Abasamuel, Yadot, Sor and Dembi SHP sites. These self-contained systems have a total installed capacity of 6.15 mw. The capacities and present status of these plants is given in Table 1.1.



Plate 2.1 Beresa Small Hydropower Scheme

The reasons for the suspension of operation of most of the plants cited in Table 1.1 are;

(i) Lack of spare parts for the older plants (with the original suppliers of equipment, all foreign, often having changed addresses or not manufacturing the required parts).

(ii) Lack of design details and references to be used in ordering the replacement parts.

(iii) Shortages of water for running the plants, which are all run-of-the river types, especially during dry season when neighboring farmers, compete for irrigating their farms.

(iv) The demand centers served by small hydro plants are now fed from the grid, thereby making parallel operation of the small hydro plants uneconomical.

Number of studies has been made over the years for the small hydro-energy resources base of the country by consultants from country and abroad, but mostly foreign-based consultants like, UNDP/EELPA, Italian consultant CENEN/EESRC, and Chinese experts. Various clients initiated the studies at different times with different objectives. Ministry of Mines and Energy, Water resources development Commission and Ethiopian electric power corporation (EEPCO) is some of those clients who initiated such studies. However, in general, there are a lot of feasibility studies which are not transformed in to implementation due to several reasons –high cost of implementation and lack of finance, since all these studies assume that

micro hydropower equipment are to be imported and foreign experts involve in the implementation of the projects, their cost is very high.

2.3 Power Scenario in Ethiopia

According to the Italian consultants (SESEN 1986), the hydro potential of Ethiopia basins is discussed with reference to three basic types of utilization;

(i) Installations with flow regulations
(ii) Small slope installations with out flow regulation
(iii) River plain plants

The potential water basins in Ethiopia are shown in Fig. 2.1. The gross hydro potential of the whole Ethiopia territory is of the order of 650 TWh/year. Between one third and one half of this potential is contributed by the Blue Nile basin (280 TWh/year). The Blue Nile and Omo basins together contribute around 400 TWh/year to the gross potential. Sizable quantities of hydro energy are also available in the Baro, the Abaya-Chamo, Genale, the Wabe -Shebele, and Awash basins.

Only some areas along the Tekeze water source may be considered to be present technically feasible sites but it seems unlikely that the power produced would always be competitive with oil based generation. There appears to be no practical hydro energy potential in any of the other northern basins, the Danakil depression, the Costal or the Ogaden basins. More than three quarters of the hydro potential is available from mountain rivers with flow regulation. Almost half of this is available from the Blue Nile followed by the Omo and the Baro.

The Awash basin and the Wabe Shebele basins hold only a small fraction (barely more than 5%) of the countries large potential that could be exploited from installations a with flow regulation.

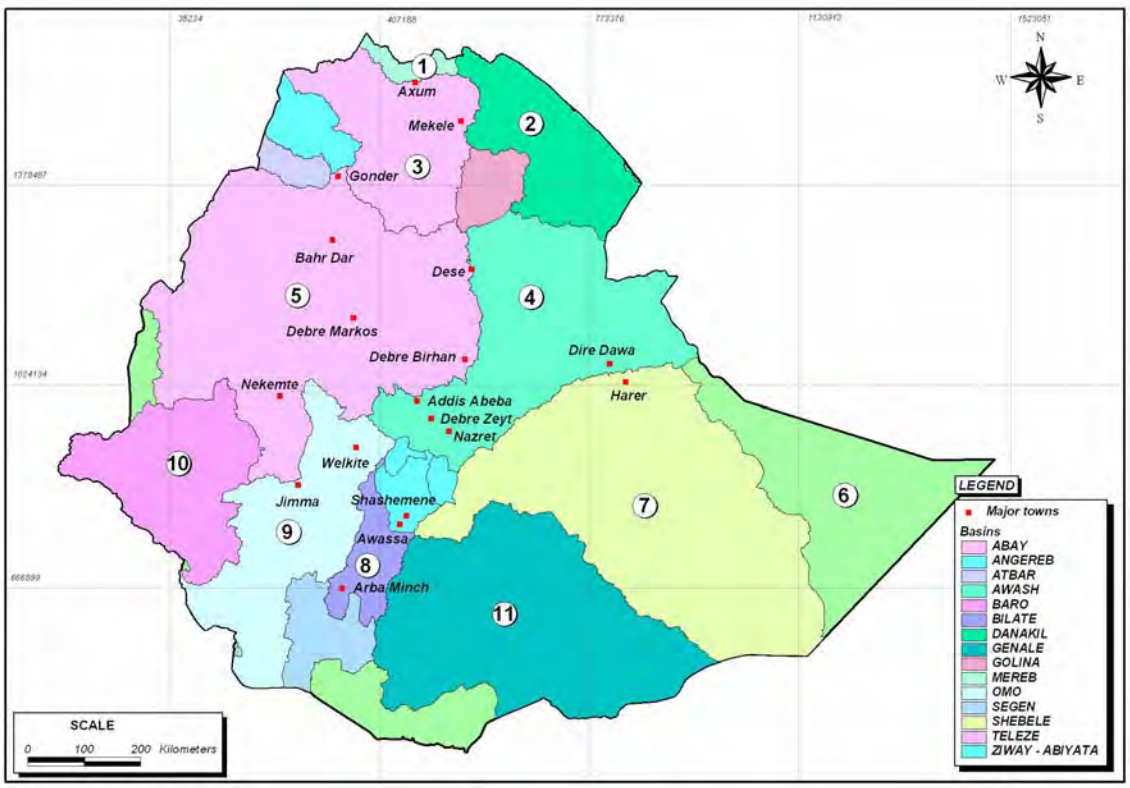


Fig. 2.1 The Water Basins of Ethiopia *[1: Mereb, 2: Danakil, 3: Tekeze, 4: Awash,* 5:Abbay, 6: Ogaden, 7:Wabe Shebele, 8:Abaya-Chamo, 9: Omo, 10:Baro-Akobo, 11:Genale-Dawa] (Figure source: Ethio GIS)

A sizeable quantity of hydro energy is also available from river plain. Gross stream potential from main water bodies of valley water-course is of the order 130 TWh/year. The Blue Nile, the Omo and the Baro rivers together contribute over 70% of the gross hydro energy available from river plain installations.

2.4 Current Energy Problem in Ethiopia

Backward Infrastructure

The generally backward infrastructural development in rural areas in Ethiopia radically limits the pace of economic growth. The rural communities are found widely scattered and did not benefit from financial allocation for development. This situation results in unequal growth rate between towns and rural communities, this has a negative impact on the over all economy of the nation since the rural communities are the basis for

agricultural development which is the back bone of the economy of the nation. In this regard due attention should be given to sustainable rural development endeavors. Out of many infrastructural rural facilities that the small communities lack is the absence of appropriate form of energy. Lack of energy has a detrimental effect on the growth of the nation since energy is the driving engine of economic development. In line with this, one of the primary objectives of the energy policy of the government of Ethiopia has been to ensure a reliable supply of energy at the right time and at an affordable price, particularly to support the agricultural development led industrialization strategy (MME 1994). Even though the objective was well tailored to the immediate need of the rural communities, its implementation lagged too much behind expectations.

The Heavy Task on Electric Supply Utilities

The Ethiopian Electric Power Corporation (EEPCO) is the government utility in Ethiopia that monopolized until recently, the electric energy generation and distribution in the country. This utility is supportive of mini hydro power for rural electrification, but concentrates highly on larger schemes, MHPG 1997. Because of its restricted budget, it adopts the criteria of cost effectiveness in its decision making to interconnect any town to the national grid. This criterion favors only big load –centers which have the necessary economic level to pay for electric supply. As a result, EEPCO has neither rural electrification (RE) department, nor has it ever assigned priority to the implementation of RE programmes (Hailu et al. 1992). It will be still concentrating on big project and on grid extension in the coming few years (Wolde .G 2000, cited in Zelalem). Thus, learning the mandate of rural electrification to EEPCO is equivalent to obscuring the effort of rural electrification under the equality over whelming task of grid-extension with which it is currently busy. The ministry of mines gives relatively better attention to rural energy supply in the country. In this regarded, the Ethiopian Rural Energy Development and Expansion Centre (ERED) has been formed under the ministry with an aim to focus on rural energy development. However, the scope of the ERED has not been expanded to a

level where the country wide RE could be made possible in the foreseeable future. This is especially so because ERED has focused on other energy sources and not yet on small hydropower development. Therefore, the current level of activity by ERED is not adequate to bring significant RE development in the country. Thus, under the prevailing energy shortage problems EEPCO appears to be unable to focus on the energy problems of rural communities.

Possibility for Private Sector Involvement in the Energy Supply

Studies made on the potentially and vitality of appropriate energy supply to rural communities have exposed the ill-effects of the trend followed by EEPCO in its mode of energy supply (Hailu and Tebike 1988). As a result, decisions have been made to slacks the monopoly of energy supply by EEPCO by permitting the participation of private energy development. The government of Ethiopia passed the law to allow private power plants developers. As a result, it is expected that there will be a significant number of independent power producers in the coming decades (Getahun 2000, cited in Zelalem).

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CHAPTER THREE THE STUDY AREA

3.1 Introduction

The present research concentrates on the portion of the Abbay drainage basin, in the central part of the country. Anger and Guder drainage sub-basins of Abbay which fall with in Oromia Regional State have been identified for the present study, the intermediate sub-basin, Fincha is excluded from the study due to the unavailability of river discharge data of which most of the gauging stations were submerged due to the construction of Fincha reservoir for hydroelectric power generation purpose. The study area covers about 42,9664Km^2. There are 3 zones 21 weredas, 65 towns in these sub-basins. The total population in these sub basins contributes to 2.8 million, which includes both urban and rural population.

3.2 Location and Access

The Guder and Anger sub-basins are located in the central part of Ethiopia with the latter one slightly located to the west. The Guder sub-basin is bounded on the east by Mugher water shade, on the south by the Awash drainage area, on the west the Fincha river sub-basin and on the north by the Blue Nile River, while smaller portions of south eastern part of Anger and Guder sub-basins in adjacent to the Omo water basin.

The Anger and Guder sub-basins are identified by their corner coordinates of (9^0 00'N, 37^0 15'E), (10^0 00' N, 36^{0}03'E] and [(8^0 70'N, 38^0 20'E), (9^0 85'N 37^0 30'E)], respectively. Fig 3.1 shows the location of the study area.

The study area is just west of Addis Ababa following the main road from Addis-Ambo-Nekemte. The access to these sub-basins is possible through all weather road (asphalt) and all weather gravel road with the nearest Guder sub-basin (from Addis Ababa) located around 125 km on asphalt road and the farthest sub-basin Anger being around at around 285 km away from Addis Ababa on road Addis to Nekemete.

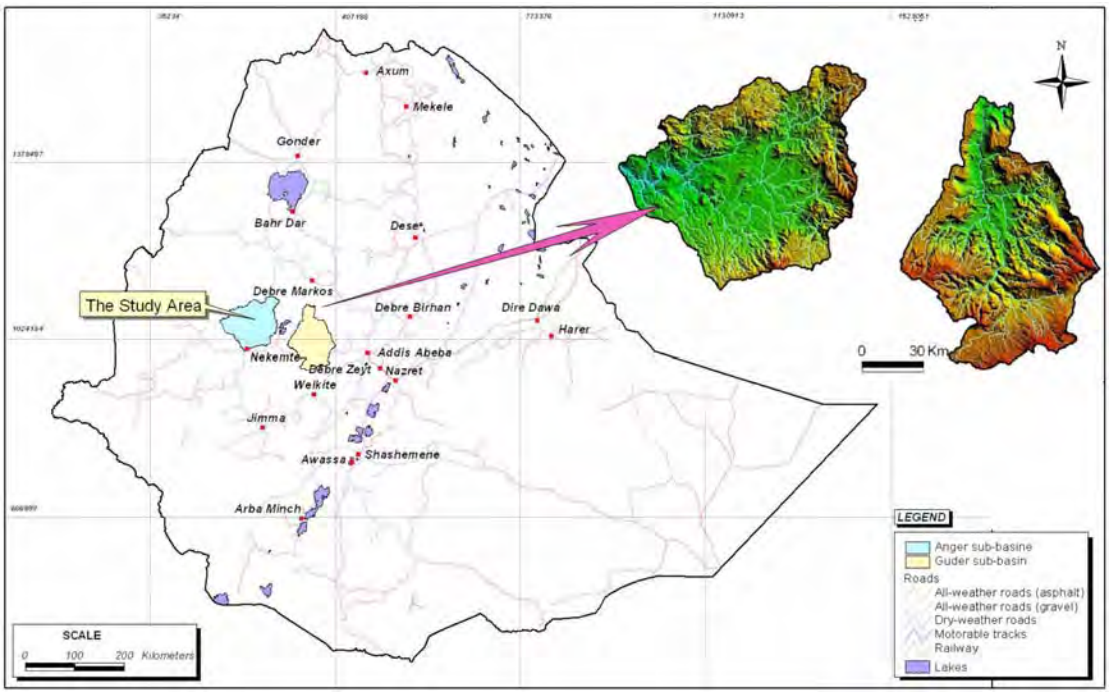


Fig. 3.1 Location Map of the study area

3.3 Climate and Drainage Characterstics

The climate in Abbay River Basin is dominated by two main factors. The near equatorial location, between latitudes 7^0 45' N and 12^0 45' N and the altitude, from 500m to more than 4,200 m above sea level. The influence of these factors determine a rich variety of local climates, ranging from hot along the Sudan border to temperate on high plateau or even cold on the mountain peaks. In accordance with the use of NMSA, a classification of climates in the Abbay river basin according to the modified KÖpen system (Trewartha, 1954, Lemma, 1985) shows the climates in Guder and Anger sub-basin are of mainly two types. More than 80% of the sub-basins fall in warm temperature climate I noted as CWb: with dry months in winters, mean temperature of the coldest months below 18^0c , more than 4 months with average temperature above 10^0c and relation between mean annual rainfall Rf and mean annual temperature t: Rf>20(t+14). This type is prevailing in the high land plateau throughout the basin. Where as the remaining part of the sub-basins is tropical climate II, noted as Aw: with dry months in winter, mean temperature of the coldest month above 18^0 and a mean annual rainfall between 680 and 1200 mm. This type is prevailing in

the north -west, the west and along the deep valleys. Most of the sub-basins run-off starts at the high land areas and travels downstream to the out let of the catchment. For Guder sub-basins the catchment's longest flow path is 109 km, while for Anger sub-basin it is around 140 km.

According to the result of Abbay River Basin Master Plan Project,1999, the mean annual runoff for Guder sub-basin is 15 liters/sec/km^2 for 85% of the catchment's area, with the remaining (15% of the catchments area)up stream area it becomes 20 liters/sec/km^2. While for Anger sub-basin, the mean annual runoff is 15 liter/sec/km^2 for the entire sub-basin. This new map of annual runoff was established unlike the previous runoff maps (particularly the one elaborated by WAPCOS) is not based on climatological or metrological consideration only, but chiefly on the results of hydrometrical studies with large catchments as well as in small ones have been taken in to account.

3.4 Topography

Perusal of Fig. 3.2 indicates that Anger river drains a large area north of Nekemte and flows from the high plateau area through sharp steep canyons in to low, wide, flat basin which has been eroded through the "plateau," Volcanics and Triassic sandstone and in to the basement crystalline rocks. The main flood plain in Anger sub-basin is about, 1300 m.a.s.l. and bounded by a range of hilly uplands ranging from 2500 to 3000 m.a.s.l.

However, in the Guder river area, the tributary streams which join to make up the upper Guder river flow off the northern slopes of high volcanic crater mountains about an elevation of 3000 m.a.s.l (Mt. Boti and Mt. Vonci).These tributary streams, again flow in a narrow V shaped gorge ranging about an elevation of1250 m.a.s.l off the eastern slope of the high volcanic mountain identified as Mt. Great Jibata. The topography is more dissected in most of the catchment area, as shown in Fig. 3.2.

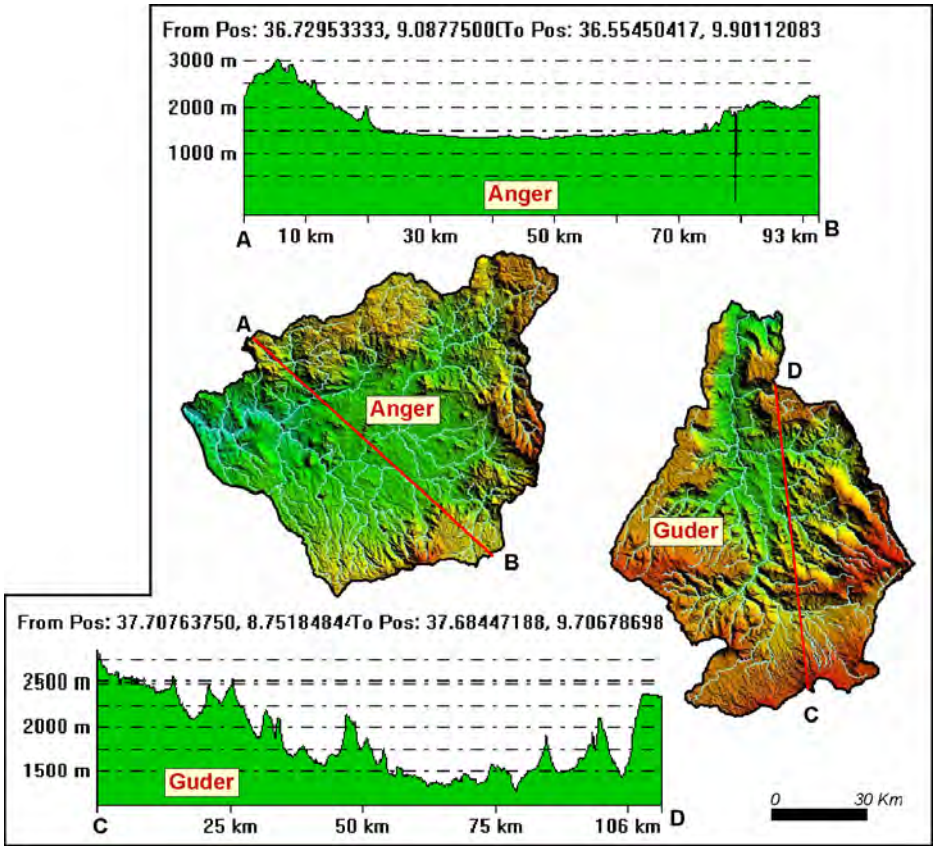


Fig. 3.2 Topography of the study area

3.5 Land Use and Land Cover

These two terms often used interchangeably, but the distinction between land use and land cover is important. Land use refers to the actual economic activity for which the land is used. Land cover refers to the covers of the earth surface with out reference to how that covers is used (BCEOM French engineering consultants, 1999)

The main economic activity in the two areas is agriculture (Fig.3.3). Though, the direct relation ship between land cover and land use may not always be true, the land cover map is mostly reclassified to land use map. A land cover classification of Abbay basin was prepared, essentially from LUPRD and WBISPP legends (Annexure I) and subsequently modified based on the field experience of BCEOM French engineering consultants in association with ISL and BRGM. Due to the specific characteristics of agriculture in the areas, many areas have multiple uses, both with in any
period of time and at different seasons of the year.

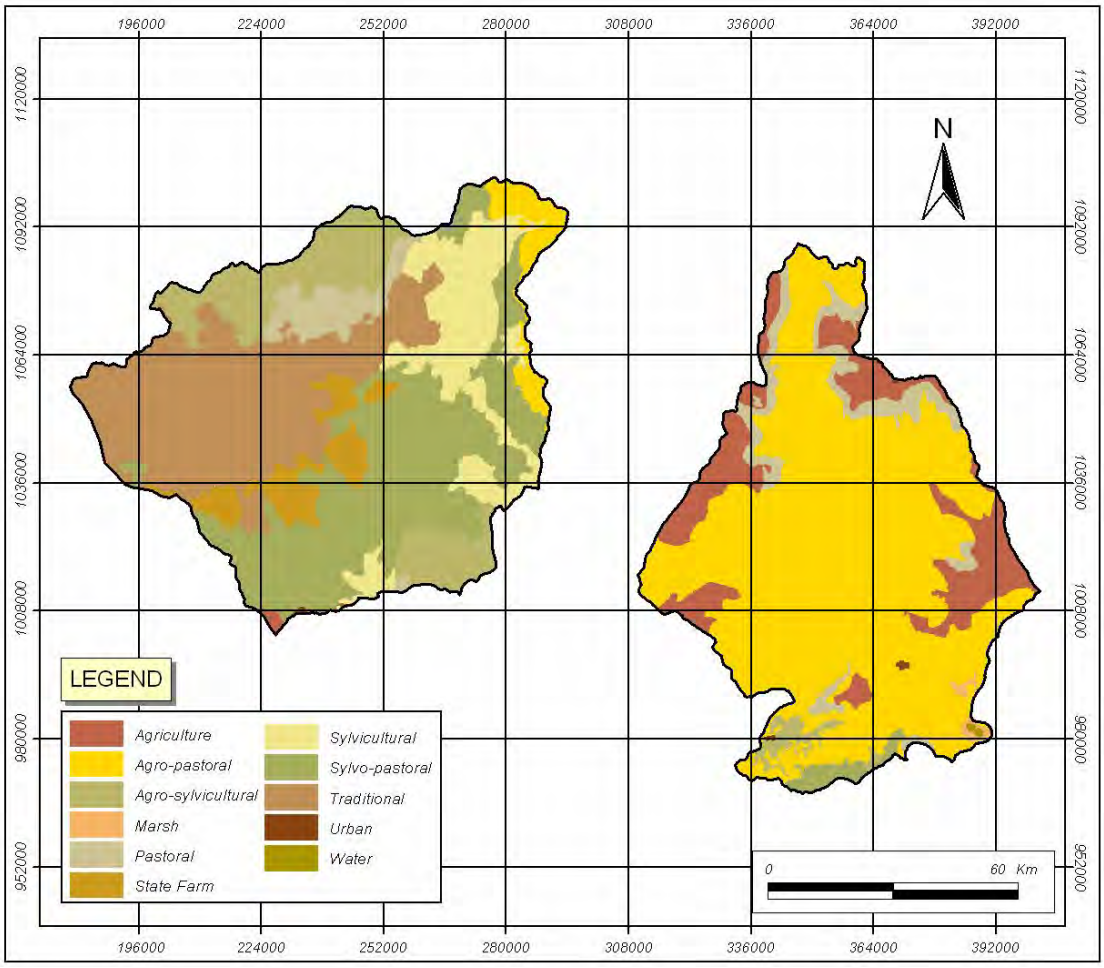


Fig.3.3 Landuse map of the study area

In Guder sub-basin most of the area is dominated by Agro-Pastoral-AP land use which is reclassified from moderately cultivated land-C2. In AP land use, only part of the area is cultivated, grazing activities are at least as important as cultivation. These areas are normally associated with various types and degrees of limitation on cultivation such as land cover properties of combination of shallow soil and slope, high population densities and climatic constraints, followed by agricultural-A use areas identified as "dominantly cultivated" on the land cover map. Although animals play an important role in these areas, they are considered as secondary to cultivation. The key economic activity in these areas is cultivation especially for grains and these areas include some of the major surplus producing regions of the country.

In Anger sub-basin most of the area's land use is equally dominated by sylvo-pastorials-Sp and traditional -T which are reclassified from open wood land -WO and wood land dense-WD respectively. In sylvo-pastoral- SP the areas provide both grazing and wood resources. There are in adequate knowledge of the economic importance of the woody species in these farming systems. And the traditional land use-T, there is not a practice here, as in many of the low lands of Ethiopia, of semi-nomadic pastoralism. Rather, traditional populations live from a mix of activities including hunting and gathering shifting cultivation and live stock rearing (especially goats). It is left that most of these areas; this adequately describes the current land use situation.

The remaining parts the sub-basins of are very scattered with different kind of land uses like, Pastorial-P, Agro –sylvicultural-AS, State farm-SF Sylvicultural-S, water –W and Urban-U. Fig. 3.3 and 3.4 presents the land use and land cover map of the study area respectively.

3.6 General Geological Setting

This part is devoted to a description as clear as possible of the general geology concerning the lithology, thickness, lateral extent and the main unconformities of the major litho logical units mapped by the Abbay River Basin Master Plan Project,1999. This approach was mainly carried out with the concern for pragmatic background intended for critical review of the present geological knowledge.

The general geological framework of the Abbay river basin is given according to Kazmin (1972), Kazmin (1975), and Merla and others (1973, 1979) and Jepsen (1960, USBR) .In Ethiopia a deep gorge has been cut in to a high plateau along the Blue Nile River, exposing hundreds of meters of geological formations and revealing the ancient geologic history of the east African continent. The oldest rocks are the sheared and folded Precambrian metamorphic and granitic rocks referred to as the crystalline basement complex of east Africa. They where uplifted, then eroded and leveled to a lowland pen plain. Some ancient valleys eroded in the

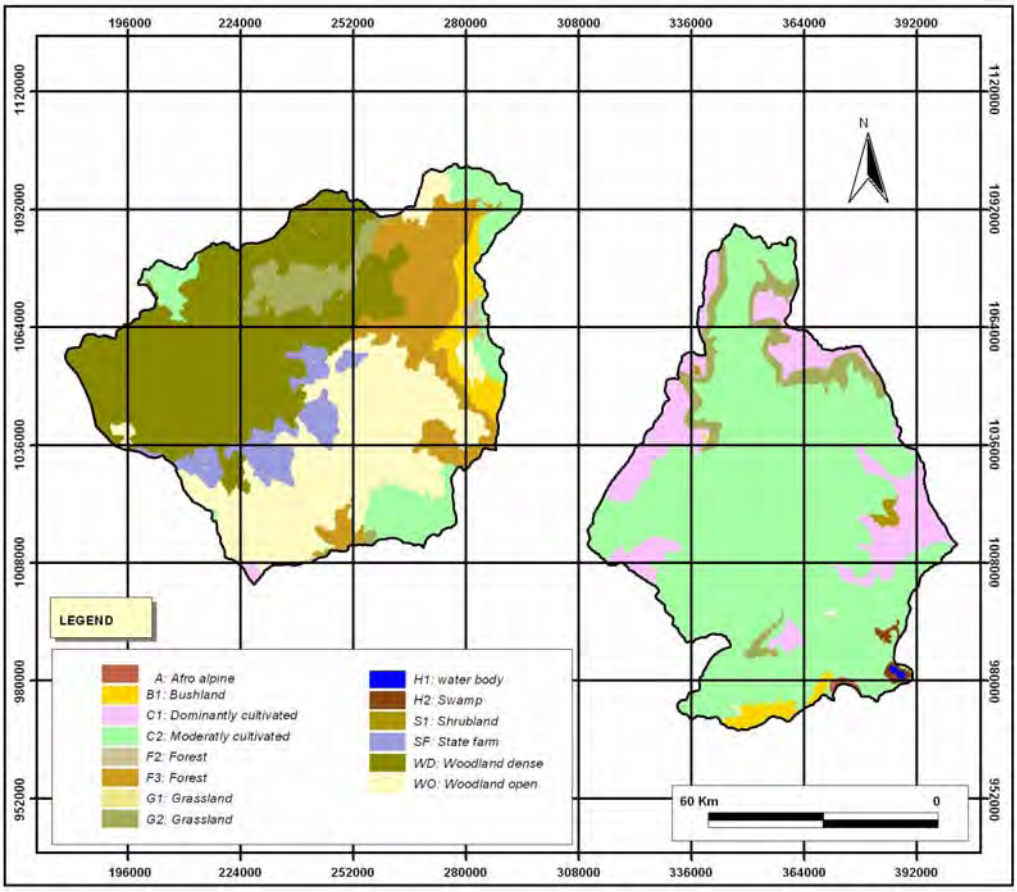


Fig. 3.4 Landcover map of the study area

Precambrian rocks and their filling with sedimentary rock have been preserved, the valleys were eroded an estimated 300 to 400 meters below the pen plained surface of Precambrian rocks. Through out Paleozoic time the region stood above sea level, then subsidence from the south east started a cycle of marine transgression and recession of the Mesozoic sea.

With in this large epicontenental sea, extensive layers of sediments were deposited to from hundreds of meters of rocks consisting of sand stone, shale, gypsum, limestone, and other varieties of bedded rocks. When the land again emerged above the sea, it was subjected to intense weathering that developed deep residual soils. This was interrupted by volcanic activity in early Tertiary time. A great thickness of plateau basalts were deposited over an extensive region and from a platform on which later phases of activity built high central volcanoes. The land mass has been broadly arched and elevated thousands of meters above sea level. Uplift occurred with

relatively little fracturing or folding beyond the borders of the great rift valley that cuts through the southern and eastern part of Ethiopia. The plateaus have been altered by extensive erosion and local out pours of more recent lava.

The general stratigraphy of the Abbay River basin can be presented as follows. The older rocks out cropping in the Abbay river basin are Precambrian. They can be more simply divided from base to top in to 3 litho logical types corresponding in the 3 main metamorphic facies of the lithosphere : Granulites (lower complex), Amphibolites (Adola group) , and Green-schist (Tsaliet and Tambien group).

Archean Lower Complex

These are high grade metamorphics of the pan African Mozambique belt with amphibolites to granulites facies including mainly gneiss.

Upper Proterozoic

The upper Proterozoic contains a very thick succession of formations with originally accumulated in subsiding marine basins. These rocks have in general sustained only slight metamorphism, being of green schist facies but locally reaching amphibolites facies.

Paleozoic

These are very frequently residual, non-metamorphosed sediments, underlying the red Adigrat Sandstone rest uncorformaby on the basement. Most of them are glacial till or wash-out deposits. In the Blue Nile basin, the Infra -Adigrat clastics consists of channeling sandstone which fill paleovalleys, incised in the Precambrian basement.

These provided a quite weathered paleoflora of Upper Carboniferous to Permian age. These grey sandstone are interpreted as leaching products of tills, deposited in fluvial and deltaic environments, under a cool climate. The overlying strata show iron and carbonate crusts, formed during warmer periods (Beauchamp and Lemoigne, 1974(a) 1974(c)).

Mesozoic

According to Le Nindre and others, 1990, the extensive layers of sediments deposited during the recession of the Mesozoic sea includes, Adigrat sandstone which is few m to 800 m, 300m in thickness, the antalo group, which has 879 m in the type section in the Abbay gorge; (Kazmin and Warden 1975), Gohatsion formation, which includes Abbay beds and Antalo lime stone together (Getaneh Assefa, 1981), unnamed volcanics (Jurassic to Cretaceous) and the Amba Aradam sandstone.

Cenozoic (Tertiary and Quaternary)

Following the late Mesozoic-early Tertiary transgression of the sea from the south east an epierogenic uplift of Afro-Arabia occurred on an immense scale. The up raised and up arched crust fissuring under tension permitted the ascension of voluminous basaltic magmas to form the so called Trap serious. According to Kazmin (1975) Ashangi group (Paleocene – Miocene) and shield group (Miocene) constitute the trap series (Blanford, 1870) included the whole volcanic stack (Oligocene-Pleistocene). Magdala group (Blanford, 1970 upper Miocene Pleistocene) consists of: rhyolites, trachytes, rhyolitic and trachyic tuffs, ignimbrites, agglomerates and basalts.

In the present study area, three main regional settings are exposed the oldest Precambrian rocks, Mesozoic sediments and Cenozoic volcanoes. Fig.3.5 shows the regional geological setting of the study area.

2.7 Geology of the Study Area

The geology of the study area has been taken from “Abbay River Basin Master Plan Project, 1999” and geologic map prepared by the project GIS. Fig. 3.6 shows the geology of the study area. The stratigraphic successions of the geologic formations exposed in Guder and Anger sub-basins are:-

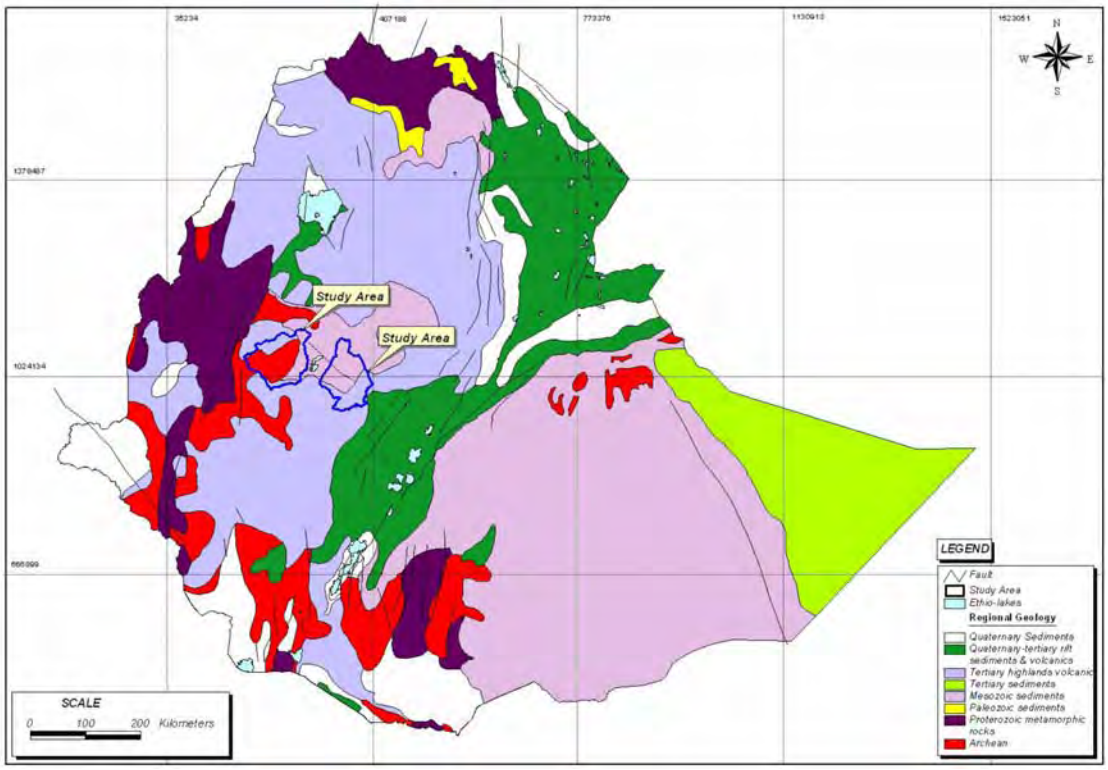


Fig. 3.5 The regional geological setting of the study area (Kazmin, 1973)

Abbay Beds

According to Beauchamp (1978) and Cauti and others (1983) ,these beds consists of alternating gypsum, limestone, dolomite limestone, sandstone and shale, partly pen contemporaneous of the Adigrat sandstone and deposited in a very shallow marine environments during the Lias. A stratigraphic gap might occur before the deposition of the next unit during the Auleno-Bajocian.

Adigrat Sandstone

Consists of variegated quartos sandstone of fluvial or littoral origin .The Adigrat sandstone rests unconformably on the basement or with slight diconformity on sedimentary rocks of presumed upper Paleozoic or Triassic age. In the Blue Nile basin, the sandstone are medium to course- grained, more silty at base. Channels are important and show current directions towards the south-east (Beauchamp, 1978).

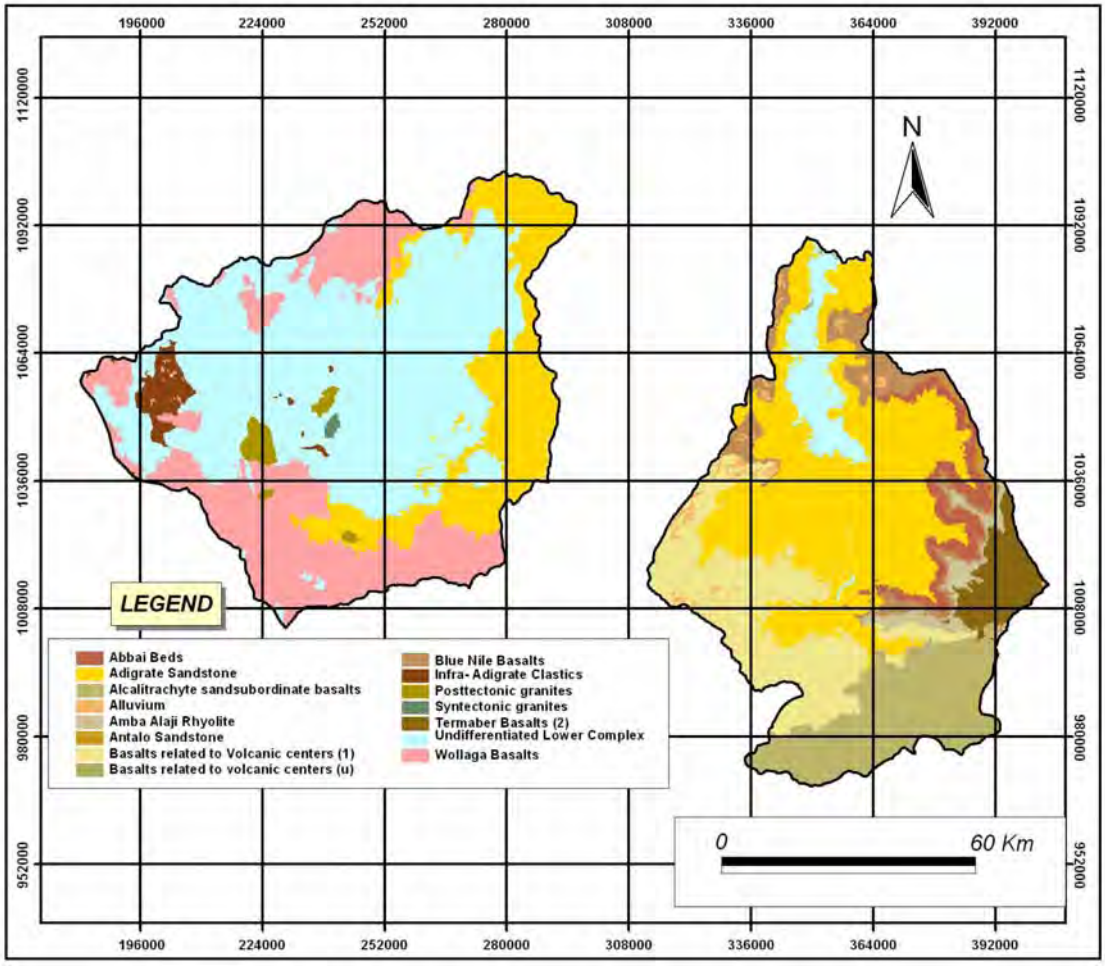


Fig. 3.6 Geology of the study area

Alkali Trachyte and Subordinate Basalts

This volcanic unit forms the huge edifices of the Guraghe Mountains and of the Badda Rogghie-Wachacha area in the west of Addis Ababa and rests on the Arrussi and Bale Basalts (upper Oligocene to upper Miocene) and on the Wellega basalts.

Amba Alaji Rhyolite

This unit mainly consists of rhyolitic ignimbrites with acidic tuffs and some basalts .A migration of the ignimberitic volcanism from north (Oligocene) to south (Miocene) has been suggested by Zanettin and others (1974) as inferred from the radiometric ages obtained. In the Blue Nile basin this unit is considered as Miocene.

Antalo Limestone

This neritic fossiliferous lime stone and marls (Merla and Minucci,1938) is sub dived in to 5 litho logical units. The stratigraphy of the unit was also described by Mohr (1962) that reported its presence on the road joining Addis Ababa to Debre Markos. This formation consists of a thick bed of limestone and marls which provided an abundant marine fauna of Bathonian-Oxfordian age. (Arkell, 1956, Ficarolli, 1968, Zeiss, 1970)

Basalt Related to Volcanic Center (1)

Among the recent basalts classified by Merla and others (1973-79) as quaternary basalts related to volcanic centers, this unit form several edifices of important relief, which include very frequent protrusions (plugs) of flood basalts and seems to be slightly older possibly of Pliocene age.

Basalts Related to Volcanic Centers (u)

These are other quaternary volcanics which were produced in a wide area from Bure to Bahir Dar. They consist of flood basalt, often scorraceous and easily weathered. The flows usually fill former deep valleys, namely the Birr river valley. Palioreliefs formed by shoulders of Blue Nile basalts and Adigrat sandstones are still visible.

Blue Nile Basalts

These are thick basaltic flows and rare basic tuffs, limited to central Ethiopia and geometrically older. In Blue Nile gorge, this unit consists of 6 flows of columnar, alkaline basalt, some exceeding 20m in thickness.

Infra Adigrat Clastics

During the Paleozoic, two major glaciations occurred: the main one at the end of the Ordovician (Ashgill), the next one at the end of the carboniferous. Palio valleys were deeply incised in older formations during the low stands of the sea level. In the Blue Nile area, such valleys were formed at the end of the carboniferous then filled by clastic alluvial material. Infra-Adigrat clastics can be quit easily differentiated of the overlying Adigrat sandstones

by their brownish-grey color related to the presence of Fe/Mg minerals such as biotite, well preserved in cold climate periods.

Syn and Post Tectonic Granites

These units lie between the metamorphic fold belts, syntectonic granitoids, including diorites, grano diorites, quartz-diorites, and tonalites .These units form rather low lands (elevation 1000-1300)of Dabus valley and Blue Nile valley ,while foliated syntectonic granites and post-tectonic granites dominates the plains of most remarkable form of a large plateau.

Termaber Basalts

Consists of lenticular basalts with a large amount of tuffs, scorraceous lava flows and typical red paleosoils. This unit overlies uncomfarbly the Amba Alaji Rhyolites and the Amba Aiba basalts and the Ashangi or the Blue Nile basalts.

These were erupted from central volcanoes of Hawaiian type. The Mangstu volcano, which is the largest and the best preserved, has a diameter of about 100km.

Wellega Basalts

Consists of predominantly columnar basalt flows with intercalation of acidic tuffs and loose fluvio-lacustrine clastics. Phonolite plugs are quite frequent. This unit overlies unconformably the Jimma volcanic.

Undifferentiated Lower Complex

These are high grade metamorphics of the Pan-African Mozambique belt, with amphibolites to granulite facies, including mainly gneiss. Although usually course-grained and well foliated, the gneisses and migmatites merge in to more homogenous varieties of granitic appearance.

In the Blue Nile basin, this group includes rocks which, generally, have not been assigned to a particular litho logic unit.

3.8 Soils

The soil units of the study area fall in to 10 main soil units in the FAO-UNESCO-ISRIC system: VIS, Acrisols, Alisols, Arenosols, Cambisols, Fulvisols, Leptosols, Luvisols, Nitisols, Regosols and Vertisols. A typical distribution of each major soil units in the study area is shown in Fig. 3.7 and the variation from the unit mean, which characterizes each family, is described.

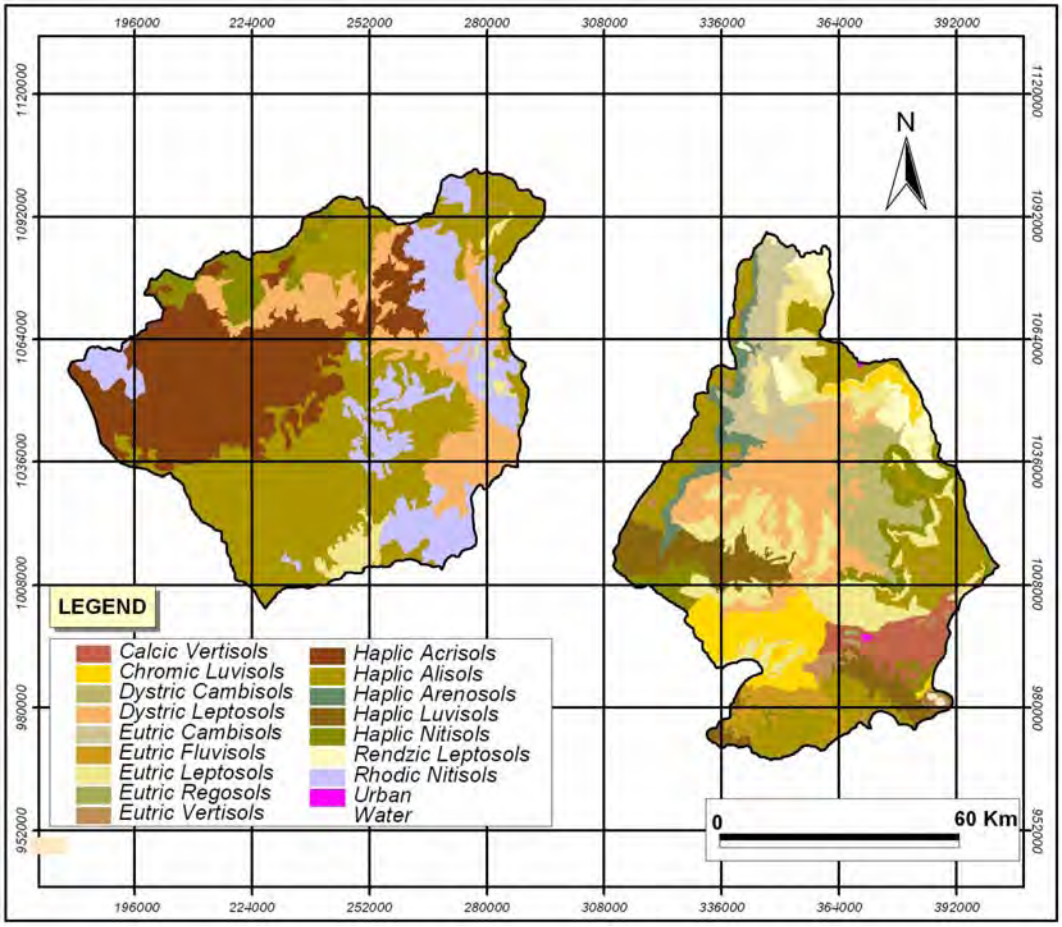


Fig. 3.7 A typical distribution of each major soil units in the study area

The soil map of the area is taken from Abbay River Basin Master Plan based on BCEOM- French Engineering Consultants in association with ISL and BRGM field experience (1999). Reference is made to (Annexure V) for detailed morphological description and characteristics of each major soil units.

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CHAPTER FOUR HYDROLOGIC ANALYSIS

4.1 Introduction

The flow characteristics of river are one of the main factors, which influence the power potential of a site. Form many years of experience (NRECA, 1980), notes that hydrologic studies are basic to the entire role process of hydropower development. The flow values play a big role in the optimization by restricting the upper limit of power potential. A flow duration curve gives the percentage of time a given flow is equaled or exceeded of the period of record. It is obtained form a hydrograph by organizing each flow measurement by size, from the largest measurement to the smallest, rather than in chronological order (Inversion 1986, cited in Zelalem 2001). The curve provides information on low flows, which are necessary to design various components of the hydropower project and to select appropriate turbines. Therefore a careful determination of the flow duration is an essential part of hydro power system development.

Normally, design is made by reading flow values directly from the flow duration curve. It is also possible to fit an equation to the flow-duration curve using least squares technique. That way, the flow duration curve can help in the analysis of different installation capacities at a particular site.

4.2 Gauging Stations in Guder and Anger Sub-basins

The collection of hydrologic and meteorological data for the flow-duration analysis is a part of the hydropower systems development phase. The hydropower sites identified in this study are located in the Guder and Anger Sub-basins of Abbay River Basin. There are eleven gauging stations on different streams in these two sub-basins of which seven are located in Guder sub-basin and the remaining four in Anger sub-basin. 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 view to establishing a regional flow duration curve. The location of gauging stations is shown in Fig. 4.1.

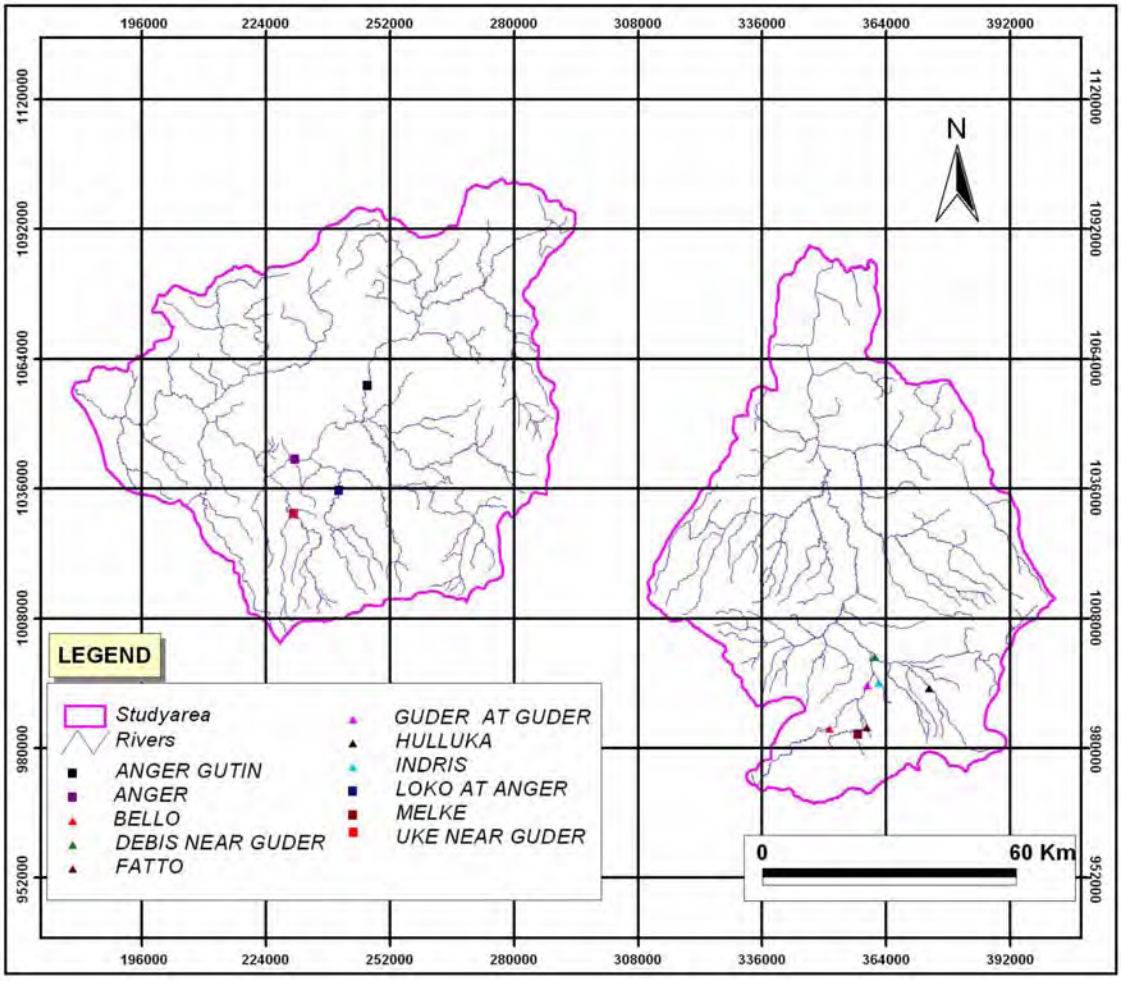


Fig. 4.1 Gauging Stations in the study area

4.3 Flow Duration Analysis for Gauged Sites

Flow duration curve is used to describe the time availability of flow at a certain point in a river. Flow duration curve is a simple plot of flow versus the percent of time that a particular flow can exceed (called the "percent exceedance"). 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 can be used to determine estimated power from a proposed hydropower installation (Fritz 1984).

The two basic methods of computing flow–duration curves at gauged points

are the ranked flow and class interval techniques. In the ranked flow – duration technique the time series of flows is rank- ordered according to the magnitude of flows. Mean annual, monthly, and weekly or daily flows may be used. The use to which the information is to be put determines the choice of what type of average flow is used. The rank –ordered values are then assigned ordered numbers. The largest beginning with order 1 the order of numbers are then divided by the total number in the record and multiplied by 100 representing the percent of time intervals (days, weeks, etc) that a particular mean flow has been equaled or exceeded during the period of record analyzed. The flow value is then plotted versus the respective "percent exceedance". As in any statistical analysis the value of the information contained is function of the length of record. Reference of the flow-duration curve is usually made as Q100, Q90, Q50, Q30, Q10 etc. indicating the flow values at the percentage point subscripted (Fritz, 1984).

In the present study area 19 gauge stations on various streams are present. Out of these, only 11 gauging stations have recorded daily discharge data form 5 to 39 years. Flow–duration curves based on monthly mean data dampen within monthly flow variability and therefore may over estimate the design flow. Fig. 4.2 shows the comparison of daily flow duration and Monthly flow duration curves at Anger Gutin gauge.

It is clear that the flow–duration curve from daily data lays under the flow duration curve from monthly data. Because of the variability of flow with in the month the flow duration curve from monthly data may not truly represent the dependable flow. It is therefore recommended to use the daily flow–durations curve for safe design. Ramsahoye, 1982 considers the determination of the average daily flow–duration curve as the unquestionably most important hydrological input for the dependent power, energy and economic studies of a hydropower project. 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 11 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) toposheets at a scale of 1:50,000 and using Arc view 3.3 GIS software by overlaying different layers, SRTM river, hydrometric locations etc.

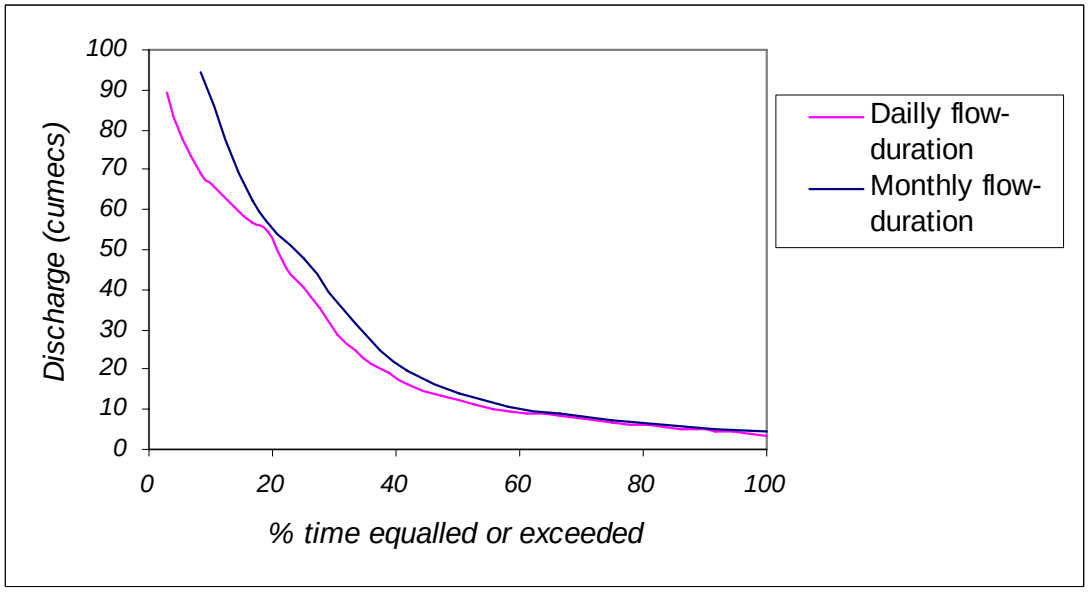


Fig. 4.2 Comparison of daily and monthly flow duration curves at Anger Gutin gauge.

Fig. 4.3 shows delineated catchments for 11 gauging stations using Arc view 3.3 GIS software. The catchments delineation includes catchments boundary, perennial stream, drainage network, roads or footpaths, highest and lowest elevation points, and contours in 20m intervals with in the catchments boundary.

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 Transfer of Flow –Duration Curves

A flow–duration curve is usually available for the river gauging station in a region. However, 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 down stream river with a drainage area containing the site's watershed. An approximation for a flow–duration at the un-gauged site can be obtained from a flow duration curve at the gauged site, modified by regional run off data, by the ratio of drainage, or by correlation between flows (Inversin, 1986, as cited in Zelalem 2001).

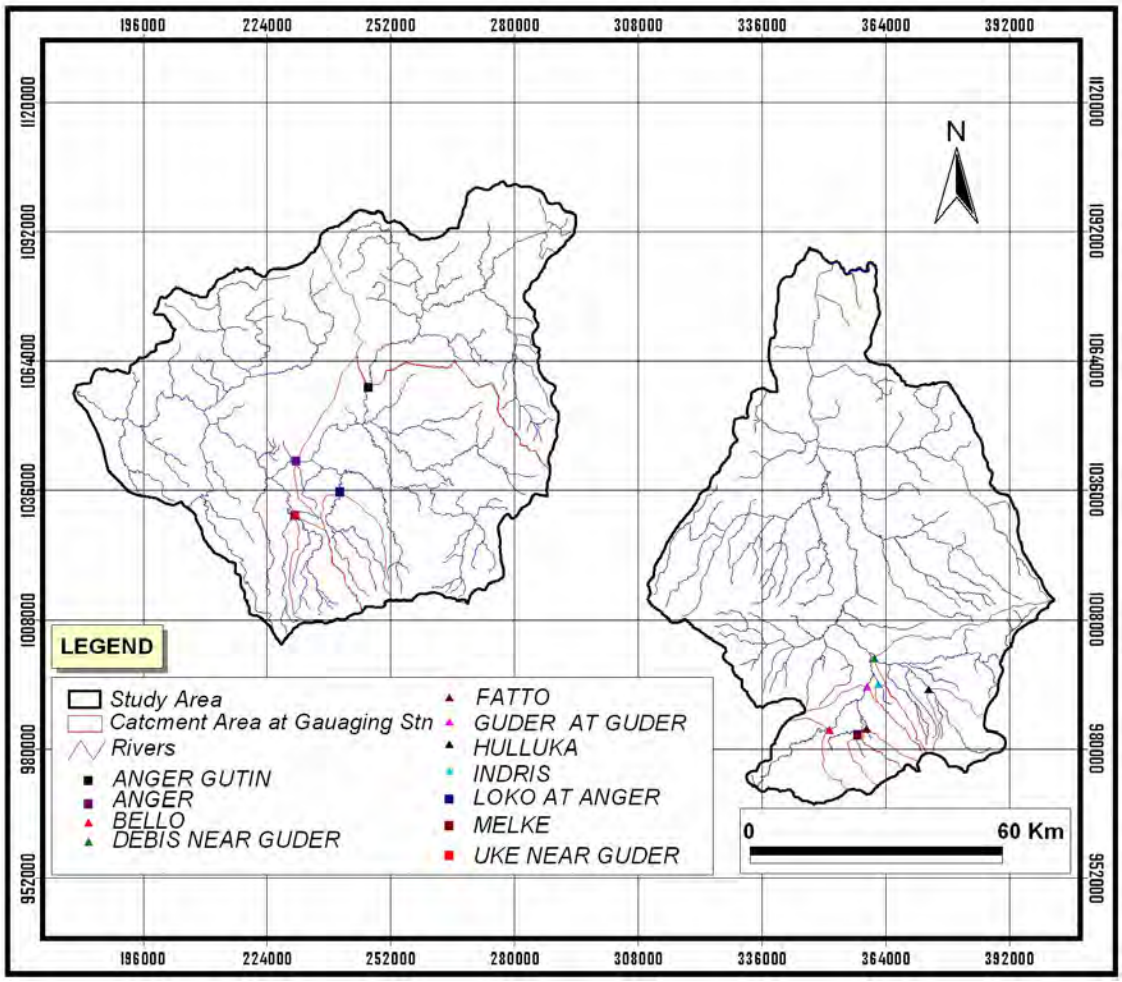


Fig. 4.3 Delineated catchments for 11 gauging stations in the study area.

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 4.1 is the common type of relation that is used to estimate flow–duration at an un-gauged site.

$$Q\ site = \left[\frac{DAsite}{DA\ guage}\right]^{\nu} Q\ gauge \qquad eq.4.1$$

Where; υ typically varies between 0.6 and 1.2

DA site drainage area of the power plant site

DA gauge drainage area of the gauge

Q site discharge at the diversion site (m^3/s)

Q gauge discharge at the gauge

When the value of υ in the formula is set equal to 1, the above relationship turns out to be a case of data transfer by proportion of areas.

Usually, the proximately of the site to the gauge is used as basis for the choice of the value of υ. 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).

4.5.1 Site in Close Proximately to Gauge

If the area of the site is within 20 percent of the area of gauge, a value of ν=1 can safely be assumed. The estimated discharge at the site will probably be within 10% of the actual discharge which is normally sufficient for practical purpose.

When using this method one has to make sure that there is no artificial or natural feature between the two points, which may radically change the pattern of river flow. If such features exist, then it is better to adopt proportion of annual flow transfer of flow–duration curve.

4.5.2 Site in Close Proximity to Upstream and Downstream Gauges

If the area of site is within 50 percent of the area of the gauge, consideration is made as to whether the data of two gauges can be combined. Equation

4.2 is an interpolation relation, which can be used to determine a weighted average flow at a site lying between upstream and down stream gauges.

$$Q\ site = \frac{(DA\ \ gauge\ 1 - DAsite)Q\ gauge\ 1 + (DAsite - DA\ \ gauge\ 2)Q\ gauge\ 2}{DA\ gauge\ 1 - DA\ gauge\ 2} \quad (eq.4.2)$$

4.5.3 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.

4.6 Mean Annual Flow at an Ungauged Sites

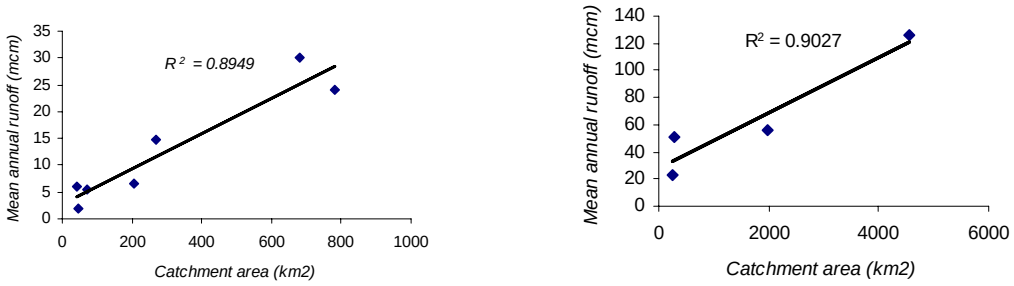
From the discussion in the previous sections, it is clear that the evaluation of mean annual flow is necessary for transfer of flow duration curves. When interest focuses to estimate the flow of one site only, then the proportion of mean annual flow at gauge and site (using techniques discussed in section 4.5) 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 (Fritz 1984).

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 runoff. 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 2nd technique is adopted for the estimation of 75% dependable discharge data in the region. Section 4.7 discusses the

approaches applied to the Anger and Guder sub-basins using easily available meteorological data and drainage parameter (Area) for correlation purpose.

4.7 Regression Analysis of Available Hydrologic Data of the Region

A perusal of Fig. 4.4 indicates that the data points (mean annual runoff versus catchments area) show a very good correlation for Anger and Guder sub-basins independently with correlation coefficient reasonably close to 0.9. Since the correlation between annual runoff and catchments area is similar for both sub-basins, the same may hold true for correlation between drainage area and annual runoff for Anger and Guder sub-basins in combination. Fig. 4.5 shows such a relationship for all gauges in Anger and Guder sub–basins. It is apparent that the drainage area correlates good with the annual runoff with a correlation coefficient again very close to 0.9 (Fig.4.5). This equivalent to saying that the transfer of the flow–duration curve for rivers in either Guder or Anger sub-basins from the combined regression analysis curve (both sub-basins) may be equally good as the transfer using each of the correlation curves for Anger and Guder sub-basins separately.



Guder sub-basin **Anger sub-basin**

Fig. 4.4 Plot of mean annual runoff verses catchment area for Anger and Guder sub-basins

This is mainly done to improve the reliability of the correlation curve for estimation of discharge by increasing the data set points as only 4 and 7 discharge measuring gauges are available in Anger and Guder sub-basins respectively.

4.8 Regional Flow – Duration Curve

A regional flow–duration curve is constructed after classifying basins according to hydrologic similarity rather than through delineation by geographic or catchments boundaries. The classification can be done by analyzing the hydrographs of the gauges under investigation. Fig. 4.6 shows the comparison of monthly hydrographs for the gauges in Anger and Guder sub-basins. Basically, two major differences are observed in the nature of the hydrographs of rivers in the sub-basin the rivers in both sub-basins show higher peaks during wet seasons.

They have relatively low flow during the dry season indicating that the variability is high. In the comparison, rivers with higher drainage area display higher peaks and others with smaller catchment area show relatively lower peaks during high flow and for both case with a stable low flow during dry season.

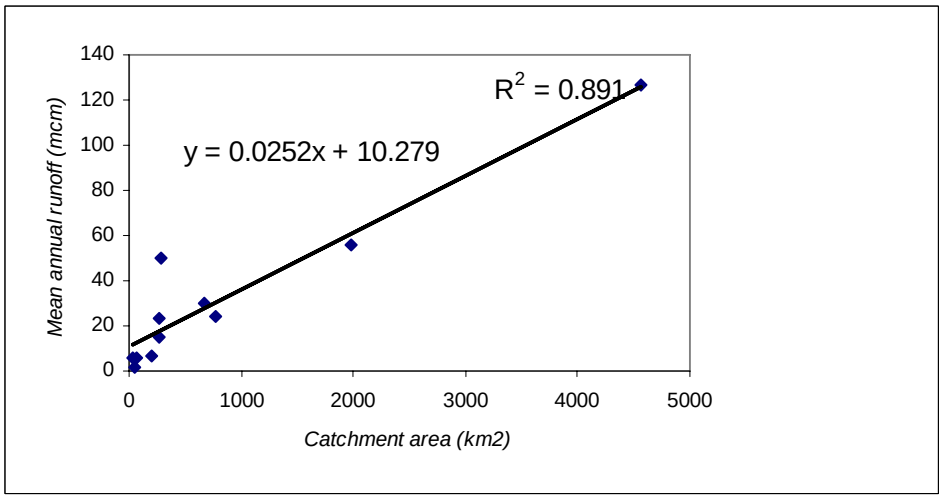


Fig. 4.5 Plot of mean annual runoff verses catchment area for all of 11 gauges in Anger and Guder sub-basins

The above observation is important for categorizing gauges in the preparation of the regional flow–duration curve. However, it may still be interesting to see the correlation between the flow exceedance and the mean annual flow for all gauges with in the Anger–Guder sub-basins. Four exceedance levels of 25%, 50%, 75% and 85% have been chosen for the

purpose. Curves for other exceedance levels could also be constructed as the need arises. Fig. 4.7 demonstrates results of the correlation based on eleven gauge data with in the Anger-Guder sub basins.

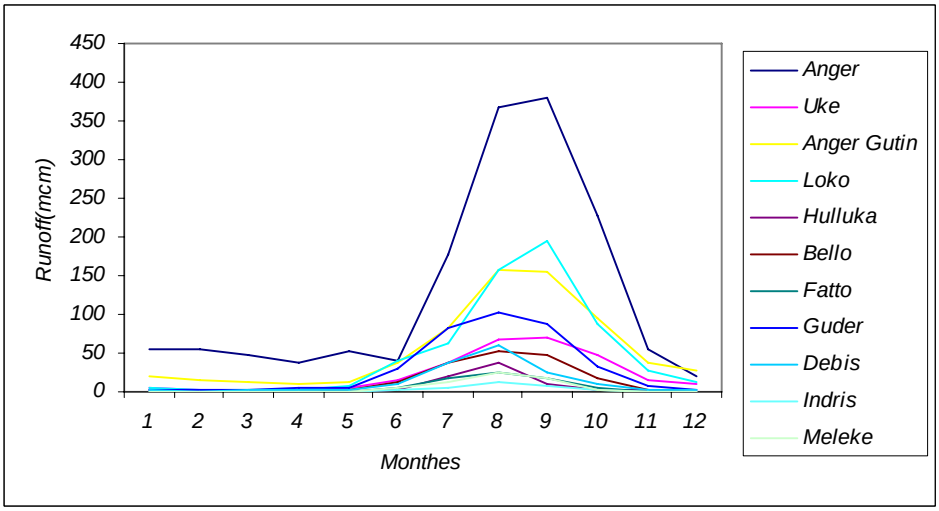


Fig. 4.6 Comparison of monthly hydrographs for the gauges in Anger and Guder sub-basins.

The correlation coefficient is also shown along with the curves. It is observed that the correlation for all exceedance level is very strong. For hydropower capacity design, however, interest lies at the low flows, in the present study 75% exceedance level is considered for dependable flow determination in calculating the power potential of the identified small hydro power sites in the two sub-basins and setting of identification criteria suitable specifically for Anger- Guder sub- basins.

4.9 Establishing Identification Criteria at Varying Hydraulic Heads and Catchments Area

For the initial identification of the small hydropower (SHP) potential sites for the present study, a systematic topographic and hydrologic analysis is con ducted by considering 5 test sites, two in Anger and three in Guder sub-basins. The sites have been selected based on the availability of discharge for production of power through out the year (perennial streams) and availability of head at different diversion structure locations ranging from low head (40m) to high head (240m) since power is the product of head and

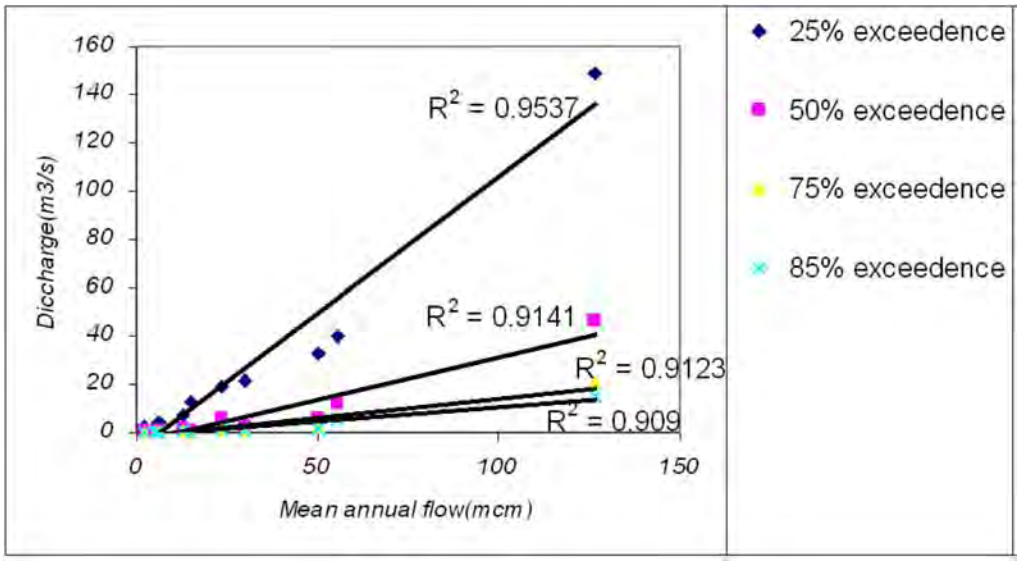


Fig. 4.7 Regionalized flow-duration curves for Anger-Guder sub-basins

discharge. The locations and elevations of the powerhouse sites at each criterion testing sites are fixed (Fig.4.8). The discharge at different diversion weir sites which corresponds to the hydraulic head of different forebay sites is estimated using the techniques discussed in section 4.5 of this chapter. In order to study the influence of different factors on the power potential, an analysis of sensitivity on the power potential has been carried out by varying drainage area and discharge, while keeping the other parameter (hydraulic head) constant.

The main aim of this analysis is that it enables the parameters to be graded in order of their importance with respect to their impact on the power potential at each test sites. Thus, the minimum limits of various factors to generate acceptable amount of electricity from a hydropower site can be worked out. The relationship between power potential and each of the parameters, thus obtained utilizing formula discussed in section 5.16 of chapter 5 is shown in Fig.4.9.

Accordingly, a minimum of 100kw power of installed capacity for optimal development of a hydro power system ranging form mini to small hydropower schemes is considered to set a cut of line for head and drainage area form the graph (Fig. 4.9).

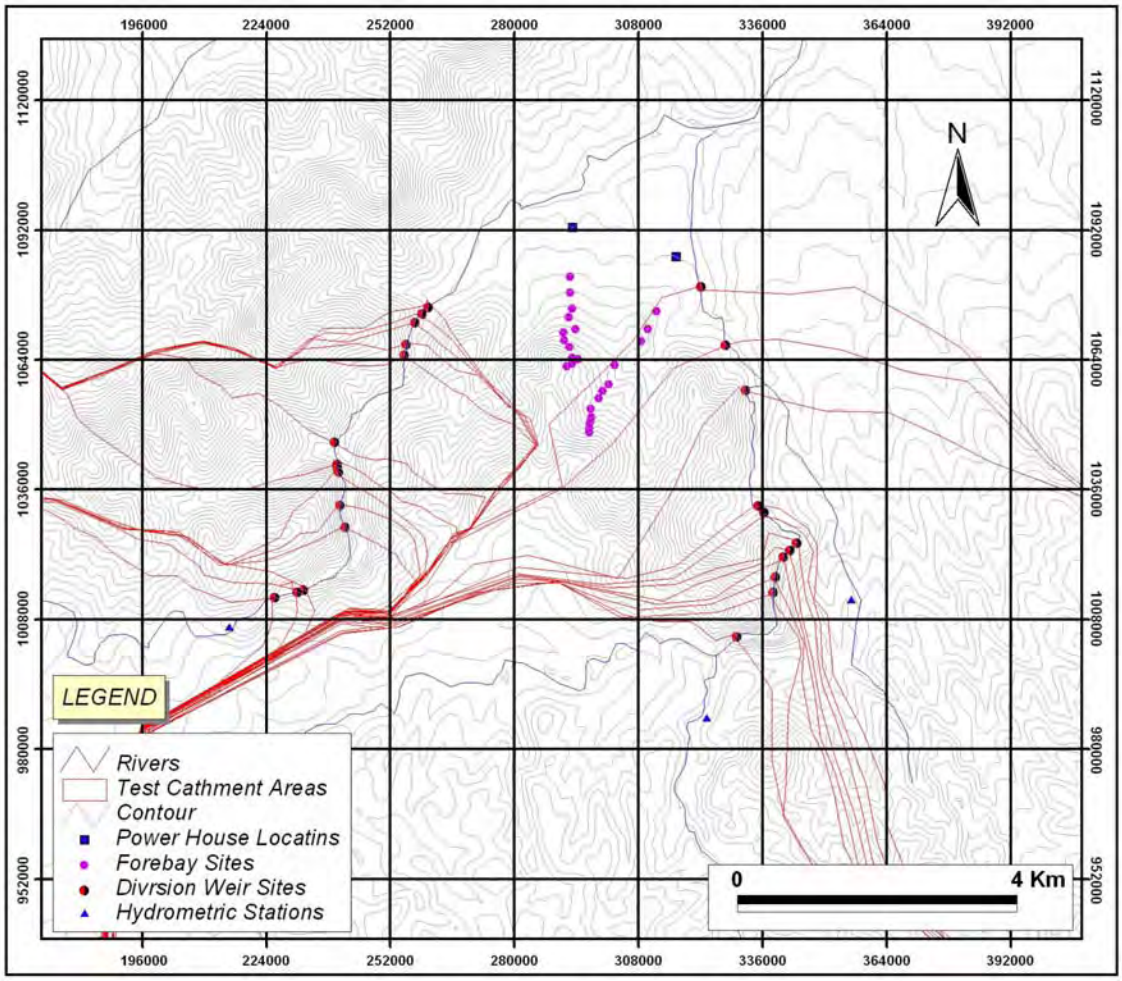


Fig. 4.8 Sample sites for criteria determination in the study area

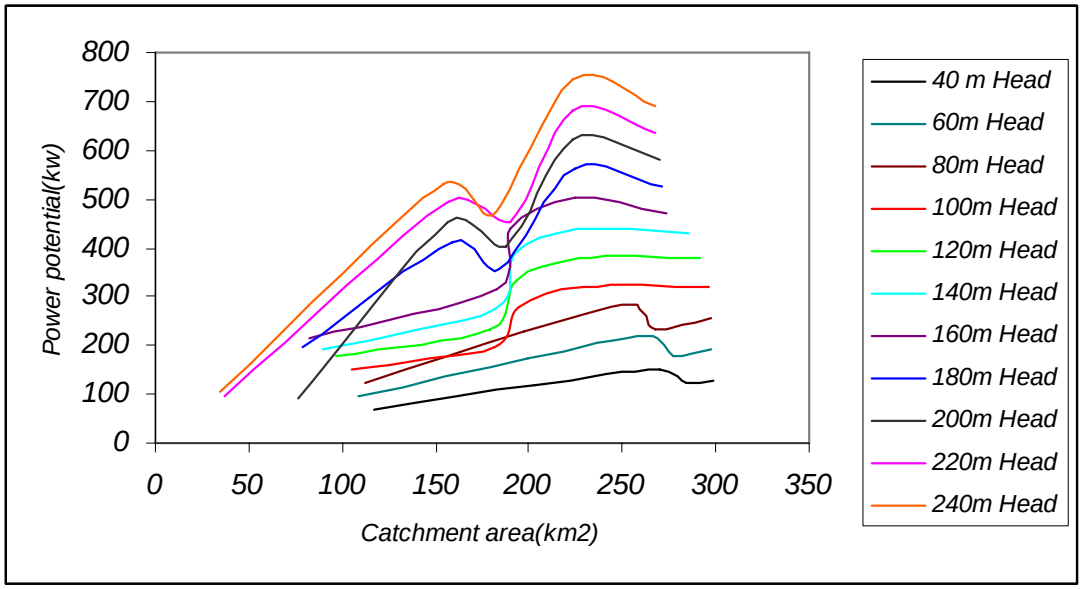


Fig. 4.9 Plot between power potential and catchment area for various gross head.

Eventually the site selection has been made based on the following criteria;

(i) Channel should be perennial in nature in EMA topo-sheets perennial streams are marked with blue color.

(ii) The catchments should be an area of the least 110km^2. This will ensure a sufficient good amount of discharge for power generation.

(iii) Main channel should have minimum length of about 10km.

(iv) Availability of head should be at least 80mt as lower head.

(v) The head race channel must be less than 5 km in length.

(vi) The potential site should be well accessible and should be located near to load centers, so as to ensure proper power utilization.

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CHAPTER FIVE POTENTIAL SMALL HYDROPOWER ASSESSMENT

5.1 Introduction

This section present 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. This section also deals with the information form chapter IV and on site specific topographical information to establish the limits of hydropower potential at each site. These limits serve as the constraints for the hydropower system. Before estimating the site specific potential, some assessment of the country wide potential and history of power supply in the country and the existing supply situation is discussed.

5.2 Hydropower Potential in Ethiopia

The hydro resource of the country is said to be as immense potential. The total hydropower potential in Ethiopia has been estimated at 30 GW. However, only about 1% has been exploited for the national grid, which is almost entirely supplied by hydropower (MHPG, 1997). The existing hydro power stations and under construction plants, that are shown in Table 5.1, were commissioned in the last 50 years and with total installed capacity of about 460 MW and a firm energy capability of about 1704 GWh/yr. However, the dependable capacity is reduced to less than 135 MW due to de-rating of nominal installed capacities (EEPCO & Acres Intr, 2002).

It is obvious that the hydropower potential is largely under–exploited even though it is economically competitive as compared to other types of energy sources. At present attention is being given to hydropower and it's likely to be the major source of power supply for many years to come. With regard to small hydropower, a total potential of the country is estimated at 20,459 GWh/year of energy. This potential is about eight times the current demand of the entire country. However, only hands full of potential sites have been considered for rural electrification purposes.

Tabel 5.1 Generation capacity of existing and under construction hydropower plants

Plant	Installed capacity (MW)	Dependable capacity (MW)
Koka	43.2	38.4
Awash II	32.0	32.0
Awash III	32.0	32.0
Fincha	100.0	100.0
Melka Wakena	153.0	153.0
Tis Abbay I	12.0	12.0
Tis Abbay II	73.0	68.0
Fincha Unit 4	34.0	34.0
Gilgel Gibe	192.0	184.0
Gojeb	102.0	102.0
Tekeze	225.0	225.0

(*Sources: EEPCO & Acres International, 2002*)

5.3 Present Status and Future Plans in Electrification Endeavors

At present, Ethiopia Electric Power Corporation (EEPCO) is the sole power producer in the country. Almost all electrification programs conducted till date are carried out by EEPCO. Most of the electrification programs conducted by EEPCO were implemented through either grid extension or decentralized diesel generation. A total of 458 towns have been electrified so far. The total installed capacity of all power plants in both interconnected system (ICS) and self-contained systems (SCS) is about 493.3 MW. This installed capacity for a population of 65 million amounts to a per capita installed capacity of merely 7.5 watts. The generation capacity of the entire power plant is estimated at 2,533.6 GWh. On the basis of this, it can be implied that per capita electrical energy consumption of Ethiopia is currently about 39 kWh. In the EEPCO system, the installed capacity of hydropower plants is about 450 MW. Out of this, some 98 % or 445MW is in the ICS and the rest 1.4 % or 6.15 MW is in SCS system. The later is particularly generated from mini or micro–hydro power plants. In the next 5 to 7 years, EEPCO is planning to build power plants with installed capacity of 644 MW at a capital outlay of 850 million USD. In addition EEPCO plans to under take rehabilitation and expansion of its transmission and distribution network (Mulugeta Adamu, 2002).

5.4 Site Specific Potential Assessment

From topographic information it is possible to identify points of high gradient for hydropower development. The potential catchment is delineated

from the Ethiopian Mapping Authority (EMA) toposheets at a scale of 1:50,000 and also using Arcview 3.3 GIS software using SRTM layer showing digital elevation data.

Fig.5.1 shows a sample delineated catchments for Bello and Bite SHP sites. A total of 46 toposheets 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 18 potential SHP sites have been identified (Table 5.2). Out of these 9 sites falls with in the Anger sub-basin and the rest

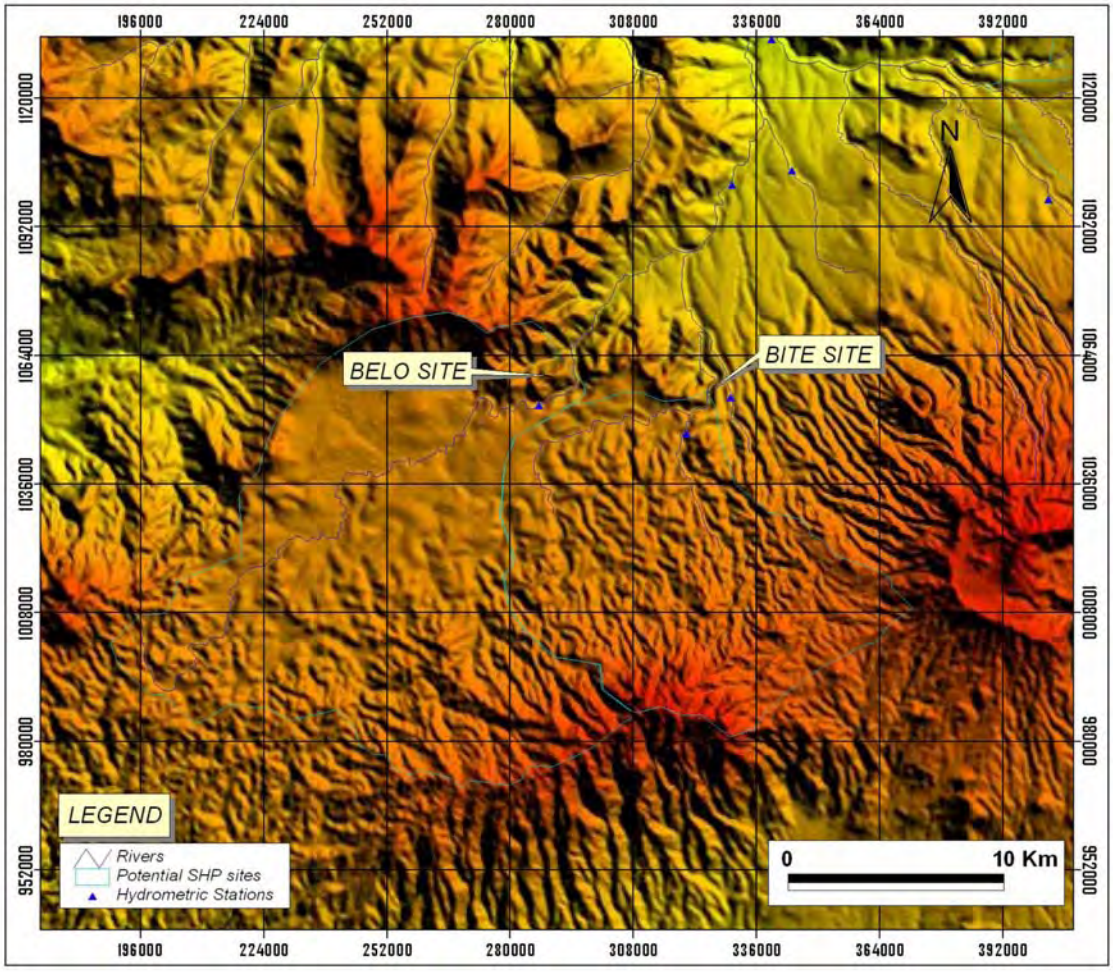


Fig.5.1 Sample delineated catchments for Belo and Bite SHP sites

9 sites form a part within the Guder sub-basin. Most of the identified sites are concentrated along the periphery of the sub-basins. SHP sites are

named after the river name on which the small hydropower scheme is identified. Fig.5.2 shows the distribution of identified potential SHP sites and the location of gauging stations on various streams in the study area.

Table 5.2 Identified potential SHP sites in the study area

S.No.	Name of SHP site	Diversion weir elevation	Location of diversion weir (UTM)		Gross head	Sub-basin	Nearest Town
			Northing	Easting			
1.	Yeyi	1300	104821	347812	80	Guder	Kombolcha
2.	Dongage	1760	106555	358802	280	Guder	Chulute
3.	Melka	2060	102991	392675	220	Guder	Gojo
4.	Dima	1820	102783	327110	160	Guder	Fechase
5.	Bello	2260	98128	355477	140	Guder	Tikur Inchini
6.	Bite	2300	980560	361399	100	Guder	Mutulu/Guder
7.	Hulluka	2440	986379	379583	100	Guder	Ambo
8.	Debis	2040	995938	377401	80	Guder	Ambo
9.	Aleltu near Ambo	2040	994588	374491	80	Guder	Ambo
10.	Tiliku Anger	1940	109662	285431	80	Anger	Alibo
11.	Gerchi	1700	107354	278336	80	Anger	Shambu
12.	Werabesa	1860	109288	252610	200	Anger	Kokofe/Ayana
13.	Indris	1480	106597	216659	100	Anger	Gellila
14.	Kile	1340	106555	214580	160	Anger	Gellila
15.	Gumbe	1360	103521	260060	120	Anger	Anger/Belo Centeral Camp
16.	Haro	1600	102243	272506	80	Anger	Rob Gebeya
17.	Aleltu	1900	102357	207261	200	Anger	Rob Gebeya
18.	Chobsa	1900	102399	237598	200	Anger	Rob Gebeya

5.5 Component of Small Hydropower Scheme

The general layout of the small hydropower scheme comprises mainly, two major component, one is the water conducting system and the other is the electro mechanical component. The water conducting system is responsible of taking water from the main stream and providing it to the power generating units, placed in the powerhouse. Electro mechanical component comprises of turbines, generators, control panels and transformer. Fig. 5.3 shows the general layout of small hydropower site (ESHA, 2004).

The various components of SHP scheme and their functions are discussed here under;

5.5.1 Diversion Weir

A hydro–system must extract water from the river in a reliable and controllable way. The water flowing in the channel must be regulated during

high river flow and low flow conditions. A weir can be used to raise the water level and ensure a constant supply to the intake. The intake of a hydro scheme is designed to divert a certain part of the river flow. This part can go up to 100% as the total flow of the river is diverted via the hydro installation.

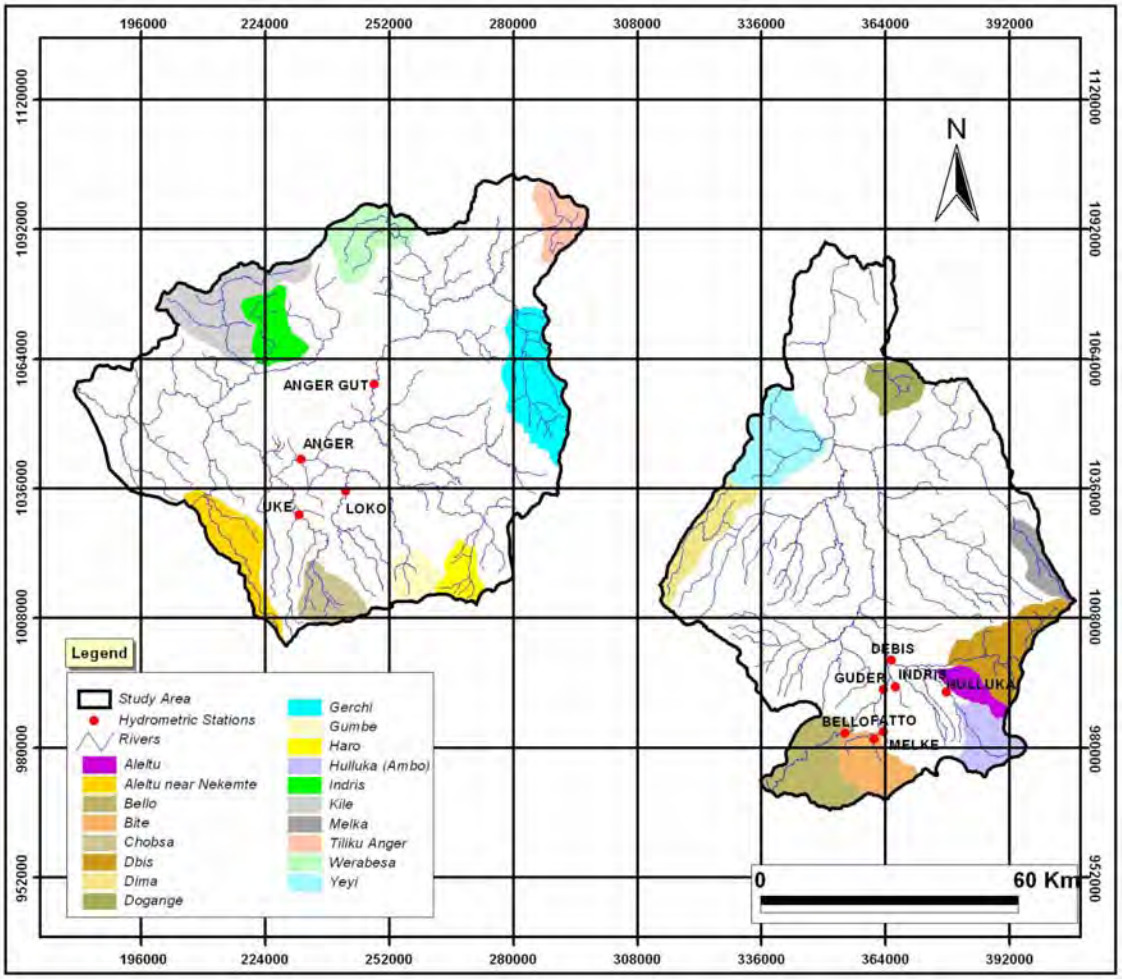


Fig.5.2 Distribution of identified potential SHP sites and location of gauging stations on various streams

5.5.2 Headrace Channel

The channel conducts the water from the intake to the forebay tank. It may be an open channel or closed or a steel pipe depending upon the site requirements. The length of the channel can be with in a length of a few kilometers to few hundred meters depending upon the site conditions. A slope of 1:500 is generally maintained along the headrace channel.

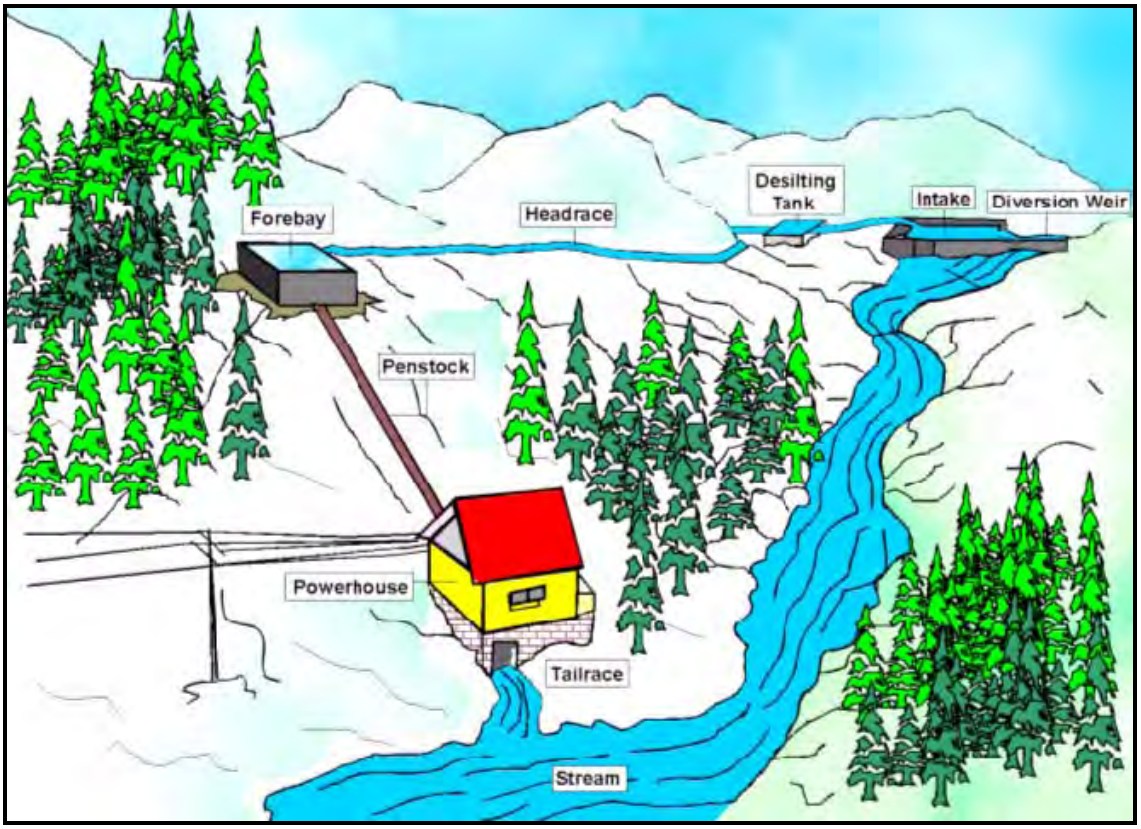


Fig. 5.3 General layout of small hydropower site (Source: AHEC, 2000)

5.5.3 Settling Basin

The water drawn from the river and fed to the turbine will usually carry a suspension of small particles. This sediment will be composed of hard abrasive materials such as sand, which can cause extensive damage to the turbine runners. To remove the suspended material the water flow must be slowed down in the settling basins, known as desilting tank, so that the silt particles will settle on the basin floor. The deposit formed is then periodically flushed away.

5.5.4 Spillways

Spillways are designed to permit controlled overflow at certain points along the channel, forebay and diversion weir. The spillway is a flow regulator for the different civil components. In addition it can be combined with control gates to provide a means of emptying the channel. The spill flow must be fed

back to the river in a controlled way so that it does not damage the foundations of the channel.

4.5.5 Forebay Tank

The forebay tank forms the connection between the channel and the penstock. The main purpose is to allow the last particles to settle down before the water enters the penstock. Depending on its size it can also serve as a reservoir to store water. The forebay is designed to supply uninterrupted design discharge to the turbine. Generally, it is designed for 2 minutes storage capacity (AHEC, 2000); this is done mainly to accommodate the surge generated due back flow of water from the penstock during immediate closure of turbines. A spillway structure is also provided to spill off the water in case of immediate closure of the turbines.

5.5.6 Trashracks

One of the major functions of the intake is to minimize the amount of debris and sediment carried by the incoming water, so trashracks are placed at the entrance to the intake and penstock to prevent the ingress of floating debris and large stones. A trashrack is made up of one or more panels, fabricated from a series of evenly spaced parallel metal bars. The maximum possible spacing between the bars is generally specified by the turbine manufacturers.

5.5.7 Gates and Valves

In every small hydropower scheme some components, for one reason or another (maintenance or repair to avoid the runway speed on a shut down turbine etc…) need to be able to be temporarily closed. Almost with out exception the power intake will incorporate some type of control gate or valve as guard system located upstream of the turbine and which can be closed to allow the dewatering of the water conduit. This gate must be designed against the maximum turbine flow in case of power failure, and it

should be able to be opened partially; under maximum head, to allow the conduit to be filled

5.5.8 Penstock

Penstock is a pipe, which conveys water under pressure from the forebay tank to the turbine fitted in the power house. Penstock pipe is well placed on the anchor blocks in between the forebay and power house.

5.5.9 Powerhouse

Powerhouse is a structure, which accommodates the hydro-turbine and generators with the control panels.

5.5.10 Tailrace Channel

Tailrace channel is a structure provided to transmit the water from the hydro-turbine, after power generation, back into the stream. It may be open channel or a steel pipe depending up on the site requirements.

5.6 Characteristics of Flow Duration Curves

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 plat. 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, 2002).

For the present study 75% of dependable flow is 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. For all the identified potential sites it has been proposed

to install two turbines of identical specifications at each site. This not only will help in operational flexibilities but may also facilitate in maintenance due to similar specifications but this may not be cost effective.

5.7 Estimation of Dependable Discharge

For the development of any small hydropower scheme an essential first step is to determine whether there is sufficient and reliable amount of water available to make the scheme economically viable. As a standard practice a gauging station should be set up and the discharge should be observed for at least two lean seasons (Kumar et.al, 2000).

The flow-duration, discussed in Chapter 4, thus has centered on computing these curves at a known gauge location. The availability of stream flow gage data at the site of interest is probably the exception rather than rule inmost areas. Because of the nature of this survey, it was necessary to predict flow–duration at ungauged points on streams.

In the present study ,18 potential SHP sites has been identified following the criteria discussed in chapter IV of section 4.9. For none of these potential streams gauge data is available at or near the proposed diversion sits. However, observed discharge data is available either in up stream or down steam locations, on the same stream or in the adjoining catchment. Therefore, methods have been developed to predict flow-duration at these potential ungauged sites. The method described in chapter 4 (Section 4.6 and 4.7) involved developing a set of parametric flow-duration curves based on flow values at gauged points. This method allows prediction of only certain exceedance values, not all values on the flow-duration curve.

Table5.3 shows 75% exceedance value used for potential power estimation in this study. This data set includes the values of Q for that particular exceedance values versus average annual run off for all gauges in the region. Each data set is plotted and curve fitting procedure is applied to that data to develop a “best fit” curve for that exceedance value. Average annual flow is

also correlated with the drainage area. Fig. 5.4 shows the correlation between annual flow and drainage area in the region.

Table 5.3 Discharge data projection for 18 potential SHP sites from surrounding gauging stations

Potential SHP site			Gauging station			Annual runoff (mcm)		Annual discharge (m^3/s)		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)		Annual runoff at site (estimated)	Annual runoff at gauge	Annual discharge at site (estimated)	Annual discharge at gauge	Site	Gauge	Q75 recorded at gauge	Q75 Estimated at site
	Northing	Easting		Northing	Easting								
Yeyi	104821	347812	Guder	989485	362578	17.0	30.1	7.1	11.3	309	679	0.97	0.605
Dongage	106555	358802	Guder	989485	362578	12.4	30.1	4.2	11.3	124	679	0.97	0.350
Melka	102991	392675	Guder	989485	362578	12.1	30.1	4.0	11.3	113	679	0.97	0.331
Dima	102783	327110	Guder	989485	362578	14.1	30.1	5.3	11.3	194	679	0.97	0.277
Bello	981283	355477	Bello	980302	353382	16.1	14.7	6.5	6.0	272	268	0.35	0.356
Bite	980560	361399	Debis	996850	364435	13.9	13.0	5.1	6.1	184	780	0.97	0.408
Huluka	986379	379583	Huluka	989438	377238	13.4	6.6	4.8	3.6	164	205	0.39	0.313
Debis	995938	377401	Debis	989438	377238	16.3	13.0	6.6	6.1	278	780	0.79	0.254
Aleltu	994588	374491	Debis	989438	377238	11.3	13.0	3.5	6.1	83	7809	0.79	0.206
Tiliku Anger	109662	282431	Anger Gutin	106108	244297	12.8	55.6	4.4	24.2	139	1977	6.92	1.407
Gerchi	107354	278336	Anger Gutin	106108	244297	18.1	55.6	7.7	24.2	353	1977	6.92	2.461
Werab-esa	109288	252610	Anger Gutin	104365	227298	14.9	55.6	5.7	24.2	223	1977	6.92	1.868
Indris	106597	216659	Anger	104365	227298	13.5	126.4	4.9	81.2	169	4570	20.79	2.875
Kile	106555	214580	Anger	104365	227298	18.5	126.4	7.9	81.2	366	4570	20.79	4.570
Gumbe	103521	206060	Uke	103074	227206	15.3	23.3	6.0	10.1	240	265	1.68	1.524
Haro	102243	252506	Loko	103621	236403	12.0	50.3	4.0	19.3	110	280	2.09	1.193
Aleltu	102357	267261	Loko	103621	236403	12.0	50.3	4.0	19.3	110	280	2.09	1.193
Chobsa	102399	265598	Loko	103621	236403	12.0	50.3	4.0	19.3	110	280	2.09	1.193

Therefore, for complete estimate of discharge values for 75% exceedance values at an ungauged location, all that is required is to have estimate of average annual runoff at that location from the correlation between catchment area and average annual runoff. Depending on the distance of a particular site to a neighboring gauge, a choice is made among three alternative techniques discussed in Chapter 4 section 4.5. Fig. 5.5 shows the result of the estimated flow–duration for Gumbe site based on observed discharge data from1995 to 2004 at Uke gauge.

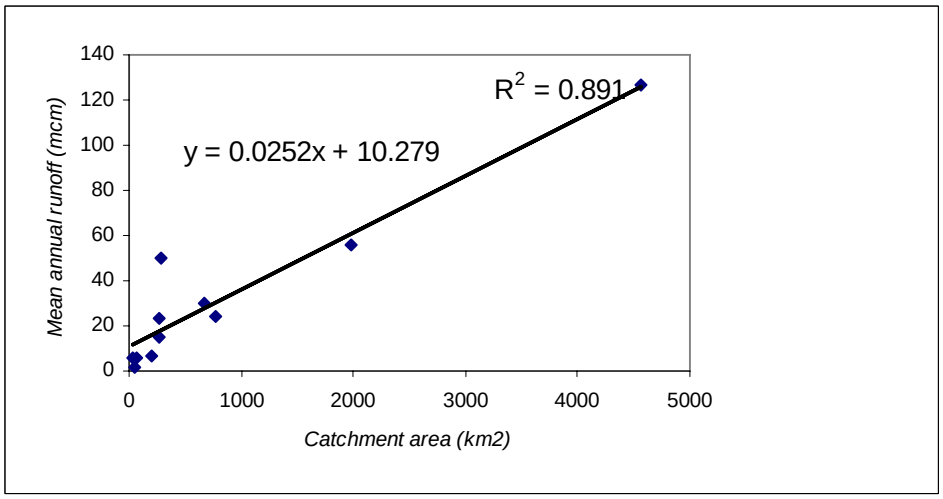


Fig. 5.4 Correlation between annual flow and drainage area in the region

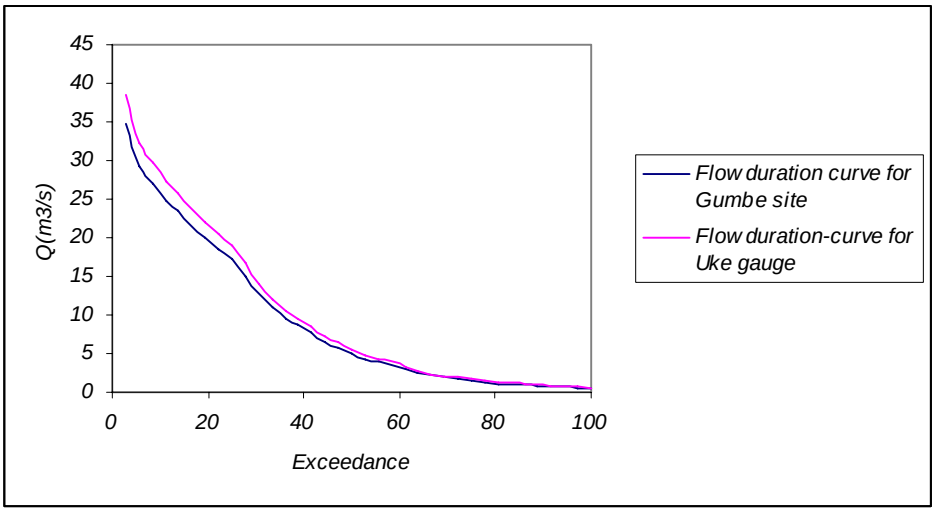


Fig. 5.5 Estimated flow–duration curve for Gumbe site based on observed discharge data from1995 to 2004 at Uke gauge

5.8 Estimation of Discharge for Power Generation

For the present study, 10 years daily-observed discharge data has been utilized to work out the dependable flows for the four ground verified sites; Aleltu, Debis, and Huluka and Bite small hydropower schemes. An approximation for a flow duration curve and design discharge at these ungauged sites is obtained from regionalized flow-duration curves developed by techniques as already discussed in chapter IV of section 4.7.

5.9 Head Losses

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. Accounting for the head losses caused by frictions, entrance, bends, trash rack, exit losses and valve losses can do this. A good profile will achieve a uniform acceleration of the flow, minimizing head losses.

A sudden acceleration or deceleration of the flow generates additional turbulence with flow separation and increases the head losses. The actual net head has been worked out by calculating head losses caused by frictions, entrance, bends, trash rack, exit loss and valve losses.

The maximum acceptable velocity and these loses have been calculated by adopting the following equations (Fritz, 1984);

Friction losses

$h_f = fLV^2/2gD$ …….. Eq.5.1

Where;
- f = Friction factor, for smooth steel pipe surface it is equal to 0.015 (Fritz, 1984)
- L = Length of penstock,
- V = Velocity of water in penstock, it is equal of 2.5m/s
- D = Diameter of penstock pipe

Entrance losses

$h_e = K_e V^2 / 2g$ ……..Eq.5.2

Where;
- h_e = Entrance loss
- Ke = Entrance loss coefficient for steel pipe with sharp edge it is equal to 0.5 (Fritz, 1984)
- V = Velocity of water in penstock and is equal to 2.5m/s

Trash Rack losses

$h_t = K_t V^2 / 2g$ …….. Eq.5.3

Where;
- h_t = Trash Rack Loss
- Kt = Trash Rack Loss coefficient and is equal to 0.5 (Fritz, 1984)
- V = Velocity of water in penstock and is equal to 2.5m/s

Exit losses

$h_e = K_E V^2 / 2g$ …….. Eq.5.4

Where;
- he = Exit losses
- $K E$ = Exit losses coefficient and is equal to 1.0 (Fritz, 1984)
- V = Velocity of water in penstock and is equal to 2.5m/s

Bend losses

$h_B = \eta K_b V^2/2g$ …….. Eq.5.5

Where
- h_B = Bend losses
- η = Number of bends
- K_b = Bend loss coefficient, for smooth bends the value is 0.2 (Fritz, 1984)
- V = Velocity of water in penstock and is equal to 2.5m/s

Valve losses (Gate Valve)

$h_{vg} = K_v V^2/2g$ Where hvg = Gate Valve losses
Kv = Gate valve loss coefficient for half open position 4.3
…….. Eq.5.6 V = Velocity of water in penstock and is equal to 2.5m/s

Valve losses (Butterfly Valve)

$h_{vb} = K_v V^2/2g$ Where hvb = Butterfly Valve losses
Kv = Butterfly valve loss coefficient when t/D ratio is 0.3 (Fritz, 1984)
……..Eq.5.7 V = Velocity of water in penstock and is equal to 2.5m/s

Therefore, total head loss is given by;

*Total Head Losses = Σ (*All losses determined from Eq.5.1 to Eq.5.7)*

Net Head = Gross head – *Total Head Losses ……Eq. (5.8)

Thus, the total Net head available for the power generation is presented in Table 5.4

Table 5.4 Net head used for the calculations of power potential

Name of the scheme	Gross Head(m)	Head Losses(m)	Net Head(m)
Bite	100	5.6	94.4
Huluka	100	7.1	92.9
Debis*	80	10.1	69.9
Aleltu*			
For Aleltu* & Debis* schemes common penstock is proposed.			

5.10 Power Potential and Installed Capacity

The power potential for the SHP sites has been worked out by using Eq. 5.13. For the computations of net head for the four ground verified sites, the method described in section 5.9 has been used. The turbine efficiency has been taken as 90% and the generator efficiency as 95%. To workout the installed capacity the power potential has been worked out for different dependable flows. The power potential thus, worked out for a different SHP site is presented in Tables 5.6 (a), (b) and (c). The installed capacity of the powerhouse has been decided on the basis of dependable flow, so that for a maximum period of time in a year two units can be run efficiently and for rest of the period, when the flows are lean, at lest one unit can be run efficiently. For efficient operations two identical units with same installed capacity has been suggested. This will facilitate to run at least one unit

during the lean flows and it will also help in operation and maintenance of turbines.

5.11 Design Discharge for Power Generation

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 through out 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. The design discharges considered for the present study are presented in Table 5.5.

Table 5.5 Design Discharge for power generation

Name of the scheme	Design Discharge(m3/s)	% of time equaled or exceeded	Power Potential(kw)
Bite	0.31	72.22	200
Huluka	0.30	72.22	200
Debis and Aleltu	0.41	63.89	300

5.12 Annual Power Generation

Annual generation has been worked out for various schemes by using eq. 5.9 and the results are presented in Table 5.7. The annual power is calculated for 90% of the operation time in a year, 10% time is left for breakdowns, maintenance and non operational periods.

Annual Power generation = Pp * 24 hours * 365 days ……Eq. (5.9)

Table5.6 (a) Power potential and installed capacity for Bite small hydropower scheme

% time equaled or exceeded	Discharge (m3/s)	Discharge for power generation(m3/s)	Power(kw)		
			Potential	Power Available	Power Available
2.78	17.66	15.89	11998	200	2X100
5.56	12.83	11.55	8717	200	2X100
8.33	10.66	9.59	7243	200	2X100
11.11	8.40	7.56	5707	200	2X100
13.89	7.27	6.54	4936	200	2X100
16.67	5.60	5.04	3803	200	2X100
19.44	4.87	4.38	3308	200	2X100
22.22	3.98	3.58	2703	200	2X100
25.00	3.09	2.78	2101	200	2X100
27.78	2.49	2.24	1694	200	2X100
30.56	2.13	1.92	1448	200	2X100
33.33	1.67	1.51	1137	200	2X100
36.11	1.17	1.05	795	200	2X100
38.89	1.02	0.92	694	200	2X100
41.67	0.88	0.80	601	200	2X100
44.44	0.80	0.72	545	200	2X100
47.22	0.75	0.67	509	200	2X100
50.00	0.69	0.62	472	200	2X100
52.78	0.60	0.54	407	200	2X100
55.56	0.52	0.47	354	200	2X100
58.33	0.47	0.42	320	200	2X100
61.11	0.44	0.40	298	200	2X100
63.89	0.41	0.37	281	200	2X100
66.67	0.38	0.34	256	200	2X100
69.44	0.36	0.32	244	200	2X100
72.22	**0.35**	**0.31**	**237**	**200**	**2X100**
75.00	**0.33**	**0.30**	**225**	**225**	**2X100**
77.78	0.32	0.28	215	215	2X100
80.56	0.31	0.28	209	209	2X100
83.33	0.28	0.25	191	191	2X100
86.11	0.26	0.23	177	177	2X100
88.89	0.24	0.21	161	161	2X100
91.67	0.20	0.18	137	137	1X100
94.44	0.18	0.16	123	123	1X100
97.22	0.15	0.13	100	100	1X100
100	0.12	0.11	84	84	1X100
*90% of average discharge available for power generation, 10% is left for environmental reasons					

Table 5.6 (b) Power potential and installed capacity for Huluka small hydropower scheme

% time equaled or exceeded	Discharge (m3/s)	* Discharge for power generation(m3/s)	Power(kw)		
			Potential	Power Available	Power Available
2.78	22.51	20.26	15296	200	2X100
5.56	15.72	14.15	10679	200	2X100
8.33	13.61	12.25	9248	200	2X100
11.11	8.23	7.40	5588	200	2X100
13.89	7.49	6.75	5092	200	2X100
16.67	6.02	5.42	4093	200	2X100
19.44	5.37	4.83	3646	200	2X100
22.22	4.07	3.66	2764	200	2X100
25.00	3.39	3.05	2304	200	2X100
27.78	3.08	2.77	2095	200	2X100
30.56	2.74	2.46	1860	200	2X100
33.33	1.50	1.35	1020	200	2X100
36.11	1.41	1.27	956	200	2X100
38.89	1.09	0.98	738	200	2X100
41.67	0.84	0.76	574	200	2X100
44.44	0.65	0.58	438	200	2X100
47.22	0.58	0.52	395	200	2X100
50.00	0.53	0.47	358	200	2X100
52.78	0.50	0.45	343	200	2X100
55.56	0.48	0.43	326	200	2X100
58.33	0.44	0.39	297	200	2X100
61.11	0.42	0.38	284	200	2X100
63.89	0.39	0.35	266	200	2X100
66.67	0.37	0.33	249	200	2X100
69.44	0.35	0.31	237	200	2X100
72.22	**0.33**	**0.30**	**226**	**226**	**2X100**
75.00	**0.31**	**0.28**	**212**	**212**	**2X100**
77.78	0.30	0.27	206	206	2X100
80.56	0.28	0.26	193	193	2X100
83.33	0.26	0.23	174	174	2X100
86.11	0.23	0.21	160	160	2X100
88.89	0.22	0.20	149	149	1X100
91.67	0.21	0.19	140	140	1X100
94.44	0.20	0.18	133	133	1X100
97.22	0.17	0.16	117	117	1X100
100	0.15	0.13	100	100	1X100
*90% of average discharge available for power generation, 10% is left for environmental reasons					

Table 5.6 (c) Power potential and installed capacity for Debis / Aleltu small hydropower scheme

% time equaled or exceeded	Discharge (m3/s)		Combined Discharge for power generation (m3/s) *	Power(kw)		
	Debis Weir	Aleltu Weir		Potential	Power Available	Power Available
2.78	13.51	10.95	22.01	13294	300	2X150
5.56	9.81	7.96	15.99	9659	300	2X150
8.33	8.15	6.61	13.29	8025	300	2X150
11.11	6.42	5.21	10.47	6323	300	2X150
13.89	5.56	4.51	9.06	5469	300	2X150
16.67	4.28	3.47	6.98	4214	300	2X150
19.44	3.72	3.02	6.07	3666	300	2X150
22.22	3.04	2.47	4.96	2995	300	2X150
25.00	2.37	1.92	3.85	2328	300	2X150
27.78	1.91	1.55	3.11	1877	300	2X150
30.56	1.63	1.32	2.66	1604	300	2X150
33.33	1.28	1.04	2.09	1260	300	2X150
36.11	0.89	0.73	1.46	881	300	2X150
38.89	0.78	0.63	1.27	769	300	2X150
41.67	0.68	0.55	1.10	666	300	2X150
44.44	0.61	0.50	1.00	603	300	2X150
47.22	0.57	0.46	0.93	564	300	2X150
50.00	0.53	0.43	0.87	523	300	2X150
52.78	0.46	0.37	0.75	451	300	2X150
55.56	0.40	0.32	0.65	392	300	2X150
58.33	0.36	0.29	0.59	354	300	2X150
61.11	0.34	0.27	0.55	331	300	2X150
63.89	**0.32**	**0.26**	**0.52**	**311**	**300**	**2X150**
66.67	0.29	0.23	0.47	284	284	2X150
69.44	0.27	0.22	0.45	270	270	2X150
72.22	0.27	0.22	0.43	262	262	2X150
75.00	**0.25**	**0.21**	**0.41**	**249**	**249**	**2X150**
77.78	0.24	0.20	0.39	238	238	2X150
80.56	0.23	0.19	0.38	231	231	2X150
83.33	0.21	0.17	0.35	212	212	1X150
86.11	0.20	0.16	0.32	196	196	1X150
88.89	0.18	0.15	0.29	178	178	1X150
91.67	0.15	0.13	0.25	152	152	1X150
94.44	0.14	0.11	0.23	136	136	1X150
97.22	0.11	0.09	0.18	111	111	1X150
100	0.09	0.08	0.15	93	93	1X150
*90% of average discharge available for power generation, 10% is left for environmental reasons						

From the observation of the table below, the total annual power generation capacity from these four sites is comes out to be 5384.8 MWh.Therefore, it would be interesting to compare the preliminary calculated annual power potential in these four sites with the lower per capita electrical energy consumption of Ethiopia.

Table 5.7 Power Potential, Installed Capacity and Annual Power generation

Name of the scheme	Design Discharge (m3/s)	Net Head(m)	Power Potential (kw)	Installed Capacity (kw)	Annual* Power (MWh)
Bite	0.31	94.4	200	2x100	1576.8
Huluka	0.30	92.9	200	2x100	1576.8
Debis & Aleltu **	0.49	69.9	283	2x150	2231.2
** Debis and Aleltu are combined scheme *The annual power is calculated for 90% of the operation time in a year, 10% time is left for breakdowns, maintenance and non operational periods					

According to EEPCO (Mulugeta Adamu, 2002) the low per capita consumption in the country is currently about 39 kWh. The conclusion to be drawn from this comparison is that the demand load centers with a total population of 138,072 within these four sites could be served with unregulated supply of power at 75% dependable supply. The comparison will also throw light on the economic significance of the 18 potential sites identified in the present study in fulfilling energy demands of load centers within the two sub-basins.

5.13 Preliminary Estimation of Power Potential of 18 Identified Sites

The dependable flows at the potential hydropower site have been summarized in section 5.7. These flows and the corresponding heads at the sites are used in equation 5.13 to estimate the preliminary unregulated power potential of each identified hydropower site. The power potential is directly proportional to the discharge and the hydraulic head available at proposed site. The term 'Head' is the altitude difference between the forebay and the powerhouse site. In other words head is the vertical height form where the water is dropped on the turbine to generate power. Practically the total available head is not actually available for the power generation as some of the hydraulic losses occur due to the friction in pipe in bends.

Therefore, actual head available after had losses is known as 'Net Head' and the head available with head losses is known as 'Gross Head'. Several methods exist for measurement of available head. Some measurement methods are more suitable on low-heads.

During the present study for preliminary measurement of head, GPS and maps at a scale of 1:50,000 with 20 m contour interval were used to measure the altitudes at the forebay and powerhouse sites.

The potential energy at a site may be computed by utilizing the following formula (Fritz, 1984):

$Ep=mgH$ ……. *eq. 5.1* 0

where 'm' is the mass of water (equals ρv being the density of water in kg/m^3 and 'v' is the volume of water in m^3) and 'g' is acceleration due to gravity.

If the power output 'Ph' of a hydro system is in *kW* that corresponds to the water flow rate 'Q' *(m^3/s)* and is given by;

Ph= ρ gH Qηp /1000 ……. eq. 5.11

where ηp is the plant efficiency (the ratio of the available electrical power to the water power.)

The standard expression for hydropower will be;

Ph= 9.81 H*Q*ηp …… eq. 5.12

where, for clean water 'g' is 1000kg/m^3 substituting the value of the 'g' in eq. 5.11

The above equation shows that power is the product of several constants, estimated efficiency, and two basic variables of 'Q' (discharge) and 'H' (hydraulic head). Once the capacity of the hydropower unit has been determined the maximum flow of water that will pass through the turbine is established if the flow–duration curve study is being used, it is recognized

that the runner discharge capacity is defined when the size of the runner is specified (Nahmeia,2005).

During the present study, initial estimation of the power potential of 18 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 loss caused by the frictions and bends in the penstock has been kept equal to 10% of the gross hydraulic head (Table5.2). Thus, the equation used for initial computation of power potential is;

$$Ph = 9.81 * Q * H\eta * \eta t * \eta g \qquad \text{..... eq. 5.13}$$

Where, 'Q' is the discharge taken equal to 90% of the 75% dependable flows, '$H\eta$' is the Net head taken 90% of the Gross head, Head losses are taken 10% of Gross head, 'ηt' is the efficiency of the turbine which is take equal to 90 % and 'ηg' is the efficiency of the generator which is taken equal to 95% (Nahmeia,2005).

5.14 Estimated Power Potential of 18 Identified SHP Sites

Perusal of Table 5.8 indicates that the total potential of 18 SHP sites in the study area comes out to be around 19564 kW. Of which, Anger basin (9 sites) contributes 16696.3 kW, whereas about 2867.5 kW is contributed by 9 sites in Guder sub basin.

Kile SHP site in Anger basin has a maximum estimated potential of 4.9 MW followed by Werabesa (2.5 MW), Indris (1.9 MW), Aleltu (1.6 MW), Chobsa (1.6 MW), Gerchi (1.3 MW) and Gumbe (1.2 MW). The remaining identified SHP sites have potential less than 1 MW and the estimated potential ranges from 112 MW to 765 MW.

Table 5.8 Estimated small/mini/micro hydropower potential of identified sites in Anger and Guder sub-basins

S.No	**Name of SHP site**	**Gross head (m)**	**Net-head (m)**	**Flow Q75 (m^3/s)**	**Discharge available for power generation (m^3/s)**	**Power Potential (kw)**
1.	Yeyi	80	72	0.605	0.544	329
2.	Dongage	280	252	0.350	0.315	665
3.	Melka	220	198	0.331	0.298	494
4.	Dima	160	144	0.277	0.249	301
5.	Bello	140	126	0.356	0.320	339
6.	Bite	100	90	0.408	0.367	277
7.	Huluka	100	90	0.313	0.281	212
8.	Debis	80	72	0.254	0.229	138
9.	Aleltu near Ambo	80	72	0.206	0.185	112
10.	Tiliku Anger	80	72	1.407	1.266	765
11.	Gerchi	80	72	2.461	2.215	1338
12.	Werabesa	200	180	1.868	1.682	2539
13.	Indris	100	90	2.875	2.587	1953
14.	Kile	160	144	4.570	4.113	4968
15.	Gumbe	120	108	1.524	1.372	1243
16.	Haro	80	72	1.193	1.074	648
17.	Aleltu	200	180	1.193	1.074	1621
18.	Chobsa	200	180	1.193	1.074	1621
Total power potential in the study area						**19563.88**

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CHAPTER SIX GROUND VERIFICATION AND ENGINEERING GEOLOGICAL APPRAISAL OF SHP SITES

6.1 General

A Chinese team in 1989 made a study on mini and micro hydropower potential in some parts of the country. The study conducted by the Chinese team identified mini and micro hydropower potential sites for rural electrification in central, west and southern parts of the country. It is evident the present study area, that is part of the country (region Oromia) covered by the Chinese team study is rich in hydropower potential (estimated potential of 945MW) when compared with other parts of the country. This study was based on assumed morphological conditions of the areas and no detailed specific studies of potential hydropower sites has been conducted to date (Mullugeta Adamu, 2002).

It is therefore, necessary to make power potential study and the justification for the detailed geotechnical investigation of the potential small hydropower sites in the sub-basins. Especially for isolated communities in countries where the cost of coal and oil is high and access to the transmission lines is limited or non-existent, development of even the smallest hydropower site may be worthwhile.

6.2 Ground Verification of Identified Small Hydropower Sites

The potential SHP sites were identified from topographic map at 1:50,000 scale at a preliminary stage of the study. In addition, the suitability of the sites for hydropower development such as actual head measurement, accessibility details and engineering geological suitability of the sites has been ascertained through field investigation. From the present study a total of 18 potential sites have been identified.

The power potential has been worked out from the dependable flows estimated using techniques discussed in chapter 4. Thus, the 18 potential SHP sites can be ground verified and be taken up for detailed engineering geological appraisal. However, with the limitation of resources, time, and

financial constraints, it was not possible to under take field investigation and detailed engineering appraisal of all 18 SHP sites. Thus, a sincere effort has been made to cover 4 potential SHP sites to under taken ground verification and detailed engineering geological appraisal. The selection of these 4 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 ground verification though there are sites which are very far form Addis Ababa.

(ii) There should be an access to all the components, viz- diversion weir, water conductor and powerhouse.

(iii) The head and drainage area at the potential sites satisfies the minimum criteria set up in chapter 4 i.e site must have a catchment area greater than 110 sq km and head greater than 80 m.

(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.

Table 6.1 Sites selected for ground verification and detailed engineering geological appraisal

Name of SHP site	**Name of stream**	**Location of diversion weir (UTM)**		*Nearest town*
		Northing	**Easting**	
Debis	Debis	995884	377328	Ambo
Aleltu	Aleltu	994753	374578	Ambo
Huluka	Huluka	986535	379586	Ambo
Bite	Bite	980560	361399	Mutulu/Guder

6.3 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 and design of the power plants. With the help of EMA topo-maps (1:50,000), it is possible to locate the intake, trace of headrace, penstock alignment and the powerhouse site, with precision enough for the

feasibility studies. Thus, the tentative location of the various components of the SHP scheme has been selected based on certain parameters.

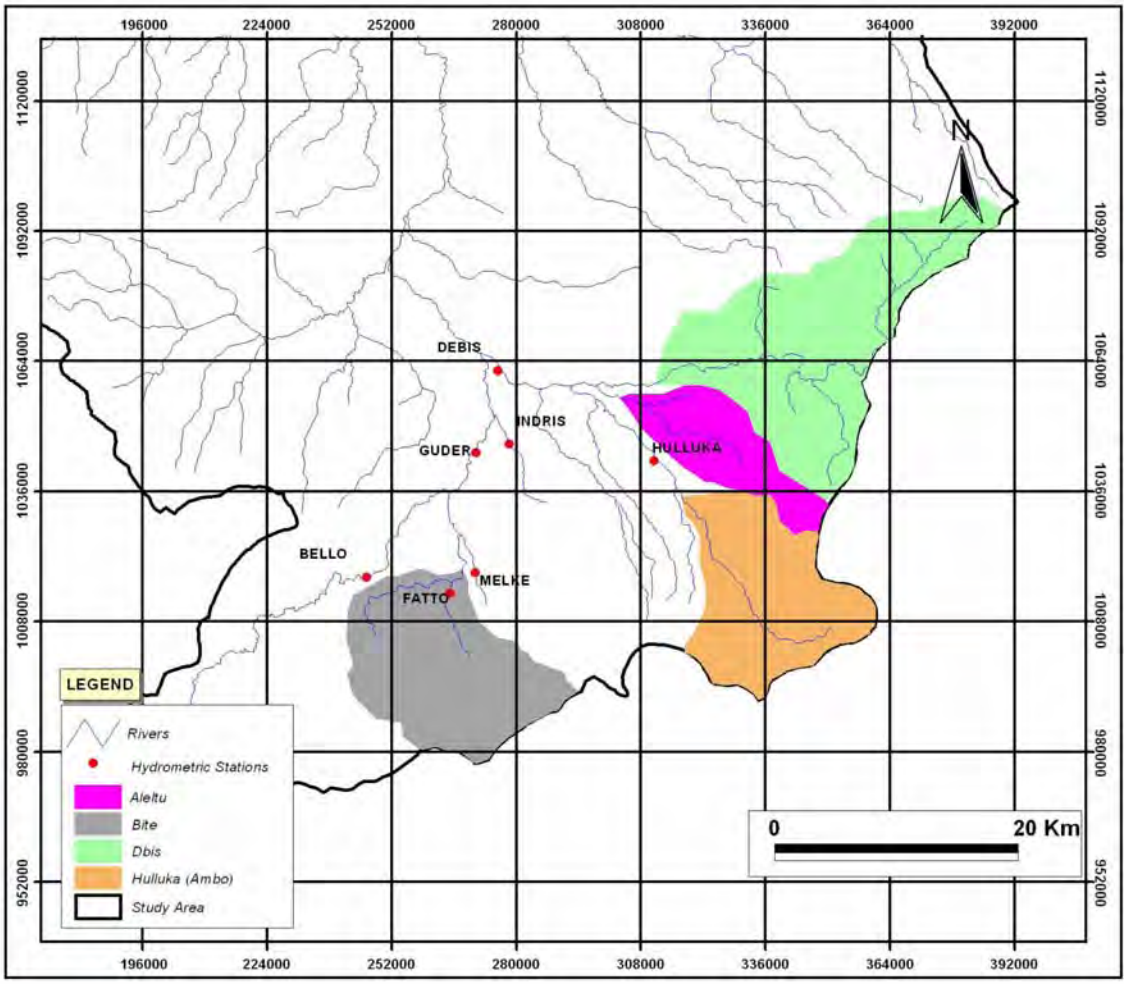


Fig. 6.1 Sites selected for ground verification and detailed engineering geological appraisal

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 and the slopes on which the water conductor is planned are relatively gentle. For each major components viz; 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 lay out 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 down stream 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 viz, diversion weir site, desilting tank, forebay and powerhouse site. Each component 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) At each site hydrological observations were carried out. Discharge has been measured by area velocity method at the proposed diversion weir site to have an approximate idea of the dependable discharge. Besides, personal interviews were conducted with the local people to qualitatively assess the flow variations in respective streams.

(iv) Though direct investigation methods such as bore hole drilling is uncommon for small hydro scheme, engineering geological appraisal of the sites at pre-feasibility level has been done to permit initial

estimates, for the security of the dam foundations, the stability of slopes and the over all conditions and strength of rocks and soils present at various components. Thus, information is complemented, with collection of soil samples for laboratory testing. 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 site selection for the different components of the scheme is such that the access is feasible and discussed here under;

6.3.1 Aleltu/ Debis Small Hydropower Sites

Debis/ Aleltu sites are located on each side of Odo Liben Giyorgis ridge near northern part of Ambo town. The site has been selected to be as a combined scheme as far as the topography of the site is concerned. The rivers Debis and Aleltu, the sources of which are near the high lands located south-eastern part of Guder sub-basin. These streams ultimately drain into Guder river after joining at the end of Odo Liben Giyorgis ridge where a common penstock, forebay and powerhouse sits is proposed. These sites are well accessible upto powerhouse site (3km from Ambo town) by a newly built gravel road which starts form the market place in Ambo town. From the common powerhouse site where water will be diverted at separate diversion weir sites on Aleltu and Debis rivers, access to the forebay, and Aleltu stream diversion weir site is on a foot path along the water conductor system. Alternate access is also possible to Aleltu diversion weir site via elementary school, which is located at the eastern part of Ambo town on the existing motorable dirt road. From this diversion weir site a footpath is present across the top of the ridge on agricultural land to the diversion weir site of Debis river on the other side of the ridge. The desilting tank site for Debis stream is also accessible through a footpath along the water conductor at the bottom of the ridge near the proposed diversion weir site.

For Aleltu site the proposed diversion weir will be located on gentle slope terrain of the river crossing, defined by co-ordinates 374578 E; 994753 N, at an elevation 2040m. The water conductor will be taken on the right bank of the Huluka stream, which will cross a dry gully by an aqueduct, located 994906 N; 374469E. The desilting tank has to be located near the proposed diversion weir site (994485N, 374768E) at an elevation 2039m.

The water conductor is further taken to the other side of the ridge after joining the common forebay site to a desilting tank site (995545 N, 373172E) for Debis scheme is proposed near the diversion weir site(995884N, 377328E) at an elevation 2040m following the left bank of Debis river.

A common powerhouse site for both Debis and Aleltu schemes is proposed at the confluence of the two rivers and will be located 995842N; 372632E, at an elevation of 1940m to have a gross head of 80m.

The general layout of all four ground SHP schemes is shown in fig. 6.2. The location and elevation of various components of these schemes are presented in table 6.2.

6.3.2 Huluka Small Hydropower Site

This site is situated in a reach where Huluka river flows straight in a deep gorge 500m upstream of the confluence of the river Kerkero with Huluka. The site controls a catchment area of 164 km^2 out of which most part is heavily inhabited with scrubs. Huluka river crosses at the center of Ambo town from south direction and joins Debis river at Senkele Fariso village to a tributary of Guder. The right and left bank of project area is crises-crossed by numerous tracks and paths. The selected diversion weir site is situated approximately 3km away in the north-east direction from the village Goremti Medhanialem church.

The site is accessible by vehicle on the main asphalt road from Addis Ababa 3km before reaching Ambo town. Taking left turn at this point by an infrequently used track of about 4km following the right bank of Huluka

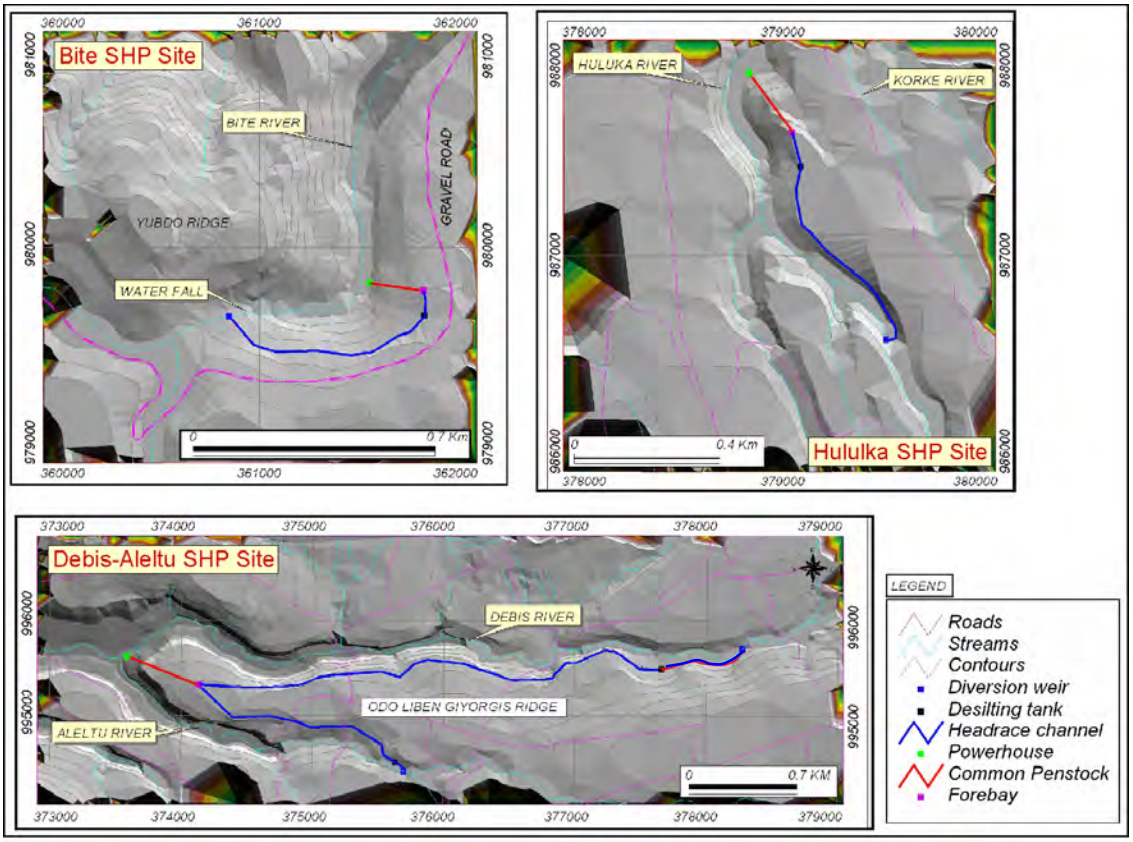


Fig. 6.2 General layout of ground verified SHP schemes on a TIN model

stream will lead to the site. After this point access to the powerhouse site, is possible through a footpath by walking about 1.5km. The main topographic feature of the proposed diversion weir site is the deep valley which Huluka river has cut and rather steep slope of the valley with nearly vertical sides. On both banks the terrain is almost flat table land of elevation of about 2500m. Access to the diversion weir is only possible through the right bank on a narrow footpath making it difficult to cross the river rendering the left bank virtually uninhabited. The proposed diversion weir will be located at an elevation of 2404m having coordinates 986535N; 379586E. The power house will be located at an elevation of 2300m, defined by coordinates 987798N, 378895E about 1km down stream of the diversion weir along the river course.

Table 6.2 Location and elevations of various components for ground verified sites

SHP site	Component	Elevation(m)	Length(m)	Location (UTM)	
				Northing	Easting
Debis	Diversion weir	2040	---	995884	377328
	Intake channel	---	200	---	---
	Desilting tank	2040	---	995545	376645
	Headrace channel	---	3800	---	----
	Forebay tank	2029	---	995342	373172
	Penstock	---	400	----	----
	Powerhouse	1940	---	995842	372632
	Tailrace channel	---	25	----	---
Aleltu	Diversion weir	2040	---	994753	374578
	Intake channel	---	20	---	---
	Desilting tank	2040	---	994485	374768
	Headrace channel	---	1800	---	---
	Forebay tank	1940	---	995342	373172
	Penstock	---	400	----	---
	Powerhouse	1940	---	995842	372632
	Tailrace channel	---	25	---	---
Huluka	Diversion weir	2404	---	986535	379586
	Intake channel	---	1100	---	---
	Desilting tank	2400	---	987325	379135
	Headrace channel	---	300	---	---
	Forebay tank	2400	---	987456	379354
	Penstock	---	150	---	---
	Powerhouse	2300	---	987798	378895
	Tailrace channel	---	25	---	---
Bite	Diversion weir	2360	---	979665	360832
	Intake channel	---	600	---	---
	Desilting tank	2355	---	979580	361688
	Headrace channel	---	200	---	---
	Forebay tank	2355	---	979780	361688
	Penstock	---	110	---	---
	Powerhouse	2255	---	979895	361441
	Tailrace channel	---	25	---	---

The water conductor will be taken on the right bank of the river. The desilting tank has to be located (987325N, 379135E), at an elevation 2400m. The headrace channel will be taken further ahead on the right bank of the stream for about 50m to join the forebay take site (987456N, 379354E) having the same elevation of the desilting tank.

6.3.3 Bite Small Hydro Power Site

Bite stream it is one of the tributary of Guder River. It falls in the southern part of the study area. Information on gradient along the river indicates, at elevation of around 2380m, Bite river experience considerable fall. The river descends 140m elevation difference in 600m stretch of its course around the

proposed diversion weir site (Fig. 6.2). The site is readily accessible form Guder town via 12km all weather gravel road, which leads to Tikur Echini town. Access to the diversion weir site is easy by taking a footpath from the main road. The powerhouse site is also accessible from the main road up to Mutulu village and down to the valley through a footpath. The proposed diversion weir will be located at an elevation 2360m, defined by co-ordinates 979665N, 360832E, just down stream of a 20m high two water falls of Melke and Beri streams. The water conductor will be taken on the right bank of Bite River just parallel to the existing road. The water conductor has to cross gulley erosion at location (97967N; 361771E) through an aqueduct. The desilting and Forebay has to be located on a flat farm land (979780N; 361688E) at an elevation of 2355m just close to each other. The proposed powerhouse site is located on the bank of Bite stream, at elevation 2255m (9798955N, 979895E).

6.4 Engineering Geological Appraisal of SHP Sites

A small hydroelectric development will generally have the same design considerations inherent in a large project. However, it can rarely afford a large budget for engineering geological exploration and mapping. Structural loadings for a small project will be relatively small, and the required structural strength of the native geological formations and soil formations will also be relatively small. However, stability of soils and geologic features cannot be compromised. Thus, it is necessary to develop a geologic map as complete detail as possible. Very often, the need to proceed with detailed engineering geological studies of a site, are under estimated. In many cases with regrettable consequences –seepage under the weir, open channel slides etc. (Fritz, 1984).

Structural integrity will be most important for the turbine and dam foundations and beneath the penstock anchorages. If the foundations of the head works or powerhouse are constructed from soft materials, careful field investigation should be carried out and the foundations be properly treated to limit their differential settlement and avoid possible liquefaction due to machine vibrations. However the main geological problem in SHP plants is

the slope instability throughout the project (Fritz 1984). The strength and deformability of slope material, particularly the shear strength properties influence the stability conditions. Therefore, it is necessary to identify potential unstable slopes in the initial stages of investigation to retain the slopes and design various engineering structures accordingly.

6.4.1 Geology of Small Hydropower Sites

Geology of Aleltu Small Hydropower Site

Aleltu river is a tributary of Debis river. The site is located near Ambo town. The geology of the site is considered from personal geological field surveys. The area is chiefly composed of rocks of the volcanic products. The rocks exposed in the project area are mainly of intermediate nature. Soil cover is thick. A description of geology at various components of the scheme is given in the following paragraphs (Fig.6.3).

Diversion and intake structure

The stream at the proposed diversion weir flows towards east with an approximate width of 10m. The rock exposed at the site is trachytic vesicular basalt. The slope is gentle and sparsely covered with vegetation on both banks. Rock exposed at the right abutment is slightly weathered with some jointing. The rock exposed at the left bank has two major joint sets with preferred orientation of J1: N110o/77o, J2: N 351o/68o (dip/amount) (Plate 5.1) and it is slightly weathered. Both the slopes are gentle towards the valley. The rock mass rating (RMR) at the diversion site indicates that the rock is of good quality (RMR value 77 to 72).

Desilting tank site

The desilting tank site for Aleltu SHP schemes is located on a table land, approximately 40m down stream of the proposed diversion weir site. The basalts exposed are highly weathered and massive. These deposits are either distributed over small area or are thinly and widely distributed covered with sallow layer of reddish brown residual soils.



Plate 6.1 Geology at Aleltu diversion weir site

Headrace channel and Forebay site

Residual soils of varying color are present at the proposed headrace channel and forebay sites as unconsolidated deposits overlaying basaltic rock. The rock out crop exposed down stream of the river bank shows that the vesicular basalt beneath is highly weathered and massive. The proposed headrace channel will be mostly crossing through these soil deposits over gentle slope of the ridge. No prominent land slides or slope failure have been recognized along this routes.

Penstock Alignment and power house site

The geology along proposed penstock alignment is also overlain by a considerable thickness of soils present at the forebay site. It is assumed that same geologic conditions exist at the penstock alignment and powerhouse as the headrace and forebay sites.

Geology of Debis Small Hydropower Site

Debis river flows down through a deep broad valley floor in SW direction at the proposed diversion weir site. The river joins Aleltu stream near the

common powerhouse area at the end of "Odo Liben Giyorgis" ridge. The geology of the site is same as that of Aleltu site since these are located on either sides of "Odo Liben Giyorgis" ridge. However, difference in degree of weathering of the basaltic rock exposed on the valley sides is observed at Debis site.

Diversion and Intake Structure

The diversion and intake site of Debis scheme characterized by alluvium soils, which consist of gravel, sand, silt and clay. Here, no out crops of rock is observed on both banks of the river at the proposed diversion weir. The physiography of the site mainly comprises of elevated ridges of basaltic hills, which form steep to gentle slopes of the diversion site area or low lying plain areas. The geology at the left bank is dominated by thin lenses of reddish friable consolidated mud rock overlain by about 1m thick alluvial deposits. The right bank of the proposed diversion weir sit is also composed of alluvium with the absence of the mud rock.

Desilting tank site

The proposed desilting tank will be constructed on a flat land at the geographical location of 995563N; 376545E at an elevation of 2040m. Here the basaltic rock is exposed at higher elevation on the ridge, which is highly weathered and massive in nature. At the proposed desilting tank site the basalt is covered with thick layer of colluvial soil formation.

Headrace channel

The total length of the water conductor of Debis SHP site is around 4 km. The water conductor is proposed along the gentle slope of the ridge covered with residual soils. At location 995678N; 376343E moderately weathered columnar basalts were exposed just beneath the proposed water conductor line. At this location signs of rock fall have been noticed. The degree of weathering of the basaltic rock increase from diversion weir site to the powerhouse location. Though most of the water conductor route is located

on residual soil, which covers the basaltic rock, no signs of slope distress were recognized.



Plate 6.2 Proposed diversion weir site for Debis small hydropower site

Since a common forebay, power house and penstock site is proposed for both Debis and Aleltu SHP sites, the geology is the same as described for Aleltu scheme at these locations.

Geology of Huluka Small Hydropower Site

The local geology of Huluka SHP site and the surrounding area can be expressed as basaltic rock covering the whole range of the ridge between Huluka and Korke rivers. Residual soil formation covers most of the table land of the ridge. The rock is moderately weathered (Class G3, Irfan and Dearman, 1978). Fig. 6.3 shows geology of Huluka small hydropower site.

Diversion and intake structure

The river width at proposed diversion weir site is about 15m and it flows towards North West. On both bank basalts are exposed. Three major joint sets are exposed on the right and left bank and the preferred orientation (Dip/Amount) is J1: $N305^0$ /23^0, J3:215^0 /83^0 and J2: N 305^0 /81^0. On both banks the slope is very steep. (Plate 6.3). The degree of weathering of the rocks is moderate and spacing between discontinuity surfaces is high.

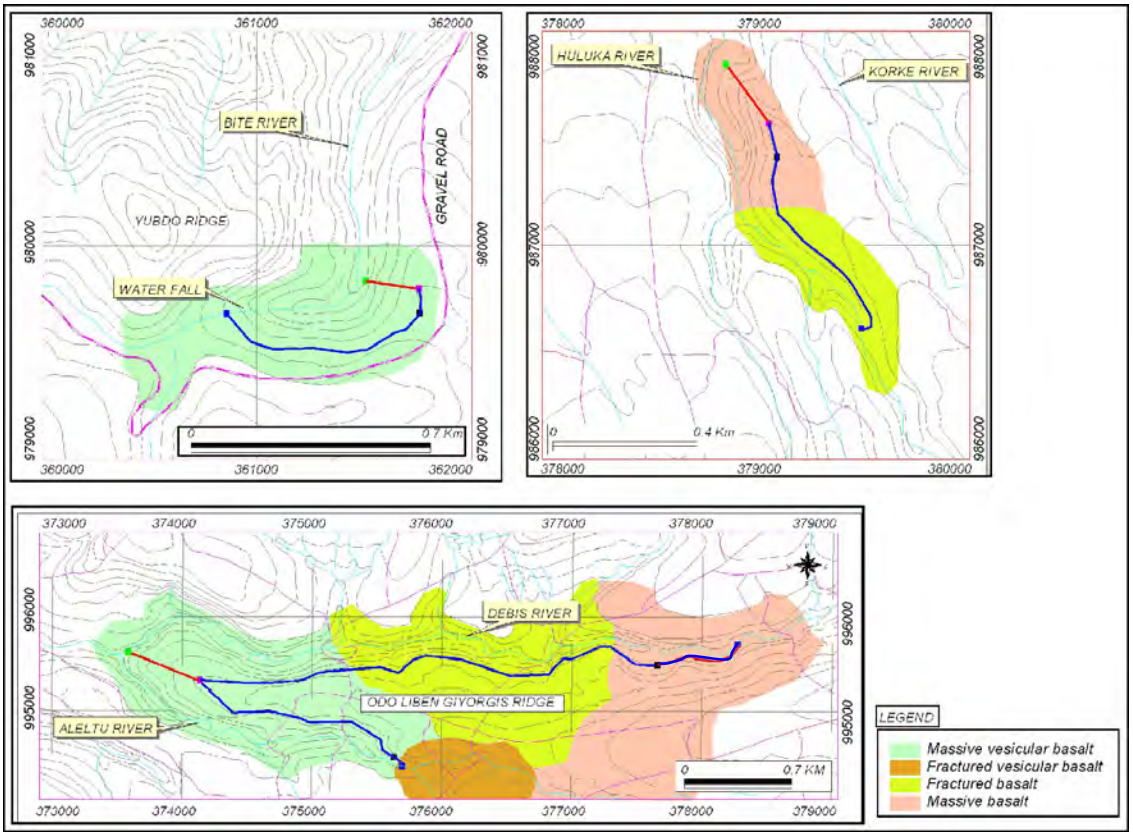


Fig. 6.3 Geologic maps for ground verified sites



Plate 6.3 Diversion and Intake site at Huluka SHP site

Evidences of big rock boulder falls are noticed around the proposed diversion wire site. The rock mass rating (RMR) at the diversion weir site indicts that the rock is of fair to good quality (RMR 58 to 65).

Desilting tank site

The desilting tank is located 600m down stream of the diversion weir. No

flat land is available for desilting tank site near the diversion weir site. At the proposed desilting tank site soil cover is thick and no rock out crop is exposed. The topography is flat and dominated by agricultural land.

Headrace channel and forebay site

The geologic condition along the waterway up to 150m is same as that of the diversion weir site. The rocks along the sides of the cliff are jointed and moderately weathered. The basaltic rocks have an unconfined strength of 156 Mpa as measured from Schmidt hammer test. After this stretch the water conductor will be aligned along the top of the ridge covered with alluvial soil deposits. The forebay site will be located on a tableland near the desilting tank site. Here, no rock out crop is exposed and the area forms part of an agricultural land.

Penstock alignment

Some out crops of massive basalts with no jointing is exposed along the penstock alignment. The basalt is moderately weathered and has an unconfined strength of 107Mpa. Residual soil cover dominates penstock alignment with thickness of about 3m.

Power house site

The massive basalt exposed along the penstock alignment is not visible at the powerhouse site. Later, colluvial and recent river deposits dominate the proposed powerhouse site. For the construction of power house these materials has to be removed and the adjoining slope has to be back cut for terrace formation to accommodate the power house.

Geology of Bite Small Hydro Power Site

The topographical differences within the project area are considered to be the geologic, which formed these. The geology considered is that of massive, slightly weathered basalt with the whole top part of the ridge covered by residual soils of varying colors. A description of geology at various

components of the scheme is presented in the following paragraphs. Fig. 6.3 shows the geological map of Bite small hydropower site.

Diversion and in take site

The diversion site is located just above a narrow 20m water fall of Bite river. The basalt is very massive with no prominent jointing. The rocks on both banks are competent. The weathering is slight and unconfined strength measured at these rocks shows strength of 155, Mpa.

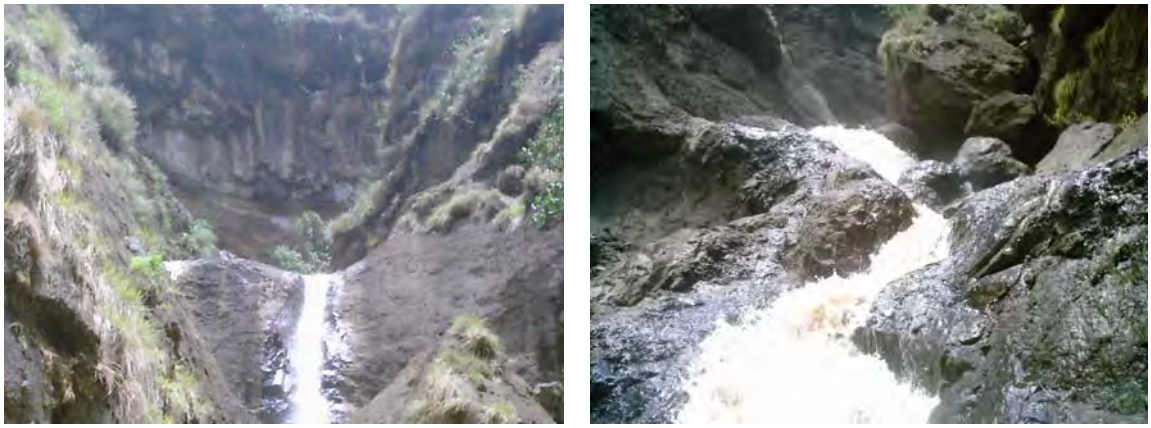


Plate 6.4 Diversion and intake site for Bite small hydro power site

Desilting tank and fore bay site

Since no space is available to accommodate the desilting tank near the diversion weir site, the proposed desilting tank will be located close to the forebay site. The geology at the proposed desilting tank and forebay site is not exposed. The site falls in a thick layer of residual soil on agricultural land. However, the same rock type (massive basalt) is exposed at the cliffs of the ridge.

Headrace channel

The proposed headrace channel will follow the steep sides of the ridge for about 80m from the diversion weir site. The rock exposed along this section of the channel is massive basalt with absence of joints. After this point the headrace channel is aligned just parallel to the existing gravel road. No rock out crop is exposed at this location. The area is covered with thick layer of

soil. As seen from gully erosion along the road side, the soil cover is more than 6m.

Penstock alignment

The penstock follows a steep formation of the basalt rock. At the upper reaches of penstock alignment, thick layer of residual soil formation over lays the massive basaltic rock. Rocks at the proposed alignment are slightly weathered with no prominent jointing. No sign of slope movement is observed at this point.

Power house site

The proposed powerhouse site is covered with shallow layer of colluvial soil, which contains cobbles and boulders of varied dimension. The basaltic rock underling the formation is moderately weathered. The proposed powerhouse site is densely covered with vegetation.

6.5 Engineering Geological Characterization of Rocks

The rocks may be involved as foundation material, in excavations or as a slope forming material. The performance of rock as foundation material or to form a stable slope entirely depends upon the properties of the rocks (Johnson, Degraff 1991). Therefore, in order to evaluate the suitability of the rock mass as a foundation material, in excavation or as a slope forming material, it is essential to characterize the rock mass based on certain engineering properties like strength, deformability, petrological name, degree of weathering or alternation characteristics of the rocks. For the present study, the rock mass rating system, known as Geomechanics Classification of Beniawski (1989) has been employed to describe the quality, stability conditions, shear strength properties, and the deformability of the rock mass exposed at ground verified SHP sites .

6.5.1 Weathering

Weathering is the process by which the rock disintegrates to form soil by physical or chemical processes. Weathering plays a significant role in

altering or controlling the engineering properties of intact rock as well as rock mass, Therefore, the depth and degree of weathering are important parameters to be considered while deciding the general alignment of SHP schemes. Local infiltration of surface water and leakage from channels or forebay may result in slope slides because these structures are located close to the ground surface where the rock is generally jointed and weathered even to a depth of several tens of meters (Jiandong 1997).

In the present work, the weathering profile reaches to the development of soil from the rock units. Some part of the area is covered by residual soils, which are the results of intense weathering of the in-situ rock. In some area, the weathering profile is not well developed but shows a different grade. In the study area, the weathering grade of rock is assigned according to Irfan and Dearman classification (cited in Trufat H., 2001). Based on this classification the study area is graded (Annexure III).

Aleltu Small Hydropower Site

According to weathering grade for rock mass by Irfan and Dearman, (1978) the weathering degree at Aleltu small Hydropower site varies from slightly weathered to residual soil formation. Rocks which are exposed at the river bank area show the degree of weathering increase from the diversion weir to the forebay site.

However, the weathering conditions along the water conductor and powerhouse area are extremely weathered because of which all the rock material is disintegrated and changed residual soil formation.

Debis Small Hydro Power site

The weathering degree of Debis small hydropower site varies form slightly weathered to residual soil. Rocks, which are exposed at higher elevation on the ridge are slightly weathered and the degree of weathering increased form the diversion weir sites to the forebay and power house. The rocks along the water conductor are extremely weathered and have changed to residual soil.

Huluka small hydropower site

Rocks exposed at Huluka small hydropower site have varied degree of weathering grade, the degree varies form moderately weathered to extremely weathered classes (Irfan and Dearman (1978)). Rocks which are exposed at the river banks are moderately weathered from the diversion weir to power house site. Rocks exposed at forebay and 60% of water conductor area indicate high weathering degree which has resulted rocks into residual soil formation, which means that all the rock material is converted to soil.

Bite small hydropower site

The weathering degree of Bite small hydropower site varies form slightly weathered to residual soil. Rocks which are exposed at the river bank are slightly weathered and the weathering degree increases from the diversion weir site to forebay and decreases from forebay to the powerhouse sites. At the diversion weir site the weathering of rocks show discoloration of the rock material, which indicates slight weathering grade. The weathering degree of rocks along the water conductor is similar to that of diversion weir site for 40% of the area and with the remaining 60% of the alignment completely weathered to residual soil formation. The rocks at the powerhouse and penstock alignment are moderately weathered.

6.5.2 Rock Mass Classification

Rock mass classification is a widely used, economical and extremely useful basis for determining engineering properties. Rock mass classification is the bases to make a definitive decision on engineering projects involving rock, since rock mass classification can represent the actual site conditions than intact rock classification do. The stability and deformability of the structures is dependent on the strength and deformability of the rock mass. Discontinuities such as bedding surfaces, faults, joints and foliations are the most important characteristics of the rock mass. The presence of discontinuities reduces the strength of the rock mass. Besides, discontinuities primarily control the mass strength and deformability of the rock mass. Thus, the use of rock, whether as foundation material in

excavations and tunnels or in maintaining stable slopes involves determinations of properties of rock mass in which the presence of discontinuities govern the engineering character numerous methods have been developed to guide the judgments of rock qualities for engineering purposes (Bieniawski, Z.T., 1989).

During feasibility, preliminary design and excavation/construction stages when very limited information on rock mass properties is available, the use of rock mass classification system can provide considerable input on engineering properties of the rock mass. Using rock mass classification schemes it is possible to estimate support requirement during excavation and estimate strength and deformation properties of the rock mass.

The rock mass strength and deformability governed by the presence of discontinuity planes joint, fault, and bedding planes, in addition the spacing and filling material also significant effects the engineering properties of the rock mass. Though numbers of rock mass classification schemes are available however, classification system proposed by Bieniawiski is widely used. Geomechanics classification or Beniawski rock mass rating (RMR) considers the following six parameters to classify rock mass;

(i) Uniaxial compressive strength of rock (UCS)
(ii) Rock Quality Designation (RQD)
(iii) Spacing of discontinuities
(iv) Condition of discontinuities
(v) Ground water condition
(vi) Orientation of discontinuities

For the present study the data pertaining to RMR has been collected from both banks at the proposed diversion weir sites of Aleltu and Huluka SHP sites.

Based on the conditions the ratings for each of the 6 parameters were assigned from the standard RMR table and are added to get the RMR value. The RMR data collected from various locations at different SHP sites is summarized in Table 6.3.

The uniaxial compressive strength (UCS) has been determined by Schmidt Hammer and the Barton and Choubey, 1977, relation has been used to work out UCS from the Schmidt rebound number;

$\log_{10}(\sigma_c) = 0.00089\gamma R + 1.01$ --------eq (6.1)

Table 6.3 Summarized RMR data collected from various locations at different SHP sites

S.No	RMR Data Locationtion	*Parameters Ratings*										RMR	Rock Mass Class
		UCS			RQD			Spacing	Condition	GWC	Orientation		
		SHV	UCS (Mpa)	*Ra*	Jv	RQD	*Ra*						
Huluka Small Hydropower Site													
1	DW R1	56	157.9	12	5	98	20	15	6	10	-5	58	Fair rock
2	DW R1	55	155.1	12	6	98	20	15	6	10	-5	58	Fair rock
3	DW L1	48	135.3	12	7	98	20	15	13	10	-5	65	Good rock
4	DW L2	44	124.1	12	8	95	20	15	13	10	-5	65	Good rock
Aleltu Small Hydropower Site													
1	DW R1	50	141.1	12	5	98	20	15	25	10	-5	77	Good rock
2	DW R2	56	157.9	12	4	95	20	15	25	10	-5	77	Good rock
3	DW L1	65	183.4	12	5	92	20	15	25	10	-5	77	Good rock
4	DW L2	51	143.9	12	6	88	15	15	25	10	-5	72	Good rock

Where; 'σ_c', uniaxial compressive strength in Mpa, 'γ' is the Dry rock density in KN/m^3 and 'R' is the Schmidt rebound number.

The Rock Quality Designation (RQD) has been determined by Palmstorm's Volumetric Joint Count method (Palmstrom, 1982), according to which;

RQD = 115 – 3.3 Jv ----------eq (6.2)

Where; 'RQD' is the Rock Quality Designation (%), 'Jv' is the total number of discontinuities greater than 10cm in length in 1m cube of Rock mass.

For other parameters, like; Spacing, Condition of discontinuities, Ground water condition, and Orientation of discontinuities visual observations and

measurements have been made and accordingly, the ratings were assigned from the standard RMR table.

Shear Strength of Rock Mass as Determined from RMR

The shear strength is very important engineering property of the rock mass, as it directly influence the stability of rock mass. As already discussed, most of the water conductor of SHP scheme has to be laid down on the slopes; therefore the shear strength behaviour of the rock mass is very important from the point of view of stability of slopes and the safe functioning of the scheme. The Shear strength parameters of rock mass as determined from RMR are summarized in Table 6.4.

Table 6.4 Summarized shear strength parameters and modulus of deformation Ed as determined from RMR

S.No	RMR Data Location	RMR Value	Shear strength parameters				Modulus of deformation Ed (Gpa)			
			Cohesion (Range) (Kpa)	Angle of Friction 'ϕ' (Range)	Cohesion *	Angle of		Bieniawiski's Relation	Agarwal et al Relation	Design value for Ed
***Huluka* Small Hydropower Site**										
1	DW Rt1	58	200-300	25°–35°	2.9	34.0	15.85	16	3.63	3.63
2	DW Rt1	58	200-300	25°–35°	2.9	34.0	15.85	16	3.63	3.63
3	DW Lf1	65	300-400	35°–45°	3.25	37.5	23.71	30	5.01	5.01
4	DW Lf2	65	300-400	35°–45°	3.25	37.5	23.71	30	5.01	5.01
Aleltu Small Hydropower Site										
1	DW Rt1	77	300-400	35°–45°	3.85	43.5	47.32	54	8.71	3.63
2	DW Rt2	77	300-400	35°–45°	3.85	43.5	47.32	54	8.71	3.63
3	DW Lf1	77	300-400	35°–45°	3.85	43.5	47.32	54	8.71	5.01
4	DW Lf2	72	300-400	35°–45°	3.6	41.0	35.48	44	6.92	5.01
* Cohesion 'C' = 0.05 RMR * Angle of internal friction 'ϕ' = 0.5RMR + 5										

Strength of the Rock Mass by Hoek and Brown Failure Criteria

For the present study the strength of the rock mass at various locations at different Small hydropower sites has been worked out by using empirical failure criteria proposed by Hoek and Brown, 1989 and later modified by Hoek et al, 1992. The Hoek and Brown failure criteria for jointed rock mass is given by Eq. 5.3. To determine the material constants mb, 'S' and 'a' used in equation 5.3, Hoek and Brown used RMR (Rock Mass Rating) of Bieniawiski (1989). Using RMR, Hoek & Brown developed a new Geologic Strength Index (GSI).

For RMR89 > 23, GSI = RMR89 – 5

$$\sigma_1' = \sigma_3' + \sigma_c \left(mb \frac{\sigma_3}{\sigma_c} + S \right)^a \quad \text{..... Eq(6.3)}$$

Where; m_b - is the value of the constant m for the rock mass.

S & a- are constant which depend upon the characteristic of the rock mass.

σ_c - is the uniaxial compressive strength of the intact rock pieces.

σ_1'&σ_3' are the axial and confining effective principal stresses respectively.

Thus by using GSI material constants can be estimated; For GSI > 25 (undisturbed rock mass)

$$\frac{m_b}{m_i} = \exp\left(\frac{GSI - 100}{28}\right) \quad \text{..... eq (6.4)}$$

Where, m_i may directly be obtained from standard table.

$$S = \exp\left(\frac{GSI - 100}{9}\right) \quad \text{..... eq (6.5)}$$

$$A = 0.5$$

For GSI < 25

$$S = 0$$

$$a = 0.65 - \frac{GSI}{200} \quad \text{..... eq (6.6)}$$

Thus, the shear strength parameters as determined for different rock mass at various locations are summarized in Table 6.5 and Fig.6.4

6.6 Application of RMR in Determination of Rock Slope Stability Conditions

The slope stability along various components of SHP schemes is very important for safe functioning of any project. The instability of slopes may pose serious problems during construction stage. Identification of instability of the slopes in the initial stages may help in evolving proper remedial measures. Therefore, it is essential to carry out the stability analysis of slopes in the initial stages of investigation and planning. During the present

study rock mass exposed on the right and left abutment slopes of diversion weir of Huluka SHP site is traversed by discontinuity planes mainly joints. Failure of big rock blocks is also observed at the proposed diversion weir site (Plate 6.5) along this weakness planes. In order to work out the stability condition of the slopes, RMR data is collected on both banks of the river, and Romana's (1985) classification system for stability of rock slope called Slope Mass Rating (SMR) is utilized.

Table 6.5 Shear strength of rock mass as determined from Hoek and Brown failure criteria

GSI	*Material constants*			*UCS σc (Mpa)*	*Confining Stress (σ_3) (Mpa)*	*Axial Stress σ1(Mpa)*	*Shear strength*	
	mb	*s*	*a*				*C*	*Φ*
***Huluka* Small Hydropower Site**								
55.6	3.6	0.008	0.5	143.1	1	27.03	3.8	45°
					5	57.30		
					15	103.77		
Aleltu Small Hydropower Site								
70.8	6.0	0.039	0.5	156.6	1	44.53	4.0	48°
					5	80.15		
					15	137.60		
Mb, s and a are material constant which depends upon geologic conditions. C is cohesion and Φ is the angle of friction								

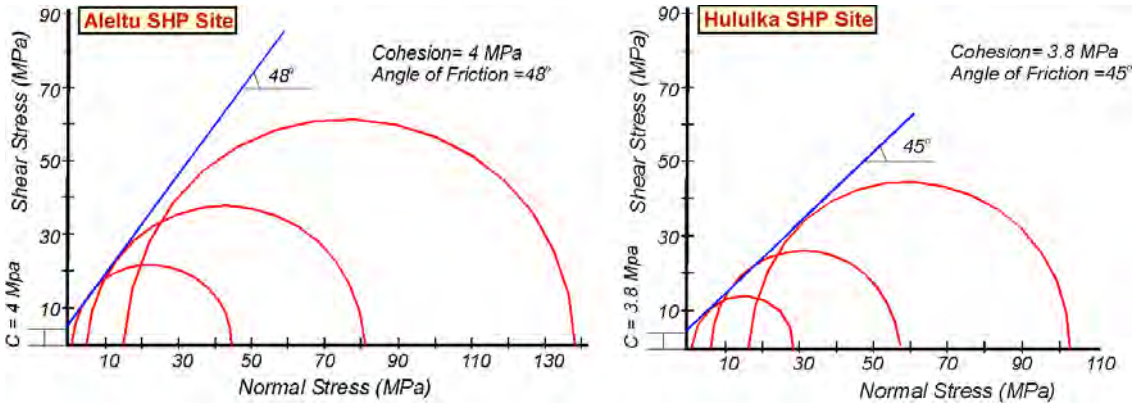


Fig. 6.4 Shear strength of rock mass as determined from Hoek and Brown failure criteria

For slope mass rating, Romana utilized Bieniawiski's Rock Mass Rating system (RMR). Initially Romana develop SMR to account for only plane andtoppling mode of failure, later this was modified by Ambalagan, Sharma and Raghuvanshi (1991) to account for wedge mode of failure also.



Plate 6.5 Failure of big rock blocks observed at Huluka proposed diversion weir site

SMR = RMR basic + (F1 x F2 x F3) + F4 ----------eq (6.7)

Where, RMR basic is evaluated according to Bieniawiski (1979, 1989) as discussed in section 6.5.2 of this chapter. The F1, F2, F3 are adjustment factors related to joint orientation with respect to slope orientation and F4 is the correlation factor for method of excavation. The ratings for these 5 parameters are obtained from the standard SMR table shown as Annexure VI.

For the present study stability of rocks exposed on both banks is evaluated as per SMR stability classes and is summarized in Table 6.6.

Table 6.6 Summarized stability conditions of right and left abutments at proposed diversion weir site of Huluka SHP scheme as determined from SMR

Data Location	Parameters Rating					SMR Value	Rock Mass Description	Stability	Probability of Failure
	RMR	F1	F2	F3	F4				
DW R1	57	0.85	1	0	0	64	Good	Stable	0.2
DW R2	57	1	1	0	0	64	Good	Stable	0.2
DW R3	57	1	0.4	-60	0	40	Bad	Unstable	0.6
DW L1	67	1	1	0	0	0	Good	Stable	0.2
DW L2	67	1	0.15	-60	0	61	Good	Stable	0.2

Perusal of Table 6.6 indicates that the probability of failure of slope on the right bank is very high, therefore some form of remedial measure has to be provided to this slope section and for which a detailed stability analysis

using limit equilibrium method has to be worked out during the detailed investigation stage.

6.7 Engineering Characterization of Soils

Soil Description

Soils in general can be defined as a heterogeneous accumulation of soil grains that are not cemented. For engineering purpose soils are sub-divided based on distribution of various grain sizes and the plasticity nature of the fine particles, as coarse grained and fine grained, respectively. A standard method is used for identification and classification of soils into categories or groups represented by symbol that have distinct engineering characteristics. This facilitates a common understanding of soil behavior just by knowing the classification. From the classification it is possible to estimate permeability, shear strength, volume change potential of soil when interact with water…etc (ASTM, 1996)

These properties are of greater significance in engineering construction, since engineering structures are founded on undisturbed natural soil particles. Engineering geological soil mass contains details of soil unit with their genetic type. The description is based on ISRM (1981) which contain;

(i) Soil name: genetic type and including minor constituents with their plasticity limits.
(ii) Soil material properties: color, texture sate of weathering
(iii) Soil mass properties: structure, discontinuities.

In the present study area, the engineering geological soil units are grouped under their genetic types, as residual and colluvial deposit. For the present study, soil samples were collected from different location along various components of different SHP schemes and were analyzed in the laboratory for the grain size distribution and index properties. The results obtained are presented in Table 6.7. For soil classification many standards are available. However, for present study, unified soil classification (USCS) has been adapted.

Residual Soils

Residual soils develop in-situ from disintegration and decomposition of rock. The distinction between rock and soils is difficult when the transition is gradual as in the case of most rocks. The depth and types of soil cover that develops are often erratic, since they are a function of the mineral constituents of the parent rock, climate, the time span of weathering exposure and topography (Hunt, 1984).

In the present study area, it has been identified that there are different types of residual soils. These show different nature according to the present material, particularly those, which developed on fractured and weathered basalt. The most abundant soil within this genetic group is clay with gravel, sandy clays, silty soils and organic clays of high plasticity.

Table 6.7 Summary of grain size analysis and index properties of soil samples at different SHP sites

Sample No.	*SHP Name*	*Depth (cm)*	*Origin*	*Color*	*Sieve Analysis (mm)*				*Index Value*			*USCS*
					%pass 4.75	**%pass 2**	**%pass 0.425**	**%pass 0.075**	**LL**	**PL**	**PI**	
1	Aleltu	54	Residual	Red*	81.2	62.4	60.8	54	66.7	34	32.7	MH
2	Aleltu	50	Residual	Dark*	99.8	99.2	99	98	78.4	41.2	37.2	OH
3	Aleltu	55	Residual	Yellow*	94.2	87.7	81.4	63.5	49.9	28.1	20.7	CL
4	Aleltu/ Debis	63	Colluvial	Brown*	91	72	75	46	41	31.88	9.02	ML
5	Debis	56	Residual	Gray*	100	99.8	99.6	97.9	70.1	37.2	32.9	MH
6	Debis	54	Residual	Dark*	99.9	99.4	99	98.4	80.5	42.9	37.6	OH
7	Huluka	73	Residual	Yellow*	98.7	86.9	82.4	65.7	50.2	28.8	21.4	CL
8	Huluka	52	Residual	Red*	80.9	62.3	60.4	55	66.3	34.5	31.8	MH
9	Bite	55	Residual	Red*	81	63.1	60	54.7	66	34.4	31.6	MH
10	Bite	55	Residual	Gray*	100	99.6	99	98.2	79.5	42.7	36.8	MH
LL-Liquid limit, PL-Plastic limit, PI-Plasticity index, red*-reddish brown, dark*-dark gray, gray*-light gray, yellow*-yellowish brown, brown*-dark brown												

Inorganic silts of high plasticity (MH)

This soil type is the most abundant soil found in all of the four ground verified SHP sites. This soil has an average liquid limit of 66% and plasticity index of 28%. The average grading characteristic of this soil indicates more than 75% of the soil particles pass through 0.075mm sieve.

Organic clays of medium to high plasticity (OH)

This soil type is found at Aleltu and Debis potential SHP sites. The laboratory test conducted on this soil type shows it has very high liquid limit and plasticity index of 80% and 37%, respectively. The organic nature of this soil has been identified readily on the basis of its dark brown color, odor and presence of organic matter within the soil. Further, laboratory analysis for organic impurities on the soil conducted using AASHTO T21-81 method shows the color is darker than color chart number-3, indicating presence of high organic materials. The grading characteristics also shows more than 98% of this soil particle pass through 0.075mm sieve.

Inorganic clays of low to medium plasticity (CL)

This soil type is exposed at the proposed penstock alignment of Huluka SHP site. This soil has a liquid limit of 50% and medium plasticity index of 21.4%. The grading characteristic of this soil shows about 65.7% soil particles passing through 0.075mm sieve.

Colluvial soils

Colluvial soils are deposited displaced from their original location of formation or deposition by gravity forces during slope failures. Their engineering characteristics vary with the nature of the original formation and the form of slope failures. They typically represent an unstable mass, often of relatively weak material and frequently are found burying very weak alluvial soils. Their recognition therefore is important.

In the present study area, the occurrence of colluvium is noticed at the toe of the slope or far beyond the toe of slope around the proposed diversion weir sites for Aleltu and Debis SHP sites. The soil sample collected from these colluvial deposit shows inorganic silts with low plasticity.

Inorganic Silts and Clayey fine sand with slight plasticity (ML)

This soil type is exposed at the toe of the slopes where a diversion structure for Aleltu and Debis SHP sites is proposed. Laboratory determinations for

index properties show that this soil possesses a liquid limit of 40.8% and low plasticity index of 9.4%. The grading characteristics of this soil indicate that less than 50% of the particles pass through 0.075 mm sieve.

6.7.1 Soil Classification

A soil classification system is the arrangement of different soils having similar properties into groups and sub-groups based on their application. It provides a common language to express briefly the general characteristics of soil. Most soil classification systems developed for engineering purposes are based on simple index properties like particle size distribution and plasticity. Atterberg limits and consistency tests are index properties for determination of fine grained soil whereas for coarse grained, grain size distribution and relative density are the important index properties.

Among the several soil classification systems, the unified soil classification system (USCS) is applied in this work. According to this classification the soils in the study area have been classified as MH, CL, OH and ML. Fig.6.5 presents the plasticity chart of soils of the study area based on USCS classification system.

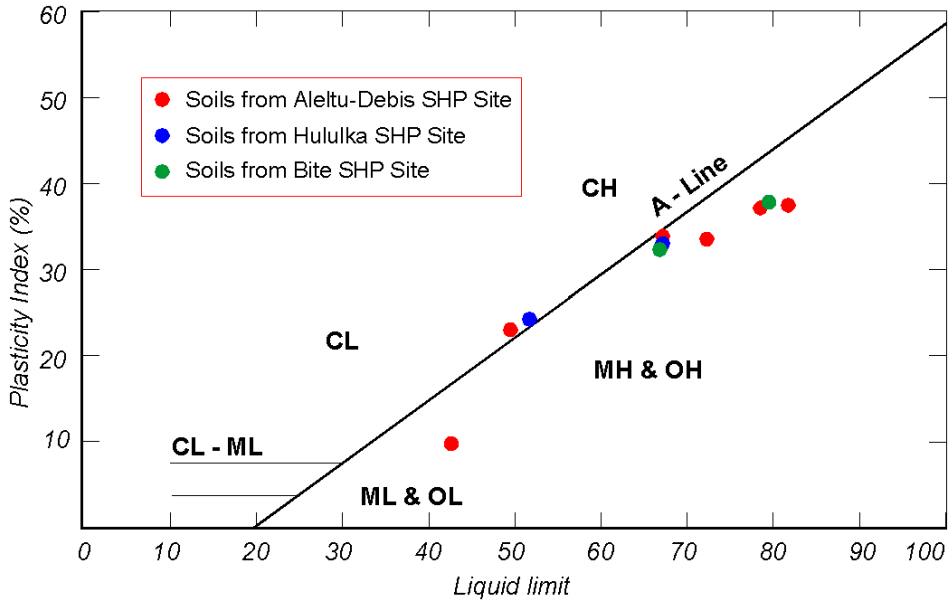


Fig. 6.5 **Plasticity chart of soils of the study area based on USCS classification system.**

6.7.2 Assessment of Potential Expansiveness of Soils

Data obtained from index tests together with description of visual observation are often sufficient for design purpose of minor structures. This information is used also in making preliminary design for determining probable cost of a major structure and to limit the amount of detailed testing (ASTM, 1996)

The foundations of the channel should meet two requirements;

(i) Must be stable: channels are rigid structures and do not permit deformations.
(ii) Should be permeable: channels do not support thrusts or uplift pressures (ESHA, 2004).

For the present study most of the alignment of the water conductor for the ground verified SHP sites passes over residual soils. Analysis of the physical properties indicates that most of the soils in these four sites fall under OH and MH category, using the USCS classification system.

Therefore, an attempt is made to evaluate expansive potential of these soils aimed to avoid possible damages caused by settlements and up lift pressure of the soils on the proposed water conductor alignment.

Estimation of Potential Swell

Many tests and methods have been developed or modified for estimating potential swell. These include both indirect and direct measurements. Indirect methods involve the use of soil properties and classification schemes to estimate swell potential. Direct methods provide actual physical measurements of swelling. For the present study, indirect measurement of potential swell, Casagrande's plasticity chart and the criteria put by Holtz and Gibbs (1956) (Table 6.8) is applied to estimate the swelling potential of the soils found in the four SHP sites.

Fig. 6.6 shows the plot of plastic limit against liquid limit to detect the potential swell of the soils in accordance with Casagrande's plasticity chart.

The plot shows that most of the samples are clays and distribution of the samples with in the principal clay minerals. Using the criteria put by Holtz and Gibbs (1995) most of the soils in the study area can be classified as having 'High' to 'very high' potential to swell.

According to Casagrande's plasticity chart (Fig. 6.6) the zone typical for Montmorillonite (smectites) implying that it has a high potential for swelling. Soils that plot above the A-line are clays and those, which plot below it, are silts. The U-line indicates the upper bound for natural soils, thus no soil should fall above U-line.

Table 6.8 Classification of potential swell based on plasticity (Holtz and Gibbs, 1956)

Classification of potential swell	Liquid limit (LL), %	Plasticity Index (PI), %	Shrinkage limit (SL), %
Low	20-35	<18	>15
Medium	35-50	15-28	10-15
High	50-70	25-41	7-12
Very high	>70	>35	<11

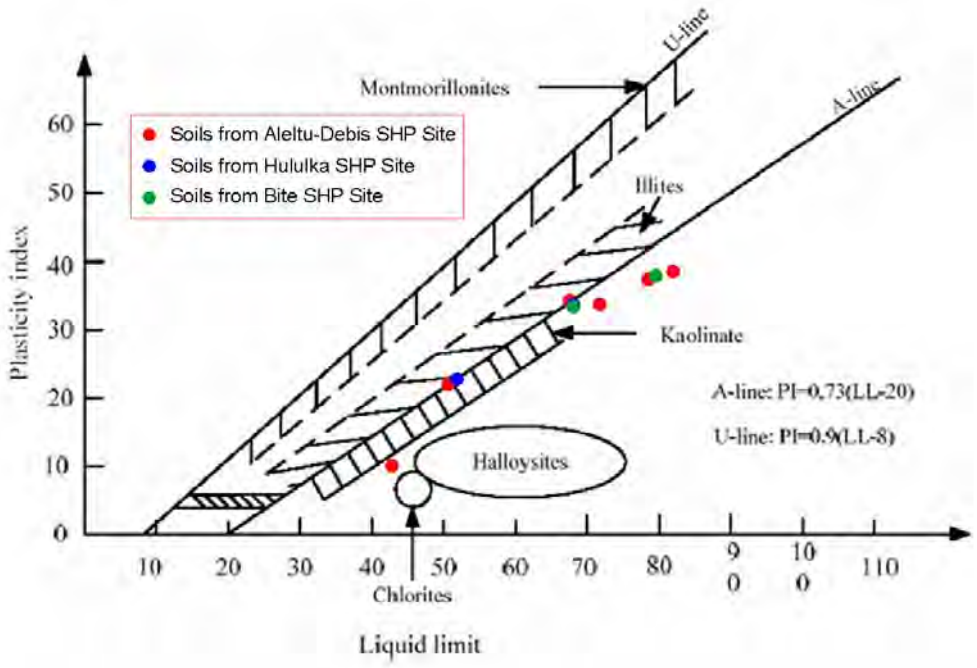


Fig. 6.6 Plot of plastic limit against liquid limit to detect the potential swell of the soils in accordance with Casagrande's plasticity chart.

Thus, having such problem soils may lead to failure of cannels, hence the necessary remedial measures to minimize or avoid the damages caused by them should be considered during design and construction phase.

6.8 Slope Stability Studies

Stability of slope is influenced by various factors like, geometry of slope (slope height slope angle and upper slope angel), shear strength parameters (cohesion and angle of internal friction) and water saturation conditions. When the driving forces exceeded the resisting forces the slope fails. Therefore, it is important to know the relationship of these driving forces with respect to the resisting forces. This relationship can be well understood if the factor of safety for the given slope is determined. The factor of safety is the ratio between the resisting forces to the driving forces. (Nahmeia. S. 2005).

Topographically, all structures are generally located on or at the slope and slope instability becomes the main engineering geological problem in the construction of small hydro power plants (Jiandong, 1997). If the slopes are not stable the various structures may fail and entire scheme may become non-functional. Therefore, it is important to study the stability conditions of slopes on which the various components are proposed.

For the present study, the potential unstable slopes were identified by examining various traces of instability, like:

(i) Slope failures resulting from slope cuts.
(ii) Toe erosion by the stream.
(iii) If the preferred orientation of discontinuity planes is dipping towards the valley.
(iv) Slope failure due to creeping of an old slide.
(v) Slope failure resulting from weathering and jointing of rock slope.
(vi) Local small scale failures within or near to the slope in question.

Huluka Small Hydro Power site

At Huluka small hydropower site, the slopes in general are stable along the water conductor over residual soil formation. However, signs of rock slope failures at the proposed diversion weir site have been observed. Further, the

stability conditions at the proposed diversion weir and some sections of the headrace channel evaluated for potential slope instability using slope mass rating system indicates that the slopes are unstable. Along the penstock alignment the soil slopes are suspected of slope instability due to the steep geometry of the slope and observed local small scale failures near to the slope in question. Therefore, it is found to be necessary to study the stability conditions of this slope, to avoid possible penstock and powerhouse failures.

The stability analysis of this slope section has been carried out by using SARC computer program. A brief description of this program is given at Annexure VII .The slope is potentially unstable for circular mode of failure. The slope section is shown in Fig. 6.7. Table 6.9 presents the input parameters used for the determination of factor of safety. The Factor of safety has been determined for static and dynamic condition for different saturation condition. The calculated results are presented in table 6.10.

Perusal of table 6.10 indicates that the factor of safety for this slope under all conditions is less than unity. Thus, it indicates that the slope is unstable and may pose problems of instability and may damage the penstock and power-house. Therefore, some form of remedial measure has to be provided to this slope section. Keeping in mind the size of the project it may not be economically feasible to retain the entire slope section. Therefore, it may be suggested to provide the local remedial measures just at the alignment where the penstock will be passing on this slope. These remedial measures may be in the form of terracing and providing retaining wall.

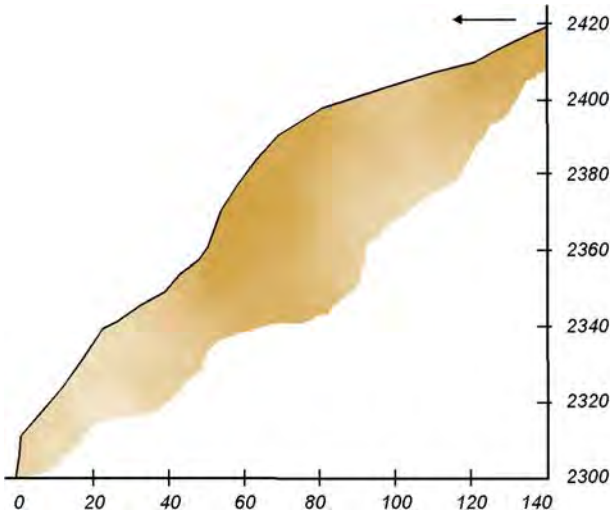


Fig. 6. 7 Slope Cross section for Huluka site

Table 6.9 The input parameters used and the calculated factor of safety for static and dynamic conditions

Input parameters		
Parameter	**Value**	**Where**
N =	15	N = Number of profile coordinates(< 50)
X(I),Z(I) I =	1 to N	(X,Z) = Coordinates of profile points (X(I) < X(I+1))
C =	7.59	C = Cohesion of soil/rock
PHI =	25.1	PHI = Angle of internal friction (Degree) of soil/ rock
GAMA =	1.76	GAMA = Unit weight of soil/rock
GAMAW =	1.0	GAMAW = Unit weight of pore water
BBAR =		BBAR = Pore water pressure/(GAMA * Average height
AH =	0.2	of slices)
AVR =	1.0	AH = Horizontal component of EQ. acceleration
EQM =	8	near crest of slope
NENP = 1		AVR = Vertical component of EQ. acceleration / AH
ENTX (I), ENTY (I) = (0.0,2200)		EQM = Corresponding EQ. magnitude on Richter Scale
NEP = 0.0		NENP = Number of entry points of slip circles (<10)
NOPT = 0.0		ENTX = X-Coordinate of entry point of circle
XEXITI =	70	ENTY = Y-Coordinate of entry point of circle
XEXITL =	140	NOPT = 0 ,When only minimum factor of safety is required
GAP =	70	= 1,When all F.S. corresponding to all exit points are also required
		NEP = Number of exit points(<50)
		= 0 , When no individual point is given)
		XEXITI= X-Coordinate of first exit point of circle
		XEXITL= X-Coordinate of last exit point of circle
		GAP = Horizontal distance between consecutive exit points
		XEXIT = X-Coordinate of exit point of circle

Table 6.10 Results of Stability Analysis

	FOS	***Weight***	***Coordinate Of Center***	***Exit Point***	***Radius (m)***
Static Dry	0.91	$0.75x10^4$	(-109.93,2569.92)	(140,2420)	291.44
Static Mod. Sat.	0.42	$0.78x10^4$	(-93.04,2550.21)	(140,2420)	266.95
Static Fully Sat.	0.002	$0.55x10^4$	(-425.36,2937.92)	(140,2420)	766.73
Dynamic Dry	0.64	$0.75x10^4$	(-110.42,2570.49)	(140,2420)	292.16
Dynamic Mod. Sat.	0.24	$0.73x10^4$	(-125.92,2588.57)	(140,2420)	314.85
Dynamic Fully Sat.	UW*	$0.425X10^4$	(-2989.41,5929.31)	(140,2420)	4701.97
FOS=Factor of Safety, UW*-unstable wedge					

6.9 Engineering Geological Mapping of the Sites

The engineering geological mapping of ground verified SHP sites has been carried out on the basis of engineering characterizations of soils and rocks exposed along the alignment of the different civil components of the schemes. For the estimation of the strength of the rock, Schmidt hammer has been used. To classify the rocks based on its strength, classification proposed by Hoek and Bray (1977) has been utilized (Annexure II).

The weathering grade have been visually assed and classified using Irfan and Dearman (1978) classification of weathering grade (Annexure III). The RMR value has been determined based on Bieniawiski's Geomechanics classification system (Table 6.3). Thus based on the above criteria, the rocks around ground verified SHP site has been classified into two classes:

S.No	Class	Description
1.	Ab Unit	Good quality rock (RMR 61-80) Strong rock strength Slightly weathered
2.	As Unit	Fair quality rock (RMR 41-60) Strong rock strength Moderately weathered

The soils have been classified on the basis of their relative susceptibility for instability and swelling potentials. Fig. 6.8 presents engineering geological map of ground verified SHP sites.

For this, colluvial soils are considered most susceptible for slope instability and less susceptible for potential swell. However, residual soils are comparatively more consolidated, therefore considered less susceptible for slope instability and high potential to swell as per the criteria discussed in section 6.6 of this chapter.

Thus, based on these criterions, the soils around the ground verified SHP sites are classified in to two classes as:

S.No	Class	Description
	Resdual Soils	
1.	MH Unit	Less susceptible for instability High swelling potential
2.	OH Unit	Less susceptible for instability Very high potential to swelling
3.	CL Unit	Less susceptible for instability Low potential to swelling
	Colluvial Soils	
4.	ML Unit	Most susceptible for instability No potential to swell

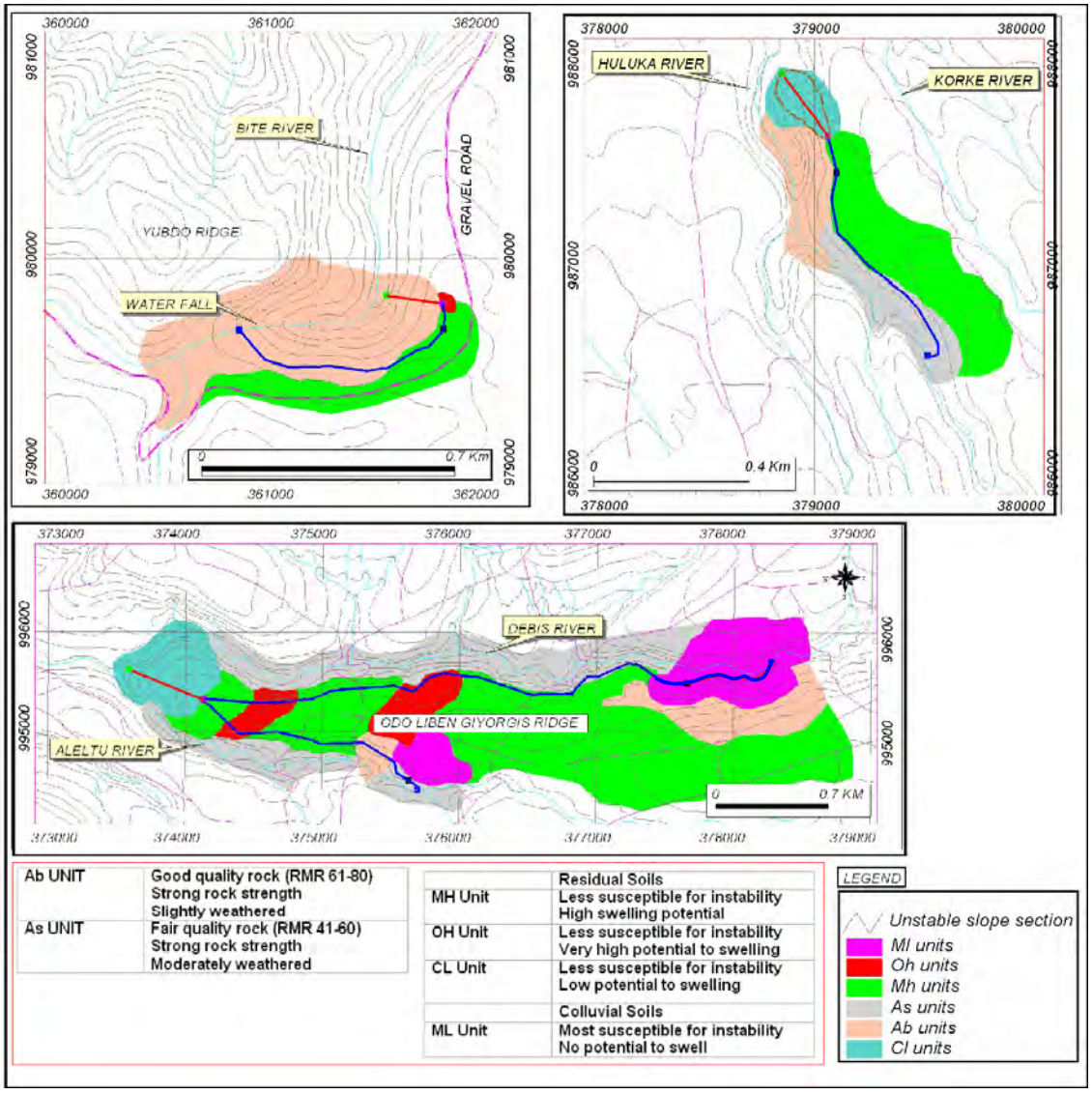


Fig. 6.8 Engineering Geological map for ground verified sites

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CAPTER SEVEN CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Small hydropower development for rural electrification shows very slow progress due to many and varied constraints. This dissertation started by discussing the constraints of rural electrification based on factual information in Ethiopia as well as in literature survey from recent experiences of many researchers who are engaged in promoting small hydropower development for rural electrification.

The discussion ascertains the fact that the promotion of small hydropower is an important pre-requisite for the true economic development of rural communities which is about 85% of the population of Ethiopia and for the prevention of deforestation and associated environmental degradation.

The presence of abundant small hydropower potential as indicated in another research by Nahmeia Solomon, 2005, justified the necessity of an in-depth investigation of other sites adjacent to the previous study area. In this regard, this dissertation focused especially on developing initial site identification criteria for selection of potential SHP sites with reasonable power out put. Thus, during the present study a total of 18 potential sites have been identified, 9 in Anger and 9 in Guder sub-basins following the identification criteria developed during present study.

The challenging aspect of potential site selection lies on the availability of discharge data on all of the rivers within the present study area .To overcome this challenge, an attempt is made for establishing regionalized flow-duration curves based on easily available hydrological data of the region for the projection of discharge to potential SHP sites. Ranked flow technique has been employed to compute flow duration curves at the proposed diversion weir sites for 18 identified potential streams. For all 18 small hydropower (SHP) potential sites, identified during the present study, daily observed discharge data has been projected from adjacent gauged

streams using the regionalized flow-duration curves prepared during the present study.

Initial estimation of the power potential of 18 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 18 identified sites for which discharge data was available, comes out to be 19564 kW.

Thus, these 18 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 18 SHP sites. Therefore, a sincere effort has been made to cover 4 potential SHP site to undertake ground verification and detailed engineering geological appraisal, at pre feasibility level. The selection of these 4 sites, as first priority, has been done based on certain minimum criteria. Thus finally, 4 identified small hydro power sites satisfy the criteria, these sites were, Aleltu-Debis, Huluka and Bite.

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. Commonly, engineering geological mapping for any site is done by characterizing the lithology present aiming to avoid possible damages to the structure being built. For the present study, engineering geological mapping was 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. In an effort to incorporate these factors, the rock mass exposed along the water conductor was characterized by utilizing the strength properties derived from Rock Mass Classification system and by determining the grade of weathering of rocks by utilizing Irfan and Dearman

Weathering Classification, 1978. The soils were characterized based on their susceptibility to slope failure and their potential to swell that could cause uplift and settlement problems on the proposed channel section.

Further, topographically since all structures for SHP schemes are generally located on or at the slope. Slope instability becomes the main engineering geological problem in the construction 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.

At Huluka SHP site, signs of rock slope failures at the proposed diversion weir site have been observed. The stability conditions at the proposed diversion weir and some sections of the headrace channel evaluated for potential slope instability using slope mass rating system indicates that the slopes are unstable. Further, along the penstock, the soil slope section was identified as potentially unstable. The stability analysis of this slope has been carried out for static and dynamic condition under varied water saturation. The calculated factor of safety for this slope under all conditions is less than unity. Thus, it indicates that the slope is unstable and may pose problems of instability and it may damage the penstock and powerhouse. Therefore, some form of remedial measure has to be provided to this slope section. Keeping in mind the size of the project it may not be economically feasible to retain the entire slope section. Therefore, it may be suggested to provide the local remedial measures just at the alignment where the penstock will be passing on this slope. These remedial measures may be in the form of terracing and providing retaining wall.

Based on the engineering geological appraisal and the general order of pre feasibility study it may be concluded that out of four ground verified SHP sites Aleltu, Debis and Bite Small hydropower sites are feasible sites with minimum engineering geological problems. However, the other site Huluka is considered less feasible site. Along the penstock alignment and diversion site, the slopes are potentially unstable which may pose problems in safe

running of the scheme. Thus, in case if this site has to be taken up for development it must be considered on less priority.

Finally, the usefulness of the demonstrated regionalized flow-duration curves for transfer of discharge data on ungauged sites in this study is dependant on the amount of available hydrological data of the area. The better the amount of the data the more reliable the model is likely to be. Therefore, the present study may serve as guide to develop and extend similar type of hydrologic study for other regions of the country, which will help in the speedy development of small hydropower sector.

7.2 RECOMMENDATION

Based on the result of the present study following systematic recommendations are made;

Before any further development of ground verified sites, it is recommended to observe the actual discharge of the streams at the proposed diversion weir sites at least for two years covering two lean seasons. The regional flow duration curve/ model developed for this study has attempted discharge estimation considering various empirical correlation methods suitable for ungauged catchments due to the lack of measured discharge data at the potential SHP sites. Further research and improvement of the regionalized flow-duration curves are required by a multi disciplinary study to provide the accuracy for estimation of dependable flows of ungauged 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 constrains, therefore the results/ findings should be considered as indicative only. Before the final development of SHP sites it is strongly recommended to conduct Engineering Geological appraisal with elaborate laboratory testing of rock and soil material, as for the present study various empirical techniques were utilized to estimate these properties.

Many measurement inputs were taken from topo map at 1: 50,000 scale, thus the dimensions taken for the computations may vary when detailed survey on 1: 200 or 500 scale will be carried out. The dimensions and figures for various SHP components presented through this study must be considered as indicative only and more elaborate engineering estimations are required during later studies.

The research indicates that there are many small hydropower potential sites in the study area. The study shows that there is a possibility of generating electricity at a level of Micro, Mini and Small Hydropower in the study area. As per the statistical data of CSA (Central Statistic Authority, 1996.), the electric demands in the zones, which falls in the study area is comparatively high. Therefore, the generation of the electric power from the selected potential sites may contribute to meet out a part of power needs within the study area, particularly for those areas which are remotely located and can not be easily connected to the grid.

Small hydropower is technically more feasible than large hydropower for covering rural energy demand in remote localities. Actually it is not a good practice to treat small and large hydropower as being mutually exclusive. Both are necessary to cater for the energy need of a country with a large population size like Ethiopia. However, the constraints on decentralized energy systems in general and on small hydropower in particular are much more difficult and complex. This constaints could be assured by the Universal Electric Access Project being carried out by EEPCO currently in the country which has a plan to cover 50% load centers though inter-connected gird systems. Therefore, the recommended policy in the future should give more support and promotion for the development of small hydropower, since history has proven that grid-based central power plants are unable to promote rural electrification in Ethiopia as well as in many developing countries.

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REFERENCES:

*Abiy Awoke *Dr, 2002: Technology Transfer of Micro Hydropower Equipment (A strategy proposal). Proceedings of Energy Conference. Energy in Ethiopia: Status, Challenges and Prospects UNCC, Addis Ababa, 21-22 March 2002*

Agarwal C.K, Mehrotra V.K , Mitra S 1991: Need of Long-Term Evaluation of Rock Parameters in Himalaya, Seventh International Congress on Rock Mechanics, Aachen, west Germany.

Alternate Hydro Energy Center(AHEC) 2001: Detailed Project Report Relichu Small Hydropower Project Sikkim, India, Unpublished Report.

Arora, K.R., 1997: Soil mechanics and foundation engineering. Bhargave printers, New Delhi

ASTM 1998: Standard Specifications for Transportation Materials and Method of Sampling and Tessting-American Society for Testing Materials

B. Raja M Das, 1989: Introduction to Soil Mechanics and Geotechnical Engineering. The Idwa State University Press, India.

BC hydro- Draft, May 2002: Hand book for developing MICRO HYDRO In British Columbia ,http:// WWW.bchydro.comlrx_files/environment/environment1837.pdf, accessed on 5/16/2007

BCEOM French Engineering Consultants 1999: Abbay River Basin Integrated Development Master Plan Project: Natural resource. Ministry of Water Resource, Addis Ababa, part 1, volume 1, 2 and 3.

BCEOM French Engineering Consultants 1999: Abbay River Basin Integrated Development Master Plan Project: Land resource development. Ministry of Water Resource, Addis Ababa, phase 2, part 2, volume 9, and volume 10.

Bieniawski, Z.T., 1989. Engineering Rock Mass Classifications. Wiley, New York.

Bieniawski, Z.T., 1989: Engineering Rock Mass Classifications, A Wiley Inter-Science Publication, USA.

Carter, M., and Symons, M.V., 1989: Site investigation and foundation explained. Pentch Press, London

DCS – Technology Development, 1998: Survey & Layout Design Manual for Private Micro Hydropower Plants, Butwal, Nepal.

E. Hoek & J.W. Bray, 1997: Rock Slope Engineering, Revised Third Edition. Published for the INSTIUTE OF MINING AND METALLURGY by E & FN SPON

EEPCO & Acress International, 2002: Past Experiences and a25-Year Electric Development Plan of Ethiopia. Proceedings of Energy Conference. Energy in Ethiopia: Status, Challenges and Prospects UNCC, Addis Ababa, 21-22 March 2002

Energy research centre: University of Cape Town, April 2004- Energy for sustainable development South African profile

ESHA, 2004: Guide on How to Develop a Small Hydropower Plant, esha@arcadis.be.pdf, accessed on 4/29/2007

F.G.Bell, 1992: Engineering properties of soils and rocks. Third edition, British Libray cataloguing in publication data, great Britain.

Fekadu Kebede and Laike M. Asfaw 1996: Seismic Hazard Assessment For Ethiopia and the Neighbouring countries. SINET: Ethiopia. J. Sci., 19(1): 15-50.

Fritz, Jack J., 1984: Small and Mini Hydropower Systems, Resource Assessment and Project Feasibility, McGRAW-HILL BOOK COMPANY, USA.

Greitzer, Y., 1970: Stratigraphy, Hydrogeology and Jurassic Ammonites of the Harar and Dire Dawa Area, Ethiopia, Ph.D. Thesis, Hebrew Univ., Israel.

Holtz, W.G. and Gibbs, H.J. 1956: Engineering properties of expansive Clays, Transactions, American Society of Civil Engineers, vol.121

IBC & GTZ, 2004: "Forest Resources of Ethiopia: Status Challenges and Opportunities". Proceedings of a National Conference, 27 - 29 November 2002. Organized by Institute of Biodiversity Conservation (IBC) and German Development Cooperation (GTZ). In connection with the inauguration of the Forest Gene Bank. Addis Ababa, Ethiopia.

Indian Standard, 1991: Guidelines for Selection of Hydraulic Turbine, Preliminary Dimension and Layout of Surface Hydroelectric Power Houses IS: 12800 (Part 3), New Delhi, India.

Joseph E Bowels, 1992: Fourth Ed. Engineering Properties of soils and their measurements, McGraw Hill, USA.

Karl Terzaghi, Ralph B. Peck, Gholamreza Mersi, 1996: Third Edition, Soil Mechanis in engineering practice, John Wiley & Sons, Inc., USA.

Kazmin V et al. 1978: The Ethiopian basement: Stratigraphy and possible manner of evolution.

Kazmin V. 1972: The Geology of Ethiopia. Minstry of Mines, Addis Ababa.

Kazmin V. 1975: The Precambrian of Ethiopia and some aspects of the Geology of the Mozambique Belt. Bulletin of Geophysical Observatory Addis Ababa 15: 22-43, Addis Ababa.

Kazmin V. et al. 1973: Geological Map of Ethiopia (1:2000,000), 1st edition. Geological Survey of Ethiopia Addis Ababa.

Kumar, A., Rees G., Raghuvanshi T.K., 2002: Small Hydropower Assessment A Solution through Hydra HP Soft ware, Proceedings on International conference Power on Demand by 2012, Feb. 8-9, 2002, New Delhi, India.

Kumar, A., Singhal, S.K., Saxena, N.K., 1990: Design Aid on Desilting Tanks for Micro Hydro Station. Alternative Hydro Energy Centre, University of Roorkee, Roorkee, India.

Laike Mariam Asfaw 1986: Catalogue of Ethiopian earthquakes, Earthquake Parameters, Strain Release and Seismic Risk. In: proceedings of the SAREC-ESTC conference On Research Development and Current Research Activities in Ethiopia, pp. 252-279.

Merla, G., 1979: Explanation to the Geological Map of Ethiopia and Somalia 1:2,000,000 Scale. Department of Geology and Palaeon., University of Florence, Italy.

Micro-Hydropower: Practical Answers to poverty, Intermediate Technology Development Group- http://microhydropower.net

Mohr, P.A., 1968: The Arabo-Ethiopian Swell: In Tectonics of Africa, 1968.

Mulugeta Adamu,2002: Some Options of Rural Electrification in Ethiopia. Proceedings of Energy Conference. Energy in Ethiopia: Status, Challenges and Prospects UNCC, Addis Ababa, 21-22 March 2002

Nahmia Solomon ,2005: Identification and Engineering Geological Appraisal of Small Hydropower Potential in Mugher, Jemma and Waleka Sub-basins (Centeral Ethiopia). Addis Ababa University unpublished Msc Thesis

Nancy D. Gordon, 1993: Stream Hydrology An Introduction for Ecologists, JOHN WILEY & SONS, New York

Palmstorm, A (1982). "The Volumetric Joint count – a useful and simple measure of the degree of jointing" IV Int. Cong., IAEG, New Dehli, India.

Proceeding – International Course, 2003: "Technology selection for Small Hydropower Development, Alternative Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee, India.

R. K. Tatiti, 2002:Behavvior of Saturated Expansive Soil and Control Methods (Revised and Enlarged Edition). IDH Publishing Co. TVT.LTB.,66 Jampath, New Delhi, India

Robert B. Johnson, Jerome V. DeGraff, 1988: Principle of Engineering geology, John & Wiley & Sons, Inc, USA.

Roy E. Hunt, 1984: Geotechnical Engineering Investigation Manual. Mc Graw Hill Book Company, New York

Seleshi Bekele Awulachew, 2000: Investigation of Water Resuorces Aimed at Multi-Objective Development with Respect to Limited Data Situation Ph.D. Thesis. Technische Universitat Dresden, Germany

Serafim, J.Z., Pereira, J.P., 1983. Consideration of Geomechanical Classification of Bieniawski, Proc. Int. Symp. Eng. Geol. Underground Construction, Boston.

Singh B, Goel R.K., 2002: Software for Engineering Control of Landslide and Tunnelling Hazard, A.A.Balkema Publishers, The Netherlands.

Study Team from People's of Republic of China, April, 1989: General Report of Small Hydropower Investigation in Ethiopia, Addis Ababa, Ethiopia.

Tong Jiandong, Zheng Naibo, Wang Xianhuan, Hai Jiing, Ding Huishen, 1996: Mini Hydropower, JOHN WILEY & SONS

Trudy Konemud, 2002: The House Hold Energy Crisis in Ethiopia, a Possible way out. Proceedings of Energy Conference. Energy in Ethiopia: Status, Challenges and Prospects UNCC, Addis Ababa, 21-22 March 2002

Trufat H/Mariam, 2001: Geotechnical and Engineering Geological Investigation of Sibilu Dam Site, Reservoir and Catchment Area, Addis Ababa University, Ethiopia.

University of Peradeniya, Sri Lanka Water Professionals Symposium:October, 2004, Possibility of Using Small Hydropower as an Environmental Friendly and Low Cost Energy Source

USBR, 1964: Land and Water Resources of the Blue Nile Basin, Volume 2

USBR, 1987. Design of Small Dams, A water Resource Technical Publication, United States Department of Interior Bureau of Reclamation.

Zelalem Hailu G. Chirstos, 2002: Optimization of Small Hydropower Sites for Rural Electrification. Ph.D. Thesis Technische Universitat Dresden, Germany

Annexure I A land covers classification of Abbay basin

Category	Class	Sub-class
1	Cultivated	Rain fed Irrigated Perennial Sate farm
2	Afro-Alpine	
3	Forest	Disturbed Very disturbed
4	Plantation	Eucalyptus
5	Woodland	Dense Open Riparian
6	Bushland	Dense Open Riparian
7	Shrubland	Dense Open
8	Bamboo	
9	Grassland	Open Bushed/Shrubed Wooded
10	Wetland & Water body	Water body Perennial Swamp/marsh Seasonal swamp/marsh
11	Bare land	Rock
12	Urban	

Annexure II Classification of rocks based on strength (Hoek and Bray, 1997)

No.	**Description**	**Rock Type**	**Uniaxial Compressive strength (UCS) MPa**
R1	*Very week rock* – crumbles under sharp blows with geological pick point, can be cut with pocket knife	Chalk, rock salt	1.0 - 25
R2	*Moderately weak rock* – shallow cuts or scraping with pocket knife with difficulty, pick point indents deeply with firm blow.	Coal, schist, silt stone	25 - 50
R3	*Moderately strong rock* – knife can not be used to scrape or peel surface, shallow indentation under firm blow from pick point	Sandstone, slate, shale	50 - 100
R4	*Strong Rock* – hand held sample breaks with one firm blow from hammer end of geological pick.	Marble, granite,gneiss	100 - 200
R5	*Very strong rock* – requires many blows from geological pick to break intact sample.	Quartzite, dolerite, gabbro, basalt	> 200

Annexure III Weathering grade for rock mass by Irfan and Dearman, 1978

Term	*Description*	*Weathering Grade*
Fresh	No visible sign of rock material weathering; perhaps slight Discoloration on major discontinuity surface.	I
Slightly Weathered	Discoloration indicates weathering of the rock material And discontinuity surface	II
Moderately Weathered	Less than 35% of the rock material is decomposed and/ or disintegrated to a soil. Fresh or discolored rock is present Either as a continuous frame work as core stone.	III
Highly weathered	More than 35% of the rock material is decomposed and/ or Disintegrated to a soil. Fresh or discolored rock is present either as a continuous frame work as core stone.	IV
Extremely weathered	All the rock material is decomposed and/or disintegrated to A soil. the original mass structure is still largely intact	V
Residual soil	All the rock material is converted to soil. the mass structure And material fabrics are destroyed.	VI

Annexure IV Manning roughness coefficient (Fritz, 1984)

Value of n	Condition of channel
0.011-0.012	Smooth clean wood, metal or concrete surfaces, without projections, and with straight alignment
0.013	Smooth wood, metal, or concrete surfaces without projections, free from algae or insect growth, mostly straight alignment
0.014	Good wood, metal, or concrete surfaces with only small projections, with some curvature, slight algae or insect growths, and minimal gravel or sand deposition. Troweled gunnite surfaces
0.015	Wood with large and moss growth, concrete with smooth sides and rough bottom, metal with shallow projections
0.016	Metal flumes with large projections. Wood or concrete with well-developed moss or algae growths
0.017	Rough concrete or untroweled gunnite surfaces
0.018	Smooth natural earth cannels, free from growths with straight alignment
0.019-0.020	Smooth natural earth, free from growths with some curvature. Large cannels in good condition
0.020-0.025	Small cannels in good condition, larger cannels with some growth
0.025-0.035	Cannels with dense aquatic growths

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Annexure V Description for the soil groups in Abbay Basin

Soil Group	Depth	Colour	Texture	Structure	Consistency	Drainage
Acrisols	Deep to very deep	Very dark grayish Brown	Clay	Subangular blocky	Friable, sticky and plastic	Well
Alisols	Deep to very deep	Reddish brown	Clay/clay loam/Silty clay	Subangular blocky	Friable to firm, sticky and Plastic	Well
Arenosols	Shallow to Moderately deep	Dark yellowish brown	Loamy sand	Weak, fine sub-angular blocky and single grain	Slightly hard/friable, sticky and non plastic	Well to excessive
Cambisols	Moderately deep	Brown/dark brown	Silty clay	Angular/Subangular Blocky	Hard/friable, slightly Sticky and slightly plastic	Well
Fluvisols	Deep to very deep	Variable	Clay/Silty clay	Weak to massive		Well
Leptosols	Shallow to very shallow	Brown to yellowish Brown	Loam/clay loam/Clay	Subangular blocky	Firm to slightly hard/ Friable; slightly sticky & Slightly plastic	Well
Luvisols	Deep to very deep	Brown/reddish brown	Clay/Silty clay	Subanngular blocky	Friable to firm, sticky and slightly plastic	Well
Nitisols	Deep to very deep	Reddish brown	Clay/Clay loam/Silty Clay loam	Subangular blocky	Friable to firm, sticky and plastic	Well
Phaeozems	Deep	Dark grey	Clay loam/clay	N/A	Slightly sticky & slightly plastic, wet	Moderately well to poor
Regosols	Shallow to moderately deep	Brown	Clay/Silt/Loamy sand/ Loam/Silty clay/ Sandy loam	Angular/subangular Blocky	Slightly hard/friable, Slightly sticky and slightly Plastic	Well
Vertisols	Deep to very deep	Dark grey black	Clay	Subangular/Angular blocky	Hard firm, very sticky and Very plastic	Imperfect to poor

Annexure VI Values of ratings of parameters based on SMR (Romana, 1985)

Case of slope Failure		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
P T W	$(\alpha_j - \alpha_s)$ $(\alpha_j - \alpha_s - 180^o)$ $(\alpha_i - \alpha_s)$	$>30^o$	$30 - 20^o$	$20 - 10^o$	$10 - 5^o$	$<5^o$
P/W/T	$\mathbf{F_1}$	0.15	0.40	0.70	0.85	1.00
P W	(β_j) (β_i)	$<20^o$	$20 - 30^o$	$30 - 35^o$	$35 - 45^o$	$>45^o$
P/W	$\mathbf{F_2}$	0.15	0.40	0.70	0.85	1.00
T	$\mathbf{F_2}$	1.0	1.0	1.0	1.0	1.0
P W T	$(\beta_j - \beta_s)$ $(\beta_i - \beta_s)$ $(\beta_j + \beta_s)$	$>10^o$ $<110^o$	$10 - 0^o$ $10 - 120^o$	0^o $>120^o$	$0 - (-10^o)$ $>120^o$	$<-10^o$ -
P/W/T	$\mathbf{F_3}$	0	- 6	- 25	- 25	- 60

F_1 – depends upon parallelism between joints and slope face strikes.

$(\alpha_j - \alpha_s)$ where, α_j is joint strike and α_s is slope strike.

F_2 – refers to joint dip angle (β_j) or plunge of line of intersection of two wedge forming planes (β_i).

F_3 – depends upon relationship between joint dip or plunge of line of intersection of two wedge forming planes and slope inclination.

$(\beta_j - \beta_s)$ or $(\beta_i - \beta_s)$ where, β_s is the inclination of the slope.

F_4 – Method of Excavation. It includes the natural slope, or the cut slope excavated by pre splitting, smooth blasting, normal blasting, poor blasting and mechanical excavation.

Annexure VII SARC Computer Program

A Brief outline of SARC computer program

The computer program SARC is prepared by Prof. Bhawani Singh, Department of Engineering, Indian Institute of Techonology. The program (x) is written in Fortran 77 and EXE files work in DOS environment. The users' manual is also indexed as IX.NEW for preparation of input data files. Further, typical input data files are also given as IX.DAT beginning with I. The corresponding out put files OX.DAT are added, beginning with O.

The typical computer commands are:

NE IX.DAT- To open input file

NE OX.DAT- To open out put file

X- Name of computer program

IX.DAT- Input file name

OX.DAT- Output file name

2- For execution

1- For help menu

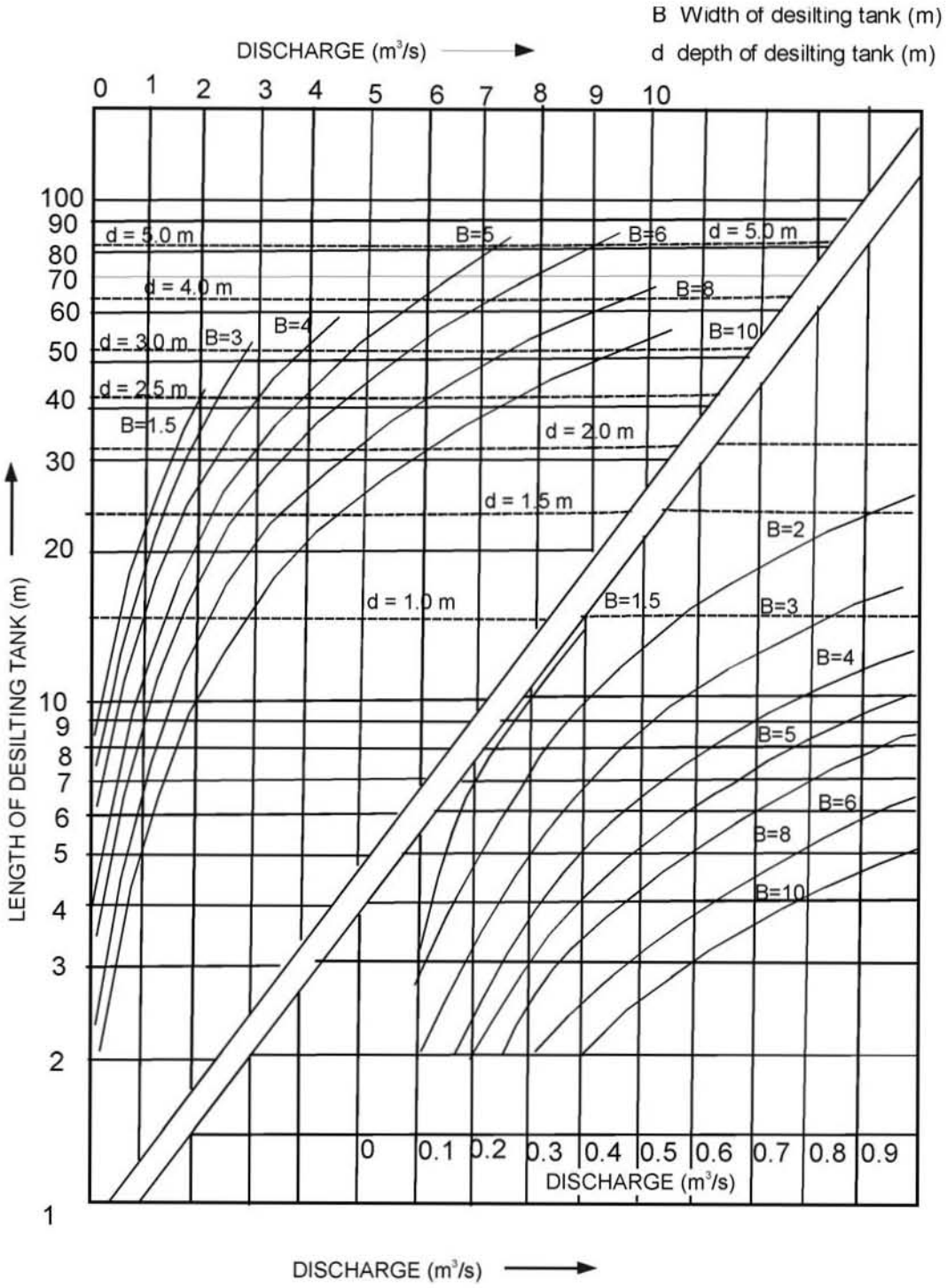
NE OX.DAT- To see the output file OX.DAT

SARC

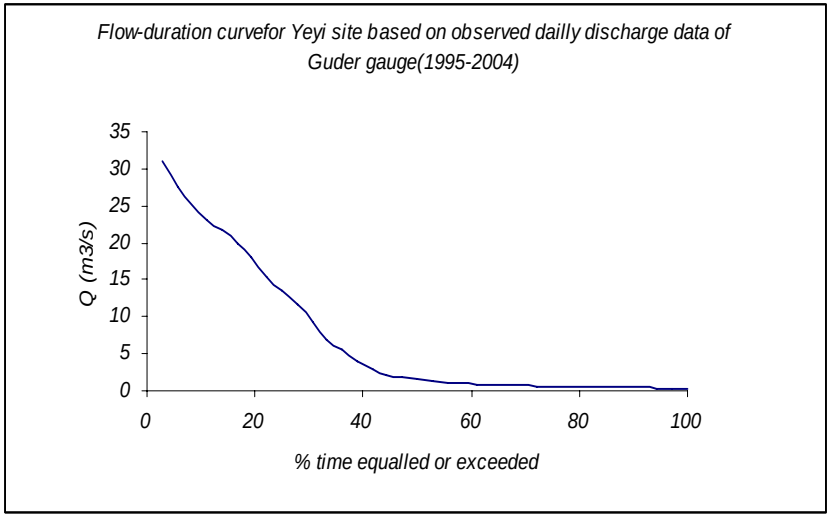
This program facilitates to compute the factor of safety with circular failure surface emerging at the toe. It analyses any general profile of the slope surface and for various forces that is pore water pressure, depth of tension crack at the top of the slope, depth of water in tension crack and earthquake force. In the first step it draws the various slip surfaces along which failure can take place. Then it calculates the radius and center of each slip surface.

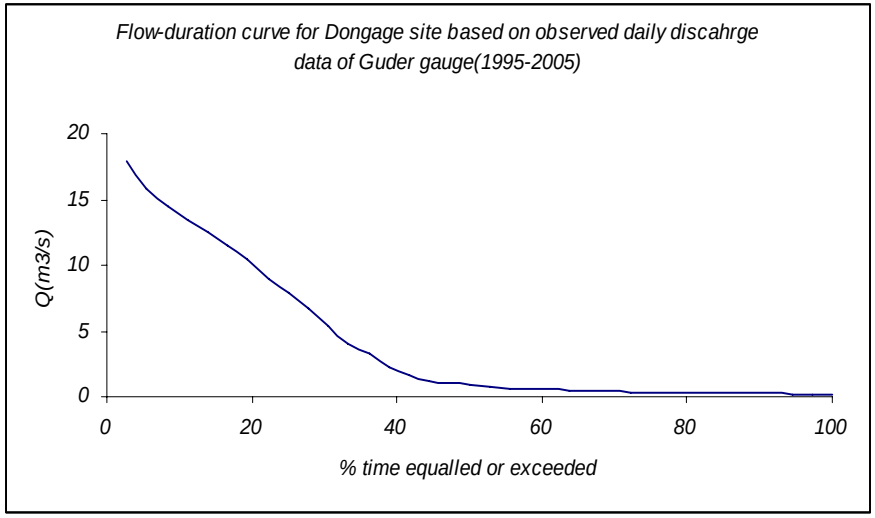
In the next step, the factor of safety is computed using Bishop,s equation for various slip surfaces until a minimum factor of safety is obtained. The analysis evaluates critical acceleration for slopes with factor of safety less than unity and compute dynamic displacement utilizing coorelation developed by Lavania et al. (1987).

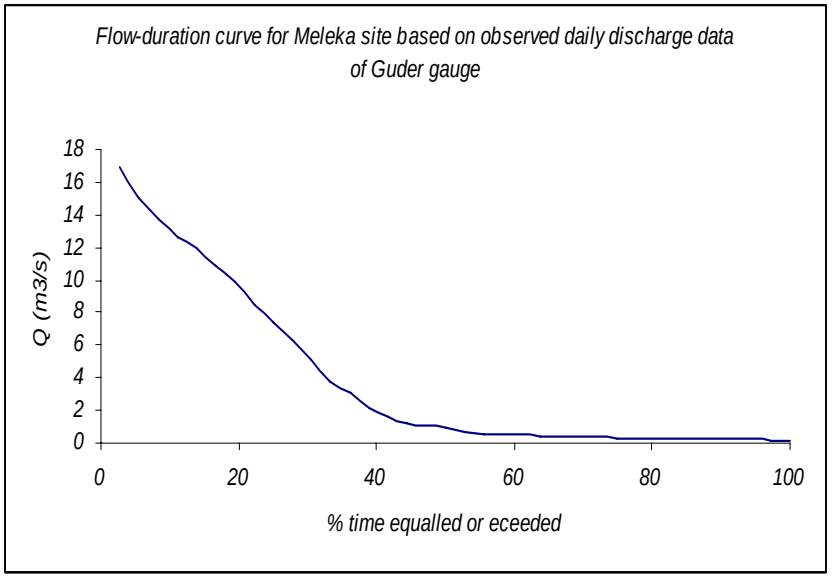
Annexure VIII Graph used to determine design dimensions for desilting tank (Kumar et al, 1990)

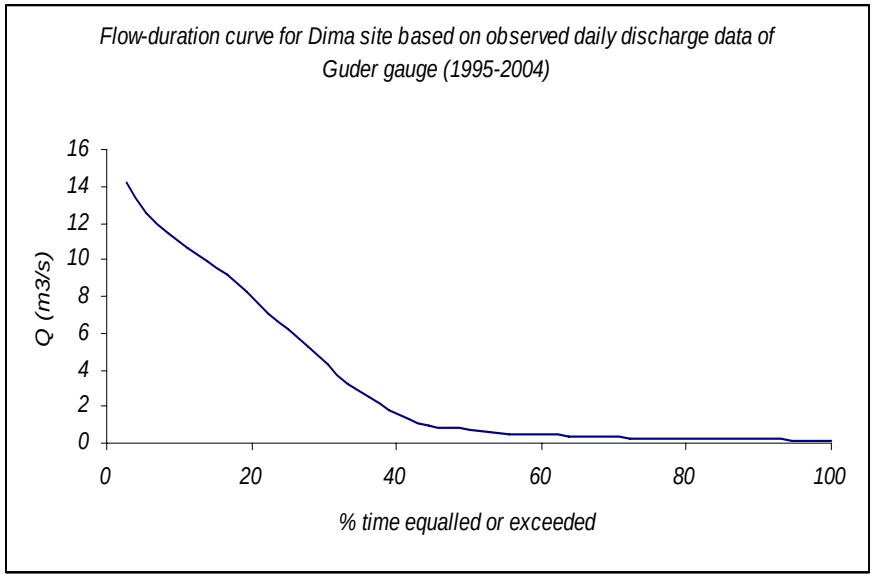


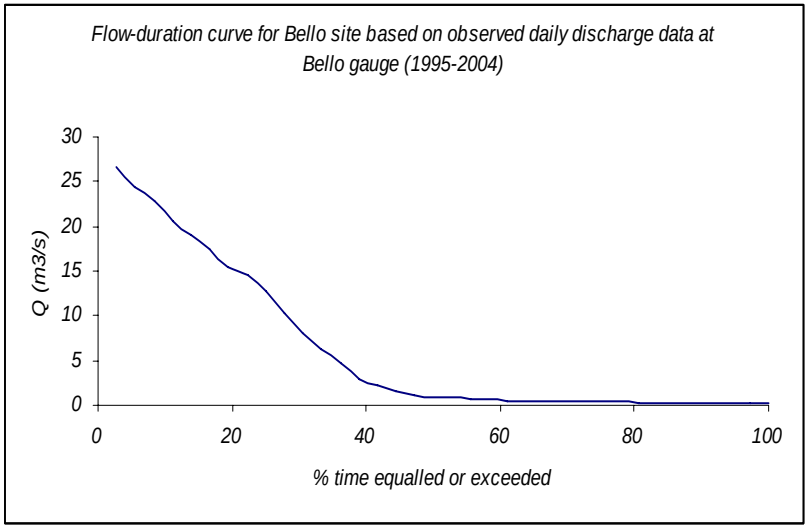
Annexure IX Flow- duration curves for potential streams

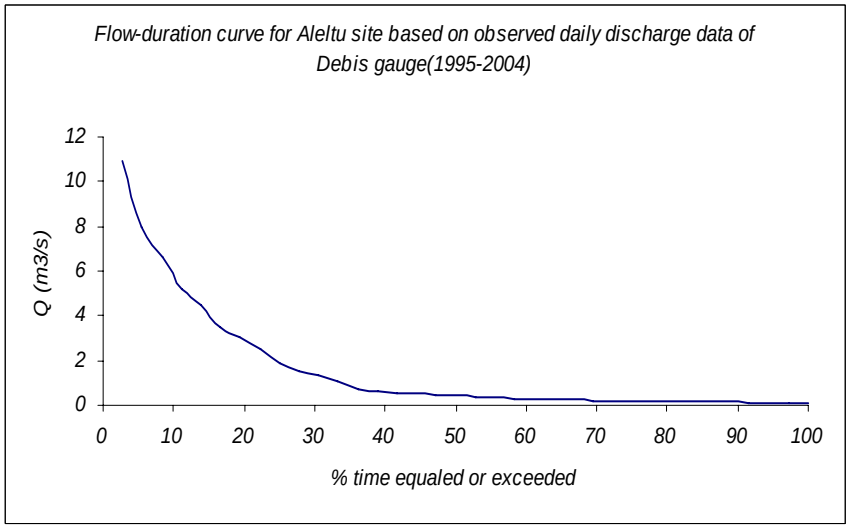


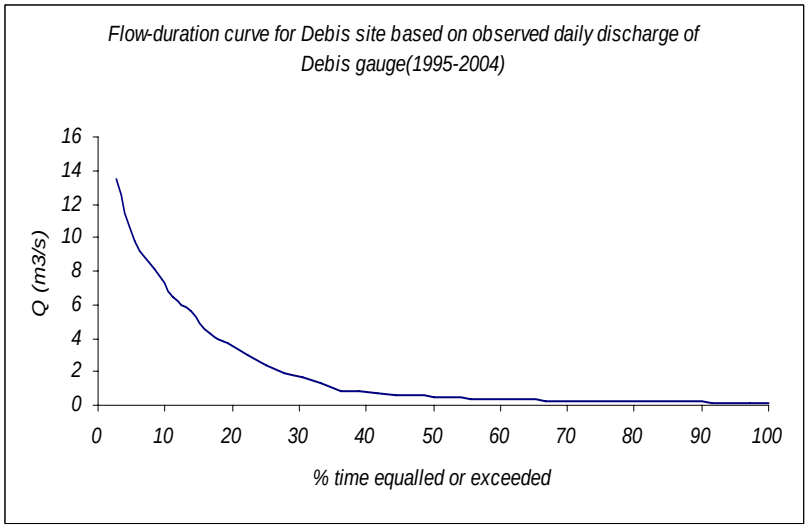


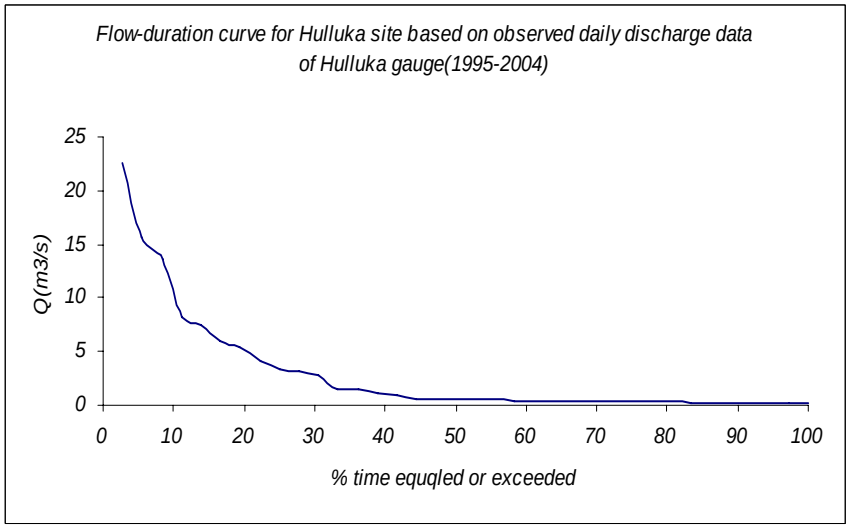


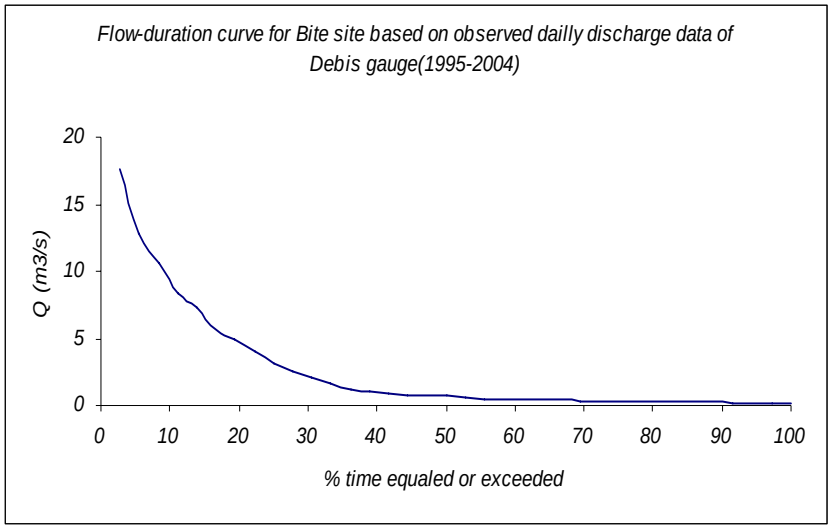


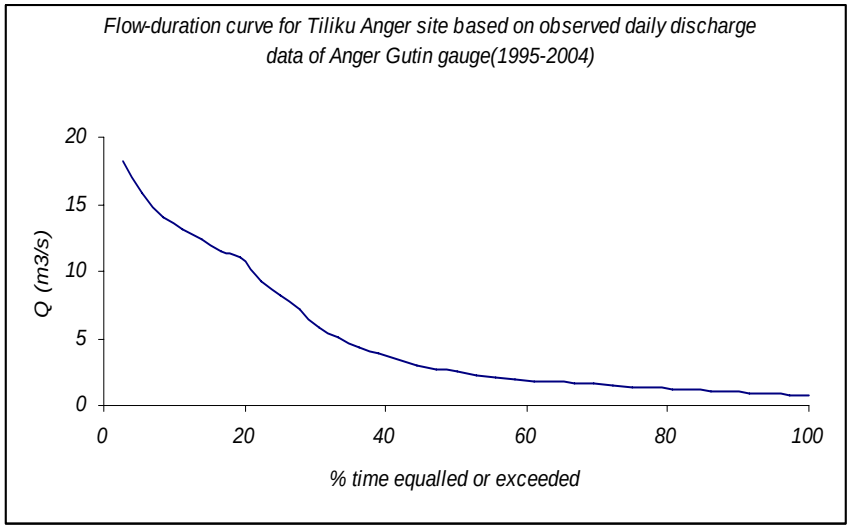

Flow-duration curve for Bello site based on observed daily discharge data at Bello gauge (1995-2004)
Q (m3/s)
30
25
20
15
10
5
0
0
20
40
60
80
100
% time equalled or exceeded

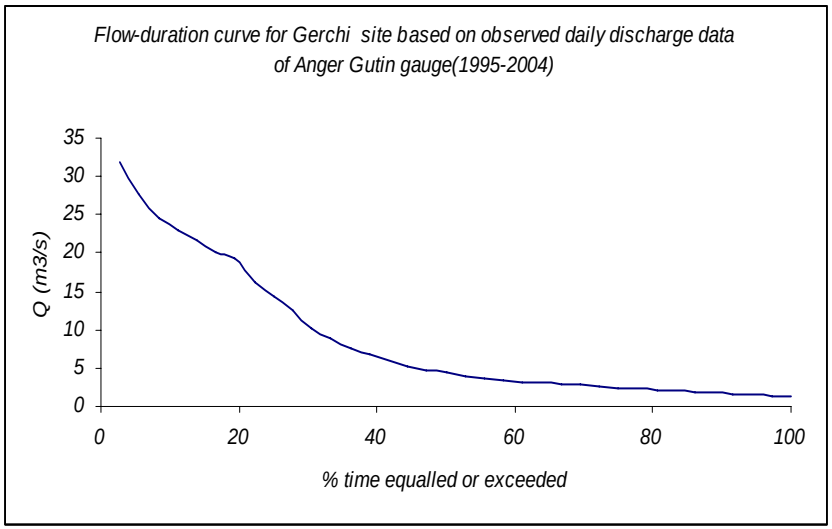

Flow-duration curve for Aleltu site based on observed daily discharge data of Debis gauge(1995-2004)
Q (m3/s)
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
% time equaled or exceeded

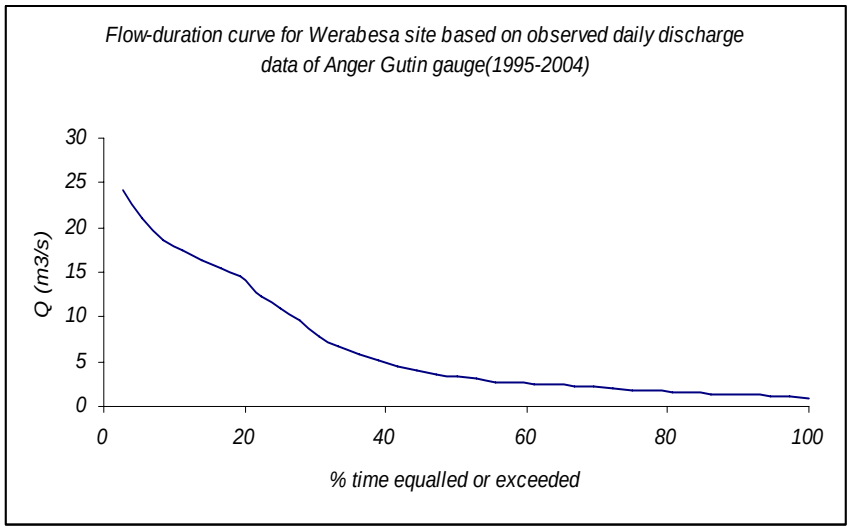

Flow-duration curve for Debis site based on observed daily discharge of Debis gauge(1995-2004)
Q (m3/s)
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
% time equalled or exceeded

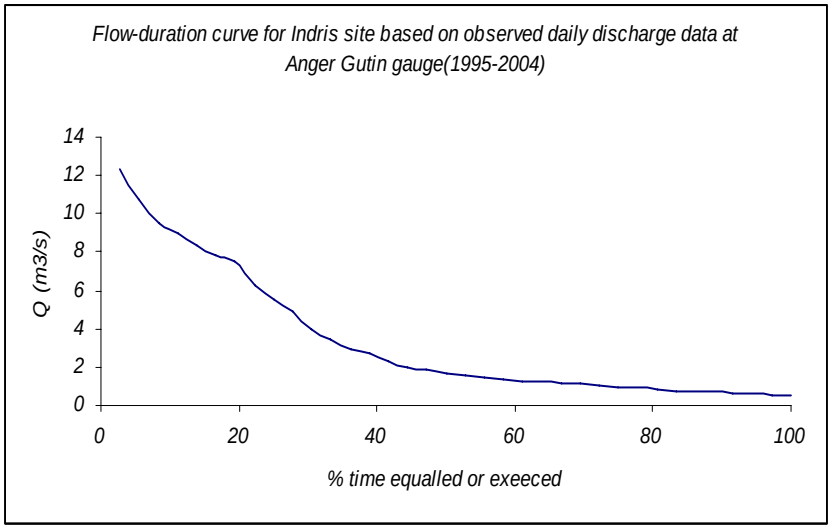

Flow-duration curve for Hulluka site based on observed daily discharge data of Hulluka gauge(1995-2004)
Q(m3/s)
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
% time equqled or exceeded

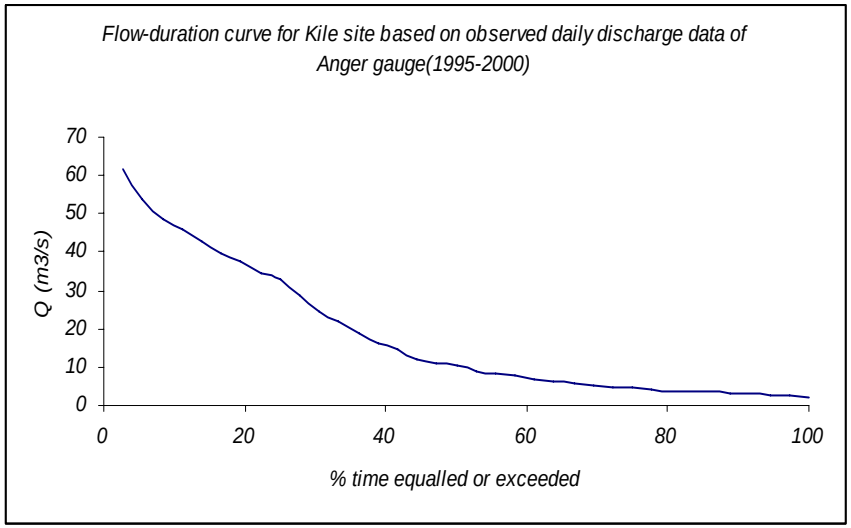

Flow-duration curve for Bite site based on observed dailly discharge data of Debis gauge(1995-2004)
Q (m3/s)
0
5
10
15
20
0 10 20 30 40 50 60 70 80 90 100
% time equaled or exceeded

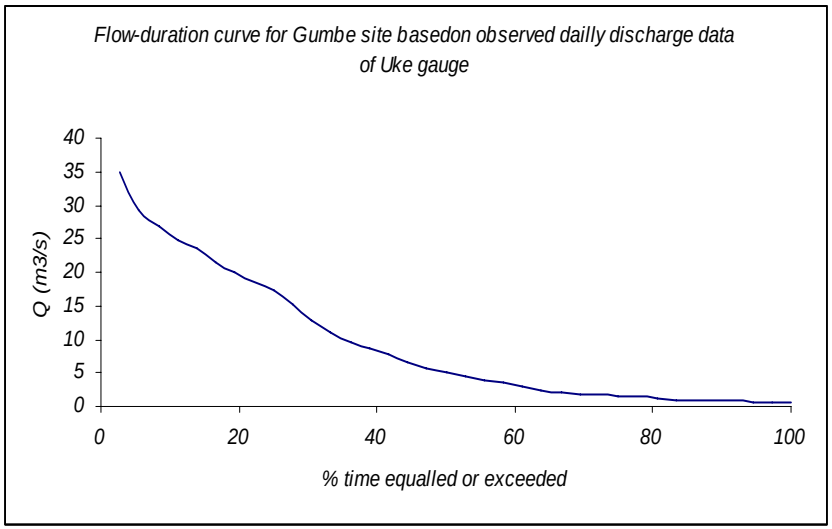

Flow-duration curve for Tiliku Anger site based on observed daily discharge data of Anger Gutin gauge(1995-2004)
Q (m3/s)
0
5
10
15
20
0 20 40 60 80 100
% time equalled or exceeded

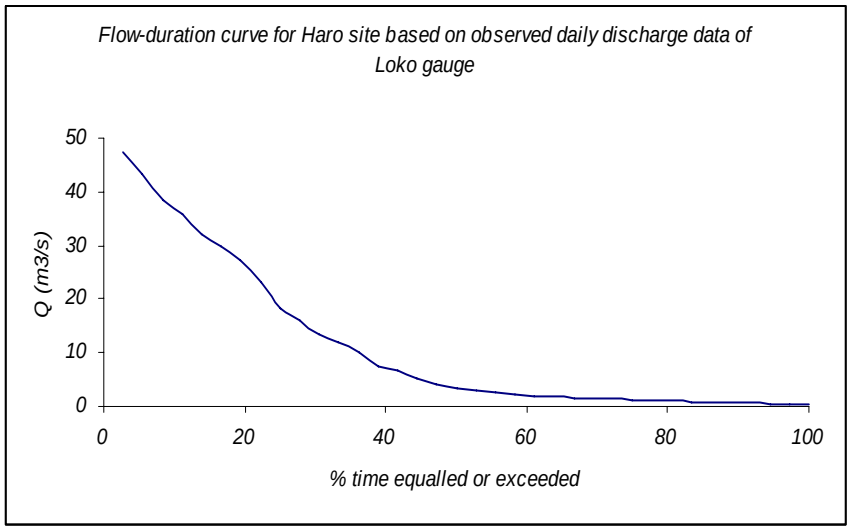

Flow-duration curve for Gerchi site based on observed daily discharge data of Anger Gutin gauge(1995-2004)
Q (m3/s)
0
5
10
15
20
25
30
35
0 20 40 60 80 100
% time equalled or exceeded

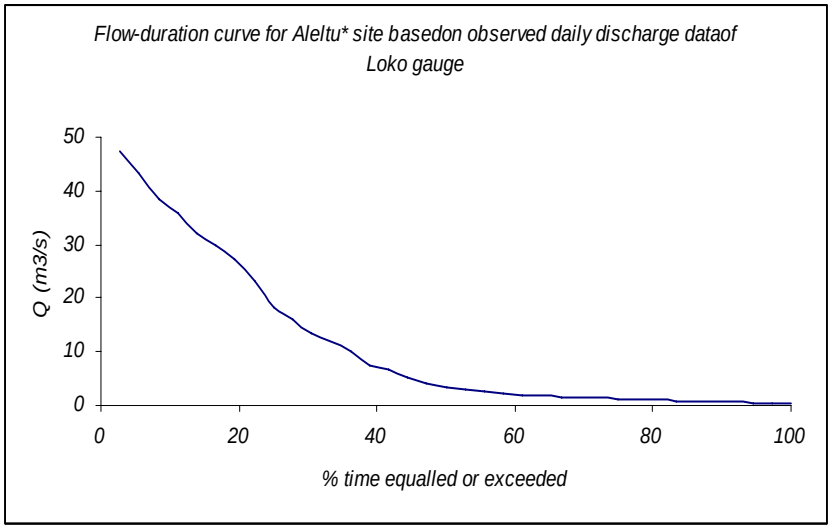

Flow-duration curve for Werabesa site based on observed daily discharge data of Anger Gutin gauge(1995-2004)
Q (m3/s)
0
5
10
15
20
25
30
0 20 40 60 80 100
% time equalled or exceeded

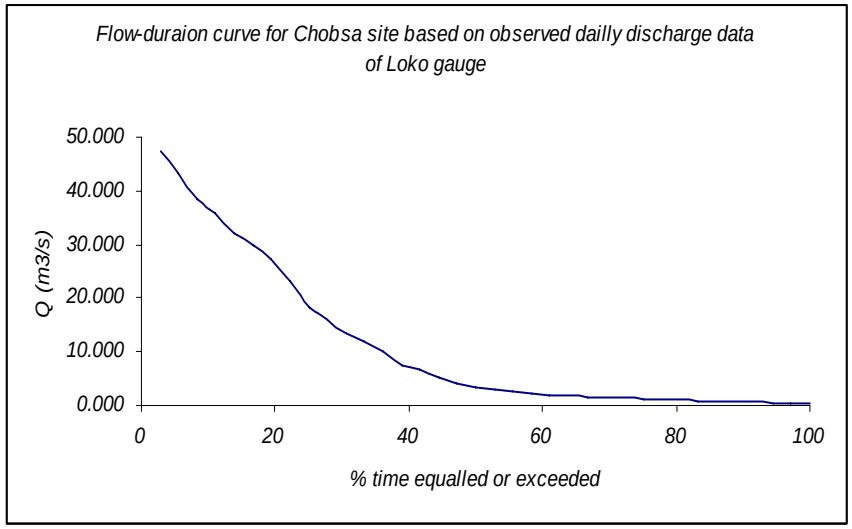

Flow-duration curve for Indris site based on observed daily discharge data at Anger Gutin gauge(1995-2004)
Q (m3/s)
14
12
10
8
6
4
2
0
0
20
40
60
80
100
% time equalled or exeeced


Flow-duration curve for Kile site based on observed daily discharge data of Anger gauge(1995-2000)
Q (m3/s)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
% time equalled or exceeded


Flow-duration curve for Gumbe site basedon observed dailly discharge data of Uke gauge
Q (m3/s)
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
% time equalled or exceeded


Flow-duration curve for Haro site based on observed daily discharge data of Loko gauge
Q (m3/s)
50
40
30
20
10
0
0
20
40
60
80
100
% time equalled or exceeded


Flow-duration curve for Aleltu* site basedon observed daily discharge dataof Loko gauge
50
40
30
20
10
0
Q (m3/s)
0
20
40
60
80
100
% time equalled or exceeded


Flow-duraion curve for Chobsa site based on observed dailly discharge data of Loko gauge
50.000
40.000
30.000
20.000
10.000
0.000
Q (m3/s)
0
20
40
60
80
100
% time equalled or exceeded

ADDIS ABABA UNIVERSTY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCES

ENGINEERING GEOLOGICAL STUDIES OF SMALL/MICRO/MINI HYDROPOWER SITES (A case study in Anger and Guder Sub-basins)

BY
ASHENAFI GEZAHEGN
ENGINEERING GEOLOGY PROGRAMM

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Advisor	
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Advisor	

D E C L A R A T I O N

I here by declare that the thesis entitled "*ENGINEERING GEOLOGICAL STUDIES OF SMALL/MINI/MICRO HYDROPOWER SITES.*(A case study in Anger and Guder sub-basines)" has been carried out by me under the supervision of Dr. Tarun Kumar Raghuvanshi, Department of Earth Sciences, Addis Ababa University, and Dr. Zelalem Hailu , Department of Civil Engineering, Addis Ababa University during the year 2007 as a part of Master of Science program in Engineering Geology. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Addis Ababa
Date:

Ashenafi Gezahegn