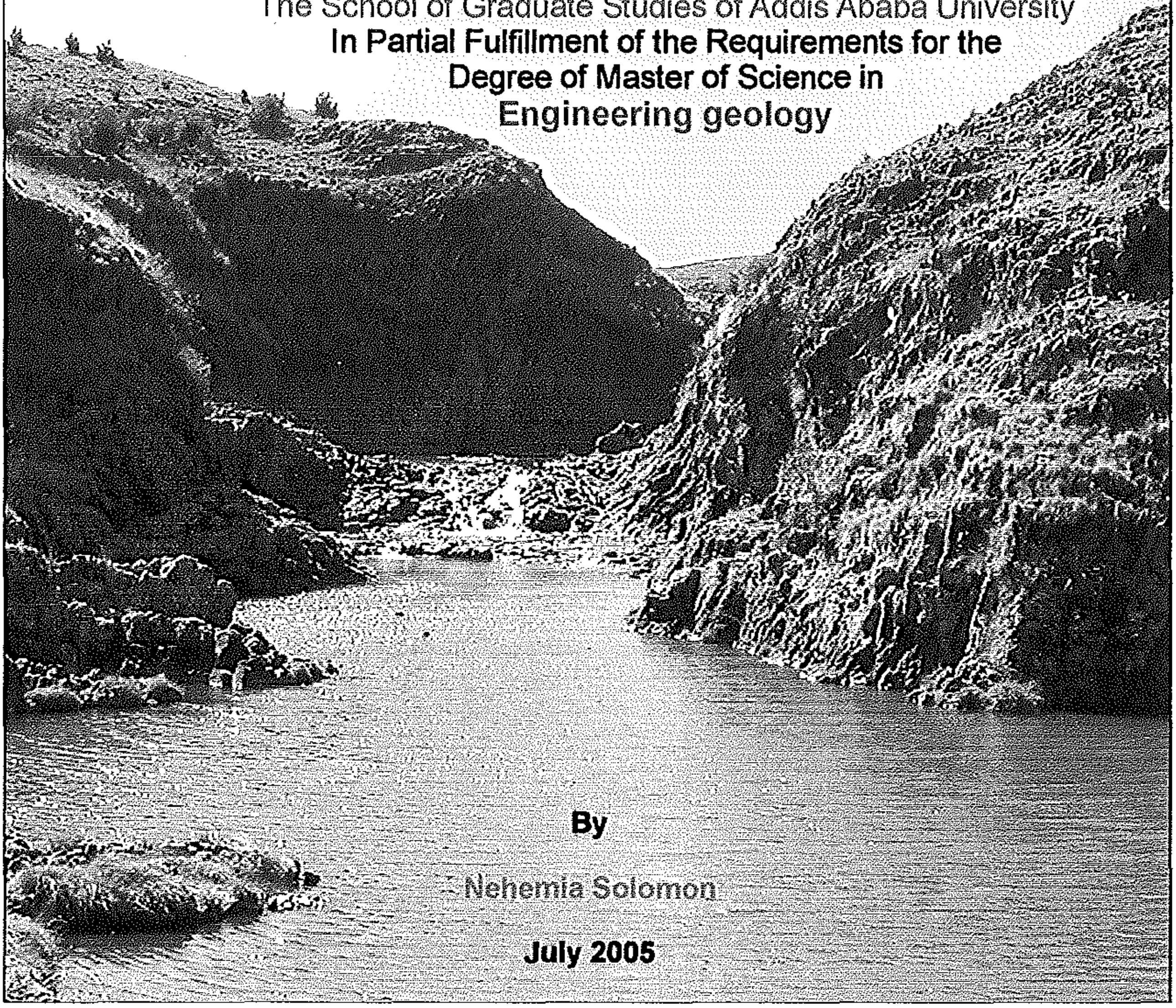
Addis Ababa University

School of Graduate Studies,
Faculty of Science

Identification and Engineering Geological Studies of Small Hydropower Sites in Muger, Jemma and Waleka Sub-basins (Central Ethiopia)

A Thesis Submitted to
The School of Graduate Studies of Addis Ababa University
In Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering geology



By

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ADDIS ABABA UNIVERSITY
DEPARTMENT OF EARTH SCIENCES
SCHOOL OF GRADUATE STUDIES

IDENTIFICATION AND ENGINEERING GEOLOGICAL STUDIES OF SMALL HYDROPOWER SITES IN MUGER, JEMMA AND WALEKA SUB-BASINS (CENTRAL ETHIOPIA)

By

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(Nehemia Solomon)

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Abstract

Electrical energy is becoming an essential commodity for the modern life. Every sector, weather industry, technology, transportation, public utilities or the domestic life, is now dependent on electrical power. The dependence on electrical power is becoming more and more, which has resulted into increasing demand for it. Therefore, with the increasing demand for power, the activities on small hydropower projects is accelerated in recent times. The small hydropower schemes are the appropriate solution to power demand as these require small capital investment and can be completed in a very short period of time, with minimum adverse environmental impacts.

The present study area is located in Abay drainage basin, in the central part of the country. Muger, Jemma, and Waleka drainage Sub-basins of Abay have been identified for the present study. The main objective of the present study was to identify potential Small Hydropower sites in the study area and to carry out ground verification with engineering geological appraisal, at pre feasibility level, of SHP sites (Selected sites).

In total 36 potential SHP sites has been identified during the present study. Out of these 36 site s observed discharge data was available for only 18 sites. For 9 small hydropower (SHP) potential sites, flow-duration curve is prepared from observed daily discharge data. However, for 9 other potential sites the observed discharge data has been projected from adjacent gauged stations by percent area ratio method for those which demonstrate similar catchment characteristic. Initial estimation of the power potential of 18 SHP sites has been computed for 75% dependable discharge and taking turbine efficiency to be 90% and efficiency of the generator as 95%. Thus, the total power potential, as estimated for 18 identified sites comes out to be 5325 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. These sites were, Beresa, Chacha, Gur and Robi Gemero. Thus, these four 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. In addition to this at all four proposed SHP sites engineering geological mapping has been carried out.

For the present study, an attempt has been made to tentatively design the various SHP components and select the turbine based on the power potential for the selected site.

Further, in the present study an attempt has been made to develop a GIS data base on small hydropower. This data base is prepared with an intention to provide all necessary information on SHP at pre-feasibility level for the present study area and may serve the planners and developers to have some form of 'first hand information' on small hydropower potential in the area. The GIS database on SHP may serve as a useful decision making tool for the planners and developers, intending to develop small hydropower schemes in the present study area.

Finally based on the results and finding of the present study, certain recommendations has been made.

CHAPTER ONE

INTRODUCTION

1.1 Preamble

In the recent times the non-renewable and exhaustible sources of energy are getting depleted at a very fast rate, which has focused attention to the non-exhaustible and renewable sources of energy. Hydropower is one of the most common renewable sources of energy abundantly available in the hilly region. However, large hydropower plants are not being taking up for execution in sufficient number as these involve huge amount of funds and also the planning and construction period is very high. Therefore, with the increasing demand for power, the activities on small hydropower projects have accelerated in recent times all over the world. The small hydropower schemes are the appropriate solution to power demand as these require small capital investment and can be completed in a very short period of time (Kumar et al., 2000).

Energy, a key ingredient for improving the living conditions and fuelling the development process, is usually in short supply and the inhabitants have to depend on local natural resources of fuel-wood and other biomass to meet their daily needs. Mankind has used the energy of falling water for many centuries, at first in mechanical form and since the late 19th century by further conversion to electrical energy. Out of the world's total primary energy supply of about 9376 Millions of Tones Oil equivalent, about 2.3% only comes out of hydro sources. Out of a total 13652 TWh of electricity production only 18.4% of electricity is generated through hydro sources. Small hydro offers a wide range of benefits – especially for rural areas in developing countries. The resource is environmentally friendly and has substantial economic advantages (AHEC, 2003).

1.2 General Layout of Small Hydro Power scheme

A typical Small hydropower system, shown in Figure 1.1, 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 consist of desilting tank (to allow sedimentation of stones and silt to avoid turbine damage), headrace channel (to guide water to the fore bay tank), weir (to divert part of river or stream), penstock (to guide the water from the fore bay tank directly to the turbine). and the power house (containing the turbine, shaft drive system, electric generator, and control unit).

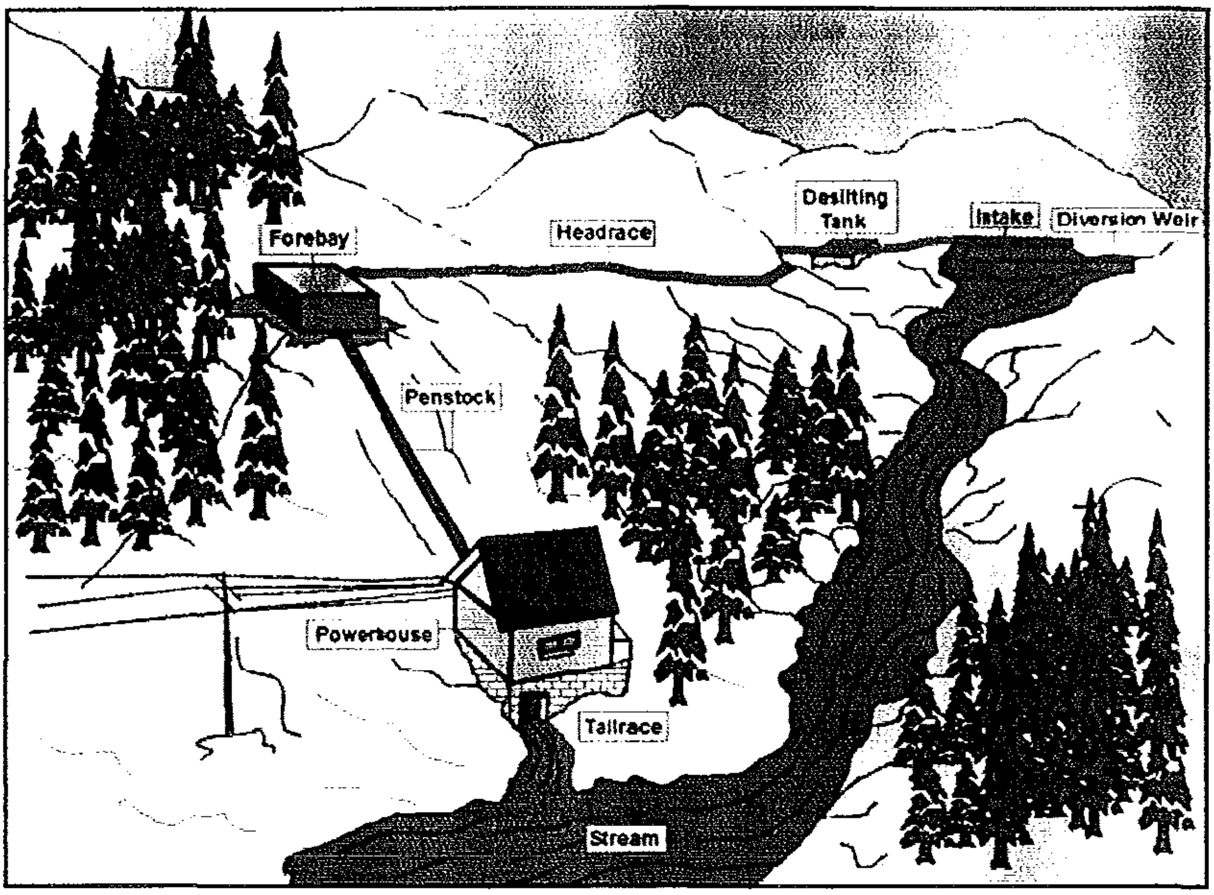

Fig. 1.1 Typical Arrangement of Small Hydro Power Station

1.3 Classification

Based on installed capacity, many countries have their own classification system for small hydropower schemes. In Ethiopia the small hydropower schemes are classified as ***micro-hydro*** (less that about 0.3 MW), ***mini-hydro*** (0.3 – 1 MW), and ***small hydro*** (1 – 10MW) installed capacity levels (AAU, Faculty of Technology, 2001).

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

- General layout
- Mode of head concentration
- Mode of discharge regulation

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

- Run of the river small hydropower

- Canal fall small hydropower and
- Dam toe small hydropower

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

- Dam scheme
- Diversion scheme
- Mixed scheme

In a dam scheme, the head is mainly concentrated by the dam which raises the upstream water level whereas, in the diversion scheme the requirement is fulfilled by water diversion structure such as an open canal or a pressure pipeline. The mixed scheme uses both dam and diversion structures.

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

- Run-of-the-river scheme,
- Daily regulation schemes and,
- Seasonal regulation schemes.

In Run-of-the-river scheme, power is generated by natural runoff without flow regulation. Firm power is guaranteed by a natural base flow with high reliability. Many hydropower plants belong to this scheme due to lower 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 discharge it in the dry season, thus enhancing the firm power output the whole year round. Most of these kinds of plants use dam scheme and mixed scheme to concentrate the water (AHEC, 2003).

1.4 Importance of Small Hydropower

Energy produced from Interconnected System is mainly consumed by major load centers like large cities and the industries around them. But, the vast majority of the population lives and works in the rural areas, i.e. in farms and the small towns, villages, and hamlets. These rarely have any kind of access to the interconnected system. Their hope for electrical energy remains in harnessing of power from locally available streams and rivers.

For rural electrification, small hydropower installations are the only possible options. as the total power demand and the available capital do not justify installations of interconnected system (AAU, Faculty of Technology, 2001).

1.5 Advantages of Small Hydropower

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

- Relocation of an existing settlement;
- Reduction of farmland and grazing land;
- Disruption of the normal migration pattern of fish or the flow of traffic;
- The presence of a dam will probably cause the accumulation of silt which will, not only adversely affect power generation but also cause the level of reservoir water to rise, resulting in further inundation of the surrounding lands;
- Increased possibility for water-borne diseases;
- Disappearance of bird and animal sanctuary because of inundation, although other birds and animals can find sanctuary at the boundary of the reservoir.

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

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

1.6 The Study Area

1.6.1 Location and Access

The present study area is located in Abay drainage basin, in the central part of the country. Muger, Jemma, and Waleka drainage Sub-basins of Abay have been identified for the present study. The study area covers about 30,585.2 km^2 and is bounded within $9^0 23'$ - $11^0 05'$ latitude and $37^0 12'$ – $39^0 33'$ longitude. These basins are partly in Addis Ababa, Amara and in Oromia region. Figure 1.2 shows the geographic extents of the study area.

There are 5 Zones, 93 Weredas and 68 towns excluding Addis Ababa in these sub-basins. The total population in these sub-basins contributes to 7.35 million, which include both urban and rural population. The access to these sub-basins is through all types of road with a total length of 2,155 km. Of the total road length, all weathered road (Asphalt) is about 299.96 km, all weathered road (gravel) is 687.78 km, dry weathered roads is 448.46 km and motor-able tracks are 718.81 km.

1.6.2 Climate of the Study Area

In the study area 34 numbers of Metrological stations are available. According to the result of NMSA, the climates in Muger, Jemma, and Waleka (MJW) Sub-basins are mainly of three types. More than 85% of the Sub-basins fall in warm climate zone whereas; the remaining parts are cool and tropical climate. Figure 1.3 shows the climatic conditions in the study area.

Aw – Tropical Climate

The dry months are in winter. The mean temperature of the coldest month is > 18^0C and the mean annual rainfall is 680-1200 mm. This type of climate prevails up to an elevation of 1750 meters above mean sea level. The length of dry and wet periods varies considerably from the western part of the northern and eastern parts of the country. This climate is characterized by tall grass, usually grass and trees are intermingled.

Cwb – Warm temperate Climate I

This climate has distinct dry months in winter. The mean temperature of the coldest month is < 18^0C and for four months the mean temperature is > 10^0C with the mean annual rainfall (mm)> 20x (T+14), where T is the mean annual temperature in ^{0}C. The rainfall distribution and amount varies considerably from area to area. Forests are predominant in areas of heavy rainfall while grass is covered in areas of moderate rainfall. This climate prevails over areas with altitude of 1750 – 3200 meter above mean sea level.

Cwc – Cool Highland Climate

This is characterized by dry months in winter. The mean temperature of the warmest month is < 10^0C and the mean annual rainfall is characterized by dry months in winter. The mean temperature of the warmest month is < 10^0C and the mean annual rainfall is 800 – 2000mm. This climate prevails over areas with altitude of > 3500m above mean sea level and is located on small isolated high grounds.

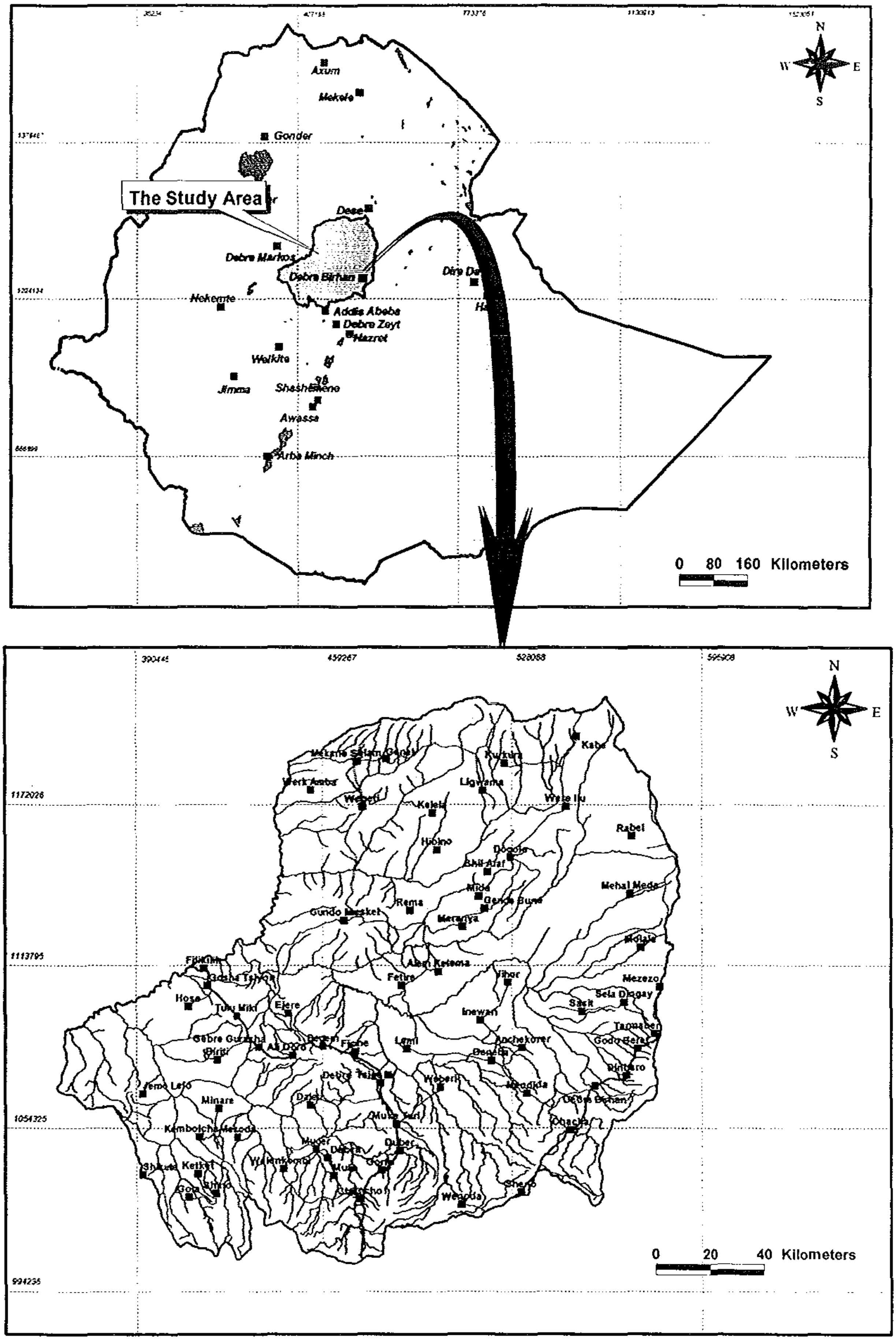

Fig. 1.2 Location of the Study Area

The northern, northeastern and southeastern parts of the country are dominated by hot and arid type of climate. The central, eastern and southern highlands are mainly dominated by warm temperate climate.

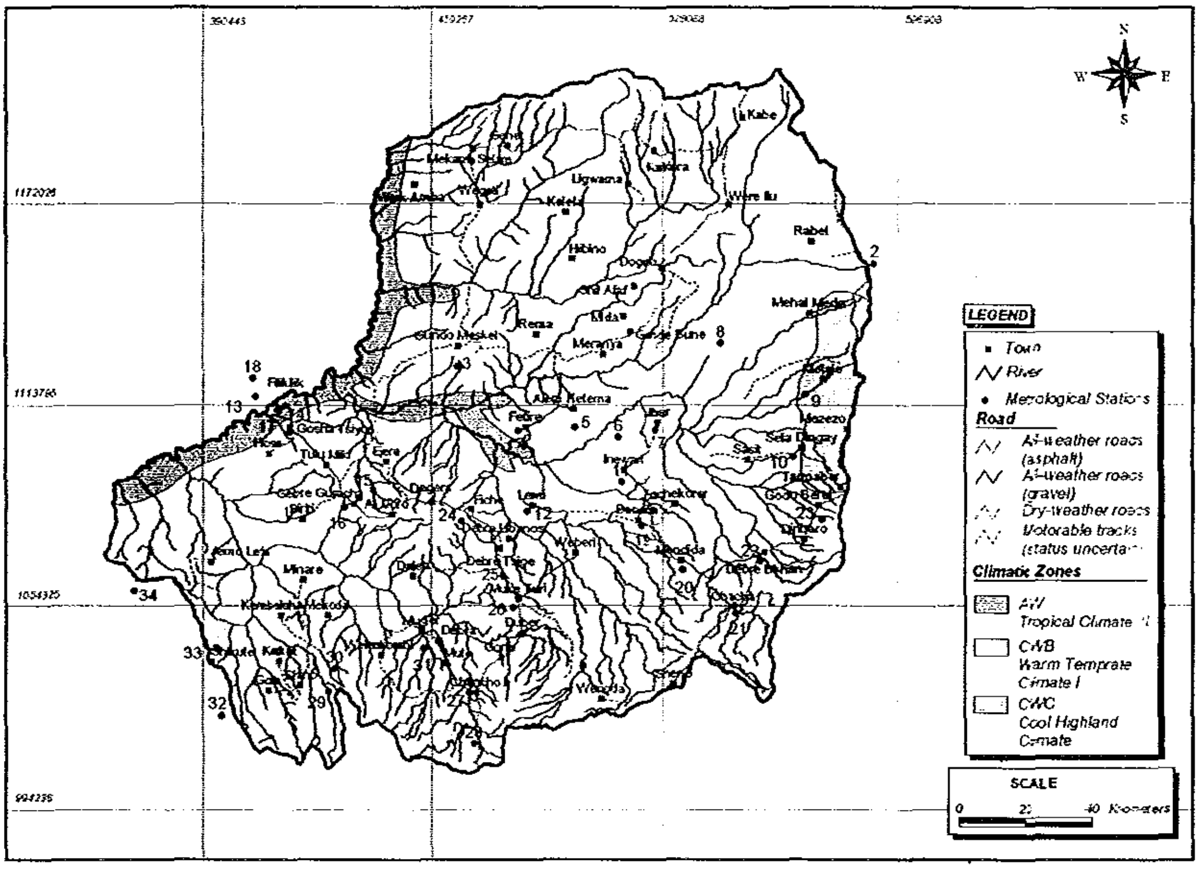

Fig. 1.3 Climate Zones in the Study Area

For the present study, rainfall data from 34 meteorological stations has been procured from the Abay Basin Master Plan and was processed to workout monthly average rainfall. The data length varies from 2 years to 42 years for all 34 stations. The average monthly rainfall processed data for all 34 stations is presented at Annexure I.

1.6.3 Physiographical Setting of the Study Area

The present study area is a part of Central Highland plateau of Ethiopia. It is bounded between the left margin of Main Ethiopian Rift and Abay gorge. The highest elevation of the area is at the Main Ethiopian Rift escarpment and the lowest point is located in Abay Gorge, with a difference of more than 2000m. Figure 1.4 presents the general Physiography of the study area.

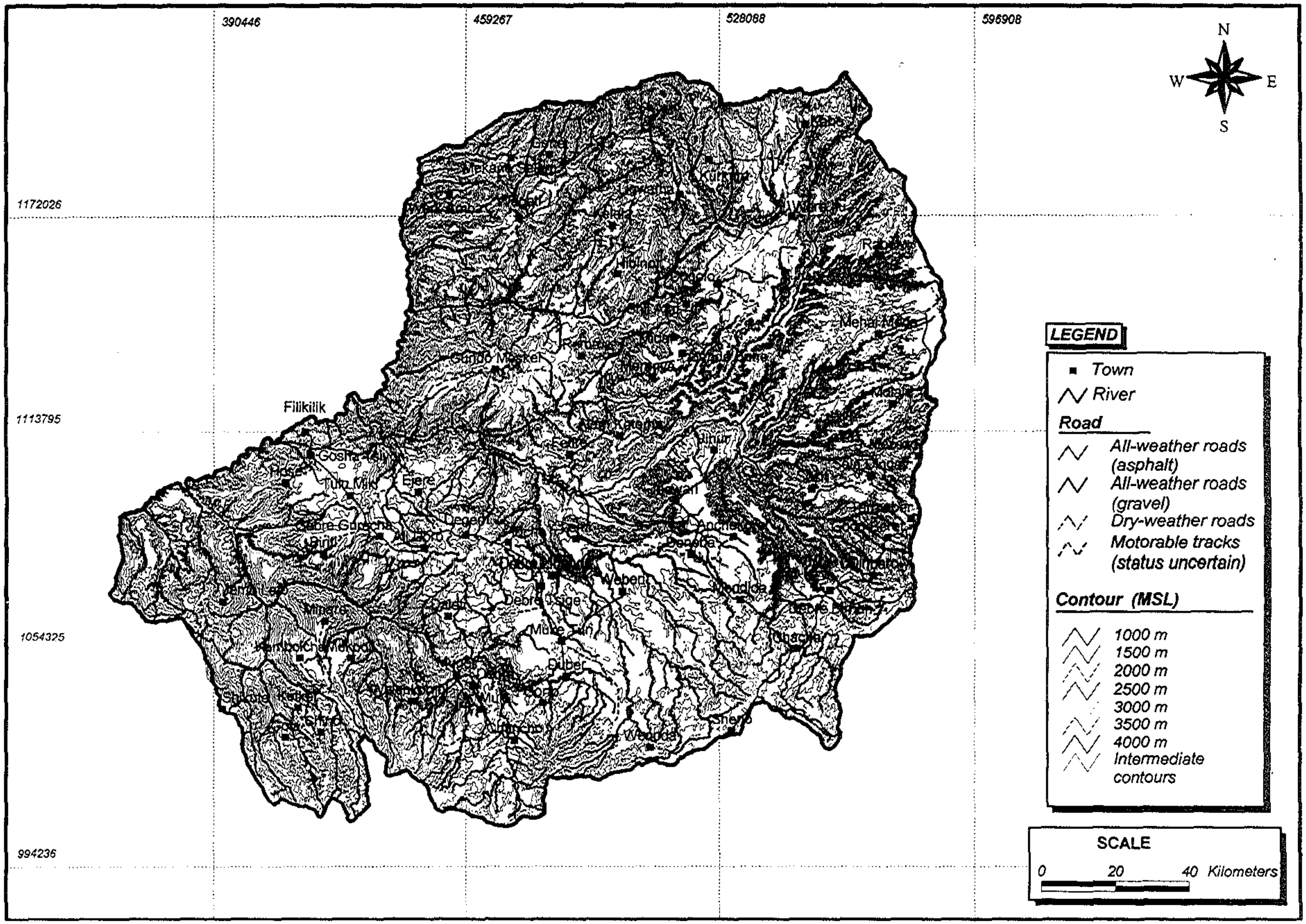

Fig. 1.4 Physiography of the Study Area

Muger-Sub basin

It is one of the sub-basins in Abay drainage basin, which has been selected for the present study. This sub-basin is located on the western part of study area. The physiographical setting of the sub-basin is mainly undulating topography. The highest point in the sub-basin is near to the periphery of Abay basin, which is close to Addis Ababa town.

Jemma-Sub basin

This sub-basin is located at the center of the study area. It is part of Abay drainage basin. This sub-basin has a flat to undulating terrain and Jemma river gorge. Because of the intensive erosion activities the Jemma river gorge formed a maximum elevation difference of 1200m.

Waleka-Sub basin

It is one of the three sub basins, which has been selected for the present study. It is located in the northern part of the study area. This sub-basin forms moderately to high undulating topography. The highest point in the sub-basin is located within this sub-basin at the escarpment of Main Ethiopian Rift, namely Tarmaber ridge.

1.6.4 Seismicity of the Study Area

Natural Hazard is defined as "the probability of occurrence within a specified period of time, within a given area of potentially damaging phenomena" (Johnson et al., 1988). Earthquake is a natural hazard resulting seismic waves (dynamic loading) that may damage natural and man made structure around the epicenter. The damage can be manifested as ground failure in the form of landslides, ground cracking, subsidence, and differential settlement.

The Seismic zone of Ethiopia have been delineated by Gouin (1979) and later updated by Laike Mariam Asfaw (1986). The 'Seismic Risk Map' produced by Laike Mariam for a hundred year return period and 0.99 probability shows that the study area falls within 7 to 8 M.M scale. The map showing the Seismic Risk zones of Ethiopia and the location of the study area is presented in Figure 1.5.

1.7 History of Small Hydropower (SHP) in Ethiopia

The first SHP site was identified by an Italian solider near Debre Birhan town at Beresa Stream, some times in early twenties (as reported by local people). As reported, this power station was generation a power of less than 100 kW by utilizing a head of 50m. This power station was functional till 1977 and the operation was then stopped as the town Debre Birhan was connected to the national grid. Presently, the country has three SHP Schemes namely, Yadot, Sor and Dembi SHP sites. These Self Contained Systems have a total installed capacity of 6.15 MW. Number of studies has been made over the years for the hydro – energy resource base of the country by consultants from country and abroad, but mostly foreign-based consultants. 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) are some of those clients who initiated such studies.

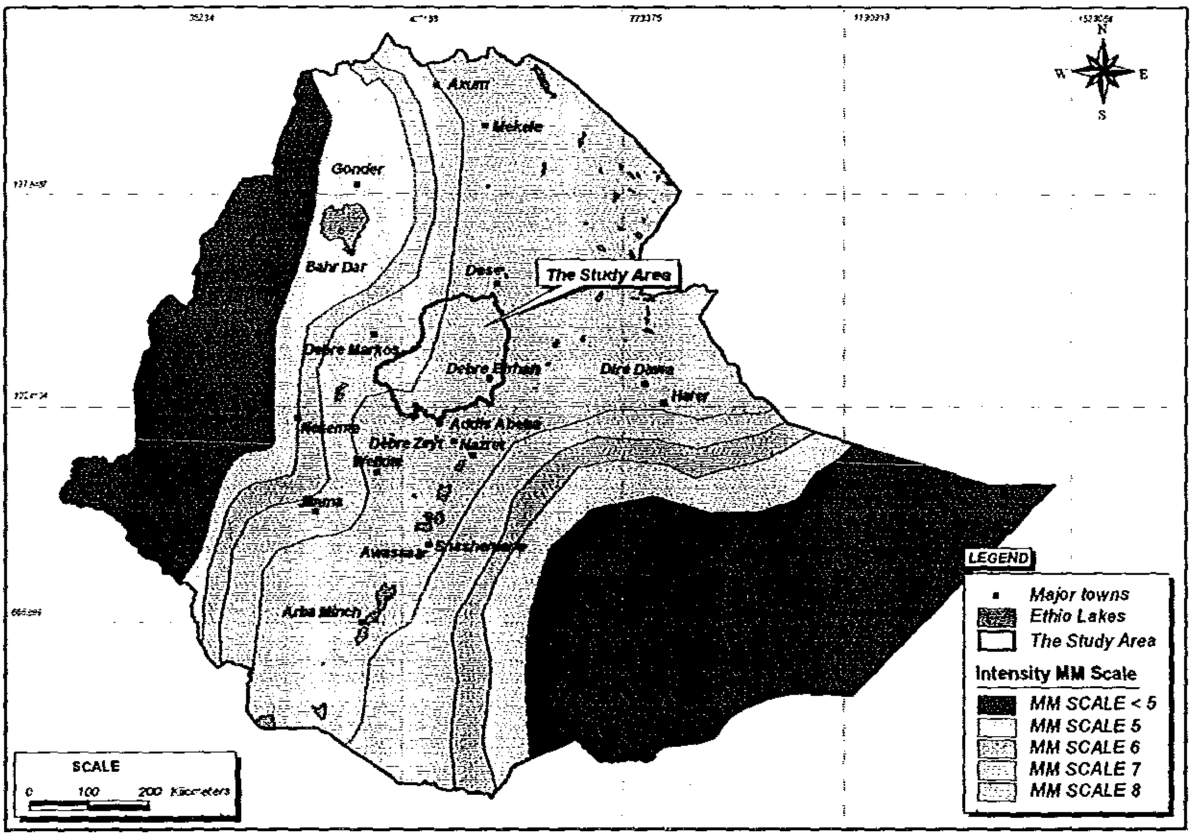

Fig. 1.5 Seismic Risk Map of Ethiopia 100 year return period, 0.99 probability ***(After Laike Mariam Asfaw,1986)***

1.8 Power Scenario in Ethiopia

According to the Italian consultant's (CESEN, 1986), the hydro-potential of Ethiopia Basins is discussed with reference to three basic types of utilization:

- Installations with flow regulations
- Small slope installations without flow regulation
- River plain plants

The Potential water basins in Ethiopia are shown in Figure 1.6 and a summary of gross hydro energy potential is presented as Table 1.1.

According to the report, 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 basin, in the Bilate-Sagan-Dawa, Genale-Gestro basins, the Wabe Shebele, and Awash basins. Only some areas along the Tekeze water source may be considered to present technically feasible sites but it seems unlikely that the power produced would always

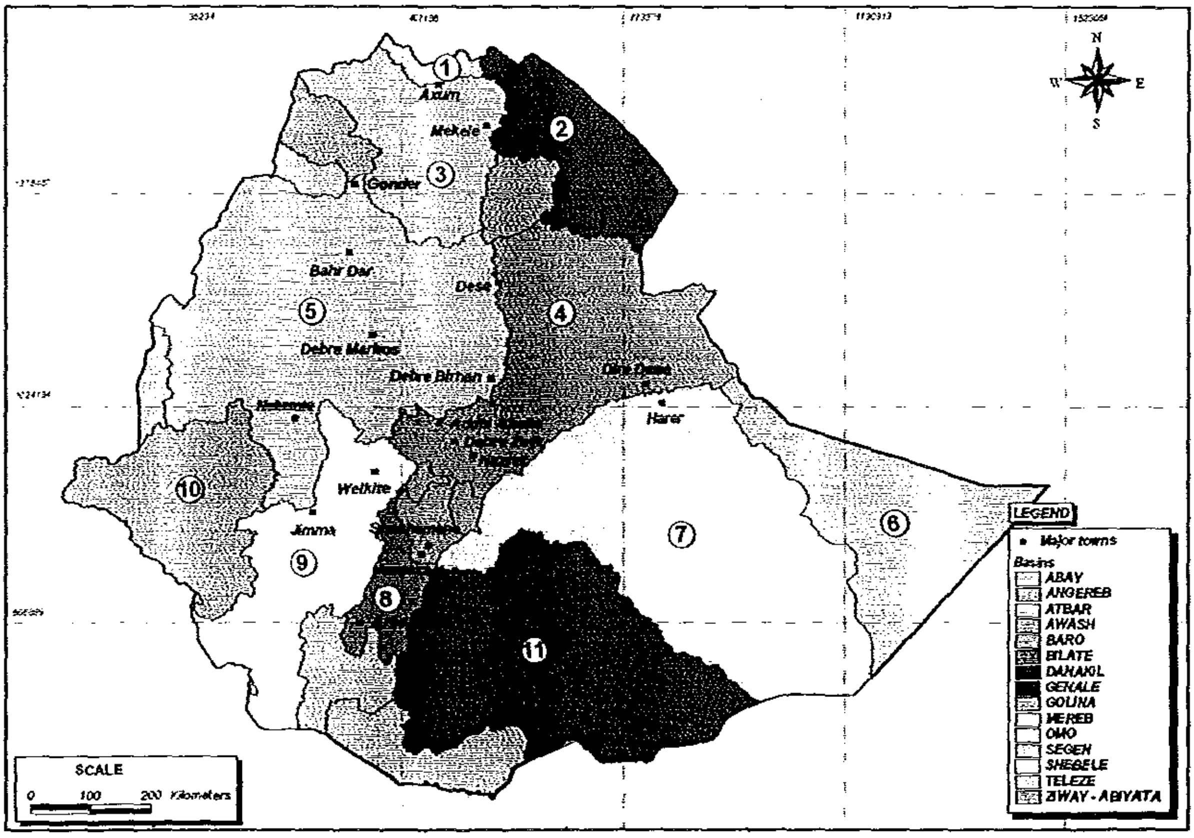

Fig. 1.6 **The Water Basins of Ethiopia** *[1: Mereb Gash, 2: Danakil, 3: Tekeze, 4: Awash, 5:Blue Nile, 6: Ogaden, 7:Wabe Shebele, 8:Bilate-Sagan-Dawa, 9: Omo, 10:Baro, 11:Genale]*

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 coastal or the Ogaden basins.

More than three quarters of the hydro potential is available from mountain reservoirs 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 that 5%) of the Country's large potential that could be exploited from installations with flow regulation. A sizeable quantity of hydro energy is also available from river plain flow. Gross stream potential from main water bodies of valley watercourse is of the order of 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. Table 1.2 presents Basin wise Summary of Gross Average Hydro Energy Densities (GWh/km^2/yr).

Table 1.1 Summary of Gross Hydro-Energy Potential

S.No	Basin	*Types of Exploitation*			
		With Flow Regulation	*Small Slope Plant*	*River Plain Plant*	*Total*
		(GWh/yr)			
1	Awash	16770	1574	4010	22354
2	Coastal	-	-	-	-
3	Barka	-	-	-	-
4	Mereb-Gash	-	-	-	-
5	Danakil Depression	-	-	-	-
6	Tekeze	23150	-	12720	35870
7	Blue Nile	221930	7197	51017	280144
8	Baro	58700	2553	18050	79303
9	Omo	73850	2961	27430	104241
10	Bilate-Segan-Dawa	47050	1910	-	48960
11	Genale	31500	2641	11360	45501
12	Gestro	4400	133	-	4533
13	Wabe Shebeli	14500	1490	8780	24770
14	Ogaden Depression	-	-	-	-
	Total	**491850**	**20459**	**133367**	**645676**

1.9 Objectives

A. General objectives

The following objectives have been planned for the present study;

i) Identification of the Potential Small Hydro Power Sites in the study area.

ii) Delineation of the potential catchment and to carry out the Hydrological study, to workout the dependable flow of the stream for power generation.

iii) To workout the possible general layout for the small hydro power projects.

iv) To estimate the power potential for small hydropower project sites.

v) Engineering Geological Appraisal of the identified small hydropower project sites (for selected sites).

vi) To prepare the Engineering Geological map for the small hydropower project sites at a scale of 1: 50,000 (for selected sites).

vii) To prepare a GIS database for the small hydro project sites in the study area.

Table: 1.2 Summary Gross Average Hydro Energy Densities

S.No.	*Basin*	*Types of Exploitation*		
		With Flow Regulation	***Small Slope Plant***	***River Plain Plant***
		(GWh/km²/yr)		
1	Awash	0.52	68	4.6
2	Coastal	-	-	-
3	Barka	-	-	-
4	Mereb-Gash	-	-	-
5	Danakil Depression	-	-	-
6	Tekeze	0.65	-	18.7
7	Blue Nile	1.44	99	55.3
8	Baro	1.78	153	62.5
9	Omo	1.35	96	26.0
10	Bilate-Segan-Dawa	0.78	79	-
11	Genale	1.50	176	16.2
12	Gestro	1.16	88	-
13	Wabe Shebeli	0.47	78	7.5
14	Ogaden Depression	-	-	-
	Average	**1.15**	**101**	**23.4**

B. Specific objectives

i) Identification of potential small hydropower sites in the study area and to work out the available head and dependable flows for power generation.

ii) Selection of diversion weir and intake site, powerhouse site, forebay site and penstock alignment and to determine the available head. To workout the general layout of the small hydropower schemes.

iii) To carryout the Engineering Geological Appraisal of the SHP Sites – to workout the Engineering Geological suitability and possible remedial measures for the diversion weir, power channel, forebay, penstock alignment and the powerhouse site.

iv) Engineering geological mapping of the selected small hydropower sites.

v) To workout the estimations on quantities for excavation and construction and to workout preliminary cost estimates for the proposed sites.

vi) To prepare GIS database for the SHP sites giving details on the geographical locations of the sites, general layout, geology, rock and soil characteristics, vegetation cover, power potential etc.

vii) To suggest sustainable recommendations.

1.10 Methodology

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

- Literature review and analysis of previous data on meteorology, hydrology and geology.
- Preparation of working map at a scale of 1: 50,000 from topographic maps and previous works.
- Identification of potential SHP sites in the study area through topographical maps.
- Delineation of potential catchments from topographical maps.
- Ground verification of potential SHP sites and finalization of general layout of the projects.
- Collection of data on geology, topography, and hydrology of the area in the field. Insitu tests on the earth materials, lithological descriptions, sampling of rocks and soils.
- Laboratory analysis for the soils by collecting samples from the field for classification.
- Slope stability studies along the water conductor system of the SHP sites, for present and possible worst conditions.
- The hydrological, meteorological, topographical, geological and geotechnical data will be interpreted in accordance with the field observation, literature review and laboratory results to reach at conclusions and to suggest possible recommendations.
- Digitization of maps and generation of various themes, preparation of database file to be attached as attribute data to the various themes, preparation of data/information attachment files including the various information on the small hydropower sites and preparation of GIS Database on SHP sites in the study area.
- Counterchecking of conclusions and validation of results.

1.11 Analytical tools and supporting materials

For the present study various analytical tools were utilized to fulfill the research objectives.

i) Topo-sheets (scale of 1:50,000) has been used to identify SHP potential sites in the study area. The topo-sheets have also been used for the delineation of potential catchments and to workout the general layout of potential SHP site.

ii) Ethiopian Geological Map at a scale of 1:2,000,000 have been used to extract the geology of the study area and regional settings.

iii) Rating schemes and empirical methods has been utilized to work out the quality and the strength characteristics of the rock mass. Bieniawiski's Rock mass rating system and Hoek and Brown failure criteria has been used for this purpose.

iv) Limit equilibrium method has been used to workout the stability conditions of the rock and soil slopes. For this purpose analytical technique of Hoek and Bray has been utilized. Besides, computer software for slope stability studies has also been used.

v) Geographic Information System (GIS) has been employed to prepare the database on small hydropower for the study area. For this purpose various thematic maps were digitized using AutoCAD Map 2000. Besides, the dada base files (*. dbf) files were prepared on Micro Soft Excel. Corel draw has been used to prepare various graphics, to be attached with GIS database. The final GIS database has been prepared on Arc VIEW (3.2 a) platform.

1.12 Limitation of the Study

All efforts are being made to perform the present study systematically with adequate scientific input and realistic facts. However, these efforts were made under limitation of resources and financial constraints. Because of limitation of time, many potential sites could not be ground verified due to difficult access and remote locations.

1.13 Future Studies and Extension of the Research Work

As discussed, Small hydropower has many advantages. It is environmentally friendly i.e. no air or thermal pollution, the energy source, i.e. water, is not consumed like fossil fuel. In Ethiopia there is a sizable hydropower potential. Unfortunately, till date this energy potential is far from being adequately exploited and the country remains one of the least users of electrical energy in the world (AAU, Faculty of Technology, 2001). The present study indicates that there is a gap between the resource and its adequate development. Further, studies may obviously declare that whether the potential SHP sites are techno-economical feasible or not. Therefore, there is a need to continue such research in the other areas of the country and come up with more potential SHP sites. Such effort will help the planners and developers to identify the SHP sites and develop them on priority basis. Thus, this study, will be first hand information for the Planners and the developers and will serve as a decision support system to develop SHP sites in the present Study area.

1.14 Proposed out come of the Study

As per the objective of the present study, the research shows that there is a Small hydropower potential in the present study area. The study indicates 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, 1994.), 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.

1.15 Chapter Scheme

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

Chapter I — Deals with an Introduction to small hydropower, extents of the study area, climatic condition, objectives, methodology, analytical tools used, importance of the study, limitations and probable future expansion of the research.

Chapter II — Describes about Regional geological settings of the study area and the geology of the sub-basins.

Chapter III — Deals with the present Land use and Land cover in the study area.

Chapter IV — Describes about Potential SHP sites in the study area. The selection criteria for potential catchments. Determination of head and dependable flows for the determination of power potential for all identified sites.

Chapter V	In this chapter Engineering Geological Appraisal of selected SHP sites has been presented. This chapter includes criteria of selection of sample sites for detailed studies, the limitations, engineering geological appraisal of SHP sites, estimation and verification of discharge.
Chapter VI	In this chapter Design calculation for various structures of SHP schemes are presented. Besides, power generation calculations, selection of turbine and estimations on quantities and cost are also presented.
Chapter VII	This chapter deals with the Small Hydropower GIS database as decision-making tools for developmental planning of SHP Schemes.
Chapter VIII	Finally conclusion and recommendations.

CHAPTER TWO

REGIONAL GEOLOGICAL SETTINGS AND GEOLOGY OF THE STUDY AREA

2.1 Regional Settings

The study of the Geology of Ethiopia goes back to 1860 by Blanford, and since then, major advances in the understanding of the geology of Ethiopia have been made from the works of various researchers, namely Danieli (1943), Mohr (1971) and Kazmin (1972, 1974, 1978). The outcome of these studies outlined the lithostratigraphy of Ethiopia into three major categories:

i) The Precambrian Basement
ii) The Late Paleozoic to Early Tertiary sediments
iii) The Cenozoic volcanic and associated sedimentary rocks.

Ethiopia can be divided into four major physiographic regions; the western plateau, southeastern plateau, the Main Ethiopian Rift and Afar Depression. The Ethiopian plateau underlain, at depth by Precambrian rocks of the Afro-Arabian Shield. The Precambrian basement is covered, for the most part, by glacial and marine sediments of Permian to Paleocene period and Tertiary volcanic rocks with related sediments. The Cenozoic volcanic succession is split apart by parts of the Great East African Rift-System in Ethiopia (i.e. the Afar Depression, Main Ethiopian Rift and related rifts).

Precambrian basement exposures are found in areas not intensively affected by Cenozoic volcanism and rifting and where the Phanerozoic cover rocks have been eroded away. Precambrian rocks outcrop in four major regions around the plateau margins. These areas are in Tigray region in the north; along the Sudan border in Gojam, Wollega, Illubaor and Kefa regions in the west, in Sidamo and Bale regions in the south and in Harerghe region in the east. Two major lithotectonic assemblages have been recognized in the Precambrian basement in Ethiopia similar to those recognized in the neighboring countries of northeast Africa and Arabian Peninsula. These are blocks of gneissic terranes and metamorphosed volcano-sedimentary belts associated with minor ultramafic bodies and intrusives ranging from mafic to granitic in composition.

Early or pre-tectonic plutonic bodies are internally foliated and concordant with their host rocks. There are, however, equi-dimensional and discordant intrusions of Late Proterozoic to Early Paleozoic and are known as post or late tectonic intrusions. Intrusions of alkaline magmas of Tertiary age are related to the early phases of rifting in the Afar are also remarkable.

Following the Proterozoic to Early Paleozoic tectonic and magmatic activity, peneplanation of the metamorphic basement took place until Carboniferous and Permian (Kazmin, 1972). Late Paleozoic to Earky Mesozoic sediments such as Enticho Sandstones, Edaga Arbi Glacials in northern Ethiopia (Dow et al., 1971), Permian eastern Ethiopia (Kazmin, 1972 & 1975) and Gura Sandsotne in southern Ethiopia (Belay, 1978) accumulated in shallow basin and narrow channels cuts in the Precambrian basement. Paleozoic continental sediments are also wide spread in Tigray, Harar regions and in the Abay River Gorge (Kazmin, 1972 & 1975).

Two major transgression-regression cycles took place during the Mesozoic era (Kazmin 1972). The first transgression started in the Early Jurassic or Late Triassic from the Ogaden region in the Southeast towards northwest and reached its maximum extent in Kimmeridgian. During this time Adigrat Sandstone, Hamanilei Formation, Abay Formation, Urandab and Antalo Formation were deposited.

The regression of the sea started towards the end of Jurassic depositing lagoonal facies of the Agula Formation in the north and Gabredare Formation eastern Ethiopia. The lowest most Cretaceous is represented by the Korahe Formation in Ogaden region. The second major transgression event took place in Aptian to Turonian depositing Mustahil Formation, Ferfer Formation and Belet Uen Formation. In the Late Cretaceous the second regression event took place depositing continental sediments, Amaba Aradom Formation.

A third and less extensive transgressive event took place in Late Cretaceous until Middle to Late Eocene deposing Jessoma Formation, Taleh Formation and Karkar Formation in the eastern part of the country.

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 upraised and uparched crust fissuring under tension permitted the ascension of voluminous basaltic magma to form the Trap Series of Ethiopia.

The first significant volcanic activity occurred in the Late Mesozoic along the margins of the Proto-Afar. Alkaline and tholeitic basalts are found interbedded with Cretaceous regressive sandstones along the southern and western margins of the Afar Depression, Kulibi and Sakota areas on the southeastern and northwestern plateau respectively. Available geochronological data strongly suggests that it was not until Late Eocene or Early Oligocene that basaltic volcanism was widespread. Superimposed on the long uplifted swell of Afro-Arabia, whose axis approximately runs north south, parts of the Great East African Rift System started to develop in the Miocene. Rifting began from the presently oceanic Red Sea and Gulf of Aden Rifts which join with the younger and continental Main Ethiopian Rift (MER) at the complexes proto-oceanic Afar triple junction (Afar Depression).

In the course of the development of parts of the Great East African Rift System in Ethiopia, a variety of continental sedimentary basins were developed since Miocene. In the Afar Depression, sediments originating from the rapid erosion of the steep escarpments together with abundant volcanic products tended to fill the depression but tectonic deepening was more rapid than volcano-sedimentary infilling. Plio-Pleistocene fluvo-lacustrine sediments are also widespread in the Ethiopian Rifts. In the MER, lacustrine sedimentation is wide spread during the pluvial periods of the Quaternary.

In the present study area, two main regional settings are there. More than 65% of the area is covered by Cenozoic volcanoes and the remaining part is Mesozoic sediments. Figure 2.1 Shows the Regional geological Settings of Ethiopia.

2.2 Geology of the Study Area

The geology of the study area has been taken from the "Exploration of the Geological Map of Ethiopia" (Mengesha, et al., 1996). The map is prepared at the scale of 1:2,000,000. For the present study the description of the geology is given at the same scale. The stratigraphic succession of the geological formation exposed in the study is presented as Table 2.1. The major formations which are present in the Muger, Jemma, and Waleka (MJW) Sub-basin are:

Alghe Group (AR1)

The Alghe Group (AR1) former Alghe Gneiss of Kazmin (1972 & 1975) consists of rather uniform, gray coarse grained gneisses. These rocks occur west of the Negele meridian and east of the Awata valley where they were originally mapped as Alghe Gneiss (Kazmin, 1978).

Similar rock types have been mapped in the eastern (Berhe, 1978), western (Gore, Gimbi, Nekemte and Abu Ramla areas) and in the southern (Hamar region) parts of the country (Mengesha, 1990; Mengasha and Berhe, 1989; Davidson, 1983).

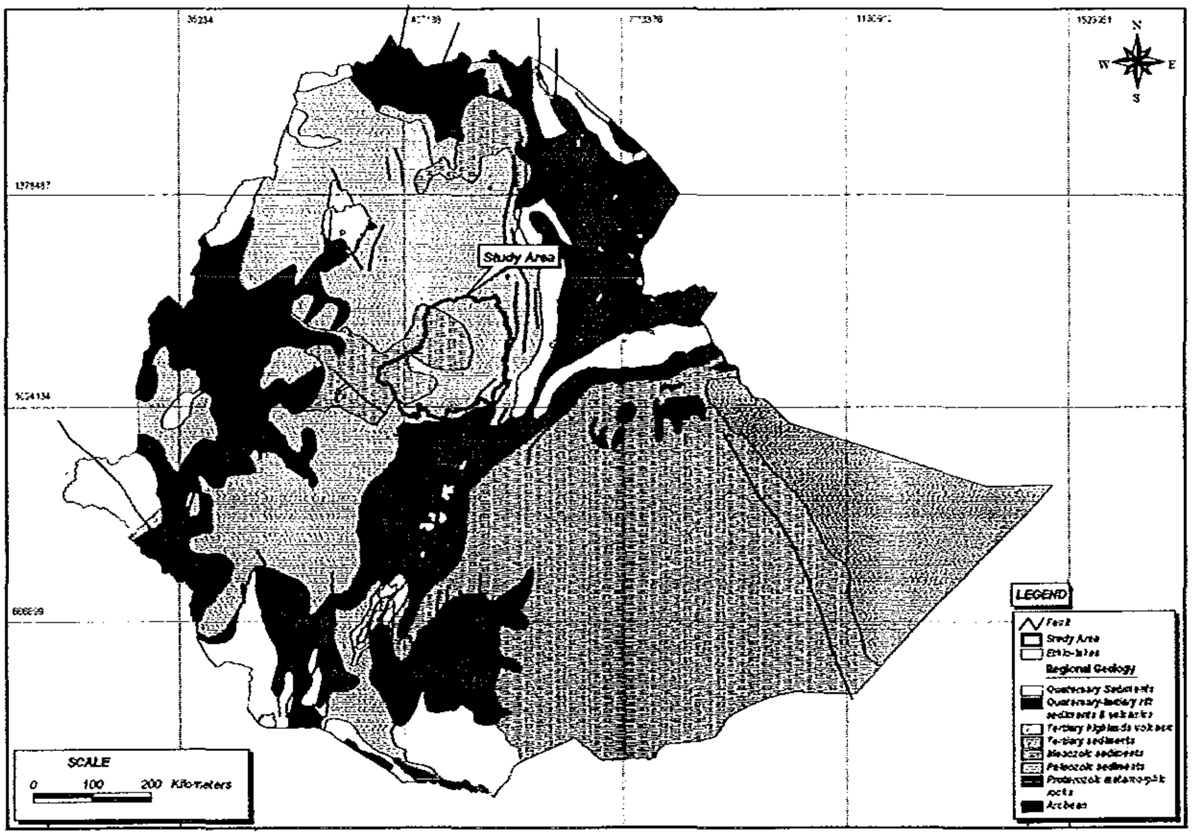

Fig. 2.1 Regional Geological setting

The Alghe Group consists of gray gneiss with variable color index showing development of layering. Much of this unit is relatively uniform and poorly layered orthogneiss, representing deformed and metamorphosed plutonic rocks of dioritic quartz and tonalitic composition. In places this gray gneiss is moderately to well layered and contains subordinate, narrow, interlayered units of mafic, quartzo-feldspathic and meta-sedimentary gneisses.

Adigrat formation

The Adigrat Formation (Ja) which varies in thickness from a few meters to 800 meters, was originally named as Adigrat Sandstone after Adigrat town in Tigray region (Blanford, 1870), and includes the whole succession of clastic rocks resting un-conformably on the Precambrian basement and overlain un-conformably by the Antalo Formation (Jt); (Dow et al., 1971; Garland, 1980). The Adigrat Formation in some parts of northern Ethiopia rests with a slight disconformity on the Late Paleozoic to Early Mesozoic sedimentary rocks of Enticho

Sandstone and Edaga Arbi Glacials (Pzt) and is overlain by Antalo Formation (Jt). However, in Harar-Dire Dawa area and deep boreholes in the Ogaden region, it is overlain by the Hamanilei Formation (Jh) (Mohr, 1965: Beyth, 1971; Dow et al., 1971; Kazmin, 1972; Garland, 1980).

Table 2.1 The stratigraphic successions of the geological formation exposed in the study area.

	Litho Stratigraphy	Age	Lithology	Symbol	Description
Quaternary	Cenozoic Volcano	Quaternary undifferentiated	Quaternary Basalt	Qb	Alkaline Olive basalt
Cenozoic		Miocene-Pliocene	Nazret	Nn	Ignimbrites, Unwelded tuffs, ash flows, rhyolitic flows, domes and trachyte
		Middle-Miocene	Tarmaber Megezzez	Ntb	Transitional and alkaline basalt
		Oligocene-Miocene	Alajea Formation	PNa	Transitional and subalkaline basalt with minor rhyolite and trachyte eruptive
		Middle-late Oligocene	Aiba Basalts	P_3a	Flood basalt with rare basic tuffs
		Eocene	Ashangi formation	P_2a	Deeply weathered alkaline and transitional basalt flows with rare intercalation of tuff,often titled (include Akobo basalts of SW Ethiopia
Mesozoic	Sediments	Cretaceous	Amba Aradom formation	Ka	Sandstone, congromerate and shale
		Late Jurassic	Antalo formation	Jt	Limestone
		Late Jurassic	Abay formation	Jb	Middle-jurassic limestoe,shale and gypsum
		Early-late Jurassic	Adigrat formation	Ja	Triassic-middle jarussic sandstone
Archean	Basement	Archean	Alghe group	ARi	Biotite and hornblende gneisses,granulite and migmatite with metasedmentary gneiss

The Adigrat Formation chiefly comprises sandstone with minor lenses of siltstone and conglomerate and laterite up to two meters thick (Garland, 1972). The formation is typically yellowish to pink with a laterized top to a depth of about 20 meters and composed of fine to medium grained, well sorted, cross bedded quartz sandstone. It is non-calcareous except at the top near the contact with the overlying Antalo Formation (Jt) or Hamanilei Formation (Jh), where thin beds of limestone have developed.

In the central part of the country, in the Abay Canyon, variegated sandstone, siltstone and shale correlable with the Adigrat Formation (Ja), occur between the Precambrian basement and the Abay Formation or Tertiary volcanics. In Harar-Dire Dawa area, the sandstone, which lies between the Precambrian basement rocks and Danakil Alps, the sandstone becomes the fine grained and calcareous and lacks cross bedding, and is intercalated with siltstone and shale indicating deeper water conditions of deposition.

Abay Formation (Jb)

The Abay Formation previously named as Abay Beds and the lower units of the former Antalo Group (Kazmin, 1972; 1975) occurs in the Abay River lying between the Adigrat and the Antalo Formations. The formation consists of 196 meters thick of sandy limestone and calcareous sandstone; a 257 meters thick unit of gypsum, as well as a 138 meters thick upper unit of a sequence of alternating shale and limestone bringing the total thickness of the formation to 580 meters. The Abay Formation (Jb) is middle Jurassic age.

Antalo Formation (Jt)

The Antalo Formation was first named by Blanford (1870) at the type locality as Antalo Limestone in Tigray Region, and later described in detail by Mohr (1963), Beyth (1971), Kazmin (1972 & 1975) and Merla (1973 & 1979). The Antalo Formation is a 750 meters thick sequence, which consists predominantly of fossiliferous yellow limestone containing thin beds of marl and calcareous shale, and occasionally arenaceous bands near the top.
In the Mekelle area, if conformably overlies the Adigrat Formation (Ja) and grade upward into Agula Formation (Jg) (Garland, 1980). In the Adigrat area, the total thickness is more than 1000 meters. In the Danakil Alps, where the unit consists of thinly bedded, pale fossiliferous limestone, the succession reaches a thickness of up to 1420 meters.

The marginal parts of the Mekelle outlier consist of sandy oolitic facies suggesting a near shore environment. While in the escarpment black limestone and shale indicates deeper water conditions of deposition. In the Abay River Canyon the Antalo Formation, whose age is considered to be Middle to Late Jurassic is restricted to the upper 288 meters thick former Antalo Group (Kazmin, 1975) and is lies between the Abay Formation and the Tertiary volcanics being separated from the Adigrat Formation by the Abay Formation.

Amba Aradom Formation (Ka)

The Amba Aradom Formation (Ka), formerly known as the upper sandstone (Beyth, 1971; Arkin et al. 1971; Kazmin, 1972 & 1975) occurs in eastern, central and northern (Tigray Region) parts of Ethiopia. The formation consists of sandstone, shale and marl. It lies conformalbly on the Jurassic Antalo Formation (Jt) in central part of the country, whereas in the Mekelle (Tigray) and Garamulata (Hararghe) areas, it lies unconformably on the Jurassic sediments, namely, Jt and/or Ja and Ju and/or Jh (Mahadi, 1968; Greitzer, 1970; Kazmin, 1975).

In northern part of the Mekelle outlier, the formation consists of claystone and siltstone with interbedded massive, sometimes cross bedded, white to pink sandstone (Arkin et al., 1971; Beyth, 1971). The rocks become progressively coarser in grain size southwards. Further south, on the southern rim of the outlier, the conglomerates and sandstones give way to fine grained sediments as the formation thickens again. In most of the area the formation is laterized.

In the Abay River Canyon the thickness ranges from 450 to 600 meters, in Garamulata, Haraghe region the unit is more than 300 meters thick whereas in the Dankil Alps, the unit is only 150 meters thick. The Amba Aradom Formation (Ka) is probably of Late Cretaceous age and represents a regressive facies to the Cretaceous sea (Kazmin, 1975).

Ashangi Formation (P_2a)

The Ashangi Formation represents the earliest fissural flood basalt volcanism on the northwestern plateau. The basalt flows are several hundreds of meters to a kilometers thick of strongly weathered, crushed, tilted basalts which lie below the major Pre-Oligocene unconformity (Zanettin et al., 1980). The Ashangi Formation consists of predominantly mildly alkaline basalts with interbedded pyroclastics and rare rhyolites and is commonly injected by dolerite sills and dykes. The upper part of Ashangi Formation is more tuffaceous and contains interbedded lacustrine deposits with lignite seams. It was believed that these early flood basalt flows are restricted to the northwestern plateau (Zanettin and Jusetin Visentin, 1975, Merla et al. 1973, 1979) until a group of early flood basalt was found in southwestern Ethiopia (Davidson, 1983) with K/Ar age here considered to be analogous with the basalts of the Ashangi Formation. The age of Ashangi Formation in the type area remains uncertain (Zanettin et al., 1980). The oldest reported age for a volcanic rock on the northwestern plateau is 54 Ma (Kazmin, 1979 and references cited therein). The general consensus remains that the Ashangi Formation have a Eocene to Oligocene age. However, basalt flows and tuffs interbedded in Jurassic and Cretaceous sediments have also been mapped in the Kulubi-Dire Dawa area on the southeastern plateau (Merla et al. 1973) and

Sakota area (Wello region) on the western plateau and appear to be evidence for an earlier basaltic volcanism related to the mantle plume which resulted in the Jurassic uplift of Afro-Arabia.

Aiba Basalts (P_3a)

The Aiba Basalts represent the second major pulse of fissural basalt volcanism on the northwesten plateau. They are generally aphyric, compact rocks, in places showing stragification and contain rare interbedded basic tuffs. The Aiba Basalt (P_3a) unconformably overlie the Ashangi Formation (P_2a) and attain a thickness of 200 to 600 meters. The basalts show a distinctive tholeiitic nature with transitions to mildly alkaline varieties. The absolute age of the Aiba Basalts (P_3a) ranges from 34 to 28 Ma placing them in Oligocene (Zanettin et al., 1980; Kazmin, 1979).

Alajae Formation (PNa)

The Alajae Formation (PNa) mainly consists of aphyric flood basalts associated with rhyolites (ignimbrites) and subordinate trachytes. This formation (PNa) ranges in age between 36-13 Ma (Kazmin, 1979; Zanettin et al., 1980). A migration of Alajae type volcanism from north to south is indicated by the occurrence of the older volcanics of this formation on the northern part of the northwestern plateau. Alajae Formation makes the bulk of the volcanic succession on both the northwestern and southeastern plateaus.

On the northwestern plateau the Alajae Formation rests conformably on the Aiba Basalts (P_3a) but in some places (e.g. Kassem Gorge, Mugher Canyon and in most outcrops on the southeastern plateau) it directly overlies on the Mesozoic sediments. The Alajae Formation contains basalts transitional to tholeiitic in nature and an increase in alkalinity is observed in the younger members of the formation. Thus the Miocene members of the Alajae Formation are more alkaline and are associated with sub-alkaline acidic members.

Tarmaber -Megezez Formation (Ntb)

Tarmaber Formation represents Oligocene to Miocene basaltic shield volcanism on the northwestern and southeastern plateaus. The central type Tarmaber Formation basaltic volcanism was followed by fissural eruptions particularly along the escarpments of northwestern and southeastern plateau. Basalts of the Tarmaber Formation in contrast to the tholeiitic and mildly alkaline nature of the earlier flood basalts typically have an alkaline affinity. On the northwestern plateau, the Tarmaber shield volcanoes become progressively younger from north to south.

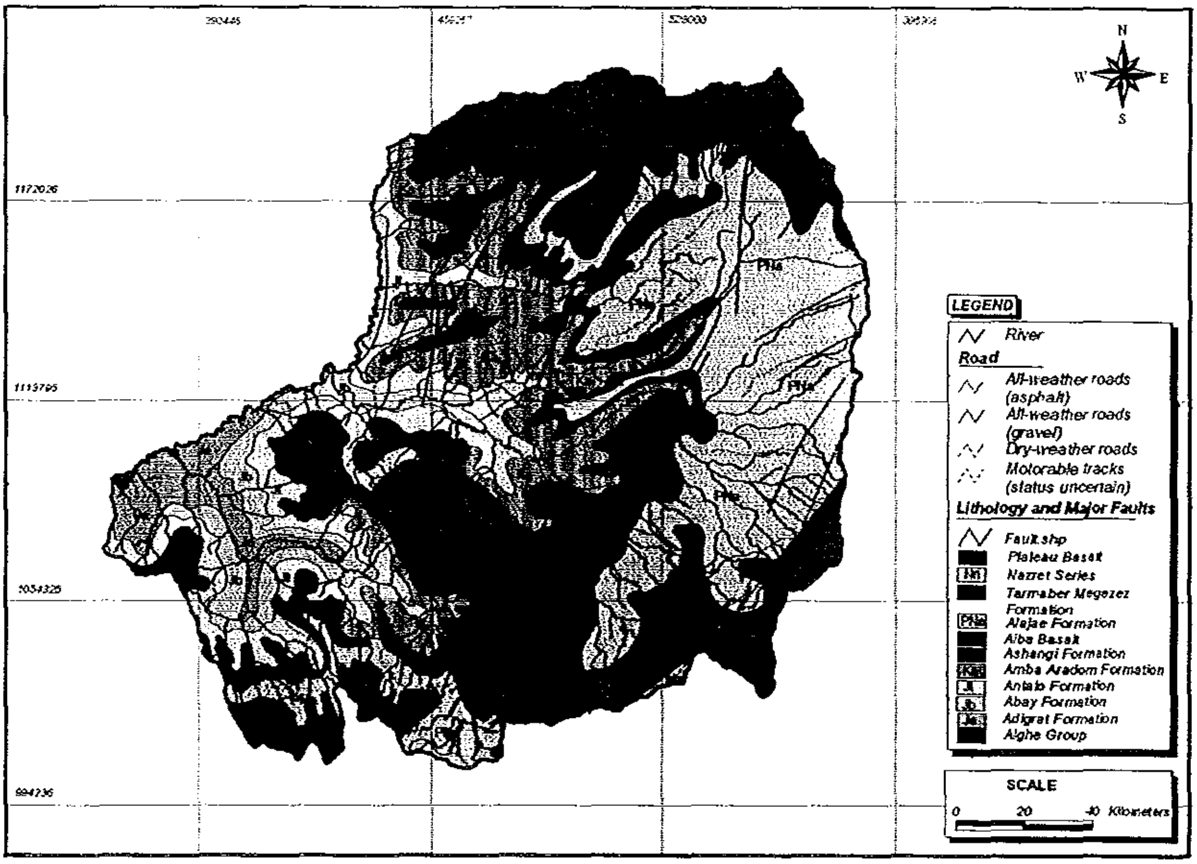

Fig. 2.2 Lithology and Major Faults in the Study Area

The classification Tarmaber Gussa Formation (pp) for the shield volcanoes of the northern Ethiopia plateau with an absolute age range of 26 to 16 Ma and the name Tarmaber Megezez Formation (Ntb) for the younger shield volcanoes with an absolute age range from 16 to 13 Ma in the southern part of the northwestern plateau and the southeastern plateau has been widely used and the latter is believed to mark the intiation of rifting of the Main Ethiopian Rift (Kazmin, 1979 and references cited therein). The upper age limit of the Tarmaber-Megezez Formation (Ntb) is lowered to 7 to 8 Ma since the large basaltic center of Arba Gugu with similar alkaline affinity is considered to be the youngest episode of Tarmaber type volcanism. Other dominantly basaltic units erupted within the age intervals from 14 to 10 Ma (Anchar basalts of Kazmin and Berhe, 1981) mapped on the eastern escarpments of the MER and southern Afar and Miocene basaltic volcanism in western Ethiopia with an age range of 9 to 10 Ma (Upper aphyric basalt of Berhe et al., 1987) are also considered with the Tarmaber-Megezez Formation (Ntb) on chronological grounds.

Nazret Series (Nn)

The name Nazret Series was given to a thick succession of welded ignimbrites with fiamme, pumice, ash and rhyolite flows and domes with rare intercalations of basalts flows which occur in the MER, rift margins and adjacent plateaus (Meyer et al. 1978). In the rift proper the Nazret Series attains a thickness of up to 200 to 250 meters and tends to thin out on the escarpments. On the plateau margins a thickness of 1 to 30 meters was reported at many localities. Ignimbrites of Nazret Series are considered to be products of eruptions mainly from marginal centers in the rift trachytes with rare peralkaline varieties. An age range of 9 to 3 Ma has been given to the Nazret Series on the basis of its relation to the Mio-Pliocene lacustrine sediments of the Chorora Formation and some absolute K/Ar age determinations (Tiercelin et al., 1980; Kazmin and Berhe, 1978).

Quaternary Plateau Basalts (Qb1)

Quaternary alkaline basalts and trachytes were erupted along preexisting structures on the northwestern and southeastern plateaux. Although not dated, their relatively unmodified geomorphological features such as the prevalence of prominent cinder cones and small collapse craters in particularly in a region of heavy rainfall and perennial streams indicate their recent age. Alkaline basalts and trachytic lavas prevail in the Tana Graben and young trachyte flows on the Batu Mountain and Sanete Basalts in Bale region (Kazmin, 1979; Merla et al., 1973) all belong to this unit. Field evidence suggests a Pleistocene age to all these rocks. Volcanic cones and flows of scoriaceous basalts are well preserved in the lake Tana Graben.

The other younger analogous unit is the relatively fresh Tepi Basalts, produced by central type eruption in southwestern Ethiopia with a Holocene age (Davidson, 1983) and is considered to be an analogous unit. These Quaternary Basalt flows are characteristically alkaline and may represent the final pulse of basaltic volcanism on the Ethiopian plateau.

CHAPTER THREE

LANDUSE AND LANDCOVER

3.1 Preamble

These two terms are 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 – food production, commercial forestry, etc. Land cover refers to the cover of the earth's surface – vegetation (by type), bare soil, urban development, etc, - without reference to how that covers is used (BCEOM French Engineering Consultants, 1999).

In many cases, land cover and land use are directly related; for example, grass (land cover) may generally be used for livestock grazing (land use). However, such close relationships may not always be true. Thus, land could have a land cover of forest; the land use could be commercial forestry, watershed protection/ conservation, National Park, wildlife, recreation, etc. Similarly grass land (land cover) could be used (land use) for wildlife grazing and the land use may be tourism. Land areas may often have multiple uses; thus a forest land cover may have multiple land uses such as commercial forestry, recreation, wildlife, etc.

3.2 Land Cover Classification

A land cover classification of Abay basin was prepared, essentially from LUPRD and WBISPP legends (Annexure II), and subsequently modified based on the field experience of BCEOM – French Engineering Consultants – in association with ISL and BRGM.

In the present study area, there are eight main classes and eleven sub-divisions (Fig. 3.1). The description of each sub-division is discussed as under:

3.2.1 Afro-alpine (A)

This occupies zones generally above 3200 m.a.s.l. Cover types include Erica, woodlands, shrub lands and scrubs.

3.2.2 Bush land (B1)

This consists of multi stemmed woody species with a height of more than 2m. It was defined as dense or open, depending on the assessed degree of ground cover.

3.2.3 Dominantly Cultivated (C1)

Three units dominate the dominantly cultivated class. The units occupy greater than 70% of cultivation area. These are the primary food producing areas of the sub-basins, and therefore of considerable importance for protection, management and development.

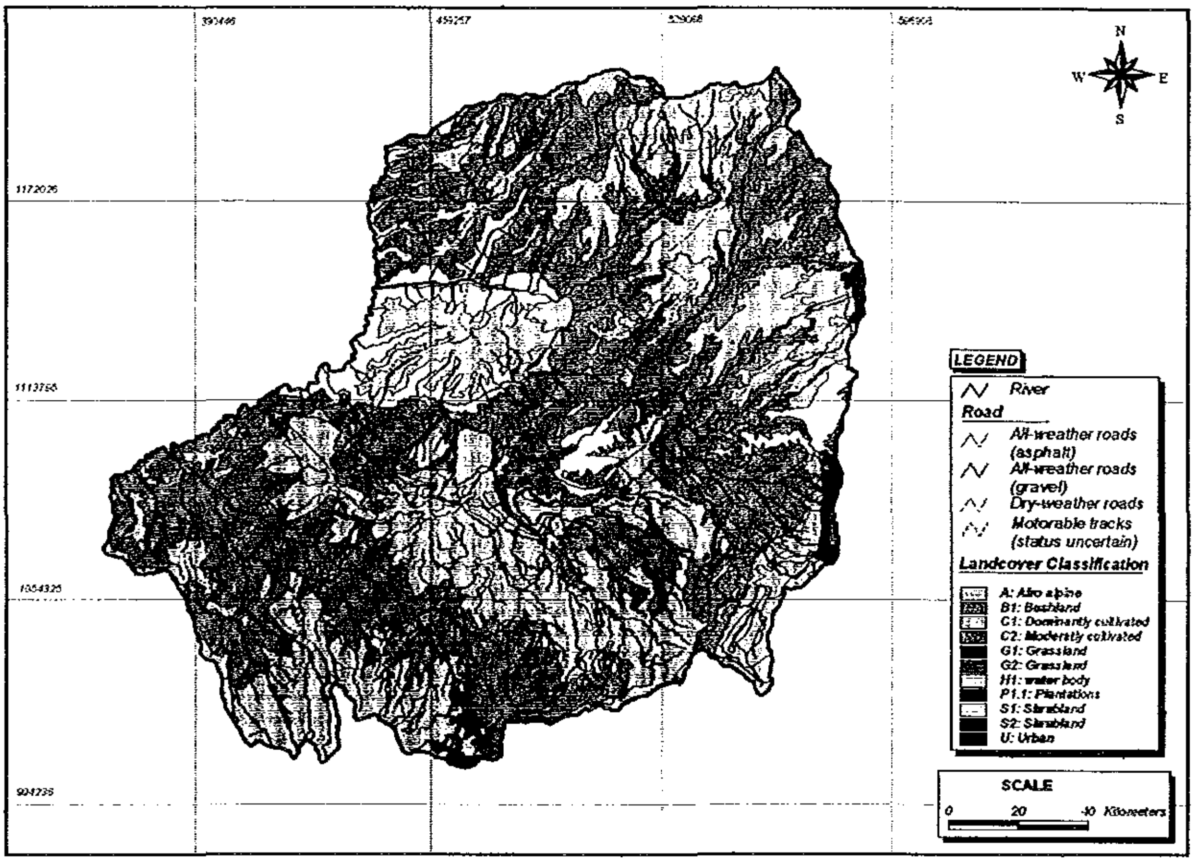

Fig. 3.1 Landcover Map of the Study Area

3.2.4 Moderately Cultivated (C2)

The moderately cultivated units are primarily associated with physical limitations. In the north-east and east of the basin these are in combination of shallow soils and slope; almost 47% of the moderately cultivated units occur on shallow soils (Leptosols and Regosols). In these areas these units are also associated with high population densities. The units are associated with the edge of the highlands, where a combination of slopes, soils, and climate constraints may be variously involved.

3.2.5 Grassland

The term 'grassland' covers a multitude of ecological variations. Firstly, there is a distinct difference between highland grasses, which are highly palatable to animals, and lowland grasses, which are generally unpalatable. Highland grasses tend to occur in two situations – on high, level, often poorly drained, and exposed areas, and in wet, depress ional areas. The latter areas may also be mixed with seasonal swamp; although separated due to the regularity of seasonal flooding. Such areas have many characteristics in common with other grassland, and are similarly intensively grazed during the dry season. In the lowlands, grassland may also occur in a variety of sites, typically on dry, often steeply sloping areas with shallow soils which will not support trees, and again on areas seasonally waterlogged to the exclusion of woody vegetation. In all these situation the grasses may be associated with varying degrees of woody cover.

Grassland (G1) and Grassland (G2)

Grassland (G1) is open grassland in which there is little or no woody cover. Whereas Grassland (G2) is shrubby Grassland in which there is some cover of bushes and shrubs, although the overall characteristic of the area remains grassland (separating it from bushland or shrubland).

3.2.6 Water Bodies (H1) and Urban

Water bodies and Urban are self-explanatory. It has only been mapped where the water bodies and/or urban area are sufficient to allow separation at the scale of mapping.

3.2.7 Plantation (P1)

This refers exclusively to Eucalyptus plantation. Such plantations are widely distributed throughout the Abay basin, but are rarely sufficiently extensive to be separately mappable. These are most frequently associated with cultivation and grassland, both at significant level. The plantations tend to be found at high altitudes – 61% occur between 2300 and 3200m, and an additional 21% above 3200m. Soils are dominantly shallow. The largest occurrences are on the watershed boundary in eastern North Shewa (east of Debre Birhan) and north of Addis Ababa.

3.2.8 Shrubland (S1:S2)

Like bush-land, this consists of multi-stemmed woody species, but generally less than 2m in height. It is typically mixed with grass. Again it was defined as dense or open depending on the degree of woody cover.

3.3 Land Use Classification

Land use refers to the economic use of the land. Identifying and separating those economic activities may be quite difficult. Many areas have multiple uses, both within any period of time and at different seasons of the year. Therefore, classifying the land use requires a decision on the dominant land use; this is difficult and to a degree subjective. Figure 3.2 presents the Landuse map of the study area.

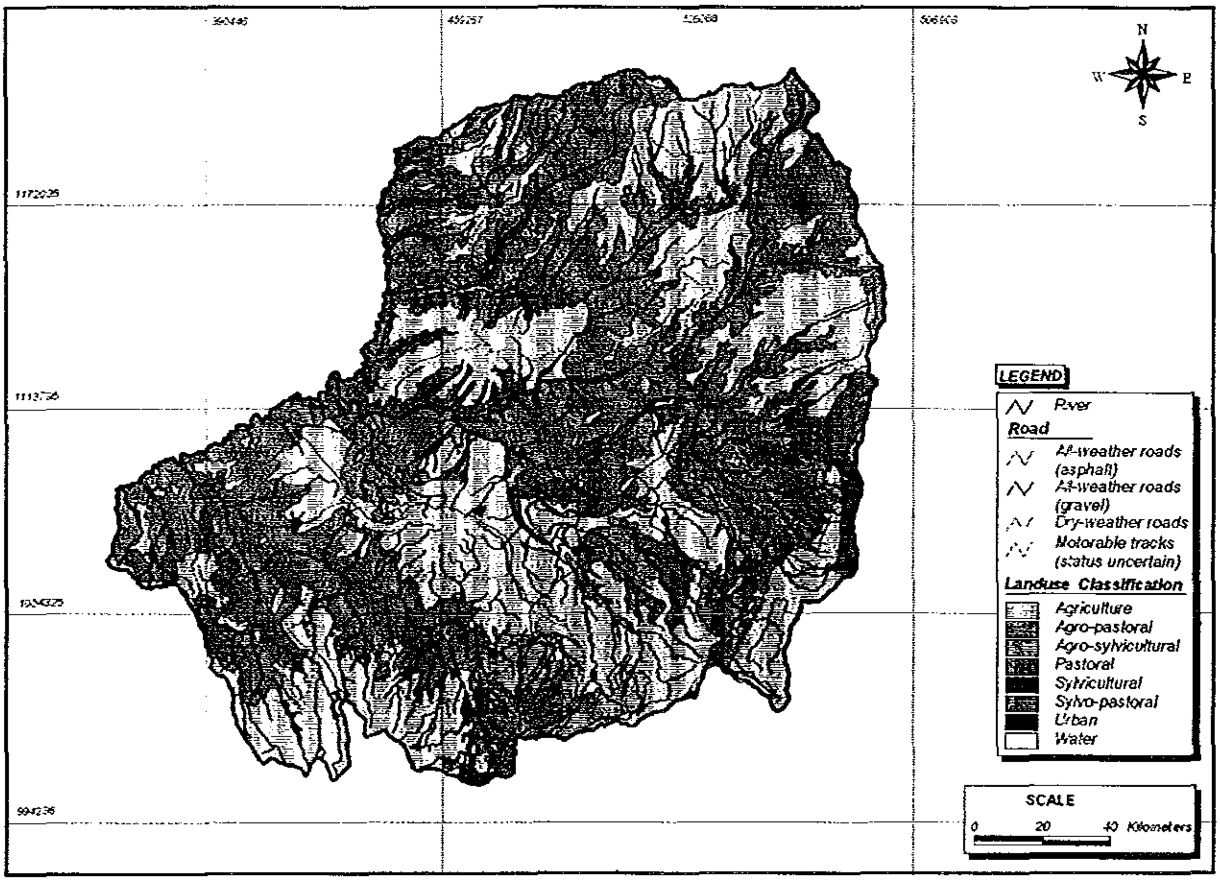

Fig 3.2 Landuse Map of the Study Area

map of the study area. The various Landuse units as identified in the study area are described below (BCEOM French Engineering Consultants, 1999).

3.3.1 A – Agricultural

These are the 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.

3.3.2 AP – Agro-pastoral

These areas are those defined as 'moderately cultivated' on the land cover map, except as defined in next unit. 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 stress/limitation on cultivation.

3.3.3 AS – Agro-sylvicultural

These are moderately cultivated areas mixed with significant forest, plantation or woodland, or forest/woodland areas with extensive cultivation. Most such areas will also be grazed. These units are classified as agro-sylvicultural because of the importance of trees.

3.3.4 P – Pastoral

These are the grassland areas, generally above 1500m altitudes.

3.3.5 SP – Sylvo-pastoral

These are the woodland, bush-land and shrub-land areas, generally above 1500m. These areas provide both grazing and wood resources.

3.3.5 S – Silvicutural

These areas are essentially confined to the intact forest areas, plantations and highland woodlands. The term 'sylvicultural' has been optimistically applied to all forest lands.

3.3.6 U - Urban and W-Water

Water and Urban are self-explanatory. It has only been mapped where the water and/or urban area is sufficient to allow separation at the scale of mapping.

3.4 Soil in the Study Area

The soil map of the area is taken from Abay Basin Master Plan (Fig. 3.3). Based on the BCEOM – French Engineering Consultants – in association with ISL and BRGM field experience (BCEOM French Engineering Consultants, 1999), the soils of the study area are classified based on 14 major groups namely, Calcic Vertisols, Eutric Cambisols, Eutric Fluvisols, Eutric Leptosols, Eutric Regosols, Eutric Vertisols, Haplic Alisols, Haplic Luvisols, Haplic Nitisols, Rendzic Leptosols, Rhodic Nitisols, Vertic Cambisols, Urban and Water. The descriptions for these groups are given at Annexure III.

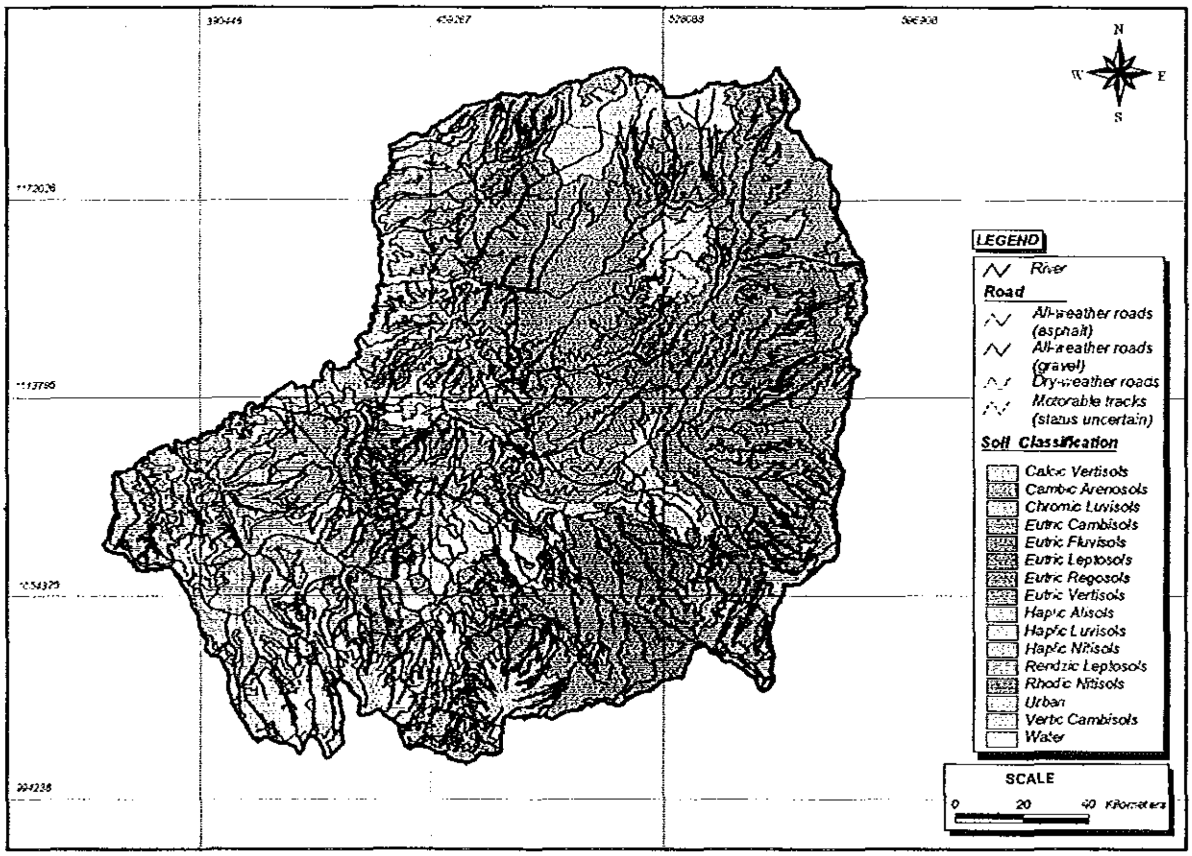

Fig. 3.3 Soil Map of the Study Area.

CHAPTER FOUR

POTENTIAL SMALL HYDRO POWER (SHP) SITES

4.1 Introduction

Electrical energy is becoming an essential commodity for the modern life. Every sector, weather industry, technology, transportation, public utilities or the domestic life, is now dependent on electrical power. The dependence on electrical power is becoming more and more, which has resulted into increasing demand for it. The electrical power can be generated from non-renewable and exhaustible sources which, unfortunately are getting depleted at a very fast rate. This has focused attention to the non-exhaustible and renewable sources of energy. Among the renewable energy sources 'Hydropower' is one of the most common and abundantly available energy in the hilly regions. This renewable energy source may be exploited by constructing large hydro power plants or simply by constructing small hydro power stations. The large hydro power plants are not being taken up for execution in sufficient number as these involve huge amount of funds and also the planning and construction period is large. Therefore, with the increasing demand for power, the activities on small hydropower projects has accelerated in recent times. The small hydropower schemes are the appropriate solution to power demand as these require small capital investment and can be completed in a very short period of time, with minimum adverse environmental impacts.

4.2 Criteria for Identification of Potential Small hydropower Site

To identify the Small Hydropower (SHP) potential sites for the present study, Ethiopian Mapping Authority (EMA) topo-sheets on 1:50,000 scale has been utilized. In total 41 topo sheets were examined to identify the potential SHP sites in the study area. The site selection has been made following certain criteria, which is listed below;

i) Channel should be perennial in nature, in EMA topo-sheets perennial streams are marked with blue colour and the stream name is written in capital letters.

ii) The catchment should have an area of at least 25 km^2. This will ensure a sufficient good amount of discharge for power generation.

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

iv) Availability of head should be at least 60 m as lower head and discharge does not yield significant power potential.

v) The headrace channel must be less than 5km in length.

vi) The potential site should be well accessible and should be located near to the cluster of population, so as to ensure proper power utilization.

4.3 Potential Catchment Delineation

The potential catchment is delineated from the EMA (Ethiopian Mapping Authority) topo-sheets at a scale of 1:50,000. Figure 4.1 shows one sample-delineated catchment for Aleletu SHP Site.

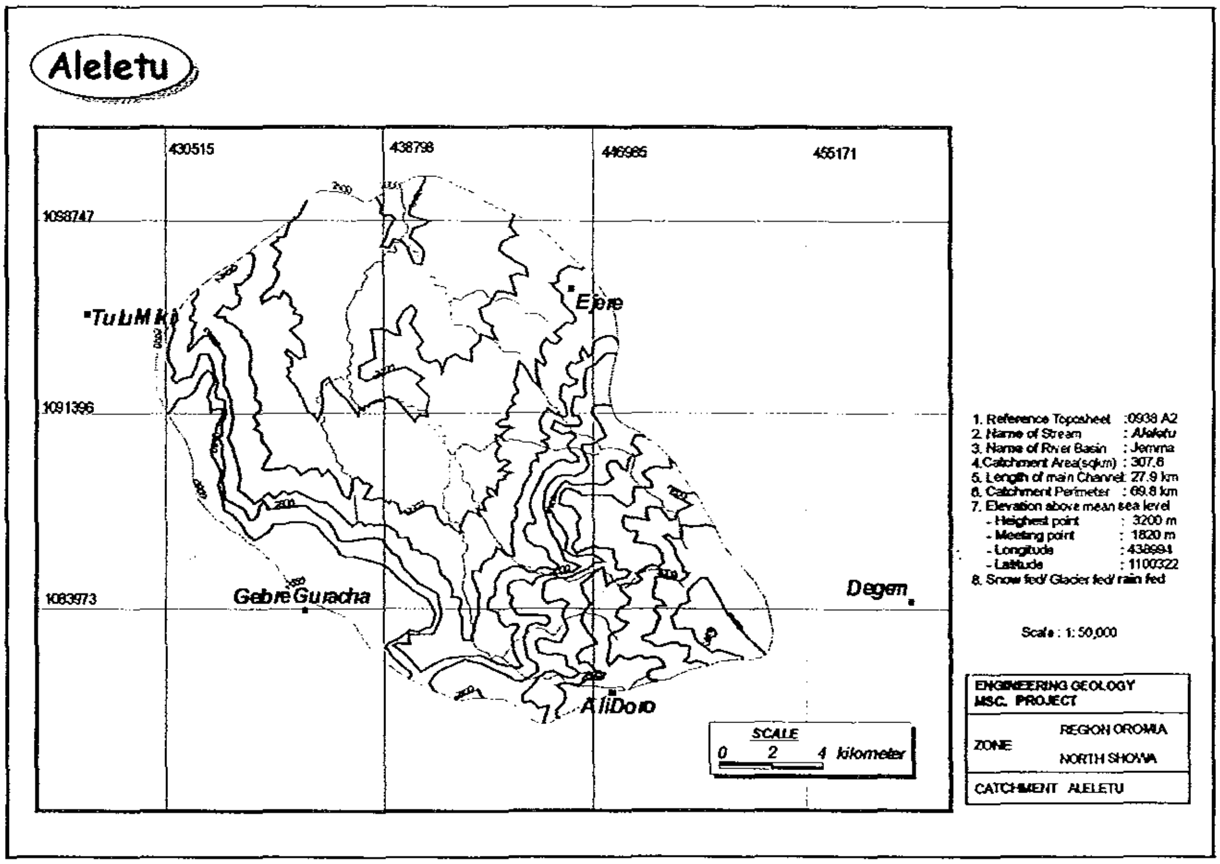

Figure 4.1 Sample delineated catchment for Aleletu SHP Site

The Catchment delineation includes catchment boundary, perennial stream, drainage network, roads or foot paths, towns, highest and lowest elevation points and contours in 100m interval within the catchment boundary. These delineated catchments were used for the calculation of catchments area, perimeter and the stream length.

During the present study a total of 36 potential SHP sites has been identified. Out of these 36 sites, 13 sites fall within Muger sub-basin, 14 in Jemma sub-basin and the rest 9 sites forms a part within Waleka sub-basin. Table 4.1 presents the identified potential SHP sites in the study area. Most of these identified sites are concentrated along the periphery of the sub-basins. Figure 4.2 shows the distribution of identified potential SHP sites in the study area.

4.4 General Layout of Small Hydropower Schemes

The general layout of the Small Hydropower scheme comprises mainly, two major components one is the 'Water Conducting System' and 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. The electro mechanical component is responsible for generating power from the water, which is provided from the water conducting system. Figure 4.3 shows the general layout of small hydropower site.

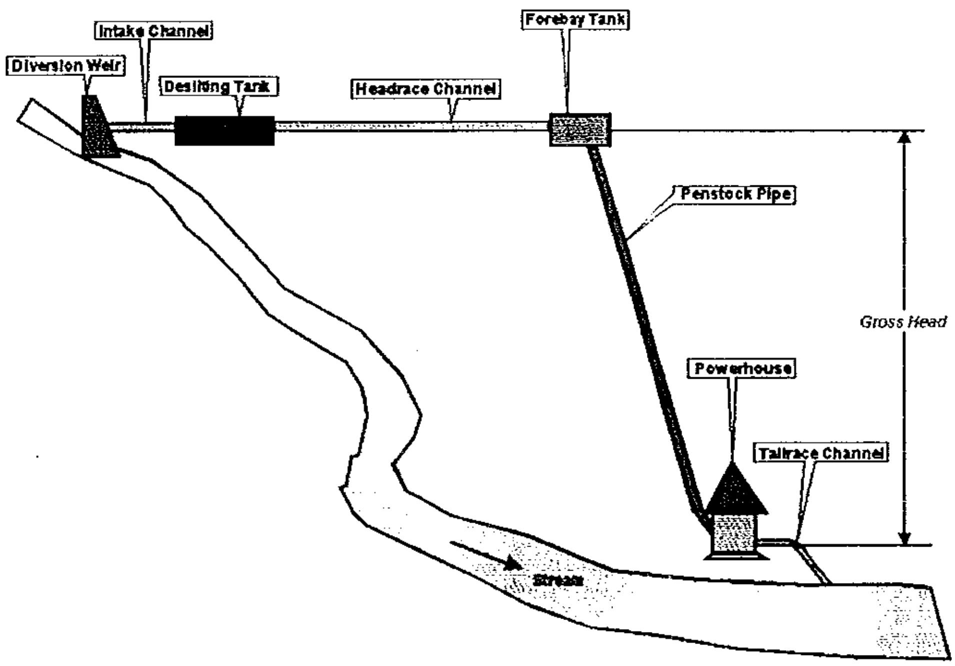

Fig. 4.3 General Layout of Small Hydro power Site

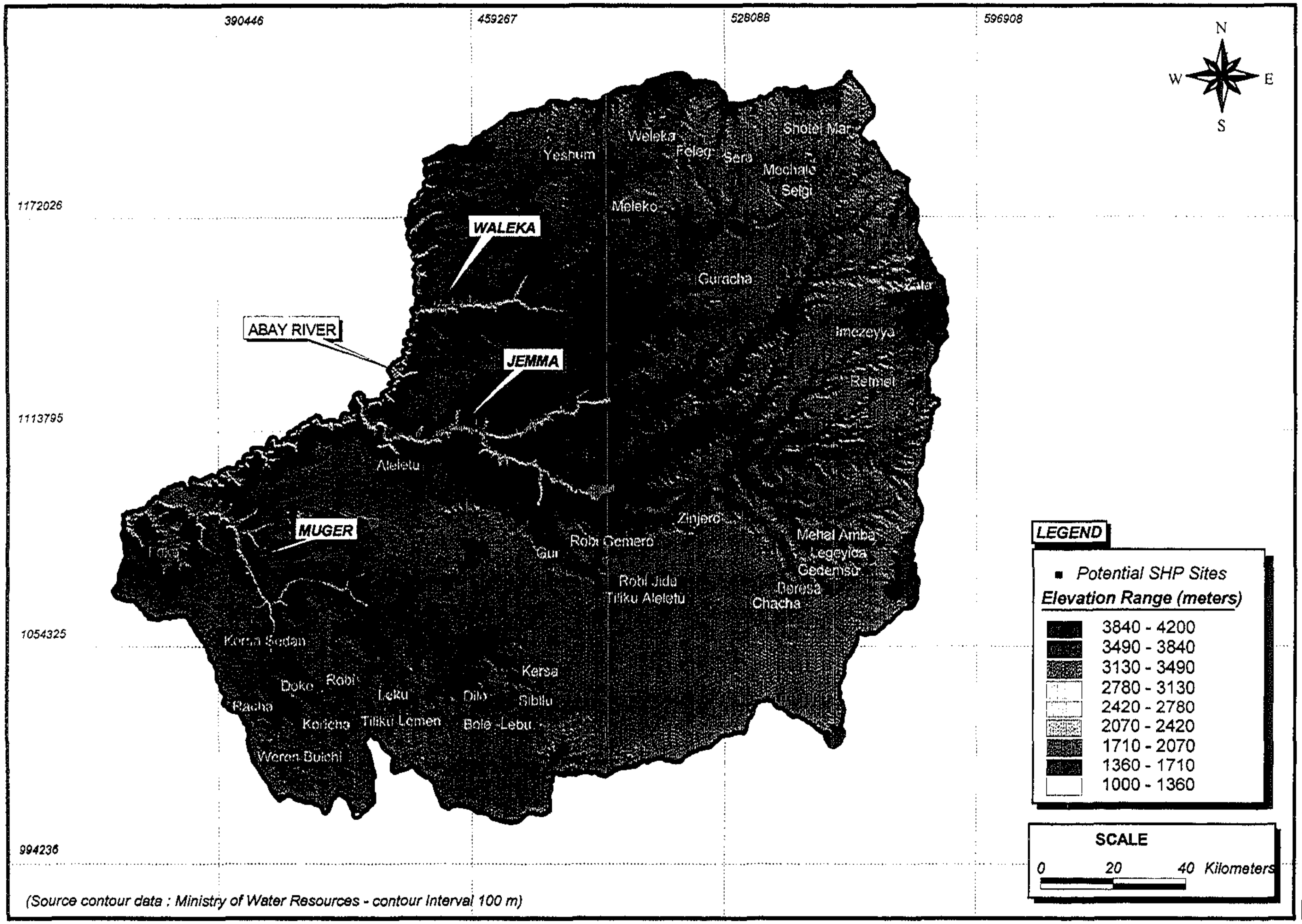

Fig. 4.2 Identified potential Small Hydropower sites in the study area

Table 4.1 List of identified potential SHP sites in the study area

S.No	*Name of SHP Site*	*Name of stream*	*Location*(UTM)*		*Sub-Basin*	*Nearest Town*	*DW* Elev. (m)*
			Northing	*Easting*			
1	Aleletu	Aleletu	1100847	541630	Muger	Ejere	1820
2	Beresa	Beresa	1069557	556306	Jemma	Debre Birhan	2725
3	Bole-Lebu	Bole-Lebu	1033823	455118	Muger	Mulo	2735
4	Chacha	Chacha	1062529	542252	Jemma	Mendida	2215
5	Dilo	Dilo	1037152	460208	Muger	Mulo	2210
6	Doke & Huluko	Doke & Huluko	1040035	416349	Muger	Ketket	1860
7	Feleg	Feleg	1186753	520249	Waleka	Kurkura	2430
8	Foka	Foka	1076370	371578	Muger	Jemo Lefo	1595
9	Gedemsu	Gedemsu	1074311	566482	Jemma	Dinbaro	2795
10	Gur	Gur	1076165	480031	Jemma	Debre Libanos	2480
11	Guracha	Guracha	1151245	527885	Jemma	Dogolo	2555
12	Imezeyya	Imezeyya	1136716	566498	Jemma	Mehal Meda	2815
13	Kersa Seden	Kersa Seden	1049966	394200	Muger	Shikute	2415
14	Kersa	Kersa	1043963	477862	Muger	Gorfo	1550
15	Koricha	Koricha	1033080	411445	Muger	Gola	2200
16	Legeyida	Legeyida	1077525	568221	Jemma	Dinbaro	2775
17	Leku	Leku	1037547	437932	Muger	Welenkobi	2235
18	Mechela	Mechela	1181789	538576	Jemma	Were Illu	2610
19	Mehal Amba	Mehal Amba	1081709	570597	Jemma	Godo Beret	2695
20	Meleko	Meleko	1171863	503832	Jemma	Kelela	2375
21	Racha	Racha	1034032	399600	Waleka	Shikute	2495
22	Retmet	Retmet	1123374	567974	Jemma	Molale	2875
23	Robi Gemero	Robi Gemero	1079127	497510	Jemma	Lemi	2170
24	Robi Jida	Robi Jida	1072373	497299	Jemma	Weberi	2210
25	Robi	Robi	1041259	420415	Muger	Ketket	2430
26	Selgi	Selgi	1181407	541630	Waleka	Were Illu	2610
27	Sera	Sera	1184844	531321	Waleka	Kurkura	2550
28	Shotel Mat	Shotel Mat	1197061	563775	Jemma	Kabe	2710
29	Sibilu	Sibilu	1040301	470093	Muger	Mulo	2215
30	Tiliku Aleletu	Tiliku Aleletu	1070480	496544	Jemma	Weberi	2215
31	Tiliku Lemen	Tiliku Lemen	1035569	449258	Muger	Welenkobi	2415
32	Weleka	Weleka	1190953	510232	Waleka	Lugama	2275
33	Werenbulchi	Werenbulchi	1026557	402984	Muger	Gola	2610
34	Yeshum	Yeshum	1185989	485505	Waleka	Genet	2090
35	Zeta	Zeta	1153154	586682	Jemma	Rabel	3355
36	Zinjero	Zinjero	1085404	521207	Jemma	Deneba	2110

* *These co-ordinates indicates the location from where the water will be diverted for the power generation – it indicates Diversion weir site- Refer Figure 4.3*

The various components of SHP projects and there functions are discussed here under;

Diversion Weir and Intake Structure

Diversion weir is the structure which is constructed across the stream to divert water from the stream to the intake structure. The primary function of the diversion weir is to provide uninterrupted water supply to the intake structure. Intake structure is the structure which receives the water from diversion weir and provides the water to the intake channel.

Intake Channel/ Pipe

Intake Channel/Pipe is a structure which carries water from the intake structure to the Desilting structure. Depending on the site requirements it may be open channel or the pipe. Generally, the intake channel is laid down at a slope of 1:200.

Desilting Tank

Desilting Tank is the structure constructed in between the intake channel and the headrace channel. The primary function of the desilting tank is to clean the water from any suspended silt or sand. It is designed in such a way that it traps all silts greater than 2mm particle size. A silt flushing system is also provided in the desilting tank. If any silt, greater than 2mm particle size, passes the desilting tank it may damage the blades of turbine under high hydraulic head.

Headrace Channel

Headrace Channel is the structure provided to transmit water from the desilting tank to the forebay tank. It may be a channel, open or closed or a steel pipe depending upon the site requirements. Generally, a slope of 1:500 is maintained along the headrace channel.

Forebay Tank

Forebay Tank is a structure which receives water from headrace channel and transmits water through a steel pipe to the turbine fitted in the powerhouse. The forebay is designed to supply uninterrupted design discharge to the turbine. Generally, it is designed for 2 minutes storage capacity; this is done mainly to accommodate the surge generated due to the immediate closure of the turbines. A spillway structure is also provided to spill off the water in case of immediate closure of the turbines.

Penstock

Penstock is a steel pipe to transmit water from the forebay tank to the turbines fitted in the powerhouse. Penstock pipe is well placed on the anchor blocks in between the forebay and powerhouse.

Powerhouse

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

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 upon the site requirements.

4.5 Determination of Head

The power potential is directly prop - ortional to the discharge and the available Head. The term 'Head' is the altitude difference between the forebay and the powerhouse site. In other words head is the vertical height from where the water is dropped on the turbine to generate hydropower (Fig. 4.4). Practically, the total available head is not actually available for the power generation as some of the hydraulic losses occur due to friction in pipe and bends. Therefore, actual head available after head losses is known as 'Net Head' and the head available before the head losses is known as 'Gross head'.

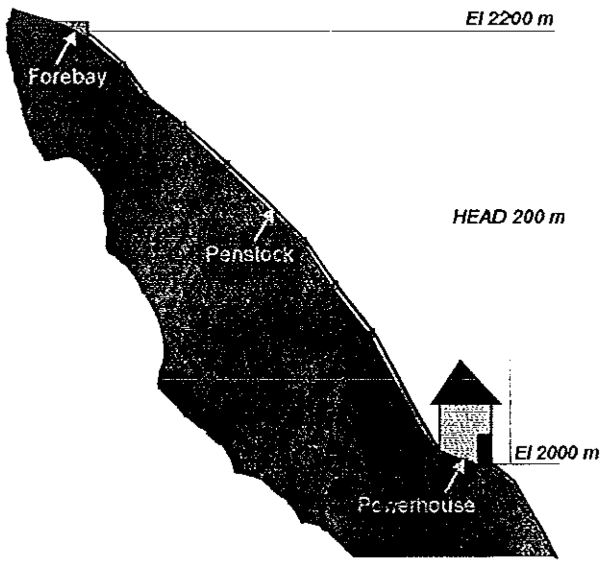

Fig. 4.4 Determination of the Gross Head

In the present study, for power potential assessment Gross head has been determined from the topo-sheet on 1:50,000.

4.5.1 Instrument used to measure Head

In field the hydraulic head can be directly measured by using Altimeter or by Geographic Position System (GPS). During the present study GPS and Altimeter were used to measure the altitudes at the forebay and powerhouse sites.

Altimeter

Altimeter is a simple instrument, which gives directly the altitude at a given point. The readings are in meters or in ft – as per the user's requirement. The instrument is physically carried to the forebay and the powerhouse site and the altitude at the two locations are noted in m/ft. The difference between the altitude at forebay and the powerhouse site will give the 'Gross Head'.

Geographic Positioning System (GPS)

Head can also be measured by using GPS. The GPS not only provides the altitude at the given location but also provides the Geo-coordinates of the given location. In order to measure the head through GPS, the instrument is physically carried to the forebay and the powerhouse location and the altitude at the two locations are recorded, the difference of the two reading will provide the Gross head.

During the present study, for initial power potential calculations the head has been determined from EMA topo-sheet at 1:50,000 scale. However, for the detailed studies of selected sites (Beresa, Chacha, Gur, and Robi Gumero), Gross head has been determined from GPS and Altimeter.

4.6 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. For planning purpose, this period is too long therefore, there is a need to utilize a regional hydrological model that enable users to rapidly estimate the temporal variability of river flows at a potential site, from which the hydropower potential can be determined (Kumar et al, 2000). Unfortunately, for the present study area no such regional hydrological models are available.

In the present study 36 potential SHP sites has been identified. For none of these potential streams, gauged data is available at or near the proposed diversion sites. However, observed discharge data is available either, in the upstream or downstream locations on the same stream or in the adjoining catchments. Figure 4.5 shows the location of gauge stations on various streams and the location of identified potential SHP streams. During the present study, for initial estimate of the power potential the observed discharge data from nearby locations have been projected at the proposed sites to work out the dependable flows. However, it is strongly recommended to observe the actual discharge, at least covering two lean seasons, before finalizing these sites for final development.

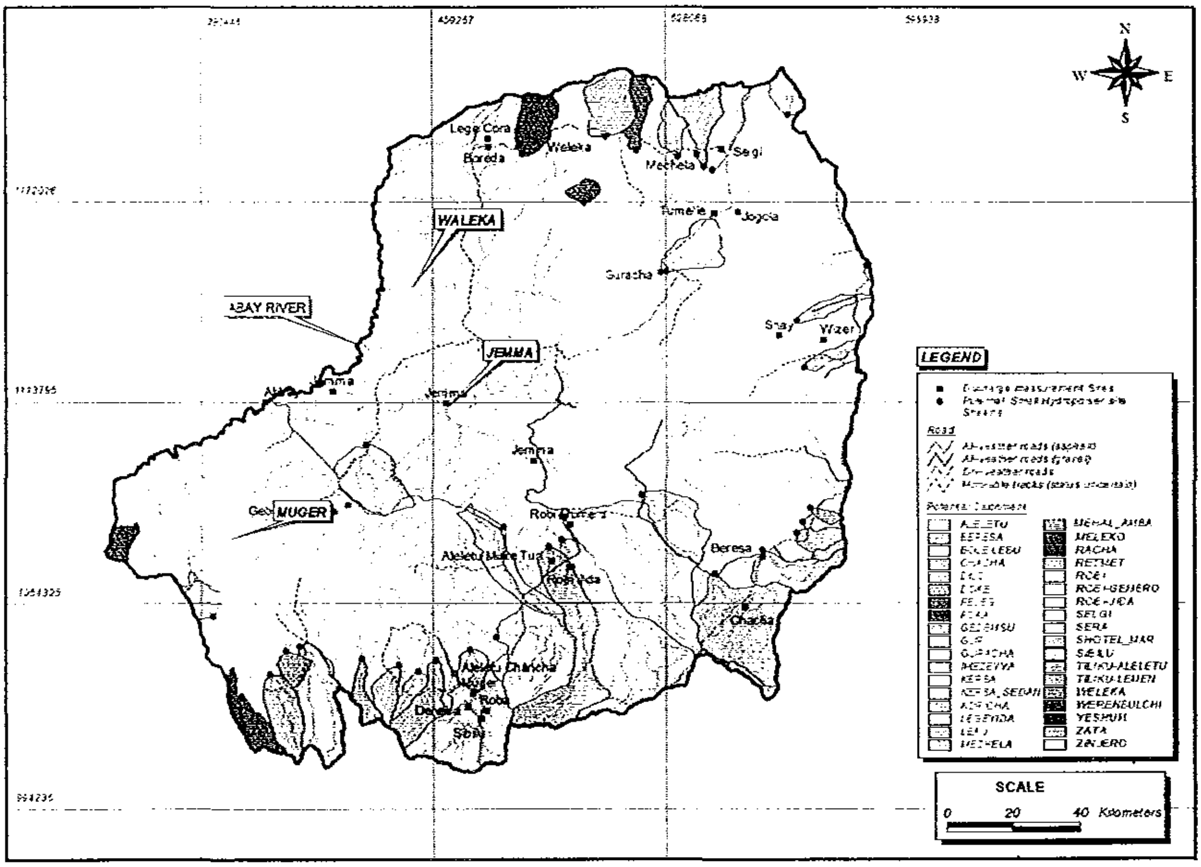

Fig 4.5 **The location of gauged stations on various streams and the location of identified potential SHP streams**

4.6.1 Flow-Duration Curve Analysis

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 particular flow can be expected to be exceeded (called the "percent exceedance"). The flow-duration curve is a very useful tool in hydrologic analysis in general and especially, useful in hydropower studies. Its compact form makes it very easy to estimate magnitudes of ***high and low flows*** and the *time availability of flows* between these two flow levels. In the hydropower analyses the flow-duration curve can be used to determine estimated power and energy from a proposed hydropower installation. The flow-duration curve is also useful in order to carry out the hydrologic investigations where the average time availability of flow is required, such as for irrigation projects.

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 magnitude of flow. 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 order numbers, the largest beginning with order 1. The order 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 a function of the length of record. References of the flow-duration curves are usually made as Q_{100}, Q_{90}, Q_{50}, Q_{30}, Q_{10} *etc.*, indicating the flow values at the percentage point subscripted (Fritz, 1984).

In the present study area 25 gauge stations on various streams are present. Out of these, only 16 gauged stations have recorded daily discharge data for 2 to 42 years, daily or weakly. The observed discharge data for 9 gauged stations were procured from Ministry of Water Resources which has been utilized to work out dependable flows for 18 identified potential SHP sites. For rest of the gauging stations the observed discharge data is not available.

In the present study, ranked flow technique has been employed to compute flow duration curve at proposed diversion weir sites for 18 identified potential streams. For 9 small hydropower (SHP) potential sites, flow-duration curve is prepared from observed daily discharge data. However, for 9 other potential sites the observed discharge data has been projected from adjacent gauged stations by percent area ratio method for those which demonstrate similar catchment characteristic. Table 4.2 presents the list of potential streams and the corresponding gauging stations from which the observed discharge has been utilized to work out the flow duration. Further, for remaining 18 potential sites, the flow-duration could not be worked out as neither, observed discharge data on the same stream or in the adjacent catchment with similar characteristics was available nor, sufficient metrological data was available to workout the discharge empirically.

Table 4.3 presents a sample flow duration computation for Beresa Stream, based on observed discharge data from 1994 to 2003 and Fig. 4.6 shows the Flow Duration curve for Beresa Stream. Similarly, flow duration for all remaining 18 potential site were computed and are presented at Annexure IV.

Table 4.2 List of Potential SHP sites and corresponding Gauging Stations

S.No	*Potential SHP Site*			*Gauging Station*			*Distance of Gauging Station from Potential SHP site Proposed Diversion Weir)*	
	*Name of * SHP Site*	*Location of Diversion weir Site (UTM)*		*Name of Stream*	*Location of Gauging Station (UTM)*		*Distance (km)*	*Direction*
		Northing	*Easting*		*Northing*	*Easting*		
1	Beresa	1069461	556378	Beresa	1067065	555855	2.06	N
2	Chacha	1062030	542311	Chacha	1052072	550857	13.36	NW
3	Dilo	1036980	459889	Sibilu	1019587	472939	21.54	NW
4	Felg	1185050	520818	Mechela	1185192	537000	17.11	W
5	Gedemsu	1074791	565943	Beresa	1067065	555855	13.79	NE
6	Gur	1075715	479404	Robi Jida	1063657	499745	23.45	NNW
7	Guracha	1151370	527729	Jogolo	1168154	548586	27.11	SW
8	Kersa	1044061	478642	Duber	1044802	484752	6.95	W
9	Mechela	1182120	539819	Mechela	1185192	537000	4.57	SE
10	Shay	1081466	570607	Shay	1131535	559842	6.75	SW
11	Robi Gumero	1078415	496129	Robi Jida	1063657	499745	15.39	N
12	Robi Jida	1073132	495827	Robi Jida	1063657	499745	9.05	N
13	Selgi	1181641	542292	Selgi	1187009	544270	6.75	SW
14	Sera	1185094	532537	Mechela	1185192	537000	4.6	W
15	Sibilu	1040327	469875	Sibilu	1019587	472939	20.50	N
16	Tiliku Aleletu	1069729	493474	Robi Jida	1063657	499745	8.84	NNW
17	Weleka	1190707	510064	Mechela	1185192	537000	27.04	W
18	Retmet	1123374	567974	Shay	1131535	559842	12.32	NW

** For the present study name of the SHP sites have been given same as the name of the stream on which the SHP scheme is identified.*

4.7 Estimation of Power Potential

The power potential is directly proportional to the discharge and the hydraulic head available at a proposed site. The potential energy may be computed by utilizing the following formula;

$$E_p = mgH \quad \text{......... (4.1)}$$

Where; *'m'* is the mass of the water (equals ρV: being the density of the water in kg/m^3 and V the volume of the water in m^3) and *'g'* is acceleration due to gravity.

Table 4.3 Computation of Flow Duration for Beresa Stream (Based on observed daily discharge from 1994 to 2003)

Month		*10 Daily average (cumecs)*	*% Time equalled or exceeded*	*Flow Duration (in descending order) (cumecs)*	*90% of discharge available for power Generation (cumecs)*
JAN	I	0.1853517	2.78	39.83	35.85
	II	0.1903829	5.56	25.32	22.79
	III	0.1800875	8.33	18.55	16.69
FEB	I	0.229604223	11.11	13.51	12.16
	II	0.199540337	13.89	10.40	9.36
	III	0.161389739	16.67	5.74	5.17
MAR	I	0.195683087	19.44	3.90	3.51
	II	0.233751104	22.22	2.39	2.15
	III	0.382314478	25.00	1.44	1.30
APR	I	0.32334455	27.78	0.94	0.85
	II	0.346777946	30.56	0.78	0.70
	III	0.502439319	33.33	0.66	0.60
MAY	I	0.440673162	36.11	0.59	0.53
	II	0.702282017	38.89	0.51	0.46
	III	0.438300085	41.67	0.43	0.39
JUN	I	0.443339537	44.44	0.40	0.36
	II	0.552861358	47.22	0.35	0.32
	III	0.697348872	50.00	0.34	0.31
JUL	I	3.284310106	52.78	0.33	0.29
	II	9.716851252	55.56	0.30	0.27
	III	19.68873419	58.33	0.29	0.26
AUG	I	32.37550907	61.11	0.27	0.25
	II	20.74558947	63.89	0.24	0.22
	III	16.82140626	66.67	0.23	0.20
SEP	I	12.42479046	69.44	0.22	0.20
	II	2.095652813	72.22	0.21	0.19
	III	1.205700897	75.00	0.19	0.17
OCT	I	1.549110256	77.78	0.19	0.17
	II	0.81372074	80.56	0.18	0.16
	III	1.244422789	83.33	0.16	0.15
NOV	I	0.331907856	86.11	0.15	0.14
	II	0.281288046	88.89	0.14	0.13
	III	0.192277573	91.67	0.13	0.12
DEC	I	0.185590565	94.44	0.12	0.11
	II	0.164105839	97.22	0.11	0.10
	III	0.145911382	100.00	0.09	0.08

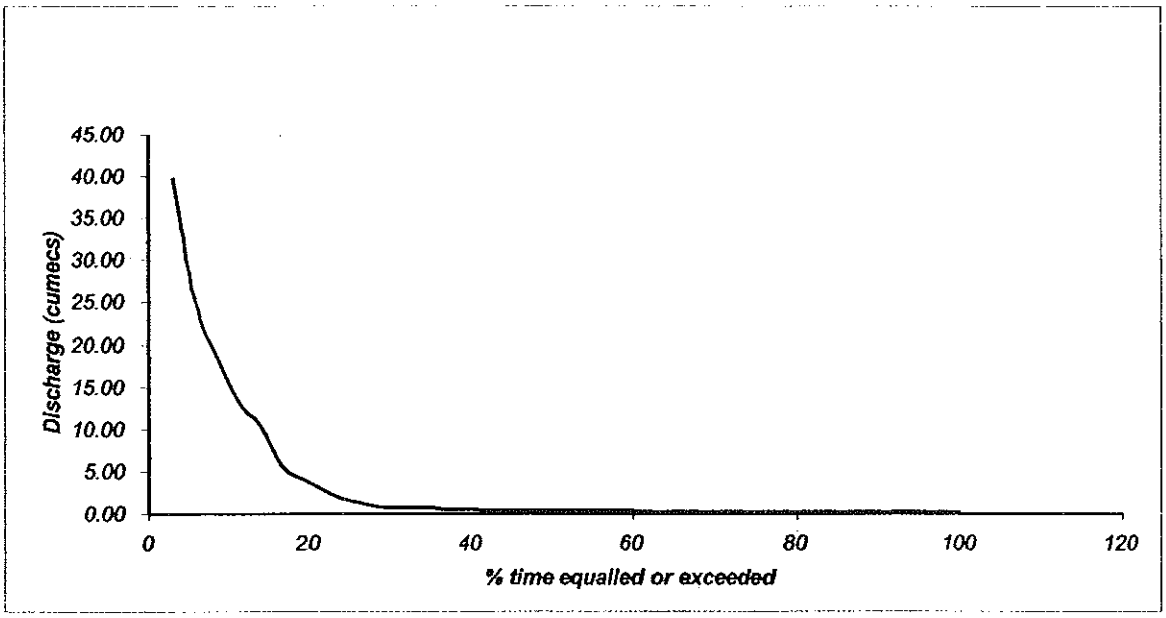

Fig. 4.6 **Flow Duration curve for Beresa Stream**
(Based on observed daily discharge from 1994 to 2003)

The power output P_h of a hydro system in kW then corresponds to the water flow rate Q (m^3/sec), and is given by,

$P_h=\rho gHQ\eta_p/1000$ ... (4.2) Where; η_p is the plant efficiency (the ratio of the available electrical power to the water power).

The standard expression for hydropower will be;

$P_h=9.81HQ\eta_p$ ... (4.3) Where; For clean water ρ is 1000 kg/m^3 and substituting the value of g in Equation (2),

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.

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 has been taken equal to 10% of the gross hydraulic head (Table. 4.4). Thus, the equation used for the initial computation of Power potential is;

$P_h = 9.81 * Q * Hn * nt * ng$. (4.4) Where

- 'Q' is discharge taken equal to 90% of the 75% dependable Flows.
- 'Hn' is the Net Head taken 90% of the Gross Head, Head Losses are taken 10% of Gross head.
- 'nt' is the efficiency of turbine which is taken equal to 90%.
- 'ng' is the efficiency of generator which is taken equal to 95%

Table 4.4 Computed hydropower potential for identified SHP sites in the study area

S.No	*Name of the SHP Site*	*Gross head (m)*	*Net* Head (m)*	*75% Dependable Discharge (cumecs)*	*Discharge available for Power Generation (cumecs)*	*Efficiency*		*Power Potential (kW)*
						Turbine	*Generator*	
1	2	3	4	5	6	7	8	9
1	Beresa	255	229.5	0.17	0.25	0.9	0.95	500
2	Chacha	405	364.5	0.20	0.27	0.9	0.95	1000
3	Dilo	325	292.5	0.08	0.12	0.9	0.95	300
4	Felg	115	103.5	0.11	0.13	0.9	0.95	125
5	Gedemsu	260	234	0.05	0.06	0.9	0.95	150
6	Gur	250	225	0.02	0.05	0.9	0.95	100
7	Guracha	235	211.5	0.012	0.028	0.9	0.95	50
8	Kersa	305	274.5	0.067	0.084	0.9	0.95	200
9	Mechela	135	121.5	0.20	0.24	0.9	0.95	250
10	*Imezzeya*	120	108	0.22	0.25	0.9	0.95	250
11	Robi Gumero	345	310.5	0.08	0.14	0.9	0.95	400
12	Robi Jida	385	346.5	0.071	0.126	0.9	0.95	400
13	Selgi	195	175.5	0.046	0.064	0.9	0.95	100
14	Sera	255	229.5	0.1	0.1	0.9	0.95	200
15	Sibilu	240	216	0.27	0.31	0.9	0.95	600
16	Tiliku Aleletu	400	360	0.048	0.069	0.9	0.95	200
17	Weleka	80	72	0.28	0.30	0.9	0.95	200
18	Retmet	160	144	0.18	0.26	0.9	0.95	300
						Total potential in the study area		**5325**

***** *Net head = Gross Head – Head Losses , for initial estimation of Net head the head losses have been estimated to be 10% of the gross head.*

CHAPTER FIVE

GROUND VERIFICATION AND ENGINEERING GEOLOGICAL APPRAISAL OF SHP SITES

5.1 Preamble

The present study area comprises of 3 Regions, 5 zones, 93 Weredas and 68 towns. According to the Central Statistics Authority the total population within the study area accounts for 7.85 million, both rural and urban (CSA, 1994). Out of total 68 towns in the study area only 23 are electrified through interconnected system and diesel generator sets. The rest 45 towns and the villages are yet to be electrified. This figure shows that there is an immediate need to provide electricity to the remaining towns and villages.

In the present study a total of 36 potential SHP sites have been identified from the Ethiopian Mapping Authority 1:50,000 scale topo-maps. Out of these 36 sites, 6 sites falls in Waleka sub-basin, 13 sites in Muger sub-basin and remaining 17 sites forms a part in Jemma Sub basin.

Out of these 36 identified sites, observed discharge data is available for 9 sites, within the same catchment and for 9 other sites observed discharge has been projected from adjacent gauged stations by percent area ratio method, for those which demonstrate similar catchment characteristic. However, for remaining 18 potential sites, the observed discharge is not available neither, observed discharge data on the same stream or in the adjacent catchment with similar characteristics was available nor, sufficient metrological data was available to workout discharge empirically. Therefore, finally the power potential could be computed only for 18 SHP sites.

5.2 Ground Verification of Identified Small Hydropower sites

The initial identification of potential SHP sites has been carried out from topographical map study at 1: 50,000 scale. For dependable discharge, observed data from gauged stations has been utilized. Thus, there is a need to ground verify the sites for the actual head, accessibility details and the engineering geological suitability of the sites.

From the present study total 36 potential sites has been identified. Out of which for only 18 sites observed discharge data is available. Thus, for these 18 sites, for which observed discharge data is available, power potential has been worked out. These 18 potential SHP sites can be ground verified and be taken up for detailed Engineering Geological Appraisal.

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. However, a sincere effort has been made to cover 4 potential SHP site to undertake 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. There should be an access to all the components, viz- diversion weir, water conductor and powerhouse.
ii) The head should be more than 200 m, this is to ensure a good power potential.
iii) The catchment is more than 200 sq. km.
iv) Observed discharge data, for minimum two years, covering at least 2 lean seasons, should be available.
v) The site must be located near a cluster of un-electrified villages, so as to ensure proper power utilization, if the scheme is to be run under stand alone mode.

The sites which satisfy the above said criteria are listed in Table 5.1 and are shown in Figure 5.1. Thus, these sites were finally taken up for ground verification and detailed engineering geological appraisal.

5.2.1 Ground Verification for General layout of Schemes

Initial general layout of SHP schemes was planned on the EMA topo-maps (1:50,000). The tentative location of diversion weir has been selected based on certain minimum criteria, such as;

i) The proposed diversion weir site is well accessible.
ii) The stream course at the proposed diversion weir site is more or less straight with comparatively minimum valley width.
iii) There should not be any tributary stream joining the main stream just at the proposed diversion weir site or just upstream of the diversion weir site.

Table 5.1 Sites selected for ground verification and detailed engineering geological appraisal

S.No	*Name of the SHP Site*	*Name of the Stream*	*Location of Diversion weir (UTM)*		*Nearest town (km)*
			Northing	*Easting*	
1	Beresa	Beresa	1069461	0556378	Debre Birhan
2	Chacha	Chacha	1062030	0542311	Mendida
3	Gur	Gur	1075715	0479404	Debre Libanos
4	Robi Gemero	Robi Gemero	1078415	0496129	Lemi

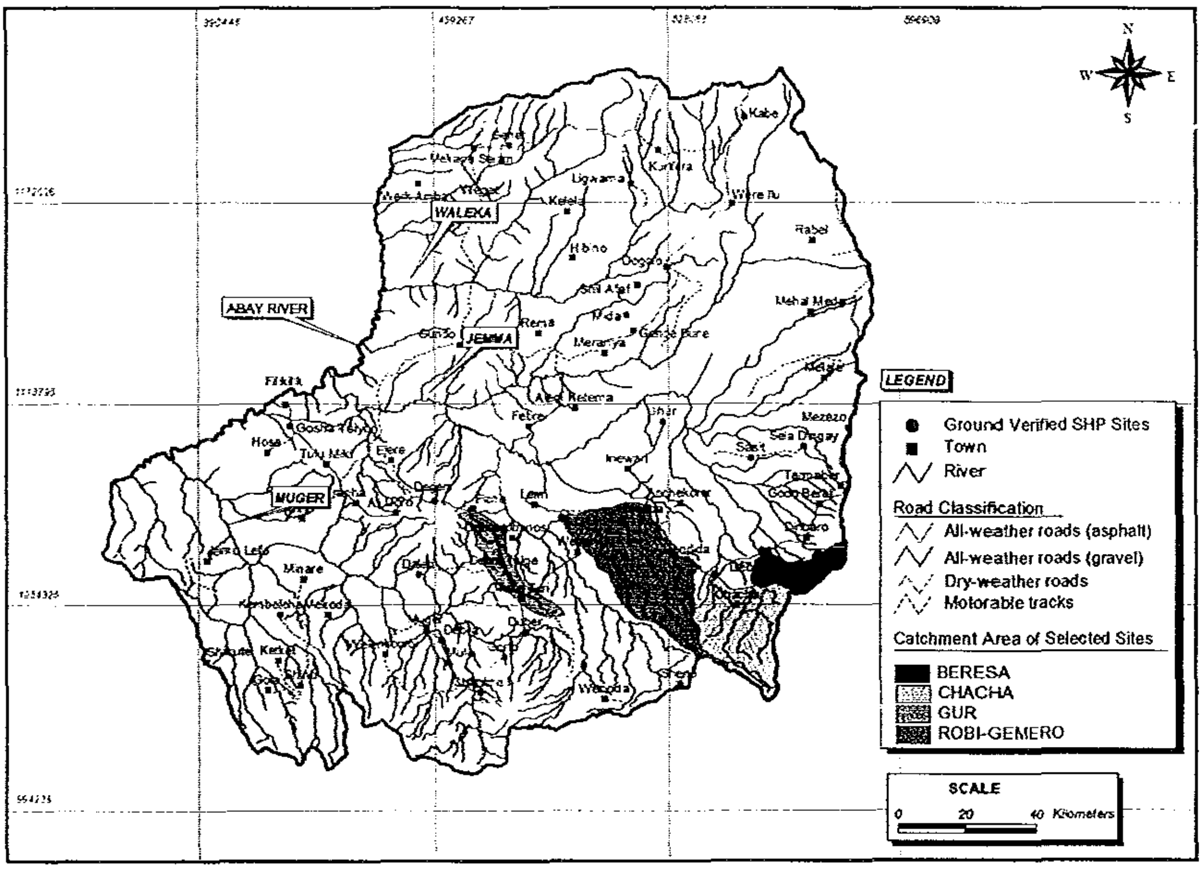

Fig 5.1 Ground Verified SHP sites

The proposed water conductor alignment has been decided on either of the stream banks, 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. If the contours are closely spaced the slope is relatively steep and if they are widely spaced the slope is gentle.

The proposed powerhouse site has been identified close to the stream bank and it must satisfy the following criteria;

i) There must be an access to the proposed powerhouse site, on EMA topo-maps foot trails are marked which helps in deciding the appropriate site.

ii) There must be a flat land or very gentle slope available to accommodate the powerhouse; this may be identified on topo map by examining the contour pattern.

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 (supports) are not subjected to scoring due to flowing water during rainy season.

The tailrace channel must meet the main stream downstream of powerhouse site, if it meets upstream of powerhouse site it may cause toe erosion at the base of the powerhouse.

Based on the above mentioned criteria, general layout for various SHP schemes, have been planned on EMA topo-sheets (1:50,000). Further, these general layouts of SHP schemes have been ground verified. As discussed in previous paragraphs, with the limitation of resources, time and financial constraints ground verification and detailed engineering geological appraisal has been carried out for 4 SHP sites, only.

For ground verification each site 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 of the components has been physically visited and observation were made and recorded.

ii) Physical verification of each of the component of SHP site and measurement for gross head has been done. The elevations and UTM co-ordinates has been recorded with the help of altimeter and GPS.

iii) At each site hydrological observations were carried out. Discharge has been measured by area velocity method, 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) Engineering Geological Appraisal of the site, at pre feasibility level has been done to workout the overall condition and strength of Rocks and soil present at various components. Stability condition of slopes on which water conductor is proposed has been studied. Besides, soil samples were collection for Laboratory testing. The detailed Engineering Geological Appraisal of Small hydropower sites are discussed at Section 5.3, of this chapter.

Ground verification for general layout of each individual SHP site is discussed here under;

Beresa Small Hydropower Project

Beresa stream, which is located near Debre Birhan, North-Eastern part of the study area has been identified as a potential stream for the hydropower generation. At this stream there exists an old defunct Micro hydro power station, which was operational till 1977. As reported this power station was generating less than 100 kW of power and was responsible to cater the power needs of Debre Birhan town. During the present study, on this stream two alternate general layouts of schemes has been proposed;

Beresa SHP Scheme Alternative I

Beresa SHP Scheme Alternative I is well accessible from Debre Birhan town. The proposed diversion weir site is about 4 km from Debre Birhan town. Upto the diversion weir site a foot path is present. From diversion weir site the access is along the water conductor (Old defunct scheme) which may lead to the forebay site. From forebay site a foot path is present which goes down on the right bank of stream 1 upto the powerhouse site (PH-1). From PH-1 along the left bank of stream-I a foot path is present which may lead to the PH-2 site via forebay (FB-2).

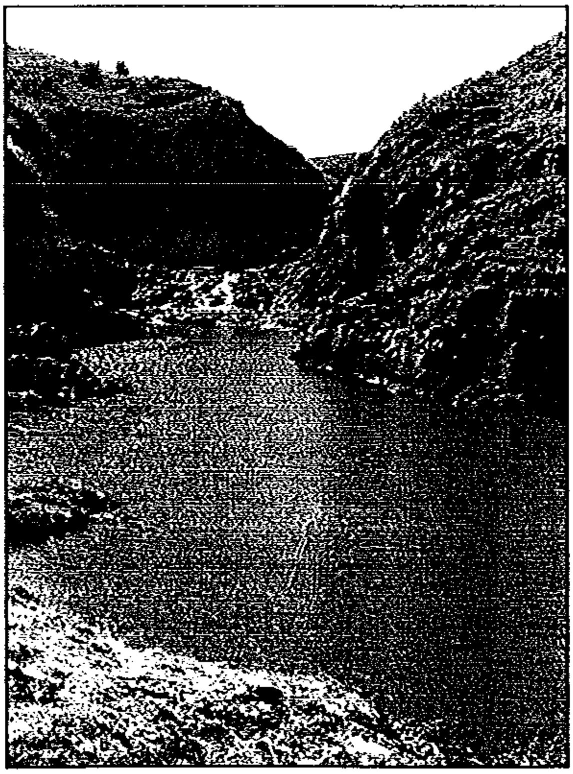

Plate 5.1 View of Beresa Stream at proposed diversion weir site

For alternative I the proposed diversion weir will be located at the existing diversion weir site (Old defunct scheme), defined by co-ordinates 1069461N; 0556378E, at an elevation 2725 m.

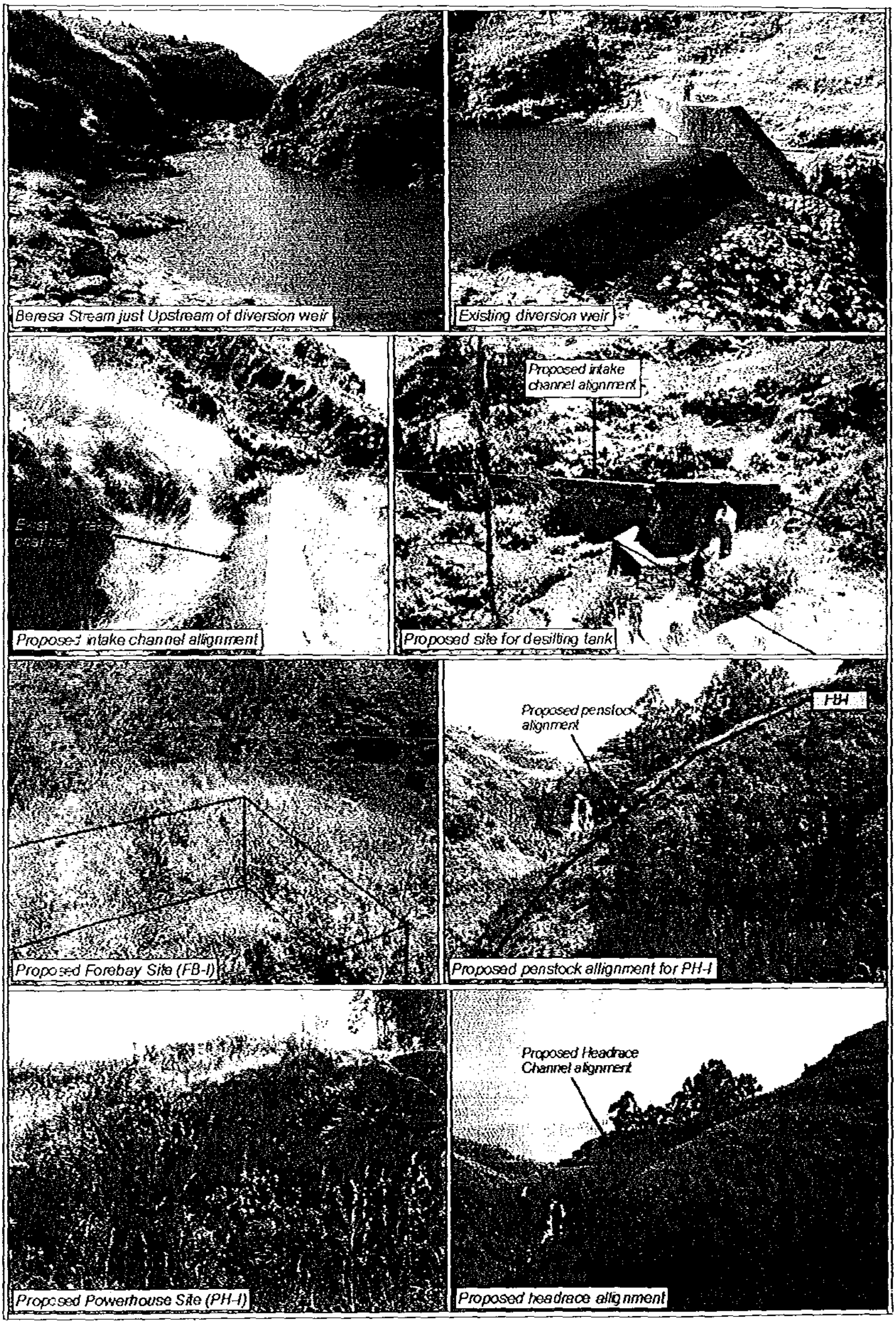

Plate 5.2 Beresa Small hydropower Scheme (Alternative- I)

The water conductor will be taken on the left bank following the headrace channel of old defunct scheme. The desilting tank has to be located at the forebay site of old defunct scheme (1069781N; 0556191E), at an elevation 2720 m (Plate 5.2). The headrace channel will be taken further ahead on left bank of stream for about 80 m to join the forebay tank site (2720 m). The forebay tank site (FB-I) is located on relatively gentle slope (1069632N; 0556094E). The proposed powerhouse site (PH-I) is located on the bank of Beresa stream, at elevation 2670 m, just before the confluence of stream-I 1069847N; 0556133E. The total gross head available for PH-I is 50 m.

The water after PH-I will be taken through a pipe, which will cross stream-1 through an aqueduct and then follow through an open channel on the left bank of Beresa stream to meet the forebay (FB-2) at an elevation of 2665 m (1069847N; 0555548E). The Powerhouse site (PH-2) is located at an elevation of 2460 m (1070004N; 0555273 E). The gross head available at PH-2 is 205 m. The general layout of Beresa SHP Scheme (Alternative I) is shown in Fig.5.2(a). The location and elevations of various components for Beresa (Alternative I) SHP scheme are presented in Table 5.2.

Table 5.2 Location and Elevations of various components for Beresa (Alternative I) SHP Scheme

Component	*Elevation (m)*	*Length (m)*	*Location (UTM)*	
			Northing	*Easting*
Diversion Weir	2725	-	1069461	0556378
Intake Channel	-	223.1	-	-
Desilting Tank	2723	-	1069602	0556191
Headrace Channel (HRC-1)	-	79.1	-	-
Forebay Tank (FB-1)	2720	-	1069786	0556094
Penstock (P1)	-	55.17	-	-
Powerhouse (PH-1)	2670	-	1069786	0556133
Tailrace Channel (TRC-1)	-	25	-	-
Headrace Channel (HRC-2)	-	627.3	-	-
Forebay (FB-2)	2665	-	1069847	0555548
Penstock (P2)	-	226.2	-	-
Powerhouse (PH-2)	2460	-	1070004	0555273
Tailrace Channel (TRC-2)	-	25	-	-

Beresa SHP Scheme Alternative II

The Beresa SHP Scheme Alternative II is well accessible from Debre Birhan town. The proposed diversion weir site is about 7 km from Debre Birhan town. Upto the diversion weir site a foot path is present. From diversion weir site the access is along the water conductor (Old defunct scheme) which may lead to the forebay site through the flat ridge and then one may walk down to the powerhouse site through a very gentle slope.

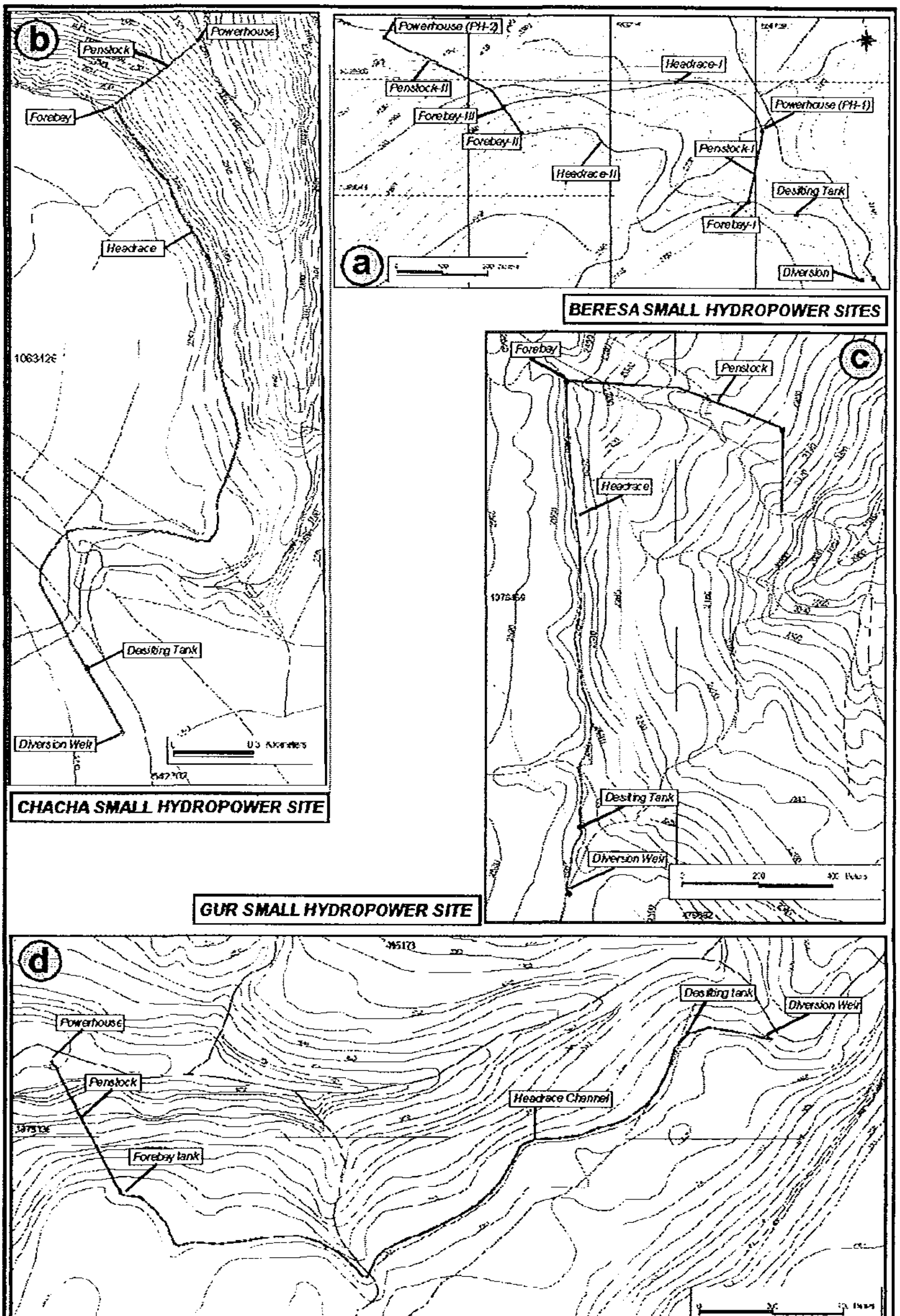

Fig. 5.2 General Layout of Ground Varified Small Hydropower Sites.

For alternative II the proposed diversion weir will be located at the existing diversion weir site (Old defunct scheme), defined by co-ordinates 1069461N; 0556378E, at an elevation 2725 m. The water conductor will be taken on the left bank following the headrace channel of old defunct scheme. The desilting tank has to be located at the forebay site of old defunct scheme (1069602N; 0556191E), at an elevation 2723 m. The headrace channel will be taken further ahead on left bank of stream for about 883 m to join the forebay tank site (2715m). The forebay tank site is located on relatively gentle slope (1069781N; 0555582E). The proposed powerhouse site is same as that of Alternative I (PH-II) is located on the bank of Beresa stream, at elevation 2465 m (1070004N; 0555273E). The total gross head available is 255m.

The general layout of Alternative II is shown in Fig.5.2(a). The location and elevations of various components for Beresa (Alternative II) SHP scheme are presented in Table 5.3.

Chacha Small Hydropower Scheme

Chacha stream is one of the major tributary of Jemma River. The stream is located in the North-Eastern part of the study area. The site is well accessible from Debre Berahan via 14 km all weather road which leads to Mendida town. From steel bridge on Chacha River an access is possible through right bank. Access to the diversion weir site is difficult as the slopes on both the banks are very steep. The powerhouse site is accessible through a foot path on right bank of Chacha stream which leads to Nigus Den village which is about 4 km from the diversion weir site.

Plate 5.3 A view of Chacha stream just upstream of proposed diversion weir

The proposed diversion weir will be located at an elevation 2735 m, defined by co-ordinates 1062030N; 0542311E, just upstream of a 25 m high waterfall. The water conductor will be taken on the left bank Chacha River. The desilting tank has to be located near to the farm land (1062284N; 0542094E), at an elevation 2732 m.

Table 5.3 Location and Elevations of various components for Beresa (Alternative II) SHP Scheme

Component	*Elevation (m)*	*Length (m)*	*Location (UTM)*	
			Northing	*Easting*
Diversion Weir	2725	-	1069461	0556378
Intake Channel	-	223.1	-	-
Desilting Tank	2723	-	1069602	0556191
Headrace Channel	-	882.2	-	-
Forebay Tank	2715	-	1069781	0555582
Penstock	-	281.4	-	-
Powerhouse	2460	-	1070004	0555273
Tailrace Channel	-	25	-	-

The headrace channel will be taken further ahead on left bank of stream for about 2932.2 m to join the forebay tank site (2670 m). The forebay tank site is located on relatively gentle slope (1064422N; 0542192E). The proposed powerhouse site is located on the bank of Chacha stream, at elevation 2265 m (1064657N; 0542516E). The total gross head available is 405 m.

The general layout of Chacha SHP Scheme is shown in Fig.5.2(b). The location and elevations of various components for Chacha SHP scheme are presented in Table 5.4.

Table 5.4 Location and Elevations of various components for Chacha SHP Scheme

Component	*Elevation*	*Length*	*Location (UTM)*	
			Northing	*Easting*
Diversion Weir	2735	-	1062030	0542311
Intake Channel	-	260.9	-	-
Desilting Tank	2732	-	1062284	0542094
Headrace Channel	-	2932.2	-	-
Forebay Tank	2670	-	1064422	0542192
Penstock	-	446.87	-	-
Powerhouse	2265	-	1064657	0542516
Tailrace Channel	-	25	-	-

Gur Small Hydropower Scheme

Gur stream has a total catchment area of 268 km^2. It is one of the major tributary of Jemma River. Gur stream falls in the Central part of the study area, about 7 km North of Debre Libanoes. The site is well accessible from the main road from Addis Ababa to Dejen town. From Enkulal bridge on Gur River an access is possible through right bank. Access to the diversion weir site is easy as the slopes on both the banks are gentle. The powerhouse site is accessible through a foot path on right bank of Gur stream which leads to Fafate village which is about 3 km from the diversion weir site.

The proposed diversion weir will be located at an elevation 2480 m, defined by co-ordinates 1075715N; 0479404E. The water conductor will be taken on the left bank of the stream. The desilting tank has to be located (1075879N; 0479442E), at an elevation 2475 m. The headrace channel will be taken further ahead on left bank of stream for about 1188 m to join the forebay tank site (2460 m). The forebay tank site is located on relatively gentle slope (1077057N; 0479402E). The proposed powerhouse site is located on the bank of Gur stream, at elevation 2210 m (1076966N; 0479979E). The total gross head available is 250 m.

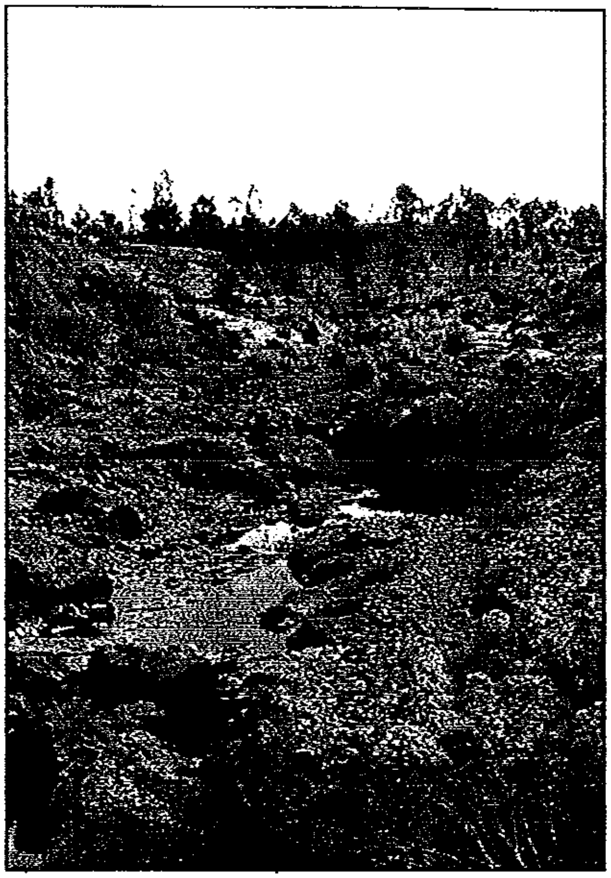

Plate 5.4 Diversion weir site on Gur stream

The general layout of Gur SHP Scheme is shown in Fig.5.2(c). The location and elevations of various components for Gur SHP scheme are presented in Table 5.5.

Table 5.5 Location and Elevations of various components for Gur SHP Scheme

Component	*Elevation*	*Length*	*Location (UTM)*	
			Northing	*Easting*
Diversion Weir	2480	-	1075715	0479404
Intake Channel	-	167.6	-	-
Desilting Tank	2475	-	1075879	0479442
Headrace Channel	-	1187.7	-	-
Forebay Tank	2460	-	1077057	0479402
Penstock	-	305.2	-	-
Powerhouse	2210	-	1076933	0479979
Tailrace Channel	-	200	-	-

Robi Gumero Small Hydropower Scheme

Robi Gumero stream is one of the tributary of Jemma River. It falls in Eastern part of the study area. The site is accessible from Muke Turi town via 57 km all weather road which leads to Lemi town. From Lemi town the Robi Gumero SHP site is about 4 km. At present the accessibility to the diversion weir site is very difficult.

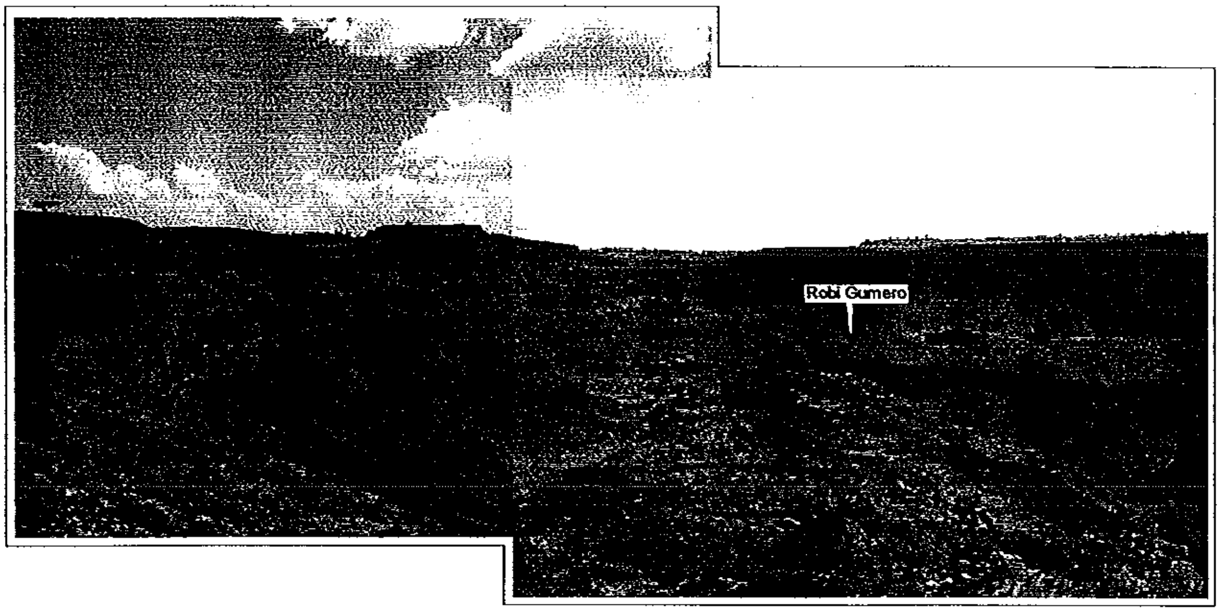

Plate 5.5 A birds eye view of Robi Gumero Site

The only possible means to reach the site is through a 15 m wooden ladder hanging along the cliff. The powerhouse site is accessible through a monastery and it is about 3 km from the ladder site. After ground verification it is found that though this site has a potential of 400 kW, but the accessibility at present is very difficult. Therefore, if this site has to be taken up for development it must be considered on least priority.

The proposed diversion weir will be located at an elevation 2170 m, defined by co-ordinates 1078415N; 0496129E. The water conductor will be taken on the left bank of the river. The desilting tank has to be located (1078435N; 0495921E), at an elevation 2165 m. The headrace channel will be taken further ahead on left bank of stream for about 1948.8 m to join the forebay tank site (2160 m). The forebay tank site is located on relatively gentle slope (1077987N; 0494348E). The proposed powerhouse site is located on the bank of Robi Gumero, at elevation 1795m (1078359N; 0494149E). The total head available is 345 m.

The general layout of Robi Gumero SHP Scheme is shown in Fig.5.2(d). The location and elevations of various components for Robi Gumero SHP scheme are presented in Table 5.6.

5.3 Engineering Geological Appraisal of SHP sites

Engineering geological investigation plays an important role in the safe designing and proper functioning of any small hydro power project. Most of the water conductor rests on the valley slopes; therefore it becomes very important to know how the stability of these slopes will behave during the adverse conditions, represented by water saturation and dynamic conditions. The strength and deformability of the 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 so as to provide proper remedial measures to retain the slopes and design various engineering structures accordingly.

Table 5.6 Location and Elevations of various components for Robi Gumero SHP Scheme

Component	*Elevation*	*Length*	*Location (UTM)*	
			Northing	*Easting*
Diversion Weir	2170	-	1078415	0496129
Intake Channel	-	194.1	-	-
Desilting Tank	2165	-	1078435	0495921
Headrace Channel	-	1948.8	-	-
Forebay Tank	2160	-	1077987	0494348
Penstock	-	398.4	-	-
Powerhouse	1795	-	1078359	0494149
Tailrace Channel	-	25	-	-

For the present study the engineering geological appraisal, at pre-feasibility level, has been carried out for the selected sites. This includes investigation for engineering geological suitability of various components of water conductor. For this data pertaining to geology, structural discontinuities, rock and soil mass quality, weathering condition, shear strength of the rock mass, stability condition of the slopes and response of the rock mass and the soils for the anticipated worst conditions, represented by varied water saturation conditions and the dynamic conditions, has been collected and analyzed.

5.3.1 Geology of the Small Hydropower sites

Geology of Beresa Small Hydropower Scheme

Beresa steam is the tributary of Jemma River. It is located near Debre Birhan town. The rocks exposed in the project area are mainly basic in nature. Soil cover is very thin. The river follows the regional structure, local faults and lineaments are present in the project area. A description of geology at various components of the scheme is given in the following paragraphs. Figure 5.3 (a) shows the geological map of the Beresa Small Hydropower site.

Diversion and Intake Structure

Plate 5.6 Prominent three sets of joints present in basalts at proposed diversion weir site

The river width at proposed diversion weir site is about 25m and it flows towards North West. On both the banks basalts are exposed. Three major joint sets are exposed on the right and left bank and the preferred orientation (Dip/Amount) is J1: N 160° /65°, J2 : N 10° /15° and J3 : N 290° /75° (Plate 5.5). The right bank slope is relatively gentle as compared to the left bank slope. Both the slopes are stable as none of the discontinuity planes are dipping towards the valley. The degree of weathering of rocks on right bank is less as compared to the rocks exposed on the left bank. The rock mass rating (RMR) at the diversion weir site indicates that the rock is of good quality (RMR =68 to 76).

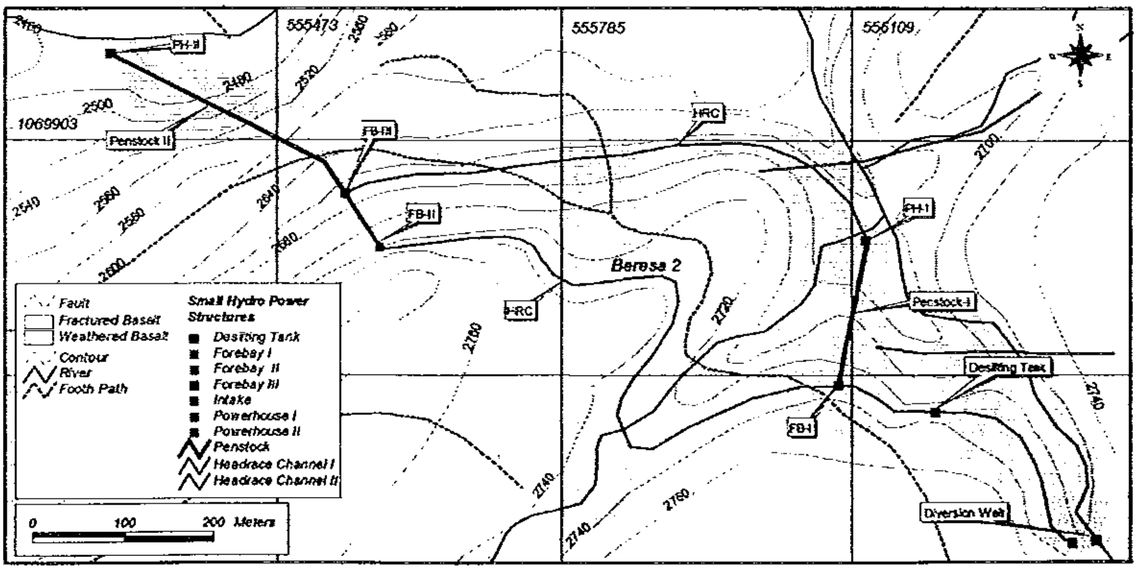

Fig. 5.3 (a) Geological Map of Beresa Small hydropower Site.

Intake Channel and Desalting Tank Site

The desilting tank is located 223 m downstream of the diversion weir. At the proposed Desilting Tank site basalts are present which have a shallow soil cover. The topography is comparatively flat. The degree of weathering in basalts is slightly high, if compared with basalts exposed at diversion weir site. The basalts exposed from diversion weir site upto the desilting site are fractured and contains mainly three joint sets with preferred orientation

(Dip/Amount) is J1: N 20° /30°, J2 : N 220° /65° and J3 : N 270° /75°. The rock all along the intake channel and desilting tank is of good quality (RMR =76 to 68) and slope is stable as no traces of instability were observed.

<u>Headrace channel and Forebay Site</u>

The geology of the water conductor from the diversion weir to the desalting tank is slightly weathered basalt. The joint sets are dipping towards the valley. But geology of the water conductor between the DT and FB1 is covered by colluvial soil. The second headrace channel, which is between the first tailrace and the second forebay, has a total length of 1.3 km. The geology also varies from site to site. The headrace channel mostly will be crossing through the colluvial soil cover.

<u>Penstock Alignment</u>

The new proposed forebay site is located at 1069632N and 0556094E coordinate at elevation of 2710m above sea level. The second forebay site is located at elevation of 2665m and coordinate of 1069847N and 0555548E. The geology at this site is basalt which is covered with shallow soil cover. The basalt is moderately weathered and of good quality (RMR = 72).

<u>Powerhouse Site</u>

The basalt with its regional joint set is well exposed at the first power house site (PH-I). The power house is located just upstream of the confluence of Beresa stream and stream-I. One local fault passes near to the site, which trends NE – SW. At the proposed powerhouse boulders of basalt of varied dimension are present, which are probably deposited by the Beresa stream. For the construction of powerhouse these boulders have to be cleared and the adjoining slope has to be back cut for terrace formation to house the powerhouse. A retaining wall has to be provided as the maximum flood mark is very close (2669m) to the proposed powerhouse terrace.

<u>Geology of Gur Small hydropower scheme</u>

Gur stream is a tributary of Jemma River. Its catchment is around 268km^2. The geology varies from fissural volcanic to Paleozoic sedimentary terrain as it decreases elevation. A description of geology at various components of the scheme is given in the following paragraphs. Figure 5.3 (b) shows the geological map of the Gur Small Hydropower site.

Diversion and Intake Site

The diversion site is located 30m above the Portuguese Bridge, which was constructed in 16^{th} centaury around 400 years ago with Ostrich egg and limestone. The rocks exposed at the diversion weir site are basalts. The basalt is amygdaloidal type. It is filled with different minerals and there is one hole. At the right abutment the basalt is very massive and its slope is varying between 80^0 and 90^0. However, the height of the slope is around 25m. The left abutment slope is gentle and is covered with shallow alluvial soil. Regional joint set cross the diversion site in a direction of N45^0/70^0 and N355^0/ 65^0. The geology of the intake site is similar to that of diversion weir site.

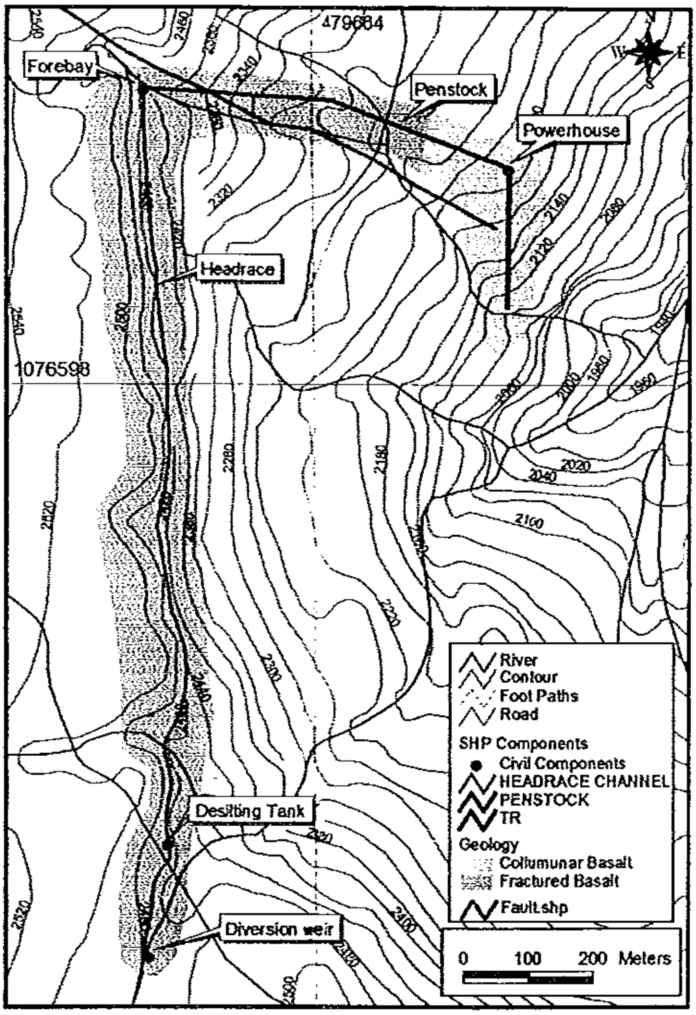

Fig. 5.3 (b) Geological Map of Gur SHP Site.

Desalting Tank Site

The proposed desalting tank site is located about 20m down stream of Enkula Bridge. The geology is well exposed and it is basalt, characterized by presence of sinkholes near to the proposed desilting tank site. As reported by the local people the maximum depth of the hole is about 15m. The regional joint sets follow the same direction as at the diversion site.

Headrace Pipe

The proposed headrace channel will follows a terrace which is formed because of local faulting. It is a normal type of fault trending North-South where the down through part is toward the stream channel. The rock exposed along the proposed headrace is massive

Diversion and Intake Structure

Here the area is mainly covered by aphenitic basalt rock. At the diversion site, along the stream, basalt out crop is clearly visible. It has a hexagonal joint setting, horizontal bedding and the rock forming minerals are not visible. Slight weathering is there along the stream channel.

Plate 5.7 Basalts as exposed near diversion weir

Desalting Tank Site

The desalting tank is located at 1062284, northing and 542094, easting. Here the basalts are mainly covered by the residual soil formation. The weathering degree of the basalt is more than the diversion site. A sufficient flat land is available to accommodate the desilting tank.

Headrace Channel

The total length of the water conductor is 2599 m. The rock exposed at the water conductor is mainly basalt, which is covered with shallow colluvial soils, but the soil cover at some location is deep. The entire water conductor course is on a flat land.

Forebay Site and Penstock Alignment

The forebay is located at geographical location of 1064422 northing and 542192 easting. The forebay would be located ata an elevation of 2670 m. The geology is mainly basalt with shallow colluvial soil formation. The forebay site would be located over a terrace, which is a part of 6 such terraces resulted mainly because of erosion. The total length of the penstock is around 447m. The geology along the penstock alignment is mainly basalt. The basalts are competent and are fair in quality (RMR = 59). The weathering degree is varying as elevation decreases.

Powerhouse Site

The powerhouse site is geographically located at 1064657, northing and 542516, easting, near to the village Engus Den on the left bank of Chacha stream. The powerhouse would be located at an elevation of 2265 m. Here, the site is covered with shallow colluvial. The rock exposed around the powerhouse site is basalt.

Geology of Robi Gumero

Robi Gumero stream is one of the tributary of Jemma River. Its catchment area is around 875km^2 and its total stream length upto the proposed diversion weir is 67 km. The geology of Robi Gumero SHP site vary from volcanic (basalt) to sedimentary rocks (Sandstone) and the colluvial soil formation cover some part of the site. It was very difficult to access the area. During the field visit of the site, it was not possible to reach all proposed SSHP components and describe their geology. Therefore, the geology of the area is extracted from the geological map of Abay River Basin Master plan.

Diversion and Intake Structure

The proposed diversion site is located at geographical location of, 1078415northing and 496129, easting. The proposed elevation at diversion weir is 2170 m. The geology exposed at the site is basalt.

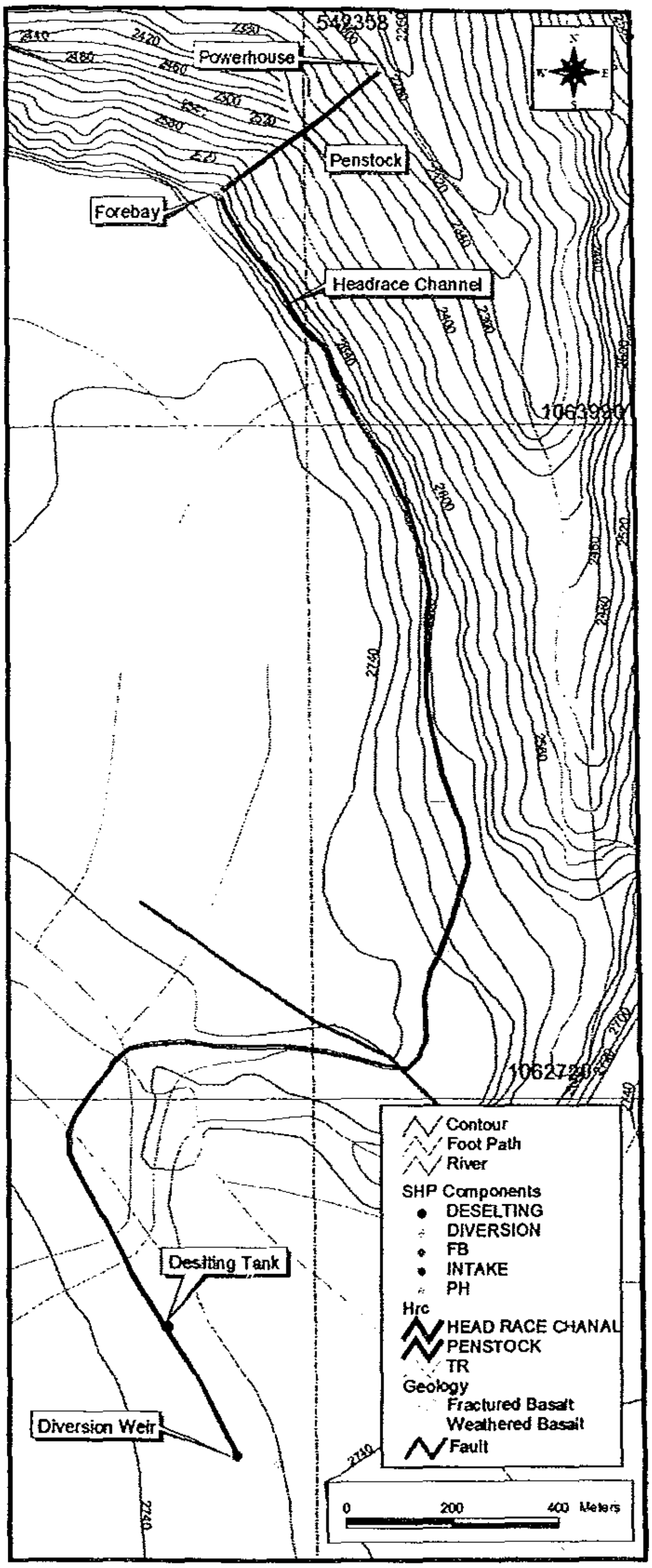

Fig. 5.3 (c) Geological Map of Chacha SHP Site.

Desalting Tank Site

The proposed desalting tank will be constructed at the geographical location of 1078435, northing and495921, easting. The proposed elevation at desilting tank is 2165 m .Here the basalt rock is covered by colluvial soil formation. Figure 5.3 (d) shows the geology of the Robi Gumero Small Hydropower site

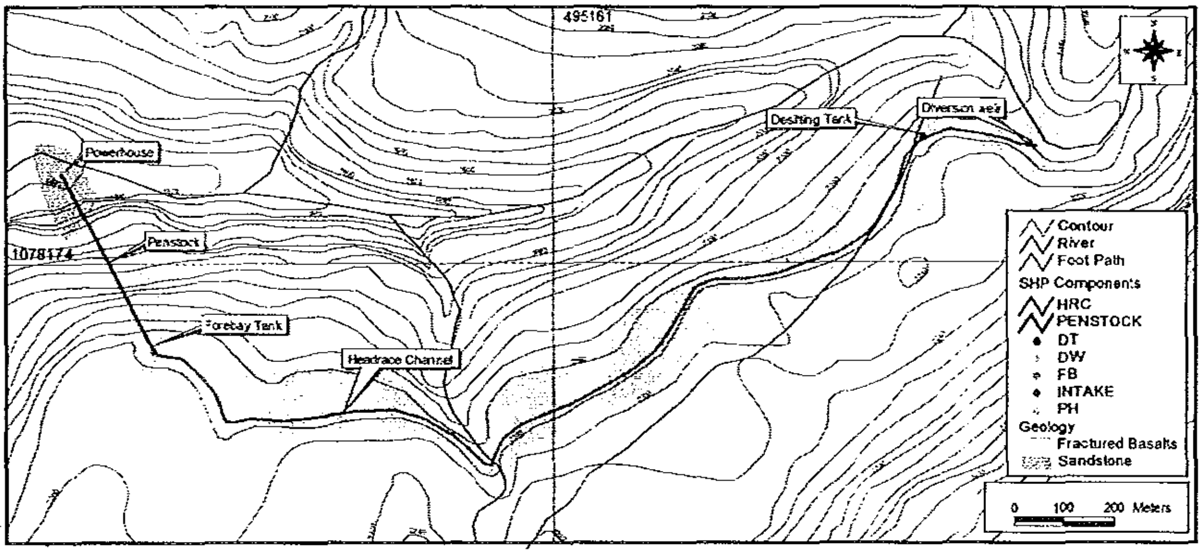

Figure 5.3 (d) Geology of the Robi Gumero Small Hydropower site.

Headrace Channel

The total length of the water conductor of Robi Gumero SHP sites is around 2595m. The water conductor is proposed along the basalt rock. At some locations the basaltic rocks are covered with shallow colluvial soil.

Forebay Site and Penstock Alignment

The proposed forebay site is located at geographical location of 1077987, northing and 494348, easting. The forebay site is located at an elevation of 2160 m. The geology of the forebay site is covered by colluvial soil formation. The penstock alignment would be along basalt and sandstone rock types.

Powerhouse Site

The proposed powerhouse site is located at geographical location of 1078359, northing and 494149, easting. The powerhouse is proposed at an elevation of 1795 m. Here the geology is sedimentary rock formation, sandstone.

5.3.2 Engineering Properties of Earth Materials

According to Annon, (1972) soil is an aggregate of mineral that can be excavated without explosive equipment for loosening. Rock, on the other hand is a natural aggregate of minerals connected by strong and permanent cohesive force. Based on the presence of rock and soil's physical and engineering properties, it is possible to classify them for engineering geological maps. Engineering properties affect the lithological, physical characteristics and spatial distribution of soil and rock by the combined effects of mode of origin, subsequent digenetic, metamorphic and tectonic history, and weathering process. This is a basic principle of engineering geological mapping; it implies not only the classification of individual rock/soil samples, but also field observations and measurement to delineate uniform and continuous rock/soil units (Trufat H. 2001).

The complete specification of a rock mass and soil requires descriptive information on the nature and distribution in space of both the materials that constitute the mass (rock, soil, water and air-filled voids) and the discontinuities which divide it (Bell, 1992).

In the present study basic investigation and analyses has been carried out to determine the engineering properties of rock and soil at each small hydropower site. Data pertaining to engineering properties of soil and rocks from various components of small hydropower site has been collected and analysed to understand their behavior and performance related to various components of SHP.

5.3.2.1 Weathering

Physical disintegration, chemical decomposition and biological activity bring about weathering of rocks. The weathering process is primarily controlled by the presence of discontinuities, in that provide access for the agents of weathering. Some of the earliest effects of weathering are seen along discontinuity surfaces. Weathering then proceeds inwards until the whole of a discontinuity-bounded block in affected.

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 weathering grade of rock is assigned according to

Irfan and Dearman classification (cited in Trufat H., 2001). Based on this classification the area is graded (Annexure V). Fig. 5.4 shows weathering map of the ground verified SHP sites.

Beresa Small Hydropower Site

Description of the state of weathering of the rock material is of particular importance in engineering rocks because weathering has profound effects on the physical and mechanical properties of the rock materials. According to weathering grade for rock mass by Irfan and Dearman, (1978) the weathering degree at Beresa Small Hydropower Site varies from slightly weathered to residual soil formation. Rocks which are exposed at the river bank areis slightly weathered and the weathering degree increases from the diversion weir site to the forebay and powerhouse. But weathering conditions along the water conductor is better than that of powerhouse.

Chacha Small Hydropower Site

The weathering degree of Chacha Small Hydropower Site varies from 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 powerhouse. The rocks along the water conductor side, which is more than 45% of the total area, are moderately weathered.

Gur Small Hydropower Site

Rocks exposed at Gur Small Hydropower Site has a varied degree of weathering. As per the weathering grade for rock mass by Irfan and Dearman (1978) the degree varies from slightly weathered to highly weathered classes. Rocks which are exposed at the river bank are slightly weathered and the weathering degree increases from the diversion weir site to forebay and powerhouse. Rocks at the diversion weir site is slightly weathered whereas, at the powerhouse the weathering degree reaches to residual soil formation, which means all the rock material is converted to soil. Along the water conductor site rocks are slightly weathered.

Robi Gumero Small Hydropower Site

The weathering degree Robi Gumero Small Hydropower Site varies from 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 powerhouse.

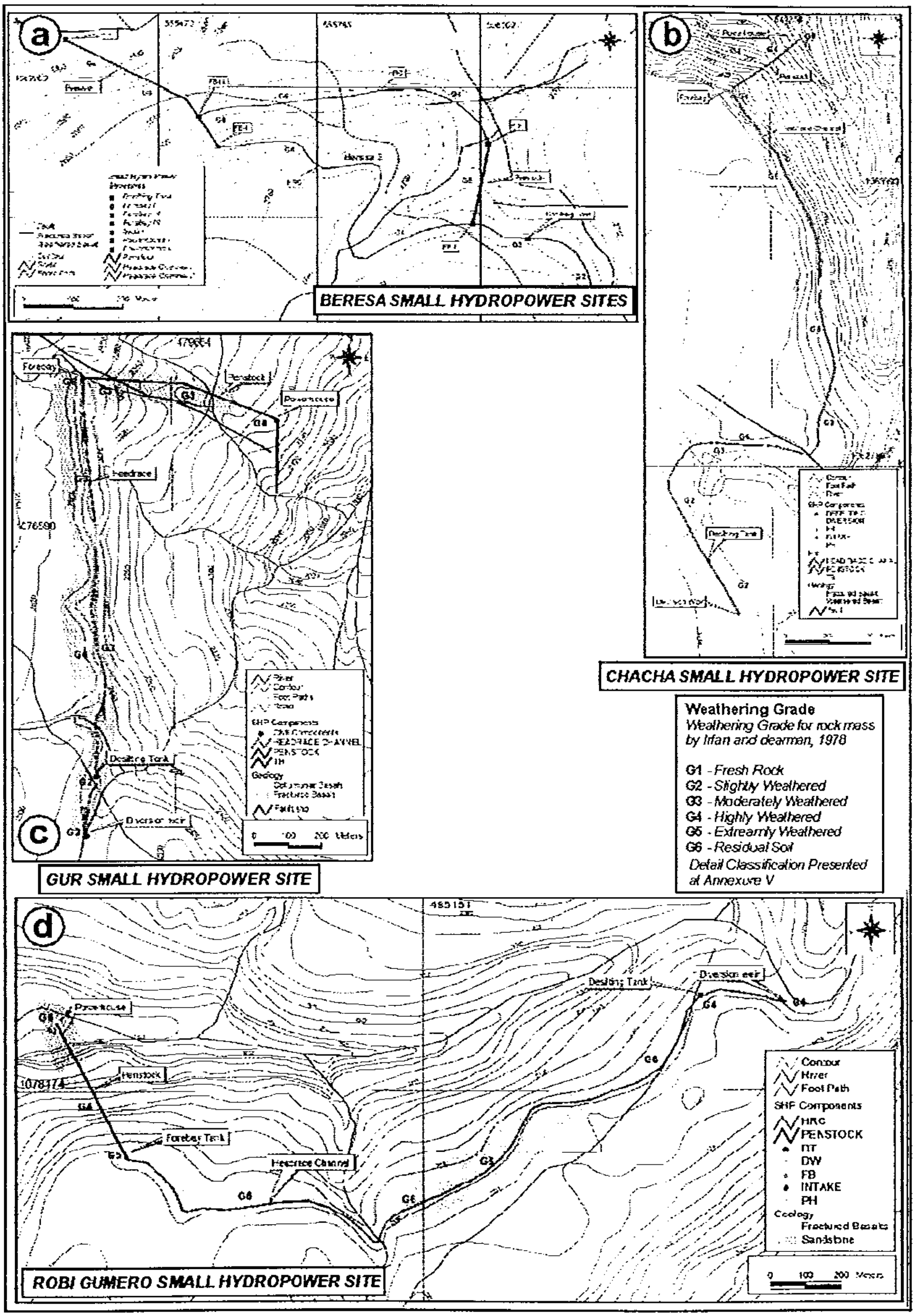

Fig. 5.4 Weathering map for Ground Varified SHP sites

At the diversion weir site the weathering of rocks show that less than 35% of the rock material is decomposed and disintegrated to make soil. The weathering degree of rocks along the water conductor is similar to that of diversion weir with slight variation. Rocks at powerhouse are highly weathered.

5.3.2.2 Characterization of Rock Mass

The properties of the intact rock are governed by the physical properties of the materials of which it is composed and the manner in which they are bonded to each other. The parameters which may be used in a description of intact rock therefore, include petrological name, mineral composition, color, texture, minor lithological characteristics, degree of weathering or alteration, density, strength, hardness, intrinsic or primary permeability, seismic velocity and modulus of elasticity (Bell, 1992).

For the present study, Rock Mass Rating System, known as Geomechanics Classification of Bieniawiski, (1989) has been employed to describe the quality, shear strength properties and the deformability of the rock mass at various SHP sites.

Bieniawski (1976) has developed a rock mass classification system knows as Geomechanics classification or Rock Mass Rating (RMR) System. Since the development of RMR system Bieniawski has made several changes, the 1989 version is followed for use and is discussed hereunder. According to RMR system following six parameters is used to determine the RMR, these are;

1. Uniaxial compressive strength of rock
2. Rock Quality Designation (RQD)
3. Spacing of discontinuities
4. Condition of discontinuities
5. Ground water condition
6. Orientation of discontinuities

The ratings for each of the 6 parameters are obtained from the standard RMR table and are added to get the RMR value. For the present study, the uniaxial compressive strength of the rock has been determined by Schmidth hammer, using the empirical relation given by Barton and Choubey, 1977;

$$\text{Log}_{10}(\sigma_c) = 0.00088\gamma R + 1.01 \quad \text{........ 5.1}$$

Where; σ_c = uniaxial compressive strength in MPa

γ = dry rock density in KN/m^3

R = rebound number of Schmidt hammer

The Rock Quality Designation (RQD) has been determined by Palmstorm's volumetric count method (Palmstorm, 1982), according to which,

$$RQD = 115 - 3.3\ Jv \quad \text{........ 5.2}$$

Where; RQD = Rock Quality Designation (%)

Jv = Total Number of discontinuities, greater than 10cm in length, in 1m cube of Rock mass

For Spacing, Condition of discontinuities, Ground water condition, and Orientation of discontinuities visual observations and measurements were made and accordingly the ratings were assigned from the standard RMR table. The RMR data collected from various locations at different SHP sites is summarized in Table 5.7. Figure 5.8 presents the RMR data collection locations at different SHP sites.

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 behavior 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 5.8.

Modulus of Deformation 'Ed' of the Rock Mass

Deformability means the capacity of rock to strain under applied loads or in response to unloads. Though in case of small hydropower schemes the magnitude of loads is very less because of the size of the structures, therefore the rocks are not subjected to deformations. However, an attempt is being made to empirically work out the modulus of deformation by using RMR.

For the present study, three empirical relations were used to workout Modulus of Deformation;

Serafim and Pereira Relation (1983)	$Ed = 10^{(RMR-10)/40}$	.... 5.3
Bieniawiski's relation (1978)	$Ed = 2RMR - 100$	.... 5.4
Agarwal et al (1991)	$Ed = 10^{(RMR-30)/50}$	.... 5.5

Table 5.7 Summarized RMR data, collected from various locations at different SHP site

S. No	*RMR Data Location*	*Parameters Ratings*										*RMR*	*Rock Mass Class*
		UCS			*RQD*			*Spa*	*Con*	*GWC*	*Ori*		
		SHV	*UCS*	*Ra*	*Jv*	*RQD*	*Ra*						
Beresa Small Hydropower Site													
1	B1	46.5	131.2	12	6	95.2	20	8	27	7	-5	69	Good
2	B2	46.5	131.2	12	8	88.6	17	8	27	7	-5	68	Good
3	B3	49	150.6	20	7	91.9	20	8	27	7	-5	76	Good
4	B4	46.5	150.6	12	6	95.2	20	8	27	7	-5	71	Good
5	B5	46.5	150.6	12	10	82	17	8	27	7	-5	68	Good
Chacha Small Hydropower Site													
1	C1	23.5	37.2	4	10	82	17	8	27	7	-5	58	Fair
2	C2	26.5	43.8	4	12	75.4	17	3	27	10	-5	56	Fair
3	C3	26.67	44.3	4	9	85.3	17	5	27	10	-5	58	Fair
Gur Small Hydropower Site													
1	G1	22.8	35.79	4	9	85.3	17	3	27	13	-5	59	Fair
2	G2	38	82.46	12	8	88.6	17	7	27	15	-3	70	Good
UCS – Uniaxial Compressive Strength (MPa), SHV – Schmidt Hammer Rebound No., Ra – Rating Jv – Volumetric count of discontinuities in 1 m cube, RQD - Rock Quality Designation (%) Spa. – Spacing of Discontinuity, Con - Condition of Discontinuities, GWC – Ground Water Condition, Ori - Orientation of Discontinuities, RMR – Rock Mass Rating													

The value of Modulus of deformation as obtained by Agarwal et al relation are close to the actual field tested Ed (Agarwal et al., 1991), thus these values may be adopted as the design values. The Modulus of Deformation of rock mass from RMR is summarized in Table 5.8.

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.

$$\sigma_1' = \sigma_3' + \sigma_c \left(m_i \frac{\sigma_3}{\sigma_c} + S \right)^a \qquad \text{............ 5.6}$$

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.

To determine the material constants m_b, 'S' and 'a' used in equation 5.6, Hoek and Brown used RMR (Rock Mass Rating) of Bieniawiski (1989).

Table 5.8 Summarized Shear strength Parameters and Modulus of Deformation Ed as determined from RMR

S.No	*RMR Data Location*	*RMR*	*Shear strength Parameters*				*Modulus of Deformation 'Ed' (GPa)*			
			C (Range)	*Φ (Range)*	*C**	*Φ**	*Serafim and Pereira Relation*	*Bieniawiski's Relation*	*Agarwal et al Relation*	*Design Value for Ed*
Beresa Small Hydropower Site										
1	*B1*	*69*	*300-400*	*35-45*	3.45	*39.5*	*29.85*	*38*	*6.03*	*6.03*
2	*B2*	*68*	*300-400*	*35-45*	*3.4*	*39.0*	*28.18*	*36*	*5.75*	*5.75*
3	*B3*	*76*	*300-400*	*35-45*	*3.8*	*43.0*	*44.67*	*52*	*8.32*	*8.32*
4	*B4*	*71*	*300-400*	*35-45*	*3.55*	*40.5*	*33.50*	*42*	*6.61*	*6.61*
5	*B5*	*68*	*300-400*	*35-45*	*3.4*	*39.0*	*28.18*	*36*	*5.75*	*5.75*
Chacha Small Hydropower Site										
1	*C1*	*58*	*300-400*	*35-45*	*2.9*	*34.0*	*15.85*	*16*	*3.63*	*3.63*
2	*C2*	*56*	*300-400*	*35-45*	*2.8*	*33.0*	*14.13*	*12*	*3.31*	*3.31*
3	*C3*	*58*	*300-400*	*35-45*	*2.9*	*34.0*	*15.85*	*16*	*3.36*	*3.63*
Gur Small Hydropower Site										
1	*G1*	*70*	*300-400*	*35-45*	*3.5*	*40.0*	*31.62*	*40*	*6.31*	*6.31*
2	*G2*	*59*	*300-400*	*35-45*	*2.95*	*34.5*	*16.79*	*18*	*3.80*	*3.80*

C is the specific value of Cohesion for a given RMR value it is determined by a relation given by Bieniawiski, 1976 C = 0.05 RMR*
Φ is the specific value of angle of friction for a given RMR value it is determined by a relation given by Bieniawiski, 1976 Φ = 0.5RMR + 5*

Using RMR, Hoek & Brown developed a new Geologic Strength Index (GSI).

For RMR89 > 23, $GSI = RMR_{89} - 5$

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

$$\frac{m_b}{m_i} = \exp\left(\frac{GSI-100}{28}\right) \qquad \text{......... 5.7}$$

Where, m_i may directly be obtained from standard table.

$$S = \exp\left(\frac{GSI-100}{9}\right) \qquad \text{......... 5.8}$$

A = 0.5
For GSI < 25
S = 0

$$a = 0.65 - \frac{GSI}{200} \qquad \text{........ 5.9}$$

Thus, the shear strength parameters as determined for different rock mass at various locations are summarized in Table 5.9.

Table 5.9 Shear Strength of Rock mass as determined from Hoek and Brown Failure Criteria

RMR Data location	*GSI*	*Material Constants*			*UCS*	*Confining Stress*	*Axial Stress*	*Rock type*	*Shear Strength*	
		mb	*s*	*a*	σ_c (MPa)	σ_3 (MPa)	σ_1 (MPa)		*C*	*Φ*
Beresa Small Hydropower Site										
B1	*64*	*2.75*	*0.018*	*0.5*	*131.22*	*1*	*26.90*	*Good*	*4.8*	*41.5*
						5	*50.98*			
						9.5	*70.64*			
B2	*63*	*2.67*	*0.016*	*0.5*	*131.22*	*1*	*26.02*	*Good*	*5.0*	*41.0*
						5	*50.03*			
						9.5	*69.53*			
B3	*71*	*3.55*	*0.04*	*0.5*	*150.6*	*1*	*38.97*	*Good*	*6.5*	*49.5*
						5	*64.84*			
						9.5	*86.87*			
B4	*66*	*2.97*	*0.023*	*0.5*	*150.6*	*1*	*32.13*	*Good*	*6.1*	*43.6*
						5	*57.52*			
						9.5	*78.57*			
B5	*63*	*2.67*	*0.016*	*0.5*	*150.6*	*1*	*28.66*	*Good*	*3.0*	*46.5*
						5	*53.72*			
						9.5	*74.17*			
Chacha Small Hydropower Site										
C1	*53*	*1.87*	*0.0054*	*0.5*	*37.2*	*1*	*9.78*	*Fair*	*2.8*	*28.0*
						5	*23.85*			
						9.5	*35.35*			
C2	*51*	*1.74*	*0.0043*	*0.5*	*43.85*	*1*	*10.20*	*Fair*	*2.2*	*30.5*
						5	*24.74*			
						9.5	*36.58*			
C3	*53*	*1.87*	*0.0054*	*0.5*	*44.25*	*1*	*10.66*	*Fair*	*2.1*	*30.2*
						5	*25.60*			
						9.5	*37.73*			
Gur Small Hydropower Site										
G1	*65*	*2.865*	*0.02*	*0.5*	*82.46*	*1*	*20.29*	***Good***	***3.1***	*40.5*
						5	*41.29*			
						9.5	*58.29*			
G2	*54*	*1.93*	*0.006*	*0.5*	*35.79*	*1*	*9.76*	***Fair***	***2.2***	*31.0*
						5	*23.79*			
						9.5	*35.27*			

mb is the value of the constant m for the rock mass.

S and *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.

C is the cohesion of the Rock mass

Φ is the angle of Friction of the Rock mass.

5.3.2.3 Characterization of Soils

Different professions give different outlooks for the term soil. To the present conception, engineering soil is roughly equivalent to regolith, to describe all unconsolidated material mantling the surface of the earth, by geologists. Regolith may include saprolite, in-place of rock that is chemically altered and coherent and that retains its original texture (Johnson and DeGraff, 1988).

Soil description

Soil particles found in nature are infinitely variable. However, soils exhibiting similar behavior can be grouped together to form a particular class in engineering uses; as per tests used to characterize the particle properties. The term index properties of soils are used for the numerical results obtained from the tests. Soil grain properties of soils are: soil grain properties and soil aggregate properties. Soil grain properties are those properties, which are dependent on individual grains and manner of soil formation. The properties in this group are mineral composition, specific gravity, and grain size. Soil aggregate properties are those properties, which are dependent on soil mass as a whole. These properties are of greater significance in engineering construction, since engineering structures are found on undisturbed, natural soil particles. The index properties are grain size distribution and Atterberg limits.

Engineering geological soil mass description contains details of the 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, state of weathering
iii. Soil mass properties: structure, discontinuities

In the study area, the engineering geological soil units are grouped under their genetic types; residual soil and colluvial deposit.

For the present study, soil samples were collected from different locations along the water conductor of different SHP schemes and were analyzed in the laboratory for the grain size distribution and there index properties viz; liquid limit, plastic limit, plastic index. The results thus obtained are summarized in Table 5.10. Figure 5.8 shows the soil sampling locations at different SHP sites. In the case of Robi Gumero site, soil sample is not taken for analysis because of its inaccessibility.

<u>Residual soil</u>

In the study areas, it has been identified that there are different types of residual soil. They show different nature according to the parent material, particularly those which developed on fractured and weathered basalt. The most abundant soil within this genetic group is clay with gravel, gravelly silt, sandy clay, fat clay, and clay with sand.

Clay with gravel: This soil is found at Gur SHP potential study area. The grading characteristics of the particles size show that: clay fraction (<0.002mm) 45%, silt sized (0.002 – 0.074mm) particles 27%, sand sized (0.074 – 2.00mm) particles are 4% and gravel sized (>2mm) are 24%. The liquid limit is 45.1 %, which is of high plasticity group (26.15%). The residual soil is yellowish in colour.

Gravelly silt: This soil type is found at Gur SHP potential study area. The grading characteristics of the particles size show that: clay fraction (<0.002mm) 17%, silt sized (0.002 – 0.074mm) particles 36%, sand sized (0.074 – 2.00mm) particles are 19% and gravel sized (>2mm) are 27%. The liquid limit is 51 %, which is of moderate plasticity group (13.45%).

Sandy clay: This soil type is found at Beresa SHP potential study area. The grading characteristics of the particles size show that: clay fraction (<0.002mm) 11%, silt sized (0.002 – 0.074mm) particles 40%, sand sized (0.074 – 2.00mm) particles are 32% and gravel sized (>2mm) are 17%. The liquid limit is 32.4 %, which is of moderate plasticity group (12.2%).

Fat clay: This soil type is found at Chacha SHP potential study area. The grading characteristics of the particles size show that: clay fraction (<0.002mm) 53%, silt sized (0.002 – 0.074mm) particles 38%, sand sized (0.074 – 2.00mm) particles are 19% and gravel sized (>2mm) are 4%. The liquid limit is 68.7 %, which is of extreme plasticity group (36.83%).

Clay with sand: This soil type is found at Chacha SHP potential study area. The grading characteristics of the particles size show that: clay fraction (<0.002mm) 30%, silt sized (0.002 – 0.074mm) particles 50%, sand sized (0.074 – 2.00mm) particles are 16% and gravel sized (>2mm) are 4%. The liquid limit is 44.9 %, which is of moderate plasticity group (24.75%).

Colluvail deposit

These soil deposits are which have been eroded and deposited under gravity forces, often with the aid of water. These deposits include;

i) Soils which are admixture of clay, sand and gravel that, have been moved down slope by combined action of soil creep and erosion by water (slope wash soils)

ii) Soils with admixture of almost all types of material from clay to large rock fragments that is large boulders embedded in a clay matrix (land slide debris).

The sample, which was colleted for colluvial deposit, shows silty sand.

Silty clay: This soil type is found at Beresa SHP potential study area. The grading characteristics of the particles size show that: clay fraction (<0.002mm) 6%, silt sized (0.002 – 0.074mm) particles 40%, sand sized (0.074 – 2.00mm) particles are 45% and gravel sized (>2mm) are 9%. The liquid limit is 41 %, which is of moderate plasticity group (9.02%). The grain shows angular and irregular form, with rough surface characteristics.

Table 5.10 Grain Size Analysis and Index Properties, as determined from various soil samples collected from different sites in the study area

Sample	*Site Name*	*Depth*	*Origin*	*Color*	*Soil Type*	*Sieve Analysis*				*Index Value*			*USCS*
						*G**	*S**	*M**	*CF**	*LL**	*PL**	*PI**	
1.	Beresa (1)	53	Colluvial	•Brown	Silty Sand	9	45	40	6	41.0	31.98	9.02	SM
2.	Beresa (2)	68	Residual	•Gray	Sandy Clay	17	32	40	11	32.4	20.2	12.2	CL
3.	Chacha (1)	47	Residual	•Brown	Fat Clay	4	5	38	53	68.7	31.87	36.83	CH
4.	Chacha (2)	78	Residual	•Brown	Clay with Gravel	24	4	27	45	45.1	18.98	26.15	CL
5.	Gur (1)	69	Residual	•Yellow	Gravely Silt	28	19	36	17	51	37.55	13.45	MH
6.	Gur (2)	55	Residual	Brown	Clay with Sand	4	16	50	30	44.9	20.15	24.75	CL

CF – Clay fraction (<0.002mm), M – silt sized (0.002 – 0.074mm), S- sand sized (0.074-2.0mm), G – gravel sized (>2.0mm), LL – liquid limit, PL – plastic limit. PI – plastic index, •brown – olivine brown, •yellow – pale yellow, •gray – light brownish gray, #brown – dark olivine brown.

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. Although several classification systems are in use, none is totally definitive of any soil for all possible applications because of the wide diversity of soil properties.

If the thickness of the area is exceeding 1m, it is mapped as soil (Scoters and Rangers, 1981), if it is less, it is mapped as rock. Among the several soil classification system, the unified soil classification system (USCS) is applied in this work. According to this classification the soil of the studied area has been classified as CH, CL, MH, and SM. Figure 5.5 presents the Plasticity Chart of soils of the study area based on USCS Classification system.

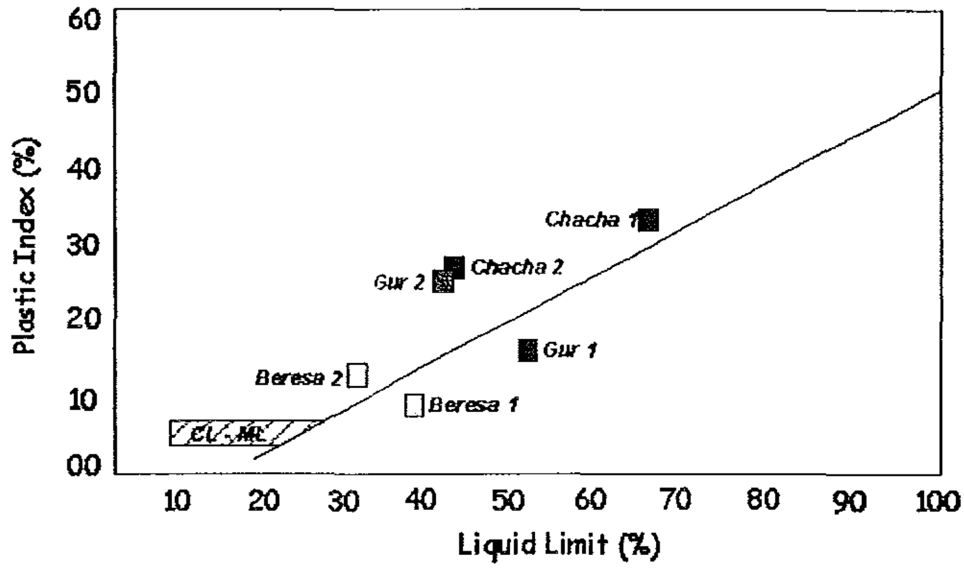

Fig. 5.5 Plasticity Chart of soils of the study area based on USCS

5.3.3 Slope Stability Studies

Stability of slope is influenced by various factors like, geometry of the slope (slope height, slope angle and upper slope angle), shear strength parameters (cohesion and angle of 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.

For small hydropower schemes the behavior of slopes for their stability becomes more important as most of the water conductor system rests on these slopes. If the slopes are not stable the various structures of the water conductor system may fail and the entire scheme may become non functional. Therefore, it is important to study the stability conditions of slopes on which the water conductor is proposed.

For the present study, the potential unstable slopes were identified, by identifying various traces for instability, like

i) Toe erosion by the stream
ii) If the preferred orientation of discontinuity planes is dipping towards the valley.
iii) Tension cracks or gully formation in the upper slope, particularly in the soil slopes.
iv) If the rock mass is highly fractured and weathered.
v) Local small scale failures within or near to the slope in question.

Beresa Small hydropower Site

At Beresa Small Hydropower site (Alternative I) the slopes in general, are stable as no traces of instability has been noticed. Both the slopes at diversion weir site area stable, on both the banks competent basalts are exposed. The rock is traversed by three major discontinuity planes which are oriented in such a way that none of them is dipping towards the valley (Plate 5.5). The intake channel, forebay and penstock alignment will be resting on the stable slope. However, few isolated pockets of instability were noticed just downstream of desilting tank. Since, these unstable pockets are of local nature they would not affect any component of the scheme. A potentially unstable slope has been noticed just upstream of the forebay (FB-2). This is a soil slope (SB-1), tension cracks and scarp face was observed near to the upper slope. Gully formation was also observed in this slope section. Since water conductor will be crossing over this slope section, it is necessary to study this slope for its stability.

Stability Studies of SB-1 Slope Section

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 VI. The slope is potentially unstable for circular mode of failure. The slope section is shown in Figure 5.6. Table 5.11 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 water saturation condition. The calculated results are presented in table 5.12.

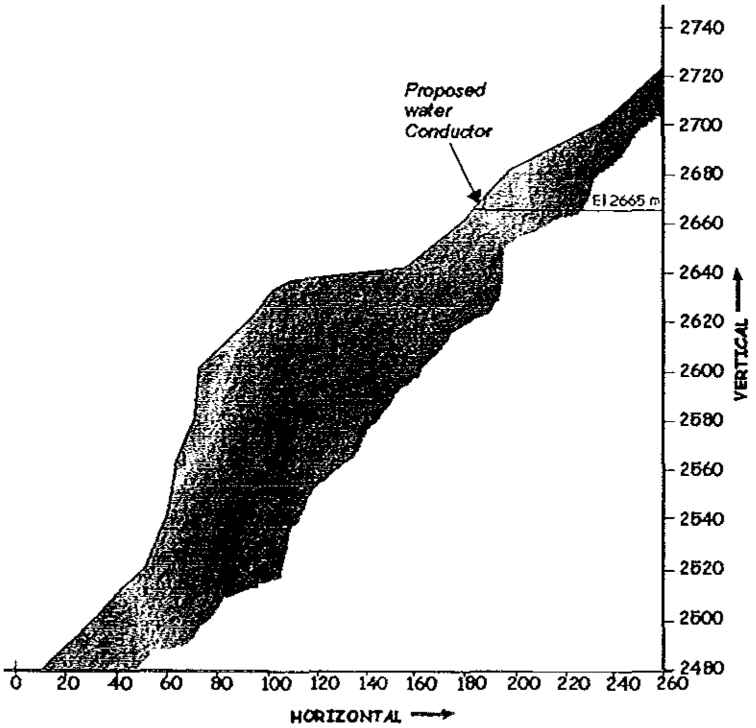

Fig. 5.6 **Slope Cross section for SB-1 Slope**

Table 5.11 **The input parameters used and the calculated factor of safety for static and dynamic conditions**

Input parameters		
Parameter	***Value***	***Where***
N =	*24*	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 =	*7.241*	C = Cohesion of soil/rock
PHI =	*25.1*	PHI = Angle of internal friction (Degree) of soil/rock
GAMA =	*1.706*	GAMA = Unit weight of soil/rock
GAMAW =	*1.0*	GAMAW = Unit weight of pore water
BBAR =		BBAR = Pore water pressure/(GAMA * Average height of
AH =	*0.2*	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) =		EQM = Corresponding EQ. magnitude on Richter Scale
(0.0,2200)		NENP = Number of entry points of slip circles (<10)
NEP = 0.0		ENTX = X-Coordinate of entry point of circle
NOPT = 0.0		ENTY = Y-Coordinate of entry point of circle
XEXITI =	*140*	NOPT = 0 ,When only minimum factor of safety is required
XEXITL =	*290*	= 1,When all F.S. corresponding to all exit points are also
GAP =	*150*	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 5.12 Results of Stability Analysis for SB-1

	FOS	*Weight*	*Coordinate Of Center*	*Exit Point*	*Radius (m)*
Static Dry	0.75	0.49 x 10^4	-114.86,2672.11	112,2640	229.12
Static Mod. Sat.	0.60	0.49 x 10^4	-114.86,2672.11	112,2640	229.12
Static Fully Sat.	0.47	0.44 x 10^4	-136.96,2686.20	112,2640	253.21
Dynamic Dry	0.55	0.44 x 10^4	-136.96,2685.99	112,2640	252.84
Dynamic Mod. Sat.	0.43	0.40 x 10^4	-158.36,2699.86	112,2640	276.93
Dynamic Fully Sat.	0.30	0.39 x 10^4	-164.69,2703.88	112,2640	283.97
FOS=Factor of Safety,					

Perusal of table 5.12 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 damage to the water conductor. 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 level where the water conductor will be passing (El 2665m) on this slope. These remedial measures may be in the form of terracing and providing retaining wall. Further, it is suggested to provide a steel pipe instead of concrete channel in this section. In future after the execution of the project if there is any possible movement the pipe may move which, may be later reinstalled.

Gur Small hydropower Site

At Gur Small Hydropower site the slopes in general are stable as no traces of instability has been noticed. Both the slopes at diversion weir site area stable, on both the banks competent basalts are exposed. The rock is traversed by two major discontinuity planes which are oriented in such a way that none of them is dipping towards the valley. The intake channel, forebay and desilting tank will be resting on the stable slope. A potentially unstable slope has been noticed along the penstock alignment from the forebay (FB) to powerhouse (PH). This is a soil slope (SG-1), tension cracks and scarp face were observed near the upper slope. Gully formation was also observed in this slope section. Since water conductor will be crossing over this slope section, it is necessary to study this slope for its stability.

Stability Studies of SG-1 Slope Section

The stability analysis of this slope section has been carried out by using SARC computer program. The slope is potentially unstable for circular mode of failure. The slope section is shown in Figure 5.7. Table 5.13 presents the input parameters used and the calculated factor of safety for static and dynamic conditions is presented at table 5.14. The analysis has been carried out for varied water saturation conditions.

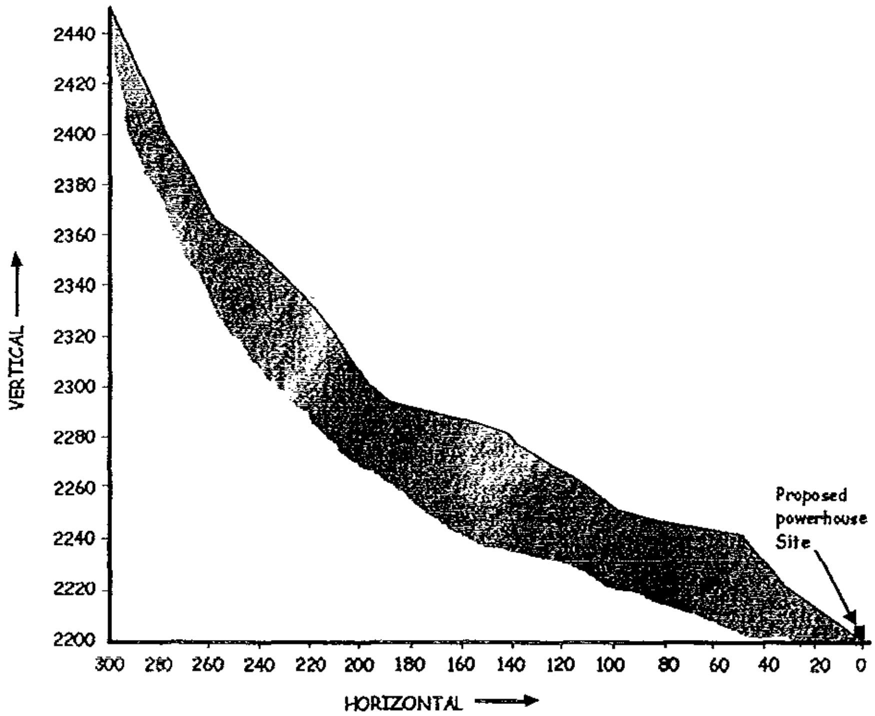

Fig. 5.7 Slope Cross section for SG-1 Slope

Chacha Small hydropower Site

At Chacha Small Hydropower site the slope in general are stable except one site. Both the slopes at diversion weir area are stable, on both banks gentle soil slopes are exposed. The soil is residual type in nature and the laboratory result show that the soil around the left and right bank of the diversion weir is fat clay (CH). The intake channel, forebay and desilting tank will be resting on the stable slope. A potentially unstable slope has been noticed along the headrace channel, just after the proposed desilting tank. This is a fractured rock slope (SC-1), debris, rock fragments and slide materials were observed during the field visit. Because of the inaccessibility to the active slide, it was not possible to collect any quantitative data, so this slope section is explained qualitatively. The rock at the unstable slope section is dipping towards the valley and the strike direction of the river is parallel (East – West) to the direction of the dip. The presence of this active rock slide influence the diversion weir site and the route of the headrace proposed channel at the upstream direction.

Table 5.13 Presents the input parameters used and the calculated factor of safety for static and dynamic condition

Input parameters		
Parameter	*Value*	*Where*
N =	*24*	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 =	*7.241*	C = Cohesion of soil/rock
PHI =	*25.1*	PHI = Angle of internal friction (Degree) of soil/rock
GAMA =	*1.706*	GAMA = Unit weight of soil/rock
GAMAW =	*1.0*	GAMAW = Unit weight of pore water
BBAR =		BBAR = Pore water pressure/(GAMA * Average height of slices)
AH =	*0.2*	AH = Horizontal component of EQ. acceleration near crest of slope
AVR =	*1.0*	AVR = Vertical component of EQ. acceleration / AH
EQM =	*8*	EQM = Corresponding EQ. magnitude on Richter Scale
NENP = 1		NENP = Number of entry points of slip circles (<10)
ENTX (I), ENTY (I) =		ENTX = X-Coordinate of entry point of circle
(0.0,2200)		ENTY = Y-Coordinate of entry point of circle
NEP = 0.0		NOPT = 0 ,When only minimum factor of safety is required
NOPT = 0.0		= 1,When all F.S. corresponding to all exit points are also required
XEXITI =	*140*	NEP = Number of exit points(<50)
XEXITL =	*290*	= 0 , When no individual point is given)
GAP =	*150*	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 5.14 Results of Stability Analysis for SG-1

	FOS	*Weight*	*Coordinate Of Center*	*Exit Point*	*Radius (m)*
Static Dry	1.26	$0.19*10^5$	(28.64,2464.45)	(290,2415)	265.99
Static Mod. Sat.	0.634	$0.23*10^5$	(44.62,2442.89)	(290,2415)	246.96
Static Fully Sat.	0.1191	$0.19*10^5$	(28.64,2464.45)	(290,2415)	265.99
Dynamic Dry	0.87	$0.19*10^5$	(28.07,2465.22)	(290,2415)	266.70
Dynamic Mod. Sat.	0.4	$0.21*10^5$	(37.37,2452.67)	(290,2415)	255.42
Dynamic Fully Sat.	0.05	$0.14*10^5$	(-0.21,2503.36)	(290,2415)	303.36
FOS=Factor of Safety,					

Perusal of table 5.14 indicates that the factor of safety for this slope under all conditions is less than unity accept for static dry condition. Thus, it indicates that the slope is unstable and may pose problems of instability and may damage the penstock. 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. However, the anchor blocks for the penstock may be founded deep. Besides, the local remedial measures particularly along the penstock alignment in the form of terracing and providing retaining walls will help in stabilizing the slope section.

5.3.4 Engineering Geological Mapping of the Sites

As it is described earlier, engineering geological maps or geotechnical maps are types of "geological maps" that provide a generalized representation of all components of geological environments. In the present study, engineering geological maps were prepared by characterizing the soil and rock mass exposed along the water conductor. The rock mass has been characterized based on the rock mass quality derived from the Rock mass classification (RMR) and the degree of weathering grade using Irfan and Dearman classification (1978) of weathering grade.

Thus, the rock mass exposed at the SHP sites has been classified into the following classes;

i) Good quality (RMR .> 60) and slightly weathered (G2)

ii) Fair quality (RMR.40) and moderately weathered (G3)

However, the soils have been classified on the basis of there relative susceptibility for instability. For this the colluvial soils are considered most susceptible for instability. Colluvial soils are the mixture of soils with rock fragments of varied shape and size. The loose unconsolidated colluvial soils show comparatively high permeability because of the voids formed by the angular rock fragments. The colluvial soils when oversaturated are subjected to swelling and this results into volume change of the soil mass. Thus the rock fragments embedded in a matric of clay tend to readjust for a more stable configuration which, results into sliding. The same process is repeated when the colluvial soils dry, in such condition there would be shrinkage in volume of the soil mass. Thus, the net effect of these processes result into the instability of the soil mass. The other soil mass present at the SHP sites are the residual soils. These soils are comparatively more consolidated therefore, these soils may be classify as soils with less susceptibility for instability.

Thus, the soil mass present at the SHP sites has been classified into the following classes;

i) Colluvial soils (SM) – Loose unconsolidated most susceptible for instability

ii) Residual soils (CL,CH,MH) – Relatively consolidated less susceptible for instability

Thus, the engineering geological maps prepared for SHP sites is presented in Figure 5.8.

Finally, based on the Engineering geological appraisal and the general pre feasibility study it may be concluded that out of four ground verified SHP sites Chacha and Beresa Small hydropower sites are feasible sites with minimum engineering geological problems. However, the other two site Gur and Robi Gemero are not feasible sites. The power potential at Gur SHP site is very less and secondly along the penstock alignment the slope is potentially unstable which may pose problems in safe running of the scheme. For Robi Gemero at present the accessibility to various components of SHP is difficult. Thus, in case if these two sites have to be taken up for development they must be considered on least priority.

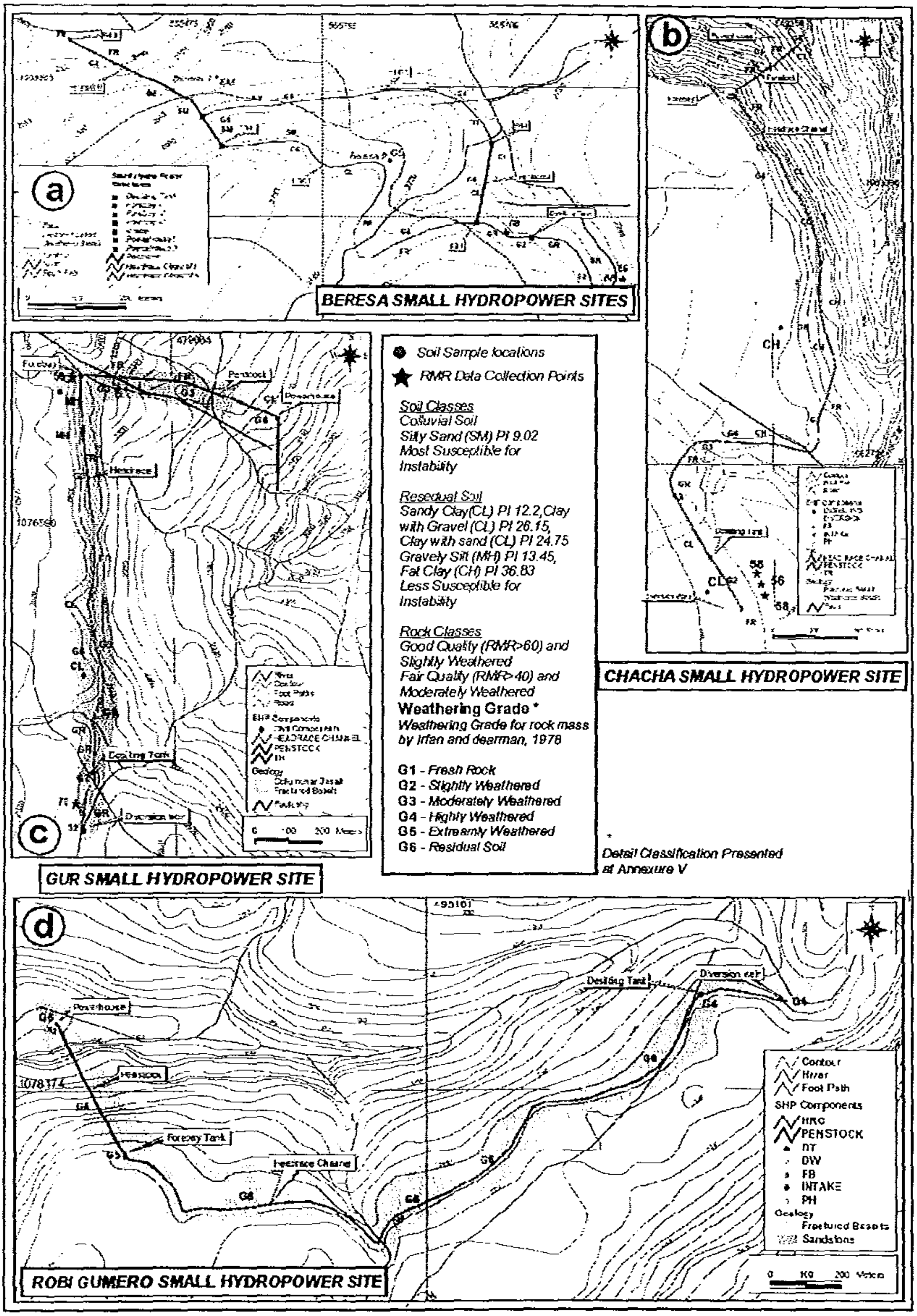

Fig. 5.8 **Simplified Engineering geological map for Ground Varified SHP sites**

CHAPTER SIX

DESIGN CALCULATIONS FOR SMALL HYDRO POWER (SHP) SITES

6.1 Introduction

The hydraulic features of a small hydroelectric development are as numerous as those of any large one. However, the loss of energy due to poorly designed flow passages may be relatively more important in a small hydro development. Design philosophy for small hydro facilities is not different from that in any other engineering design situation: An adequate design can be formulated provided all possible failure modes can be anticipated. In developing this section on hydraulic design and analysis, that philosophy has been followed in selecting the specific items to be covered.

In general it may be said that safe and effective functioning of any small hydro power project is ensured only through proper and accurate design of various components. The design discharge is the basic parameter required for the design of all civil structures involved in the SHP scheme. A proper judgment, supported with actual monitoring of flow regime, will ensure an accurate estimation of dependable flow for any SHP scheme.

6.2 Estimation of Discharge for Power Generation

In the present study, the daily observed discharge has been utilized to work out the dependable flows for Beresa and Chacha Small hydropower Schemes. However, for Robi Gumero and Gur Small hydropower schemes the dependable discharge has been worked out by projecting the actual discharge data of adjacent Robi Jida stream, which have similar catchment characteristics. Thus, from the flow duration data, design discharges for respective SHP schemes have been worked out. Estimation of dependable discharge and flow duration is already discussed in detail at Para 4.6 of Chapter IV.

6.3 Gross hydraulic Head and Net Head

The power potential is directly proportional to the discharge and the available Head. The term 'Head' is the altitude difference between the forebay and the powerhouse site. In other words head is the vertical height from where the water is dropped on the turbine to generate hydropower (Fig 4.3). Practically, the total available head is not actually available for the power generation as some of the hydraulic losses occur due to friction in pipe and bends. Therefore, actual head available after head losses is known as 'Net Head' and the head available before the head losses is known as 'Gross head'. In the present study, for potential assessment Gross head has been determined from the topo-sheet on 1:50,000 and later was ground verified in the field by making actual measurements with altimeter and GPS.

6.3.1 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. These loses have been calculated by adopting the following equations (Fritz, 1984);

Friction losses

$$h_f = fLV^2/2gD \quad \text{........ 6.1}$$

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

$$h_e = K_e V^2/2g \quad \text{........ 6.2}$$

Where;

- h_e = entrance loss
- K_e = 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

$$h_t = K_t V^2/2g \quad \text{........ 6.3}$$

Where;

- h_t = Trash Rack Loss
- K_t = 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

$$h_e = K_E V^2/2g \quad \text{........ 6.4}$$

Where;

- h_e = 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

$$h_B = \eta K_b V^2/2g \quad \text{........ 6.5}$$

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)

$h_{vg} = K_v V^2/2g$ 6.6

Where h_{vg} = Gate Valve losses
K_v = gate valve loss coefficient for half open position 4.3
V = Velocity of water in penstock and is equal to 2.5m/s

Valve losses (Butterfly Valve)

$h_{vb} = K_v V^2/2g$ 6.7

Where h_{vb} = butterfly Valve losses
K_v = butterfly valve loss coefficient when t/D ratio is 0.3 (Fritz, 1984)
V = Velocity of water in penstock and is equal to 2.5m/s

Therefore, total head loss is given by;

Total Head Losses = Σ (*Eq. 6.1 to Eq. 6.7*) 6.8

Net Head = Gross head – Head Losses 6.9

Thus, the total Net head available for the power generation is presented in Table 6.1, however the detailed calculations for head losses is given at Annexure VI.

Table 6.1 Net Head used for the calculations of Power potential

Name of the Scheme		*Gross Head (m)*	*Head Losses (m)*	*Net Head (m)*
Beresa SHP Scheme Alternative I	PH-I	50	4.6	45.6
	PH-II	205	12.3	192.7
Beresa SHP Scheme Alternative II	PH-III	255	14.8	235.2
Gur SHP Scheme		250	70.9	179.1
Chacha SHP Scheme		405	20.8	384.2
Robi Gumero SHP Scheme		345	34.2	310.8

6.4 Power Potential and Installed Capacity

The power potential for the SHP sites has been worked out by using Eq. 4.4 (chapter 4). For the computations of actual Net head, as determined in Para 6.3, 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 different SHP sites is presented in table 6.2 (a),(b),(c),(d),(e)&(f). 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.

6.5 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 6.3.

6.6 Design Calculation for Various Structures

Safe and effective functioning of any small hydro power project is ensured only through proper and accurate design of various components. The design discharge is the basic parameter required for the design of all civil structures involved in the SHP scheme. A proper judgment, supported with actual monitoring of flow regime, will ensure an accurate estimation of dependable flow for any SHP scheme.

6.6.1 Design Discharge

The design discharge for power generation of different SHP schemes is presented at table 6.3. This is the final discharge required at turbine level. Since, there will be water losses in the water conductor due to seepage, evaporation or human encroachments therefore, some additional discharge is taken at each components so as to compensate these losses. If 'X' is the design discharge required at the turbine level, increment in discharge at various levels will be (AHEC, 2003);

Penstock, Forebay, spillway	=	X		
Headrace pipe	=	A	=	(X + 0.05X) (5% extra for leakage)
Desilting tank	=	B	=	A + 0.15A (15% extra for leakage and silt flushing)
Diversion weir and intake	=	C	=	B + 0.10B (10% extra for intake losses)

Table 6.2 (a) Power potential and Installed capacity for Beresa Small Hydropower Scheme (Alternate I) PH-I

% of time equaled or exceeded	*Discharge (Cumecs)*	*Discharge * for power Generation (Cumecs)*	*Power (kW)*		
			Potential	*Power Available*	*Power Available*
2.78	39.83	35.85	14192	100	2x50
5.56	25.32	22.79	9023	100	2x50
8.33	18.55	16.69	6609	100	2x50
11.11	13.51	12.16	4814	100	2x50
13.89	10.40	9.36	3707	100	2x50
16.67	5.74	5.17	2046	100	2x50
19.44	3.90	3.51	1391	100	2x50
22.22	2.39	2.15	851	100	2x50
25.00	1.44	1.30	513	100	2x50
27.78	0.94	0.85	335	100	2x50
30.56	0.78	0.70	278	100	2x50
33.33	0.66	0.60	237	100	2x50
36.11	0.59	0.53	211	100	2x50
38.89	0.51	0.46	182	100	2x50
41.67	0.43	0.39	155	100	2x50
44.44	0.40	0.36	141	100	2x50
47.22	0.35	0.32	126	100	2x50
50.00	0.34	0.31	123	100	2x50
52.78	0.33	0.29	117	100	2x50
55.56	0.30	0.27	107	100	2x50
58.33	0.29	0.26	103	100	2x50
61.11	**0.27**	**0.25**	**98**	**100**	**2x50**
63.89	0.24	0.22	86	86	2x50
66.67	0.23	0.20	81	81	2x50
69.44	0.22	0.20	78	78	2x50
72.22	0.21	0.19	75	75	2x50
75.00	0.19	0.17	69	69	1x50
77.78	0.19	0.17	67	67	1x50
80.56	0.18	0.16	63	63	1x50
83.33	0.16	0.15	59	59	1x50
86.11	0.15	0.14	55	55	1x50
88.89	0.14	0.13	51	51	1x50
91.67	0.13	0.12	47	47	1x50
94.44	0.12	0.11	44	44	1x50
97.22	0.11	0.10	39	39	1x50
100	0.09	0.08	33	33	1x50

** 90% of Average Discharge available for Power Generation, 10% is left for environmental reasons.*

Table 6.2(b) Power potential and Installed capacity for Beresa Small Hydropower Scheme (Alternate I) PH-II

% of time equaled or exceeded	*Discharge (Cumecs)*	*Discharge * for power Generation (Cumecs)*	*Power (kW)*		
			Potential	*Power Available*	*Power Available*
2.78	39.83	35.85	60106	400	2x200
5.56	25.32	22.79	38214	400	2x200
8.33	18.55	16.69	27988	400	2x200
11.11	13.51	12.16	20388	400	2x200
13.89	10.40	9.36	15699	400	2x200
16.67	5.74	5.17	8667	400	2x200
19.44	3.90	3.51	5891	400	2x200
22.22	2.39	2.15	3604	400	2x200
25.00	1.44	1.30	2172	400	2x200
27.78	0.94	0.85	1419	400	2x200
30.56	0.78	0.70	1178	400	2x200
33.33	0.66	0.60	1003	400	2x200
36.11	0.59	0.53	892	400	2x200
38.89	0.51	0.46	771	400	2x200
41.67	0.43	0.39	656	400	2x200
44.44	0.40	0.36	597	400	2x200
47.22	0.35	0.32	535	400	2x200
50.00	0.34	0.31	520	400	2x200
52.78	0.33	0.29	494	400	2x200
55.56	0.30	0.27	451	400	2x200
58.33	0.29	0.26	437	400	2x200
61.11	**0.27**	**0.25**	**414**	**400**	**2x200**
63.89	0.24	0.22	362	362	2x200
66.67	0.23	0.20	341	341	2x200
69.44	0.22	0.20	330	330	2x200
72.22	0.21	0.19	318	318	2x200
75.00	0.19	0.17	293	293	2x200
77.78	0.19	0.17	283	283	2x200
80.56	0.18	0.16	265	265	1x200
83.33	0.16	0.15	249	249	1x200
86.11	0.15	0.14	232	232	1x200
88.89	0.14	0.13	217	217	1x200
91.67	0.13	0.12	199	199	1x200
94.44	0.12	0.11	186	186	1x200
97.22	0.11	0.10	164	164	1x200
100	0.09	0.08	140	140	1x200

* *90% of Average Discharge available for Power Generation, 10% is left for environmental reasons.*

Table 6.2(c) Power potential and Installed capacity for Beresa Small Hydropower Scheme (Alternate II) PH-III

% of time equaled or exceeded	*Discharge (Cumecs)*	*Discharge * for power Generation (Cumecs)*	*Power (kW)*		
			Potential	*Power Available*	*Power Available*
2.78	39.83	35.85	74899	500	2x250
5.56	25.32	22.79	47619	500	2x250
8.33	18.55	16.69	34877	500	2x250
11.11	13.51	12.16	25406	500	2x250
13.89	10.40	9.36	19562	500	2x250
16.67	5.74	5.17	10800	500	2x250
19.44	3.90	3.51	7341	500	2x250
22.22	2.39	2.15	4491	500	2x250
25.00	1.44	1.30	2707	500	2x250
27.78	0.94	0.85	1768	500	2x250
30.56	0.78	0.70	1467	500	2x250
33.33	0.66	0.60	1250	500	2x250
36.11	0.59	0.53	1112	500	2x250
38.89	0.51	0.46	961	500	2x250
41.67	0.43	0.39	817	500	2x250
44.44	0.40	0.36	744	500	2x250
47.22	0.35	0.32	667	500	2x250
50.00	0.34	0.31	648	500	2x250
52.78	0.33	0.29	616	500	2x250
55.56	0.30	0.27	562	500	2x250
58.33	0.29	0.26	544	500	2x250
61.11	**0.27**	**0.25**	**516**	**500**	**2x250**
63.89	0.24	0.22	451	451	2x250
66.67	0.23	0.20	425	425	2x250
69.44	0.22	0.20	411	411	2x250
72.22	0.21	0.19	396	396	2x250
75.00	0.19	0.17	365	365	2x250
77.78	0.19	0.17	352	352	1x250
80.56	0.18	0.16	330	330	1x250
83.33	0.16	0.15	310	310	1x250
86.11	0.15	0.14	289	289	1x250
88.89	0.14	0.13	271	271	1x250
91.67	0.13	0.12	249	249	1x250
94.44	0.12	0.11	232	232	1x250
97.22	0.11	0.10	204	204	1x250
100	0.09	0.08	175	175	1x250

* *90% of Average Discharge available for Power Generation, 10% is left for environmental reasons.*

Table 6.2(d) Power potential and Installed capacity for Chacha Small Hydropower Scheme

% of time equaled or exceeded	Discharge (Cumecs)	Discharge * for power Generation (Cumecs)	Power (kW)		
			Potential	Power Available	Power Available
2.78	74.66	67.20	248930	1000	2x500
5.56	47.62	42.85	158754	1000	2x500
8.33	39.27	35.34	130929	1000	2x500
11.11	26.88	24.19	89608	1000	2x500
13.89	18.32	16.49	61089	1000	2x500
16.67	10.08	9.07	33601	1000	2x500
19.44	6.72	6.05	22394	1000	2x500
22.22	4.10	3.69	13668	1000	2x500
25.00	2.18	1.96	7267	1000	2x500
27.78	1.73	1.56	5773	1000	2x500
30.56	1.25	1.13	4178	1000	2x500
33.33	1.02	0.92	3390	1000	2x500
36.11	0.73	0.65	2424	1000	2x500
38.89	0.62	0.56	2065	1000	2x500
41.67	0.56	0.51	1881	1000	2x500
44.44	0.50	0.45	1660	1000	2x500
47.22	0.45	0.41	1511	1000	2x500
50.00	0.42	0.38	1411	1000	2x500
52.78	0.36	0.33	1214	1000	2x500
55.56	0.35	0.32	1172	1000	2x500
58.33	0.31	0.28	1038	1000	2x500
61.11	**0.30**	**0.27**	**1007**	**1000**	**2x500**
63.89	0.28	0.25	921	921	2x500
66.67	0.27	0.24	885	885	2x500
69.44	0.26	0.23	852	852	2x500
72.22	0.24	0.22	801	801	2x500
75.00	0.23	0.20	752	752	2x500
77.78	0.22	0.20	724	724	2x500
80.56	0.21	0.19	704	704	2x500
83.33	0.19	0.18	650	650	1x500
86.11	0.16	0.14	536	536	1x500
88.89	0.15	0.13	484	484	1x500
91.67	0.14	0.13	473	473	1x500
94.44	0.13	0.12	430	430	1x500
97.22	0.12	0.11	407	407	1x500
100	0.12	0.11	393	393	1x500

** 90% of Average Discharge available for Power Generation, 10% is left for environmental reasons.*

Table 6.2(e) Power potential and Installed capacity for Gur Small Hydropower Scheme

% of time equaled or exceeded	*Discharge (Cumecs)*	*Discharge *for power Generation (Cumecs)*	*Power (kW)*		
			Potential	*Power Available*	*Power Available*
2.78	14.78	13.30	26492	100	2x50
5.56	11.82	10.63	21176	100	2x50
8.33	10.24	9.22	18357	100	2x50
11.11	8.60	7.74	15420	100	2x50
13.89	6.08	5.47	10892	100	2x50
16.67	3.82	3.43	6838	100	2x50
19.44	2.62	2.36	4699	100	2x50
22.22	1.36	1.22	2429	100	2x50
25.00	0.87	0.79	1568	100	2x50
27.78	0.49	0.44	879	100	2x50
30.56	0.24	0.22	432	100	2x50
33.33	0.16	0.14	281	100	2x50
36.11	0.12	0.11	217	100	2x50
38.89	0.11	0.10	194	100	2x50
41.67	0.09	0.08	159	100	2x50
44.44	0.08	0.07	148	100	2x50
47.22	0.08	0.07	138	100	2x50
50.00	0.07	0.06	126	100	2x50
52.78	**0.06**	**0.05**	**106**	**100**	**2x50**
55.56	0.05	0.05	96	96	2x50
58.33	0.05	0.04	89	89	2x50
61.11	0.05	0.04	83	92	2x50
63.89	0.04	0.04	74	82	2x50
66.67	0.04	0.03	67	74	2x50
69.44	0.03	0.03	57	63	1x50
72.22	0.03	0.03	54	60	1x50
75.00	0.03	0.02	47	52	1x50
77.78	0.02	0.02	41	46	1x50
80.56	0.02	0.02	39	43	1x50
83.33	0.02	0.02	34	38	1x50
86.11	0.02	0.02	31	35	1x50
88.89	0.02	0.01	30	33	1x50
91.67	0.01	0.01	25	27	1x50
94.44	0.01	0.01	21	23	1x50
97.22	0.01	0.01	15	16	1x50
100.00	0.01	0.01	10	11	1x50

** 90% of Average Discharge available for Power Generation. 10% is left for environmental reasons.*

Table 6.2(f) Power potential and Installed capacity for Robi Gumero Small Hydropower Scheme

% of time equaled or exceeded	*Discharge (Cumecs)*	*Discharge * for power Generation (Cumecs)*	*Power (kW)*		
			Potential	*Power Available*	*Power Available*
2.78	48.83	43.94	137974	400	2x200
5.56	39.03	35.13	110289	400	2x200
8.33	33.83	30.45	95610	400	2x200
11.11	28.42	25.58	80311	400	2x200
13.89	20.07	18.07	56726	400	2x200
16.67	12.60	11.34	35613	400	2x200
19.44	8.66	7.80	24475	400	2x200
22.22	4.48	4.03	12652	400	2x200
25.00	2.89	2.60	8165	400	2x200
27.78	1.62	1.46	4577	400	2x200
30.56	0.80	0.72	2248	400	2x200
33.33	0.52	0.47	1461	400	2x200
36.11	0.40	0.36	1131	400	2x200
38.89	0.36	0.32	1010	400	2x200
41.67	0.29	0.26	830	400	2x200
44.44	0.27	0.25	773	400	2x200
47.22	0.25	0.23	720	400	2x200
50.00	0.23	0.21	654	400	2x200
52.78	0.20	0.18	554	400	2x200
55.56	0.18	0.16	499	400	2x200
58.33	0.16	0.15	463	400	2x200
61.11	**0.15**	**0.14**	**430**	**400**	**2x200**
63.89	0.14	0.12	384	384	2x200
66.67	0.12	0.11	349	349	2x200
69.44	0.10	0.09	296	296	1x200
72.22	0.10	0.09	280	280	1x200
75.00	0.09	0.08	243	243	1x200
77.78	0.08	0.07	214	214	1x200
80.56	0.07	0.06	203	203	1x200
83.33	0.06	0.06	179	179	1x200
86.11	0.06	0.05	164	164	1x200
88.89	0.05	0.05	155	155	1x200
91.67	0.05	0.04	128	128	1x200
94.44	0.04	0.03	107	107	1x200
97.22	0.03	0.02	77	77	1x200
100.00	0.02	0.02	53	53	1x200

** 90% of Average Discharge available for Power Generation, 10% is left for environmental reasons.*

Table 6.3 Design Discharge for Power generation

Name of the Scheme		*Design Discharge (cumec)*	*% of time equaled or exceeded*	*Power Potential (kW)*
Beresa SHP Scheme Alternative I	PH-I	0.25	61.11	100
	PH-II	0.25	61.11	400
Beresa SHP Scheme Alternative II	PH-III	0.25	61.11	500
Gur SHP Scheme		0.05	52.78	100
Chacha SHP Scheme		0.27	61.11	1000
Robi Gumero SHP Scheme		0.14	61.11	400

6.6.2 Diversion Weir

Diversion weir is a structure which is constructed across the stream to divert water from the stream to water conductor system. The design discharge required at diversion weir is taken equal to 'C' where, 'C' is equal to; (X+0.05X) +0.15 (X+0.05X) +0.10((X+0.05X) +0.15 (X+0.05X)); (X is the design discharge at turbine level). For diversion weir the maximum flood discharge is required, which is an important parameter in its design.

6.6.3 Headrace Channel

Headrace channel is used to transmit water from the Desilting tank to forebay. This structure can be pipe, open channel or tunnel. The design for open channel is computed by the following formula:

$$Q = (AR^{2/3}S^{1/2}) / \eta \qquad \text{...... 6.10}$$

Where;

- Q = Design Discharge
- η = Manning roughness coefficient, for concrete surface without projections, free from algae or insect growth, mostly straight alignment η = 0.013 (Annexure VII)
- S = Slope of channel bed and is taken as 1:500
- A = Area of channel (width x height)
- R = BD/(b + 2D), for rectangular channel where b= width and D=height

6.6.4 Intake Channel and Tailrace Channel

Intake channel is used to transmit water from the intake structure to the Desilting tank. Whereas, tailrace channel is used to transmit water from powerhouse back into the stream. The slope in case of intake channel is taken 1:200 whereas, in case of tailrace channel the slope may be high as per the site topography. The design dimensions for intake channel and tailrace channel has been derived by eq. 6.10.

6.6.5 Desilting tank

Desilting Tank is the structure constructed in between the intake channel and the headrace channel. The primary function of the desilting tank is to clean the water from any suspended silt or sand. It is designed in such a way that it traps all silts greater than 2mm particle size. A silt flushing system is also provided in the desilting tank. If any silt, greater than 2mm particle size, passes the desilting tank it may damage the blades of turbine under high hydraulic head. In the present study the dimensions for desilting tank has been worked out from standard graph proposed by Kumar et al (1990) and is given at Annexure VIII.

6.6.6 Forebay tank

Forebay Tank is a structure which receives water from headrace channel and transmits water through a steel pipe to the turbine fitted in the powerhouse. The forebay is designed to supply uninterrupted design discharge to the turbine. Generally, it is designed for 2 minutes storage capacity; this is done mainly to accommodate the surge generated due to the immediate closure of the turbines. A spillway structure is also provided to spill off the water in case of immediate closure of the turbines. Thus, the forebay, in the present study is designed for 2 minute storage, i.e. Q x 2 x 60 (Q is the design discharge at forebay level).

6.6.7 Penstock

Almost all modern penstocks are built from steel; many has been built in past from wooden staves reinforced with steel bands. The penstock must be designed to provide the required flow rate for the turbine (Fritz, 1984). In the present study, the penstock diameter is calculated using the following formula:

$$Q = A \times V \qquad \ldots\ldots\ldots 6.11$$

Where, Q = Design Discharge (X)

A = Cross sectional area of the penstock, which is equal to π D/ 4 (D is the diameter of the pipe)

V = Velocity of water in the penstock

6.6.8 Results on Design Dimensions of various Civil structures of SHP

Based on the formula and descriptions given in section 6.2.1, the design dimensions for various civil components, such as intake channel, desilting tank, headrace channel, forebay tank, penstock pipe and tailrace channel, has been worked out for various SHP schemes and are presented in table 6.4.

6.7 Power Generation and Selection of Turbine

6.7.1 Power Generation

The basic data required in determining hydropower potential and capacity at specific sites are hydraulic head and discharge which are related through the general power equation. The equation is;

$$P_{kw} = \rho g Q H \eta / 1000 \qquad \text{........ 6.12}$$

Where;

P	=	*power, kw*	H	=	*head drop through turbine, (m)*
Q	=	*flow rate through turbine, (m^3/s)*	η	=	*plant efficiency*
ρ	=	*density of water, 1000 kg/m^3*	g	=	*acceleration due to gravity, 9.81 m/s^2*

If electrical power output is desired, η must include the combined efficiency of turbine and generator. Typical values of these individual efficiencies are 0.9 and 0.95, respectively. The product of the two or the overall efficiency will be approximately 0.8 to 0.9 in most cases (Fritz, 1984). Calculating the net head 'H' will involve determination of all system losses. The net head H is equal to the difference between the static water surface elevations upstream and downstream minus the sum of all losses.

For the present study, the determination of the net head and design discharge valves are presented in the tables 6.2 and 6.3. Thus, based on the design discharge and net head the power potential.

6.7.2 Annual Power Generation

Annual generation has been worked out for various schemes by using eq. 6.13 and the results are presented in table 6.5. 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 6.13

Table 6.4 Design Calculations for various components of SHP scheme.

Dimensions (meters)	*Small Hydropower Components*						
	Intake Channel	*Desilting Tank*	*Headrace Channel*	*Forebay Tank*	*Penstock Pipe*	*Powerhouse Building*	*Tailrace Channel*
Beresa SHP Scheme Alternative I (Powerhouse I)							
Length	223.1	4.50	79.10	4.00	55.2	8.00	25.00
Width	0.68	3.00	0.75	3.00	-	5.00	0.65
Depth	0.50	1.50	0.65	3.00	-	3.00	0.50
Free Board	0.30	0.30	0.30	0.50	-	1.00	0.20
Diameter	-	-	-	-	0.11	-	-
Beresa SHP Scheme Alternative I (Powerhouse II)							
Length	223.1	4.50	627.30	4.00	226.2	8.00	25.00
Width	0.68	3.00	0.75	3.00	-	5.00	0.65
Depth	0.50	1.50	0.65	3.00	-	3.00	0.50
Free Board	0.30	0.30	0.30	0.50	-	1.00	0.20
Diameter	-	-	-	-	0.11	-	-
Beresa SHP Scheme Alternative II (Powerhouse III)							
Length	223.1	4.50	879.70	4.00	281.4	8.00	25.00
Width	0.68	3.00	0.75	3.00	-	5.00	0.65
Depth	0.50	1.50	0.65	3.00	-	3.00	0.50
Free Board	0.30	0.30	0.30	0.50	-	1.00	0.20
Diameter	-	-	-	-	0.11	-	-
Chacha SHP Scheme							
Length	260.90	5.00	2932.20	4.14	446.9	10.00	25.00
Width	0.70	3.50	0.80	4.00	-	10.00	0.65
Depth	0.52	1.50	0.65	3.00	-	3.00	0.53
Free Board	0.30	0.30	0.30	0.50	-	1.00	0.20
Diameter	-	-	-	-	0.12	-	-
Gur SHP Scheme							
Length	167.60	2.80	1187.70	2.28	305.2	8.00	200.00
Width	0.35	2.00	0.41	2.00	-	5.00	0.35
Depth	0.30	1.00	0.35	1.50	-	3.00	0.28
Free Board	0.30	0.30	0.30	0.50	-	1.00	0.20
Diameter	-	-	-	-	0.02	-	-
Robi Gumero SHP Scheme							
Length	194.10	4.50	1948.80	4.00	398.4	10.00	25.00
Width	0.55	2.50	0.61	3.00	-	8.00	0.52
Depth	0.40	1.50	0.51	3.00	-	3.00	0.41
Free Board	0.30	0.30	0.30	0.50	-	1.00	0.20
Diameter	-	-	-	-	0.06	-	-

Table 6.5 Power Potential, Installed Capacity and Annual Power Generation

Name of the Scheme		*Design Discharge (cumec)*	*Net Head (m)*	*Power Potential (kW)*	*Installed Capacity (kW)*	*Annual * Power (MWh)*
Beresa SHP Scheme Alternative I	PH-I	0.25	45.6	100	2 x 50	788.4
	PH-II	0.25	192.7	400	2 x 200	3,153.6
Beresa SHP Scheme Alternative II	PH-III	0.25	235.2	500	2 x 250	3,942.0
Gur SHP Scheme		0.05	179.1	100	2 x 50	788.4
Chacha SHP Scheme		0.27	384.2	1000	2 x 500	7,884.0
Robi Gumero SHP Scheme		0.14	310.8	400	2 x 200	3,153.6

* 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.

6.7.3 Turbine Selection

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

In the present study the turbine type is selected by utilizing the standard chart, which utilizes the head and power generation in determining the turbine type (Indian Standard 12800, Part 3, 1991). Thus, the type of turbines as determined are presented in table 6.6 and is shown through plot in Fig. 6.1

Table 6.6 Turbine selection for various SHP sites

Name of the Scheme		*Design Discharge (cumec)*	*Net Head (m)*	*Power Potential (kW)*	*Installed Capacity (kW)*	*Type of Turbine*
Beresa SHP Scheme Alternative I	PH-I	0.25	45.6	100	2 x 50	Impulse
	PH-II	0.25	192.7	400	2 x 200	Pelton
Beresa SHP Scheme Alternative II	PH-III	0.25	235.2	500	2 x 250	Pelton
Gur SHP Scheme		0.05	179.1	100	2 x 50	Impulse
Chacha SHP Scheme		0.27	384.2	1000	2 x 500	Pelton
Robi Gemero SHP Scheme		0.14	310.8	400	2 x 200	Pelton

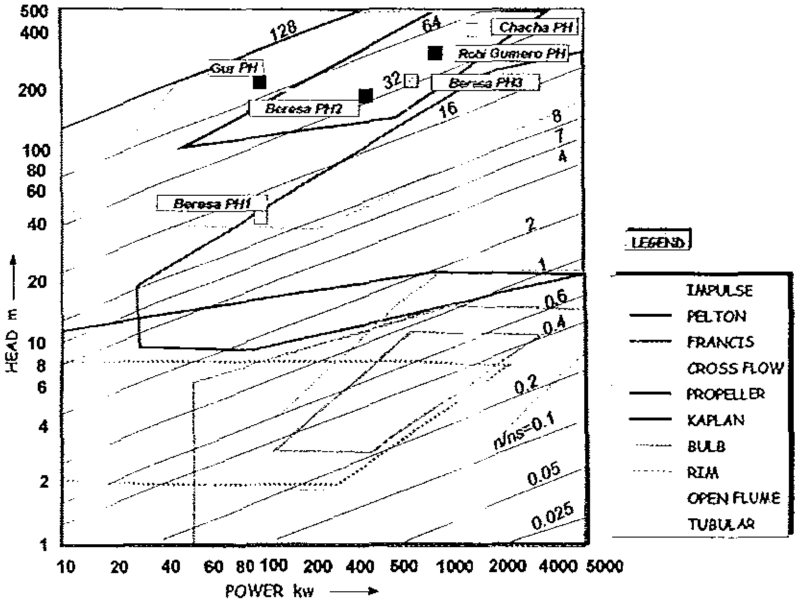

Fig 6.1 Turbine Selection

CHAPTER SEVEN

SMALL HYDROPOWER GEOGRAPHIC INFORMATION SYSTEM (GIS) DATABASE

7.1 Preamble

Geographic Information Systems (GIS) is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of geo-referenced data to solve complex problems regarding planning and management of resources (NCGIA, 1990).

Geographic information system have emerged in the last decade as an essential tool for urban resource planning and management. Their capacity to store, retrieve, analyze, model and map large areas with huge volumes of spatial data has led to an extraordinary proliferation of applications. Geographic information systems are now used for land use planning, utilities management, ecosystems modeling, landscape assessment and planning, transportation and infrastructure planning, market analysis, visual impact analysis, facilities management, tax assessment, real estate analysis and many other applications. Functions of GIS include: data entry, data display, data management, information retrieval and analysis. GIS are needed in part because human population and technology have reached levels such that many resources, including air and land, are placing substantial limits on human action. GIS help to identify the source, location, and extent of adverse environmental impacts, and may help to devise practical plans for monitoring, managing, and mitigating environmental damage and service need.

Geospatial data has both spatial and thematic components. Conceptually, geographic data can be broken up in two elements: **observation or entity** and **attribute or variable.** GIS have to be able to manage both elements. The observations have two aspects in its localization: absolute localization based in a coordinates system and topological relationship referred to other observations. A GIS is able to manage both while computer assisted cartography packages only manage the absolute one. The variables or attributes can be studied considering the thematic aspect (statistics), the locational aspect (spatial analysis) or both (GIS). Data for GIS applications includes, digitized and scanned data, databases, GPS field sampling of attributes and Remote sensing and aerial photography. Besides, a GIS database can be vector based (point, line or arc and polygon) or raster.

7.2 Small hydropower GIS Database

In the present study an attempt has been made to develop a GIS data base on small hydropower. This data base is prepared with an intention to provide all necessary information on SHP at pre-feasibility level, such as, location, power potential, general layout, geological setting, general physiographic details, soils in the area, landuse and landcover, engineering geological appraisal (for sample sites), estimations on quantities and cost. This data base is prepared for the present study area and it covers Muger, Jemma, and Waleka drainage Sub-basins of Abay. The present study area comprises of 3 Regions, 5 zones, 93 Weredas and 68 towns. According to the Central Statistics Authority the total population within the study area accounts for 7.85 million, both rural and urban (CSA, 1994). Out of total 68 towns in the study area, only 23 are electrified through interconnected system and diesel generator sets. The rest 45 towns and the villages are yet to be electrified. This figure shows that there is an immediate need to provide electricity to the remaining towns and villages.

In this context, therefore it becomes very important for the planners and developers to have some form of 'first hand information' on small hydropower potential in the area. The GIS database on SHP, prepared in the present study, may serve as a useful decision making tool for the planners and developers, intending to develop small hydropower schemes in the present study area. Moreover, the present study may serve as a model study to develop and extend similar type of GIS database for other regions in the country, which will help in speedy development of small hydropower power sector in the country.

The present study envisages to bring all the relevant data (spatial and non-spatial), at pre feasibility level, related to small hydropower schemes on a GIS platform for the speedy development in the present study area. The GIS database on SHP will help in utilizing attribute and spatial data in fundamental ways, such as (i) it may allow easier and wider distribution of data and functionality to end users, (ii) it may facilitate integration of data and functionality into other applications. Further, the GIS analysis outputs can become inputs for various applications, which will support the user in decision making, designing and executing the proposed small hydropower schemes in the study area.

7.3 Development of small hydropower GIS database

The "Small Hydropower Geographic Information System database" (SHP-GIS-Database) prepared for the present study area, includes all necessary information on SHP at pre-feasibility level, such as, location, power potential, general layout, geological setting, general physiographic details, soils in the area, landuse and landcover, engineering geological appraisal (for sample sites), estimations on quantities and cost of the project.

7.3.1 Preparation of Vector Data

Preparation of vector data is an essential component of any GIS database. For the present GIS database various vector data were generated or were directly taken from existing database. The digitization was carried out on AutoCad Map 2000 software. The preparation of the vector data includes:

i) Digitisation of delineated potential catchments from the topographical sheets (1:50,000) at real UTM co-ordinate system. Catchment boundaries were digitized as polygon data, whereas, major contours, major/minor streams, roads/foot-path/foot-trails as line data. Further, towns/villages, religious structures and highest elevation points were digitized as point data.

ii) Digitisation of delineated potential SHP sites as a point data theme.

iii) Land Use/Land Cover map of the study area has been extracted from the master plan of Abay Basin, for the description of each land use/ land cover, polygons were attached with text files in an interactive mode.

iv) Geology of the study area at 1: 2,000,000 has been digitized from the geological map of Ethiopia, procured from Ethiopian geological Survey (EGS). By using text script, descriptions were attached to each polygon.

v) Soil map of the study area has been digitized from Abay Basin Master Plan (1999).

7.3.2 Preparation of Attribute data

Attribute data is non spatial data attached to the vector data. In the present data base following attributes are attached to various vector themes;

i) To the potential small hydropower site, digitized as point data, attributes in 32 columns has been attached. The attribute table has been prepared as data base file (*.dbf file) in Microsoft Excel. These attributes are, i) name of the scheme, ii) name of the stream, iii) locational detals (UTM co-ordinates, nearest town, zone, wareda), iv) heighest elevation point, v) lowest elevation point, vi) catchment area, vii) catchment parameter, viii) gross hydraulic head available, ix) dependable discharge and x) power potential etc.

ii) To all polygon data on soil cover, geology and landuse/landcove attributes have been attached.

7.3.3 Preparation of Additional attachment data

Additional attachment data such as delineated catchment drawing, general layout of the scheme, photograps & video clipping (of selected sites), salient features, estimates on quantities and cost (for selected sites) etc. were prepared. This additional data has been prepared as Power point show (*.pps) files. Arc View 3.2a does not have a capability to run these 'pps' files. In order to run these 'pps' files in an interactive mode with ArcView, an program user's script has been prepared and loaded on SHP-GIS database (Fig. 7.1). The path to the 'pps' files has been defined as an attribute to the SHP potential sites (point data) and were 'Hotlinked' to the database.

Script1

```
   theVal = SELF
' see if the value of the field is not null
if (not (theVal.IsNull)) then
  ' if the file listed in the field exists, then view the pps
  if (File.Exists(theVal.AsFileName)) then
    ' use the path to the MS Powerpoint executable
    System.Execute("d:\Small_Hydropower\Xlator2\PPTVIEW.exe"++theVal)
  else
    ' if the file doesn't exist, tell the user
    MsgBox.Warning("File "+theVal+" not found.","Hot Link")
  end

end
```

Fig. 7.1 User's script to attach PPS files to the database

7.4 SHP-GIS Database – A decision making tool

SHP-GIS Database is a computer-based program which can be used to handle large volume of spatial data related to SHP sites (For the present study area only), which can easily be stored, viewed, queried, reproduced and analyzed as per users' requirement. It is a unique, highly effective and extremely versatile database. SHP – GIS database can be successfully utilized to provide various relevant information on small hydropower, for the present study area, quickly and effectively. The interactive SHP-GIS database will provide a unique and easy-to-use *Spatial Decision Support System (SDSS)* to explore and promote the SHP potential in the study area for the planners and developers.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusion

Electrical energy is becoming an essential commodity for the modern life. Every sector, weather industry, technology, transportation, public utilities or the domestic life, is now dependent on electrical power. The dependence on electrical power is becoming more and more, which has resulted into increasing demand for it. The electrical power can be generated from non-renewable and exhaustible sources which, unfortunately are getting depleted at a very fast rate. This has focused attention to the non-exhaustible and renewable sources of energy. Among the renewable energy sources 'Hydropower' is one of the most common and abundantly available energy in the hilly regions. This renewable energy source may be exploited by constructing large hydro power plants or simply, by constructing small hydro power stations. The large hydro power plants are not being taken up for execution in sufficient number as these involve huge amount of funds and also the planning and construction period is large. Therefore, with the increasing demand for power, the activities on small hydropower projects is accelerated in recent times. The small hydropower schemes are the appropriate solution to power demand as these require small capital investment and can be completed in a very short period of time, with minimum adverse environmental impacts.

The present study area is located in Abay drainage basin, in the central part of the country Muger, Jemma, and Waleka drainage Sub-basins of Abay have been identified for the present study. These basins are partly in Addis Ababa, Amara and in Oromia region. The main objective of the present study was to identify potential Small Hydropower sites in the study area and to carry out ground verification with engineering geological appraisal, at pre feasibility level, of SHP sites (Selected sites).

During the present study a total of 36 potential SHP sites has been identified. Out of these 36 sites, 13 sites fall within Muger sub-basin, 17 in Jemma sub-basin and the rest 6 sites forms a part within Waleka sub-basins. Most of these identified sites are concentrated along the periphery of the sub-basins.

Out of total 36 identified potential sites for none of these potential streams, gauged data is available at or near the proposed diversion sites. However, observed discharge data is available either, in the upstream or downstream locations on the same stream or in the adjoining catchments. During the present study, for initial estimate of the power potential the observed discharge data from nearby locations have been projected at the proposed sites to work out the dependable flows. However, it is strongly recommended to observe the actual discharge, at least covering two lean seasons, before finalizing these sites for development.

In the present study, ranked flow technique has been employed to compute flow duration curve at proposed diversion weir sites for 18 identified potential streams. For 9 small hydropower (SHP) potential sites, flow-duration curve is prepared from observed daily discharge data. However, for 9 other potential sites the observed discharge data has been projected from adjacent gauged stations by percent area ratio method for those which demonstrate similar catchment characteristic. Further, for remaining 18 potential sites, the flow-duration could not be worked out as neither, observed discharge data on the same stream or in the adjacent catchment with similar characteristics was available nor, sufficient metrological data was available to workout the discharge empirically.

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 has 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 5325 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, four identified small hydro power sites satisfies the criteria, these sites were, Beresa, Chacha, Gur and Robi Gemero.

Thus, these four sites were ground verified for the availability of the head, discharge and the possible layout. Further, engineering geological appraisal of these sites has been carried out. For this geological mapping were carried out along the water conductor and the powerhouse site. 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 disturbed soil samples were also collected from all the sites and were tested for the index properties and the grain size distribution. Thus based on the index properties of soils, present along the water conductor were classified.

Further, for small hydropower schemes the behavior of slopes for their stability becomes more important as most of the water conductor system rests on these slopes. If the slopes are not stable the various structures of the water conductor system may fail and the entire scheme may become non functional. Therefore, the slopes along the water conductor system were studied for their stability conditions.

At Beresa SHP site one slope section was identified as potentially unstable and which falls along the water conductor for Beresa Alternative II scheme. 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 water conductor. 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 level where the water conductor will be passing (El 2065m) on this slope. These remedial measures may be in the form of terracing and providing retaining wall. Further, it is suggested to provide a steel pipe instead of concrete channel in this section. In future after the execution of the project if there is any possible movement the pipe may move which, may be later reinstalled.

Another potential unstable slope was identified at Gur SHP site. The proposed penstock would be passing over this slope. This slope is comprised of colluvial soil and traces of instability were observed on this slope in the form of local soil failures and gully erosion. Stability analysis of this slope section has been carried out for static and dynamic conditions under varied water saturation condition. The results indicate that the factor of safety for this slope under all conditions is less than unity accept for static dry condition. Thus, it indicates that the slope is unstable and may pose problems of instability and may damage the penstock. 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. However, the anchor blocks for the penstock may be founded deep. Besides, the local remedial measures particularly along the penstock alignment in the form of terracing and providing retaining walls with proper drainage arrangements will help in stabilizing the slope section.

Further, at all four proposed SHP sites engineering geological mapping has been carried out. In the present study, engineering geological maps were prepared by characterizing the soil and rock mass exposed along the water conductor. The rock mass has been characterized based on the rock mass quality derived from the Rock mass classification (RMR) and the degree of weathering grade using Irfan and Dearman classification (1978) of weathering grade. Besides, the soil mass present at the SHP sites has been classified into Colluvial soils (SM) – Loose unconsolidated most susceptible for instability and Residual soils (CL, CH, MH) – Relatively less consolidated and less susceptible for instability.

Safe and effective functioning of any small hydro power project is ensured only through proper and accurate design of various components. The design discharge is the basic parameter required for the design of all civil structures involved in the SHP scheme. A proper judgment, supported with actual monitoring of flow regime, will ensure an accurate estimation of dependable flow for any SHP scheme. For the present study, an attempt has been made to tentatively design the various SHP components and select the turbine based on the power potential for the selected site. Thus, based on the preliminary design of the various components the quantities required has been calculated.

Finally, based on the Engineering geological appraisal and the general in order of pre feasibility study it may be concluded that out of four grounds verified SHP sites Chacha and Beresa Small hydropower sites are feasible sites with minimum engineering geological problems. However, the other two site Gur and Robi Gemero are not feasible sites. The power potential at Gur SHP site is very less and secondly along the penstock alignment the slope is potentially unstable which may pose problems in safe running of the scheme. For Robi Gemero at present the accessibility to various components of SHP is difficult. Thus, in case if these two sites have to be taken up for development they must be considered on least priority.

Further, in the present study an attempt has been made to develop a GIS data base on small hydropower. This data base is prepared with an intention to provide all necessary information on SHP at pre-feasibility level, such as, location, power potential, general layout, geological setting, general physiographic details, soils in the area, landuse and landcover, engineering geological appraisal (for sample sites), estimations on quantities and cost. This data base is prepared for the present study area and it covers Muger, Jemma, and Waleka drainage Sub-basins of Abay. The present study area comprises of 3 Regions, 5 zones, 93 Weredas and 68 towns. According to the Central Statistics Authority the total population within the study area accounts for 7.85 million, both rural and urban (CSA, 1994). Out of total 68 towns in the study area, only 23 are electrified through interconnected system and diesel generator sets. The rest 45 towns and the villages are yet to be electrified. This figure shows that there is an immediate need to provide electricity to the remaining towns and villages.

In this context, therefore it becomes very important for the planners and developers to have some form of 'first hand information' on small hydropower potential in the area. The GIS database on SHP, prepared in the present study, may serve as an useful decision making tool for the planners and developers, intending to develop small hydropower schemes in the present study area. Moreover, the present study may serve as a model study to develop and extend similar type of GIS database for other regions in the country, which will help in speedy development of small hydropower power sector in the country.

8.2 Recommendation

Based on the result of the present study and the problems faced during the present investigations, 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.
- There is a need to develop a regional flow duration curve/ model for different areas which may be utilized for the estimation of dependable flows of un gauged streams, to be utilized for the small hydropower investigations at pre feasibility level.
- For the present study the Engineering Geological appraisal carried out for small hydropower sites was an effort made under the limitations of resources, time and financial 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 actual laboratory testing of rock and soil material, as for the present study various empirical techniques were utilized to estimate these properties.
- The cost estimates for SHP schemes, made during present study, are indicative only, and may vary 10-20% as, some estimates of quantities like, excavations of loose and hard earth material were made on 1: 50,000 scale maps. Further, the general layout has been prepared on topo map at 1: 50,000 scale. Therefore, it is recommended to carry out the detailed topographical survey of the water conductor and powerhouse site on 1: 500 or 200 scale to work out the actual quantities.
- The SHP-GIS database developed during the present study may be utilized to identify the new sites for the development. This may serve as a good decision making tool for the SHP development in the present study area.
- For further study it is recommended;

  To ground verify the remaining potential SHP sites identified during the present study.

  To undertake similar studies in the other parts of the country.

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Annexure I The average monthly rainfall processed data for all 34 stations is presented at.

No.	Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1.	Chacha	12.0	24.7	44.7	39.5	47.7	66.3	286.2	269.8	109.0	13.7	8.5	1.8	923.9
2.	Chancho	24.7	33.7	60.2	61.6	58.3	152.4	323.1	304.5	124.9	26.6	7.1	15.0	1192.1
3.	Debre birhan	11.7	28.2	59.7	43.6	48.9	41.1	238.1	278.6	101.1	12.9	14.3	4.2	891.4
4.	Dejen	5.7	20.5	56.4	60.5	95.1	104.2	285.5	276.4	139.2	76.7	20.3	6.4	1146.9
5.	Deneba	16.4	38.3	36.6	56.2	52.0	83.1	326.8	264.8	115.8	34.0	2.0	6.7	1032.7
6.	Derba	22.7	43.3	60.7	70.7	76.1	135.3	324.1	339.0	174.4	29.6	11.1	15.7	1302.7
7.	Fiche	13.0	52.4	71.6	65.1	62.5	49.4	254.0	279	99.8	15.0	6.5	6.1	9744
8.	Filklik	1.8	9.8	36.3	47.5	81.0	100.3	285.0	272.9	127.9	45.0	10.0	2.5	1020
9.	Gebre Guracha	8.5	16.1	42.7	77.1	95.6	130.9	337.2	352.8	166.2	25.1	8.1	9.2	1269.5
10.	GohaTtsion	9.9	19.6	49.7	49.8	103.4	119.3	106.2	296.5	121.6	48.1	11.8	7.8	1142.7
11.	Inchini	19.5	41.0	64.7	75.9	41.7	138.7	276.4	232.5	146.4	39.1	10.1	9.3	1095.3
12.	Lemi	14.2	36.2	81.0	77.2	64.8	68.6	341.4	352.0	97.4	24.5	6.1	10.0	1173.5
13.	Molale	12.0	23.3	45.9	49.6	41.1	41.3	218.4	250.2	86.3	28.9	7.5	7.5	821.0
14.	Muke Turi	25.1	45.8	71.3	70.3	54.8	68.1	255.1	267.2	1115.3	19.9	3.9	14.7	1011.5
15.	Sela Dingay	16.0	31.7	45.0	50.7	50.7	90.1	283.6	272.4	96.5	20.1	9.2	8.5	974.5
16.	Shekute	19.6	49.9	93.7	86.6	128.3	226.8	375.7	377.8	204.6	54.2	17.7	11.7	1646.6
17.	Sheno	12.9	29.5	51.3	62.2	46.2	73.1	286.7	290.2	105.9	18.5	5.2	4.8	986.5
18.	Sululta	25.4	30.9	87.7	72.3	83.7	148.8	314.3	241.5	89.3	19.9	8.0	5.0	1148.0
19.	Tikur Inchini	25.9	45.7	93.1	93.1	138.9	215.3	271.5	331.9	202.7	70.1	16.3	10.4	1551.2
20.	Belo	0.8	3.5	32.1	52.8	153.9	253.8	316.5	277.3	323.6	101.4	13.4	5.0	1534.1
21.	Debre Tsige	11.9	34.4	66.5	78.9	27.3	49.9	259.8	236.2	113.6	13.4	1.2	9.2	902.3
22.	Dera (Gundomeskel)	7.7	20.3	68.7	73.3	36.7	66.8	301.5	373.3	115.1	12.4	6.7	19.1	1101.6
23.	Enewari	20.5	28.2	162.1	62.2	44.8	81.1	335.2	308.5	112.1	8.9	28.9	8.3	1201.1
24.	Gorfo	28.3	18.4	36.8	23.2	48.3	87.1	235.5	241.3	88.4	30.6	35.5	3.7	877.1
25.	Gudeberet	14.1	18.7	28.3	24.4	23.4	38.3	238.8	177.3	82.7	20.8	25.2	1.2	693.2
26.	Haro Aleltu	0.0	4.8	31.7	72.6	150.3	217.3	247.7	298.5	232.0	104.3	11.3	77.6	1380.2
27.	Hoha	0.0	0.3	5.4	37.0	140.0	210.9	193.7	196.4	168.3	82.1	3.7	0.6	1038.4
28.	Jeldu	39.9	78.3	143.5	180.6	109.8	250.3	426.5	403.0	386.6	131.9	11.1	15.2	2176.6
29.	Kachise	14.7	34.8	90.4	69.8	96.8	274.9	411.4	416.2	281.5	82.6	5.9	20.2	1772.1
30.	Kebe	7.7	4.9	28.3	29.3	177.5	190.2	297.2	347.3	196.8	203.6	108.9	4.5	1696.2
31.	Mehal Meda	16.0	72.3	55.6	82.1	25.0	15.3	209.4	251.5	56.0	24.5	1.4	7.1	816.1
32.	Mekane Selam	21.9	71.9	91.3	118.1	57.0	113.2	200.0	223.3	126.0	12.9	16.2	12.1	1064.9
33.	Mendida	7.1	42.0	60.3	75.9	16.2	29.9	262.7	256.6	123.9	3.7	4.3	4.2	895.8
34.	Werejiru	2.4	3.6	34.5	29.5	221.4	323.5	385.8	362.1	342.1	187.4	14.2	4.7	1911.2

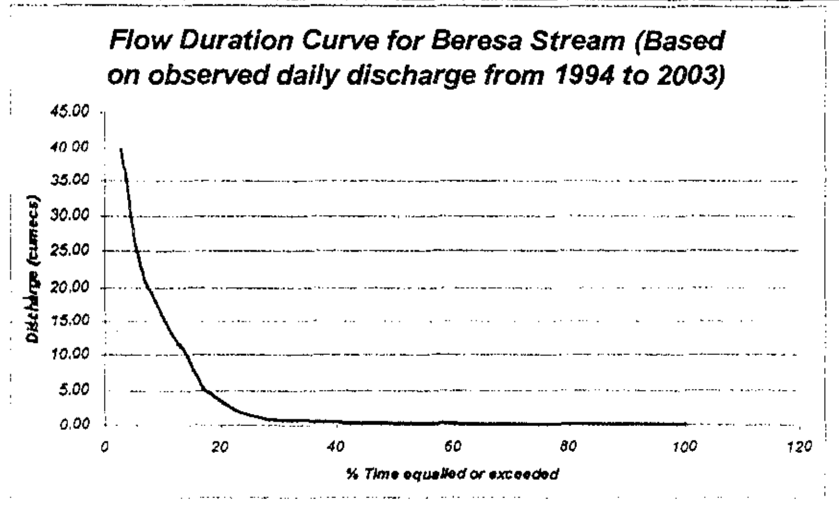
Annexure II A land covers classification of Abay basin

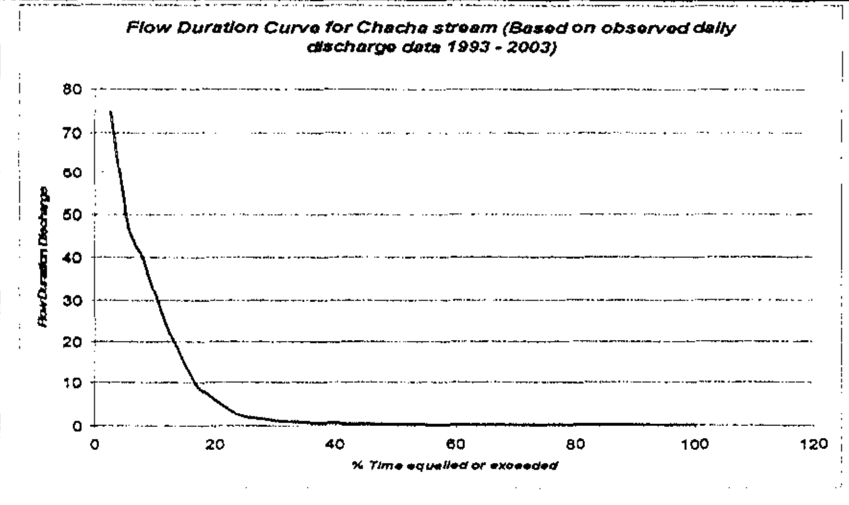
Category	Class	Sub-class
1	Cultivated	Rain fed Irrigated Perennial Sate farm
2	Afro-Alpine	
3	Forest	Disturbed Very disturbed
4	Plantation	Eucalyptus
5	Woodland	Dense Open Riparian
6	Bushland	Dense Open Riparian
7	Shrubland	Dense Open
8	Bamboo	
9	Grassland	Open Bushed/Shrubed Wooded
10	Wetland & Water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

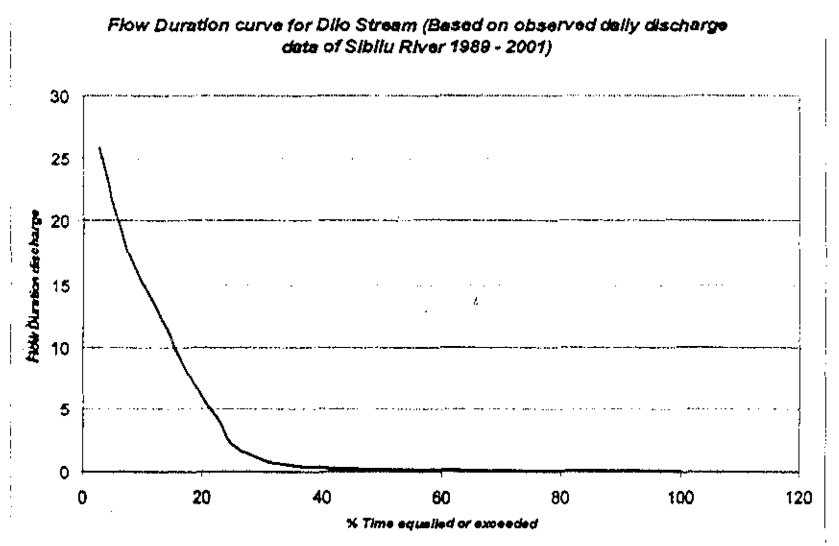
Annexure III Description for the soil groups

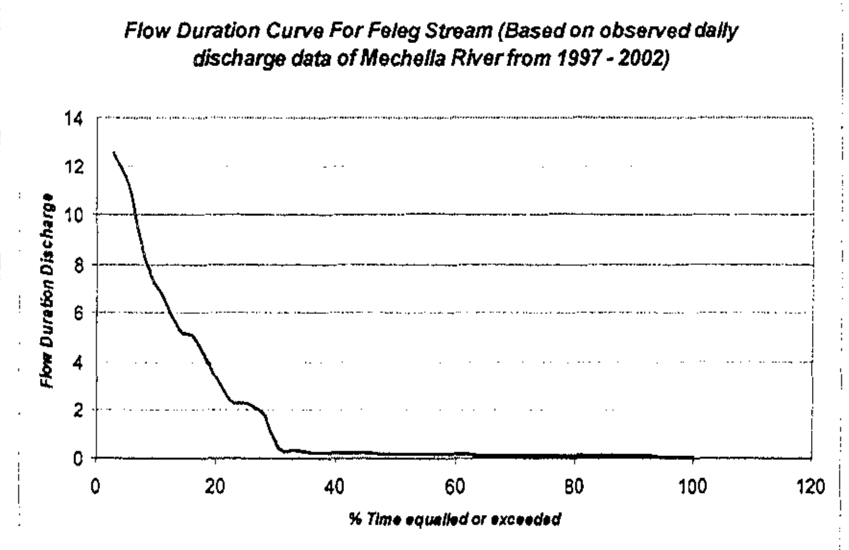
Soil Group	Depth	Colour	Texture	Structure	Consistence	Drainage
Acrisols	Deep to very deep	Very dark grayish Brown	Clay	Subangular blocky	Friable, sticky and plastic	Well
Alisols	Deep to very deep	Reddish brown	Clay/clay loam/Silty clay	Subangular blocky	Friable to firm, sticky and Plastic	Well
Arenosols	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

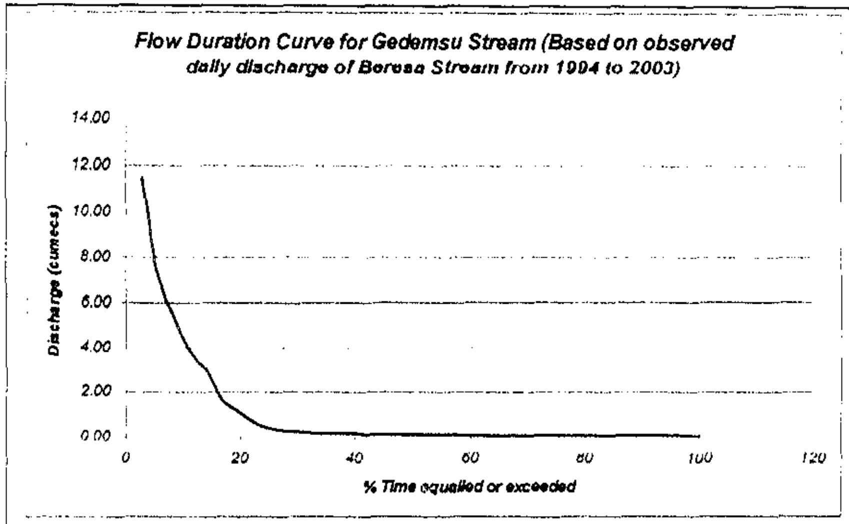
Annexure IV Flow duration curves for potential streams

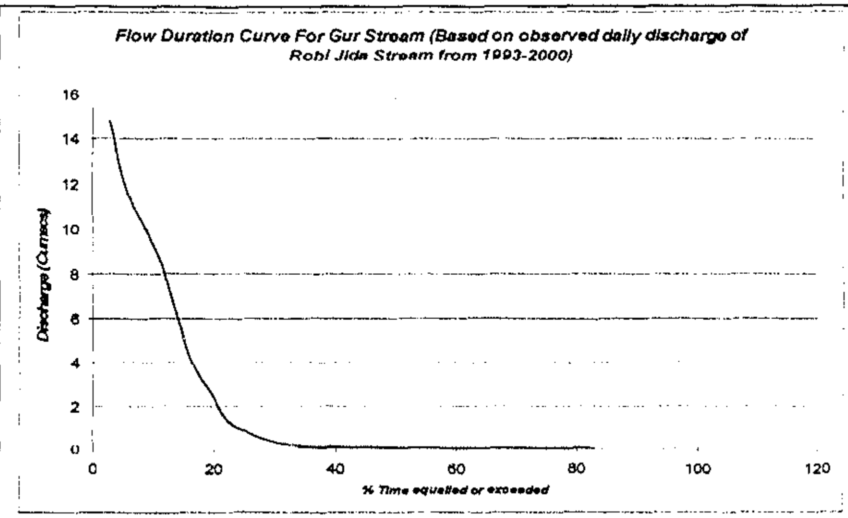


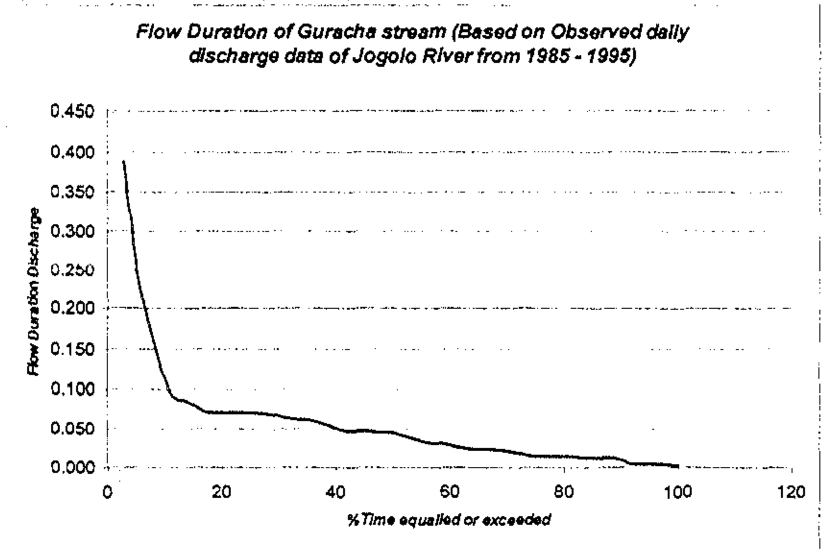


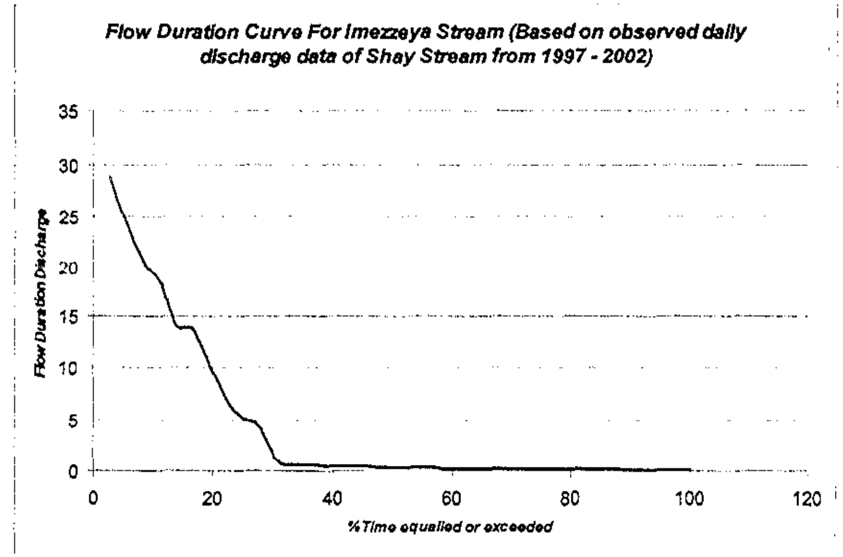


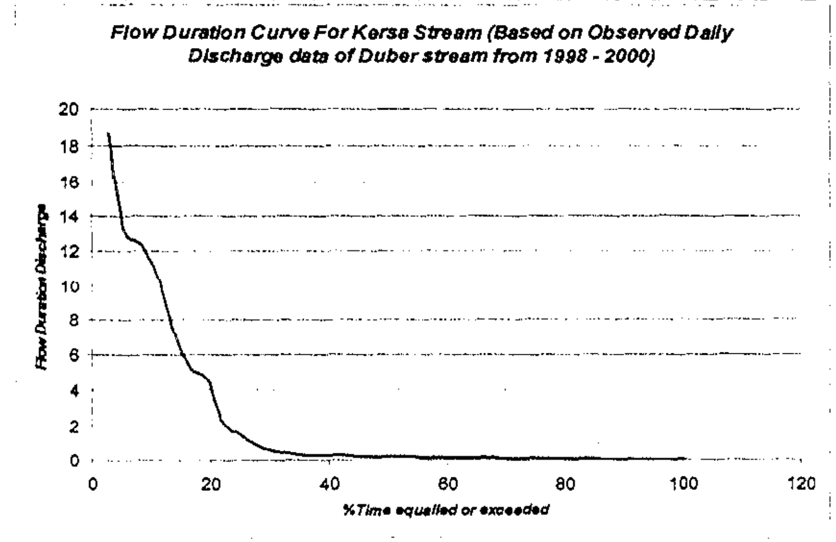


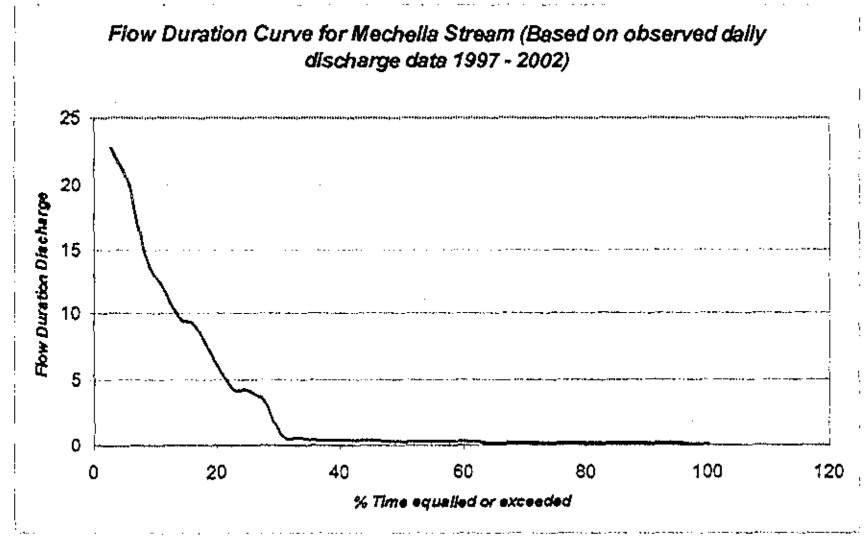

Flow Duration Curve for Gedemsu Stream (Based on observed daily discharge of Beresa Stream from 1994 to 2003)
Discharge (cumecs)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
20
40
60
80
100
120
% Time equalled or exceeded

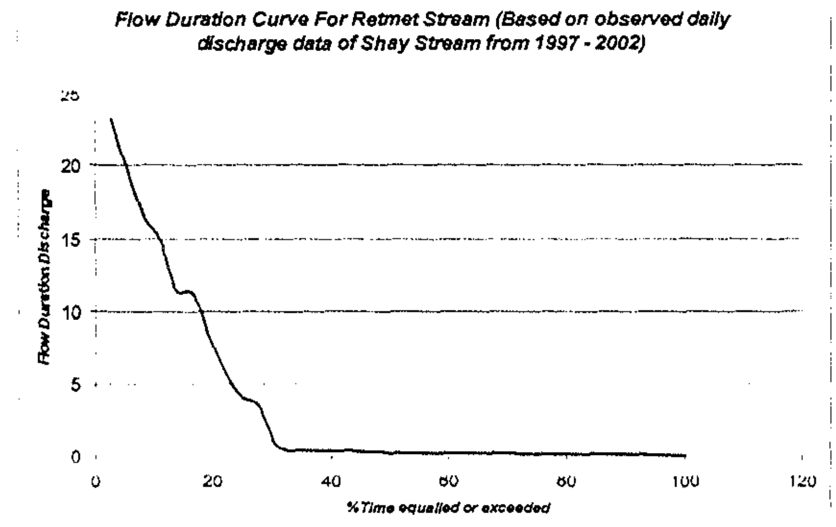

Flow Duration Curve For Gur Stream (Based on observed daily discharge of Robi Jida Stream from 1993-2000)
Discharge (Cumecs)
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
% Time equalled or exceeded

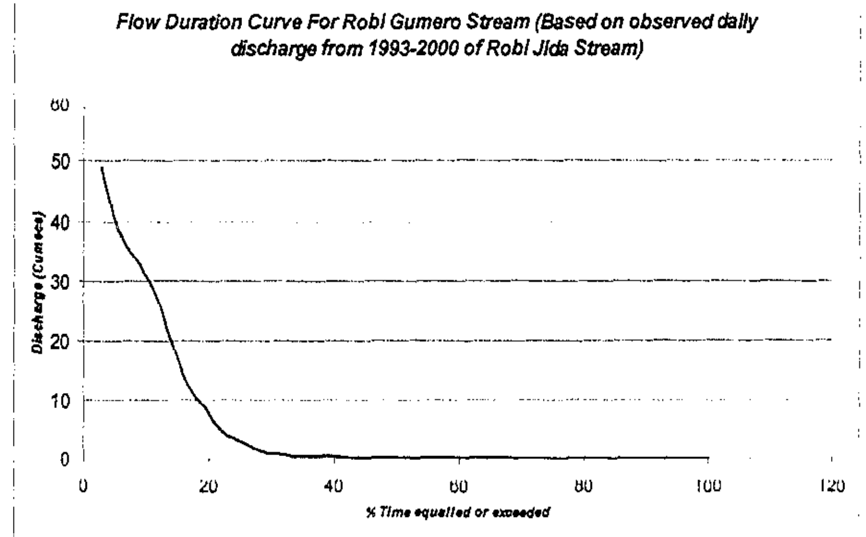

Flow Duration of Guracha stream (Based on Observed daily discharge data of Jogolo River from 1985 - 1995)
Flow Duration Discharge
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0
20
40
60
80
100
120
% Time equalled or exceeded

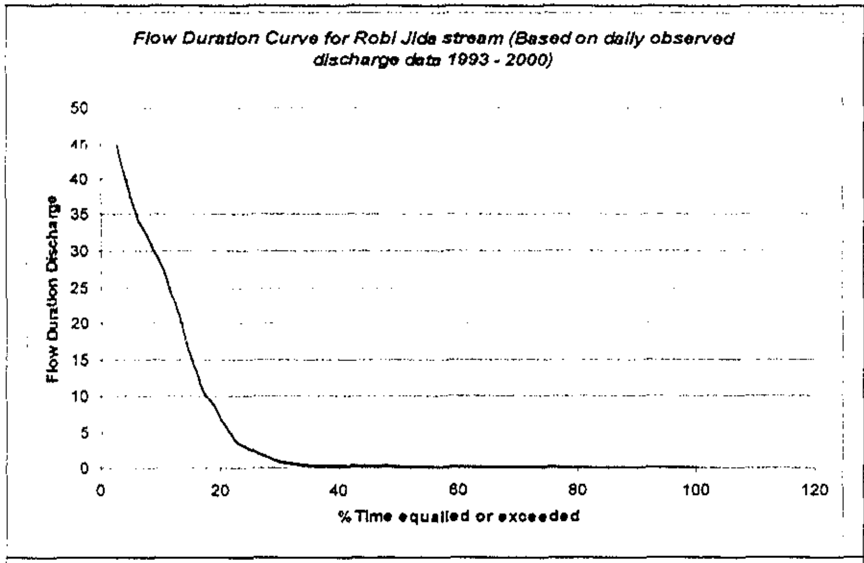

Flow Duration Curve For Imezzeya Stream (Based on observed daily discharge data of Shay Stream from 1997 - 2002)
Flow Duration Discharge
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
% Time equalled or exceeded

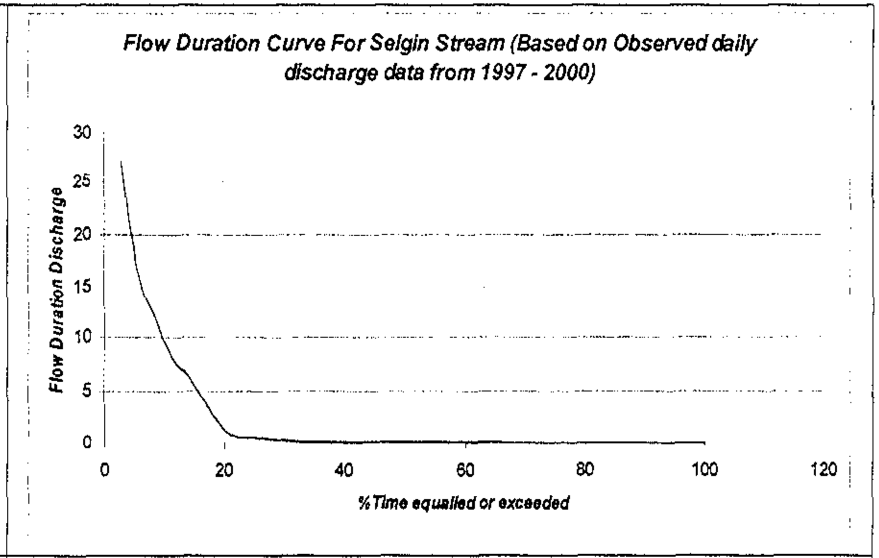

Flow Duration Curve For Kersa Stream (Based on Observed Daily Discharge data of Duber stream from 1998 - 2000)
Flow Duration Discharge
%Time equalled or exceeded

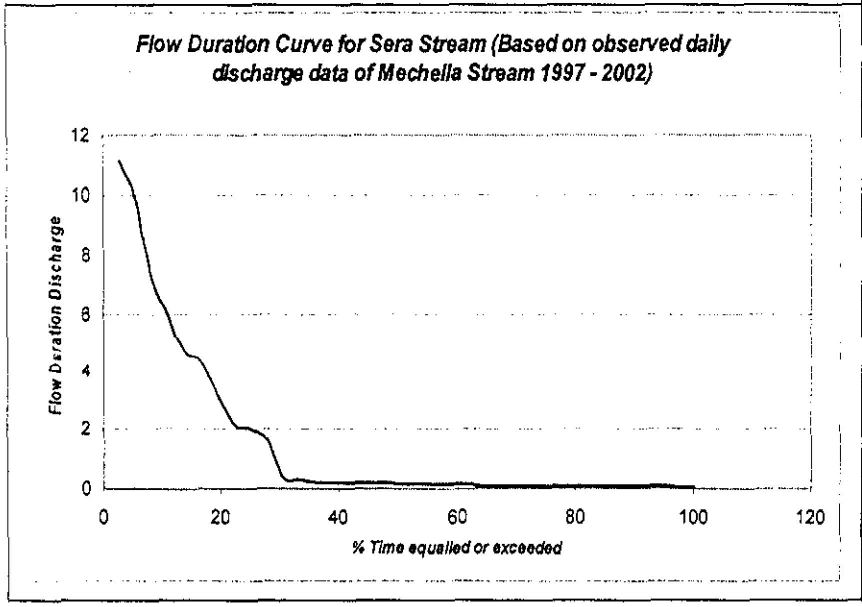

Flow Duration Curve for Mechella Stream (Based on observed daily discharge data 1997 - 2002)
Flow Duration Discharge
% Time equalled or exceeded

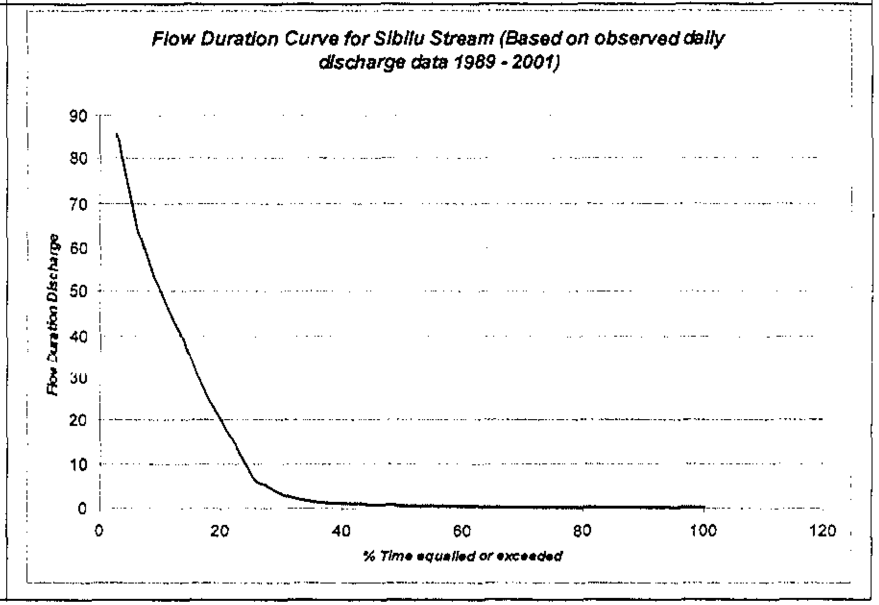

Flow Duration Curve For Retmet Stream (Based on observed daily discharge data of Shay Stream from 1997 - 2002)
Flow Duration Discharge
%Time equalled or exceeded

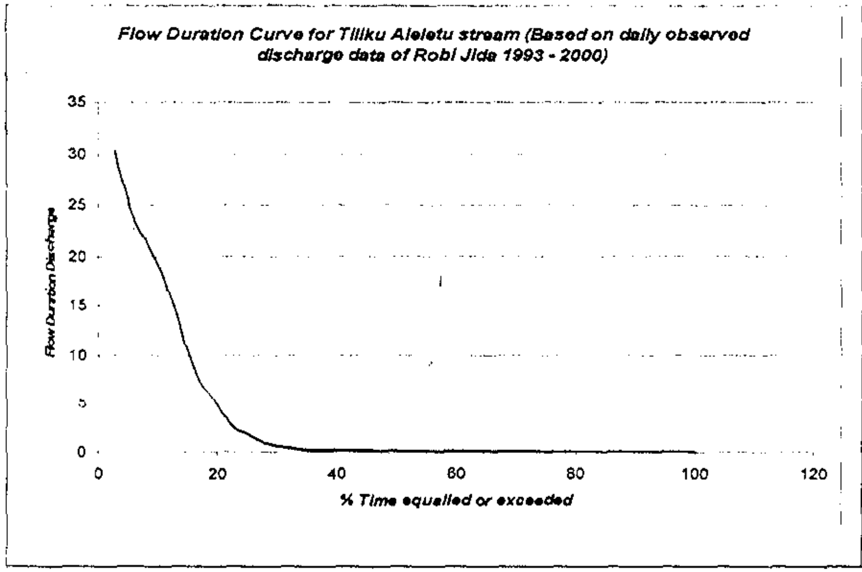

Flow Duration Curve For Robi Gumero Stream (Based on observed daily discharge from 1993-2000 of Robi Jida Stream)
Discharge (Cumecs)
% Time equalled or exceeded

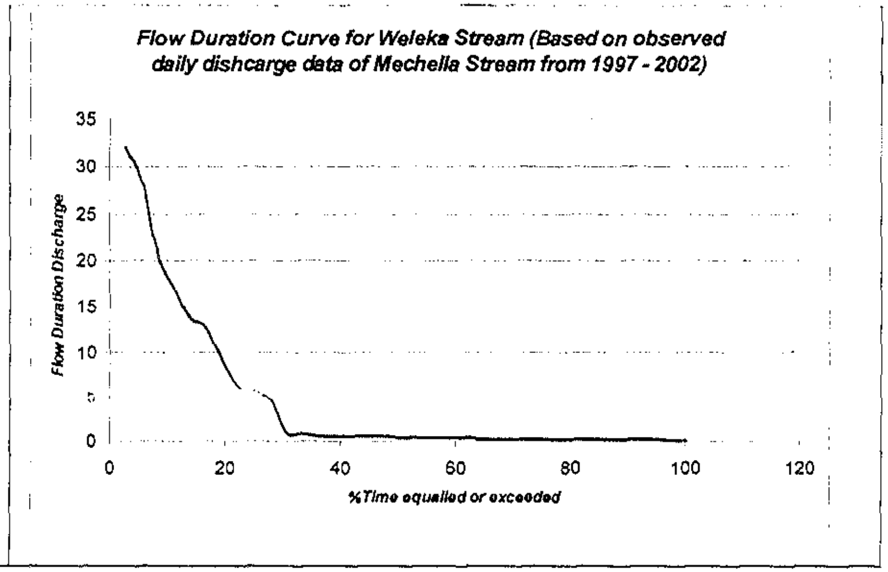

Flow Duration Curve for Robi Jida stream (Based on daily observed discharge data 1993 - 2000)
Flow Duration Discharge
% Time equalled or exceeded
0
20
40
60
80
100
120
5
10
15
20
25
30
35
40
45
50


Flow Duration Curve For Selgin Stream (Based on Observed daily discharge data from 1997 - 2000)
Flow Duration Discharge
% Time equalled or exceeded
0
20
40
60
80
100
120
5
10
15
20
25
30


Flow Duration Curve for Sera Stream (Based on observed daily discharge data of Mechella Stream 1997 - 2002)
Flow Duration Discharge
% Time equalled or exceeded
0
20
40
60
80
100
120
2
4
6
8
10
12


Flow Duration Curve for Sibilu Stream (Based on observed daily discharge data 1989 - 2001)
Flow Duration Discharge
% Time equalled or exceeded
0
20
40
60
80
100
120
10
20
30
40
50
60
70
80
90


Flow Duration Curve for Tiliku Aleletu stream (Based on daily observed discharge data of Robi Jida 1993 - 2000)
Flow Duration Discharge
% Time equalled or exceeded
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120


Flow Duration Curve for Weleka Stream (Based on observed daily dishcarge data of Mechella Stream from 1997 - 2002)
Flow Duration Discharge
%Time equalled or exceeded
0
10
15
20
25
30
35
0
20
40
60
80
100
120

Annexure V 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 VI 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 VII Head losses

Description		Friction	Entrance	Trash Rank	Exit	Bend	Gate Valve	Butterfly Valve	Total H. Losses
Beresa Alternative I	PH1	2.48	0.159	0.159	0.319	0	1.37	0.10	4.6
	PH2	10.18	0.159	0.159	0.319	0.064	1.37	0.10	12.3
Beresa Alternative II	PH3	12.67	0.159	0.159	0.319	0.064	1.37	0.10	14.8
Chacha		18.63	0.159	0.159	0.319	0.064	1.37	0.10	20.8
Gur		68.69	0.159	0.159	0.319	0.064	1.37	0.10	70.9
Robi Gumero		32.02	0.159	0.159	0.319	0.064	1.37	0.10	34.2

Annexure VIII Manning roughness coefficient

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

Annexure IX Graph to work out Design dimensions for desilting tank (Kumar et al, 1990) 1990)