ENGINEERING GEOLOGICAL CHARACTERIZATION
OF
ODA DAM SITE AND ITS CATCHEMENT AREA
(NORTHERN ETHIOPIA)

A Thesis submitted to The School of Graduate Studies,
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ABSTRACT

Dam is one of the hydraulic structures that demand the integration of many disciplines during its investigation. Geomorphological, geological, hydrological and engineering geological investigations were carried out at the proposed Oda dam so as to understand and characterize the soils and rocks of the research area from engineering geological perspective.

Oda dam is proposed to be either a masonry type its combination with a rockfill type of dam located in Tigray (Northern Ethiopia) across a seasonal river called Oda River for irrigation purpose. The catchment area of Oda is 65km^2 and according to the preliminary engineering design done so far by REST, the crest length and maximum dam height are 265m and 46.5m respectively although this can vary a little bit depending on the final choices of the dam axis.

Slope, land form and relief, soil and land use maps of the catchment area are produced at a scale of 1:50,000 to see their impact on the dam project and each unit are described.

High attitude difference and steep slopes characterize the catchment of Oda, which in turn has result in the high rate of erosion. About 74% of the total area of the watershed is covered by the sloping to moderately steep (hilly) landforms. Textural classification of the soil show that the Oda soils fall into the Sandy loam (residual origin mostly) which represent the thin soil cover (25 - 50cm) for majority of the catchment, and the silty loam soils which are restricted to the stream banks and foot slopes.

Four land uses namely grazing land, shrub land homestead and others (rock outcrops, gullies, etc.) are identified and, out of these grazing land has the largest aerial coverage (84%).

The main geomorphological processes that prevail in the study area are weathering, erosion, mass wasting, and geologic structures (faulting and dyke) which are responsible for the formation the various geomorphic units in the area.

Geological maps of the whole catchment are, and reservoir and foundation at scales of 1:50,000 and 1:1000 are produced respectively. The main lithological units of the area include the alkali olivine basalt, aphaniticbasalt, welded tuff and very small outcrops dioritic rocks. The area is covered dominantly by the oldest alkali olivine basalts, which are medium to highly weathered. Slightly weathered aphanitic basalt, which occurs as dykes, sills, cape rocks and they have variable trends. The welded tuff is found at the upper part of the Oda catchment. Overlying the basaltic units and are characterized by sparsely and scattered small sized lapilli (2mm to 4mm in diameter) through out the matrix of ash. Small and negligible outcrops of dioritic outcrops are also observed in a small part of the central part of the Oda River (not mappable) and to the north of the reservoir area just on the water divide of Oda-Tengago catchments. The quaternary deposits are recent deposits found below the dam axis forming the plain areas.

Dominantly two joints sets trending WNW-ESE and NNE-SSE affect the basaltic units although some third joint sets trending nearly E-W are also observed at places.

23 years of rainfall records of both the Alamata and Korem station is used to calculate arithmetic mean annual rainfall of the study area and is found to be 869mm. The calculated actual evapotranspiration value (based on long-term water balance approach) is 478.6mm. Comparison of rainfall and PET shows that rainfall exceeds PET only in the months of July and August.

The ground water condition of the catchment area is insignificant as is characterized by steep slope, thin weathered layer, and most fractures of the olivine basalt, which dominantly cover the catchment, are filled by calcite precipitates. According to the water chemistry analysis, most of the chemicals are with in the acceptable limits for potable, irrigation purposes except hardness, which can corrosion on steel pipes and concrete.

The computed average sediment yield of the catchment is 2,653.9 $t/km^2/yr$ as determined using the USLE and other empirical relations.

The Oda dam is located in seismically active zone the western margin of Afar depression and thus, the dam requires seismic resistant design. Land slide and shallow slope instabilities like rock fall, rockslide, debris slide etc. are common with in the catchment.

Engineering--geological mapping of the catchment and reservoir and dam foundation at a scale of 1:50,000 and 1:1000 are conducted respectively. Moreover, the reservoir and foundation materials are zoned and mapped depending on their permeability nature at a scale of 1:1000. Depending on the field and field-tests the soils and rocks of the study area are studied and characterized. From the three variant dam axis options proposed previously, the upstream dam axis option is selected by making certain shifts down stream ward by taking in to consideration the permeability, stability and reservoir water capacity aspects.

Relevant construction materials for the proposed dam type are assessed in terms of their quantity, suitability and proximity from the dam site as influences the safety and cost of the project.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Agriculture is one of the main activities in most developing countries like Ethiopia and plays a major role in economic development. Recent statistical data of the country depicts that more than 80% of the 60 million of Ethiopian people depend on subsistence farming. The living status of Ethiopians is below the standard as it is devastated by recurrent drought and severe land degradation for centuries in its history. For example, according to the Human Development Report 2000 (REST, 2000) Ethiopia is placed 171st of the 174 countries, with a purchasing power parting (P.P.P) of GDP per capita of $ 383 for females, and $764 for males. An estimated 75% of the people have no access to safe water supplies, 45% have no access to health services, and 81% have no access to sanitation facilities. These indicators give Ethiopia a poverty rating 53.3% on the Human poverty index. Only seven other countries, all but one of them in Africa, has a poverty rating of over 50%. The continuing level of chronic poverty is illustrated by the low life expectancy, 44.4% years for women and 42.5 years for men (REST, 2000).

Agriculture in particular has been severely affected for it is highly dependent on erratic and seasonal rainfall, environmental degradation and backward agricultural practices. Tigray where the dam site is located, in the northern Ethiopia, is one of the regions prone to recurrent drought and famine i.e. food insecure region. Thus, hunger is a continuous threat to many parts of Ethiopia in general and Tigray in particular; and the only way to wipe it is to step up agriculture by developing irrigation facilities and hence combating the repeated havoc caused by drought in the region. That is, water security has to come in the first place to achieve food security and other water related developments such as drinking, power generation, industrial activities and of course, many others.

The core policy of the present government of Ethiopia is based on agriculture led industrialization to improve the food security of the nation. Currently about 52% of its population are food unsecured (REST, 2000).

In a region like northern Ethiopia, which is characterized by the erratic and seasonal nature of rainfall, water security is almost impossible without introducing water harvesting structures such as dams, river diversion, boreholes, ponds etc. For developing countries like Ethiopia, which is totally dependent on water for meeting the food needs of the country, studying and construction of such water harvesting structures, especially dams for irrigation is extremely crucial. The role of Engineering-geology and geotechnics in this sector is very important. Engineering-geology deals with the geologic materials useful for either as a foundation or as a construction material for Engineering structures such as dams, roads/bridges, rail ways, multistory buildings, tunneling and other subsurface structures and geotechnic is a sub discipline of civil engineering that involves natural materials found close to the surface of the earth. Engineering geological research and mapping are therefore mainly directed towards the understanding and the interpretation of the relationship between the geological environment and engineering situation; the nature and relationship of the individual geological components; the active geodynamic processes and prognosis of processes likely to result from the changes being made (UNESCO, 1976).

Dam, that is vital for the storage of water that in turn is useful for irrigation, hydropower, water supply, requires a very detailed engineering-geological and geotechnical investigation.

Thus, engineering-geological/ geotechnical studies are useful to assess the project cost and safety of civil engineering structures and helps to select a technically feasible and appropriate methods of construction to ensure the longer span of the life of a given engineering structure. Engineering structures that lack the benefit of geologic input are likely to cost more than necessary, function below their expected optimum or fail all together (Johnson and Degraft, 1988).

At present the government of Ethiopia in general and that of Tigray in particular give a special attention to water resource development by studying, designing, and implementing the water harvesting structures such as dams, river diversion weirs, ponds, pumps, etc to enhance the agricultural production of the country. So far many small earth dams and river division weirs are constructed in the region for dry period irrigation purposes mainly by both Commission of Sustainable Agricultural and Environmental Rehabilitation for Tigray (CO- SAERT) and Relief Society of Tigray (REST). For instance, REST constructed about 10 dams and more than 15 river diversions and CO-SAERT constructed more than 40 dams and many river diversions. According to the preliminary investigations carried out in the failed dams in both Organizations, the major problem identified is found to be geological/Engineering geological. Depending on the unpublished reports written by REST study and design team and data obtained (in table form) from the study and design department of CO-

SAERT about 64.3% of the dams of REST and about 65.9 % of SAERT are failed in giving their intended objectives due to Engineering -geological and geological problems respectively (Table1.1 and table 1.2).

REST also conducted an integrated agricultural development study in the Raya valley, which is located in the southern zone of Tigray between the longitude 39^0 22' and 39^0 53'E and latitude 12^0 16' and 12^0 55' N which covers an area of 2430 km^2 (REST, 1997).

1.2 Objectives of the Research

The general Objectives are:

- To study the engineering characteristics of the rocks and their weathering products) at the catchment, at the foundation & reservoir of Oda, and determine the engineering-geological viability of the Oda dam Project.
- To provide geological, engineering geological and geo-technical data for the Oda dam project.

The specific Objectives:

The specific objectives of the research include:

- To produce Engineering Geological maps of the whole catchment area of the dam project at a scale of 1:50,000 and at a scales of 1:1000 for the reservoir and foundation by characterizing the rocks and soils according to their engineering geological and geotechnical behaviors.
- To assess the hydrological and hydro-geological conditions of the study area as these affect land use, planning, site selection, costs durability and even safety of the dam structure.
- To determine the quality of surface and ground water either for construction purpose or for irrigation.
- To assess the quality and proximity of the construction materials required for the proposed dam structure

1.3 Location and Accessibility

The dam project is located in northern Ethiopia, southern zone of Tigray region at about 70 km south of Maichew town, in Alamata wereda. The nearest town to the project area is the Alamata town situated on the Addis Ababa - Mekelle main road at about 600 km north of Addis Ababa. The Oda dam axis is found at about 5km south of Alamata and to the west of the Addis-Mekelle main road. Its geographical location is at

39^0 23' 18" to 39^0 32' 03" E longitude and12^0 21' 03" to 12^0 25' 53" N latitude. The total watershed area is $65km^2$ and has a very rugged topography and its catchment altitude ranges between 1600m to 3070 m.a.s.l. Access to the dam axis is possible only through a dry weather road along the Oda river channel, which is currently used for the haulage of local construction materials for a distance of about 4 km. However, the rest 800m - 1000 m (up to the dam axis) and the whole catchment is only accessed on foot by crossing ups and downs of the mountain, ridges, hills and gorges. Recently there is a rural road from Alamata town to Merewa village constructed by the local community but with out further maintenance it is very inconvenient to derive on (Fig. 1.1).

1.4. Review of the Previous Works

No work was done in engineering- geology and geotechnic aspects in Oda dam project (catchment, reservoir, and foundation) before 1996. However, REST conducted an integrated study in Raya-valley covering a catchment area of $2340km^2$ for the development of irrigated agriculture when the water supply for irrigation becomes a hot issue since 1996. The geotechnical part of the Raya-valley document identifies and studies seven dam sites, 11 river diversion weirs and 5 alternative weir sites, including the Oda dam site. This report focuses only on the dam site and reservoir areas with no much work on the catchment engineering- geology. Besides, detail geotechnical investigation was not conducted on the selected dam sites (REST, 1997). For the above reasons and other related siltation problems, none of the dams have been transferred into implementation stage so far.

Regional geology of the area is covered at a very small scale by many researchers and workers such as Mohre (1971; Zanetin and Justin (1974; Kazmin (1975); Zanetin, et al (1978; Mohre (1983), Ethiopian Flood Basalt Province; Zanetin (1992); and Pike, et al (1998).

(Fig. 1.1) Location map of the study area

1.5 Methods and Materials Used

The following methods and approaches are used to accomplish this research work. These include: preliminary office data collection using aerial photographs, topographic maps, geological and hydro geological map of the Raya valley and other existing literatures in the office, followed by two phase fieldworks. The first fieldwork was held from August 27/2002 to September 5/2002 and during this fieldwork, some preliminary geological mapping, geomorphological and land form assessment, digging of few test pits at the reservoir area and part of catchment area, soil sampling, field water quality analysis and water sampling were conducted. Then these data were analyzed, summarized, and interpreted at the preliminary phase and the remaining works are identified.

Based on the first phase analysis and results, a second fieldwork was conducted from February 22/2003 to March 20/2003. During which detailed geological, engineering- geological and/or geotechnical works were carried out at the reservoir, foundation, and catchment of the study area. These include detailed field description of soils and rocks, structural data measurements, digging additional test pits, conducting in-situ field permeability tests, unconfined strength of soils and rocks, and collecting rock samples and some additional soils for laboratory analysis of the geotechnical parameters. Many traverses were made along the complicated and rugged sites, rock and soil out crops of streams, ridges, and gullies in the field mapping and description of the geological materials at the area of interest. Finally, the collected data are processed and interpreted. Data processing and presentation were accomplished using different computer softwares such as MS word, MS excel (for synthesis and analysis of the different data collected), map digitizing and editing programs, using Auto CAD 2000 (for plotting of graphs and charts), and stereo for plotting rose diagrams.

The materials and equipments used during this research work include:

- Nineteen aerial photographs that cover the study area at a scale of 1:50,000.
- Two topographic maps (Alamata and Arteta sheets) at the scale of 1:50,000 and one topographic map of Maichew at a scale of 1:250,000 prepared by the Ethiopian Mapping Agency.
- Geographic positioning system (GPS).
- Portable PH, EC, and TDS meters (PH scan2 and TDS scan model).

- Photometer for field chemical analysis of some elements such as sulphate and PH.
- Pocket penetrometre for field determination of the strength of soils.
- Common geological instruments such as geological compass, hammer, meter tape (50m), sample bag for soil and rock sampling and plastic (one litre) for water sampling.
- Guelph permiametre for in-situ permeability test on the soil units.
- Schmidt hammer for determination of unconfined compressive strength of the rocks.
- Geological and hydro-geological map of the Raya valley project area prepared at a scale of 1:50,000.
- Computer, stereoscope, planimetere.
- Shovels, hoes, buckets during digging test pits.

CHAPTER TWO

GENERAL OVERVIEW OF THE PHYSIOGRAPHY AND CLIMATE OF THE AREA

2.1 General description of the study area

In a given catchment area the factors climate, geomorphology, land use, soil, and drainage are interrelated to other and their combination effect has great role in changing the engineering geological and geotechnical behaviors of the geologic materials that constitute the catchment area. Geomorphology is the science of the study of landforms and processes that create them (Coats, 1976) and is useful in evaluating geologic hazards (such as landslide, flooding, etc) and other environmental planning and management. Landform variations are associated with local and regional changes in earth materials, rainfall run-off and infiltration relationships, ground climate, and the nature and intensity of weathering eroding and transporting agencies (Wright, 1987).The land use of a catchment is dependant up on the existed land form, geomorphic processes and climatic factors. Vegetation and drainage conditions of the given catchment are also a good indicators of the the climatic, surface and subsurface geomorphic and geologic conditions of that particular area. Hence, most engineering structure requires at least some basic information about the above mentioned factors. Dam is one of the engineering structures that demand such information in an area. Thus, the brief description and study of geomorphology, climate, land use, vegetation cover, soil and drainage density of the study area are given below.

2.2 Climatic Characteristics

According to the World Metrological Organization (WMO), climate is defined as the synthesis of weather conditions in a given area, characterized by long-term statistics (variance, probability of extremes etc. of metrological elements in an area). The acceptable limit for long term climate is usually defined by statistics of 30 years series. The important elements of other climatic elements for both agricultural and hydrology are evaporation, temperature and precipitation (NEDECO, 1998).

The climate of Ethiopia ranges from equatorial desert to hot and cool steppe, from tropical Savanah and rain forest to warm temperate, and from hot low land to cool high lands (Tenalem and Tamiru, 2001). As part of the Ethiopian highland massifs, Tigray has generally a cool tropical semi-arid climate and is characterized by frequent drought. The length of crop growing period varies generally from 45 to 120 days (Marc Corbeels et al, 1998).

The climate of the study area is influenced by the physiographic position, distribution of rainfall, temperature, humidity and wind regime. The variations of climate during the year are largely associated with the macro level pressure changes and monsoon flows related to these changes (Griffiths, 1972). The seasonal rains of Ethiopia follow the movements of the Inter-tropical Convergence Zone (ITCZ), a zone at which north easterly and South Westerly trade winds meet together (Daniel Gemechu 1977, as cited in REST, 1997). The ITCZ is a wide zone characterized by relatively low surface pressures, rising air movement and convergence of air masses. In March, the ITCZ is located south of Ethiopia moving northwards. A low pressure system in Sudan and Arabia, a high pressure system over the Gulf of Aden and Indian Ocean develop the high pressure and this generates a moist and easterly air current over south eastern Ethiopia and these air masses produces a little rain from March to May in the study area. On the other hand, from June to early October the anticyclones over the Sudan and Arabia are replaced by the highest rainfall season (Kiremt) and these will appear over the country and these conditions are also true at the study area (REST, 1997).The traditional way of classifying climatic zones of Ethiopia depends on altitude, annual temperature, rainfall distribution and potential evapo-transpiration of the area (table2.1).

The altitude of the study area varies between 1600 m near the dam axis to 3076 m just at the water divides. Rainfall records are collected from National Metrological Services Agency (NAMSA) for the nearby stations Alamata and Korem (chapter four) as there is no station within the studied catchment.

Table 2.1 Ethiopian Climatic Zones (Daniel Gemechu, 1977, as Stated in REST 1997)

Altitude (m.a.s.l)	Annual Mean Temp. (^{0}C)	PET (cm)	Class Name (Traditional)
>3000	13-16	80	Alpine (Wirch)
2300-3000	16-20	80-110	Temperate (Dega)
1500-2300	20-24	110-125	Sub-tropical (Woina Dega)
800-1500	24-28	125-160	Tropical (Kolla)
<800	>28	>160	Desert (Berha)

The altitude of Alamata and dam axis, and the upper catchment and Korem stations respectively are similar. The mean annual rainfall of Alamata and Korem are 738.1 mm and 1002 mm respectively. Thus based on the above table the climate of the area varies between subtropical (woina-dega) to temperate (dega) but the area down stream of the dam axis (which is near to the irrigable land) is categorized as tropical (Kolla).

2.3 Geomorphologic Characteristics

The study area is situated in the northern part of the Northwestern (NW) Ethiopian plateau, which is characterized by two nearly parallel western and eastern horsts farming a graben (valley), called the Raya Valley in between. The two horsts are mainly composed of flood basalts (Ashengie, Aiba, Alaje Volcanic), while the valley is filled by thick Quaternary sediments. The Oda dam site is found at the western side of the valley, which is characterized by rounded ridge crests, severely dissected, steep-straight valley slopes and dry streams headed hollows, the catchment is deeply weathered basalts while the eastern side of the valley is still with rolling volcanic mountain ranges. Towns like Maichew and Korem are found at the top part of the western plateau and that of Chercher is at the eastern plateau of the valley while Alamata town is found within the valley just at the foot of the western plateau.

The study of geomorphology thus is based on the principle that all landforms can be related to a particular geologic process or sets of processes. For instance, the different landforms of the study area are the results of volcanism, tectonism and structure, which later further modified or obliterated by weathering and erosional processes. The geomorphic characteristic of the study area was interpreted from aerial photographs, topographic maps and field works. The main purposes of describing the geomorphology of the study area are:

- To determine the general landscape of the study area
- To visualize sedimentation, flood, landslide prone areas, which may cause problem to the dam site.
- To locate and map the potential area for construction materials

The different landforms of the study area are described as follows.

2.3.1 Land Form and Relief

Landform refers to one of the multitudinous features that takes together to make up the surface of the earth. It includes all broad features such as plain, plateau, mountain, hills, valleys, slope, canyon and alluvial fan where as relief refers to the difference in elevation between the high and low points of land surface.

For surface-engineering structures (dams, diversion weirs, roads, house construction (especially multistory buildings, quarrying, etc.), the study of engineering geomorphology has paramount importance because of the steepness of the slopes, slope instabilities, localized gully erosions, talus and screens and mud flows (Dearman, 1991).

The catchment of the Oda dam site is characterized by high relative relief, with a maximum basin relief of 1460 m. High relief results in very rapid erosion and consequent steep slopes. Slope category maps depict average inclination over an area and make it easier to perceive the distribution of steep slopes. Slope steepness has a considerable importance in land management; it frequently poses the restricting factor in route location, agriculture and urban development.

A slope map of the study area is prepared (fig 2.1). Three main types of landform characterize the Oda catchment namely, nearly flat to gently sloping (undulating), sloping to moderately steep (Hilly land) and steep to very steep land (Fig 2.2).

A. Nearly Flat to Gently Sloping (Undulating) Land: - this landform covers a very small area of 0.75 km^2 (1.2%) of the total catchment area localized here and there at the western side of watershed. It represents relatively flatter to gently slope areas of micro intermountain or hilly area. The elevation of this area varies between 2075 m to 2120 m having a relief intensity of 45 m. Grazing land is its main land use (fig. 2.3).

B. Sloping to Moderately Steep (Hilly) Land: - its aerial coverage is 48 km^2 (73.8%) of the total area of the watershed composing most part of the central and the right side of the catchment including the reservoir area. The main geomorphic units (landforms) encompassed here are volcanic hills of moderately steep slopes and rounded crests, active and/inactive flood plains, and sloping foot slopes. It is characterized by higher internal relief of 1130 m having a maximum spot height of 2470 m. This part of the catchment can be categorized in to moderately steep slope (8-15%), which comprises 18.23% of it, and sloping range (15-30%) composing of 81.77% of this landform. The moderately steep slope is found at the reservoir and in some places at some central part while the sloping one dominates the central and western part of the catchment. Its main land is grazing land, homestead and minor cultivated lands. The main geomorphologic processes prevailing here include erosion (both rill and gully erosion), small slides, weathering and undifferentiated (combination of various processes).

C. Steep to Very Steep Landform:- its aerial coverage is calculated to be 16.3 km2 (25%) of the total area of the catchment with a relief and maximum spot height of 1080 m and 3075 m respectively. It is situated in the northern and western side of the study area.

Fig 2.1 Slope map of the study area

Geomorphic processes such as weathering, erosion (rill, and gully), mass wasting (shallow slides, rock falls etc) and faulting are responsible for the present landscape of the area.

Depending on the slope ranges this area can be grouped in to steep (30-50%) and very steep (>50%) covering an area of 12.25 km^2 (78.5%) and 3.5km^2 (21.5%) of it respectively. The land use of the former is shrub land and that of the later is miscellaneous (rock out crop mostly).

2.3.2 Geomorphological Processes

The rate at which landforms change is extremely variable and affected by many influences of variable intensity. That is, there are a number of geomorphic processes responsible for the formation of the various geomorphic units. However, their dominancy on creating the landform varies from place to place. For instance, the most dominant geomorphic processes in the Oda dam catchment are weathering, erosion, mass wasting, volcanism and geologic structures (dykes and faulting) and their detail description is provided below.

A. Weathering: - is the process of alternating and breakdown of the rock and soil materials at and near the earth's surface by physical, chemical and biotic processes (Selby, 1991). Factors that can affect weathering are numerous; however, the main ones according to Spark (1960), Ollier (1975) and Selby (1993) are mineral compositions of rocks, textures and structures, climatic factors (Rainfall, Temperature, athers), relief and biological activities.

The study area is covered by basaltic rocks (alkaline, aphantic, and intercalation of scoraceous basalts) and very large part of the catchment is covered by alkali olivine basalt. This has been demonstrated by the mineralogical, geochemical and petrographical studies on the north western plateau that includes the Oda dam catchment and its surroundings by many researchers such as Pik et al (1998). The geochemical behavior of this alkaline olivine basalt is characterized by low silica and high magnesium and iron contents and according to order of minerals stability to chemical weathering susceptibility, olivine, augite plagioclase are the least stable minerals and highly affected by chemical weathering. Moreover, the olivine basalt of the catchment area is medium to coarser texture and is affected by jointing and these conditions are one of the favorable conditions for the existence of high weathering condition in the study area. This is because generally coarse grained minerals weather more rapidly than do fine grained types of similar mineralogical composition and the

Fig 2.2 Land Form and Relief

Presence of discontinuities represent planes of weakness along which weathering is concentrated (Bell, 1983). There is a deep weathering profile along the fractures/joints in the study area. Rock jointing (small, 1978) is a factor of the utmost importance in all types of weathering, for jointing has the effect of increasing greatly the area of rock surface which is available to be attacked by chemical processes, allowing the entrance of water and oxygen, and of providing lines of weakness which can be utilized by mechanical agents.

Climatic conditions determine the temperature and moisture regime in which weathering takes place. Under conditions of low rainfall, mechanical weathering is dominant and, therefore, combinations of particles occur, with little alteration of their composition (Selby, 1993). All types chemical weathering operate most effectively in a very warm climate (like the lower part of the catchment), and wet areas (relatively middle & upper section of the study area) for water is vital to chemical processes such as hydration, hydrolysis and carbonation. However, oxidation (chemical weathering) is only really effective above the water table, where the rock can be penetrated via joints and pores by atmospheric oxygen (Small, 1978). This type of chemical weathering prevails in the area of study as compared to the other types of chemical weathering, as it is easily detected by the changes of colors it induces, such as green, yellow, brown, purple, red are among the observed oxidation colors showing the different stages of chemical weathering of the olivine basalts by oxidation.

The other vital factor is relief, which is very essential in the Oda catchment in particular and the highlands in general. Renewal of the exposure of the live rock is essential to the continuation of mechanical weathering. As the relief and landform map of the study area depicts, it is highly characterized by mountains, hills, escarpments which favors the mass transportation processes such as land slides, soil creeps, and rock falls indicating mechanical weathering as the dominant one in the area. The high relief of the area allows existence of thin soil cover that does not hold water for longer time enhancing mechanical rather than chemical weathering and as a result coarser detritus (sands, gravels, boulders etc) dominate over the finer one at the foot of the slopes. However, chemical weathering is also important in the small plots of inter basin and lower parts of the catchment including the reservoir area which have relatively gentler slopes.

Other factors such as humidity, wind speed, biological (plants, and animals) and human interventions also have a considerable effect on the weathering of the materials found in the area of interest.

Several geomorphologists have attempted to set up a series of climatic regimes within the intensity and relative significance of the different geomorphic processes. There may well be a correlation of type and intensity of weathering with different climatic regions. For instance, in arid regions, whether hot or cold, there is likely to be less chemical weathering (Ollier, 1975).

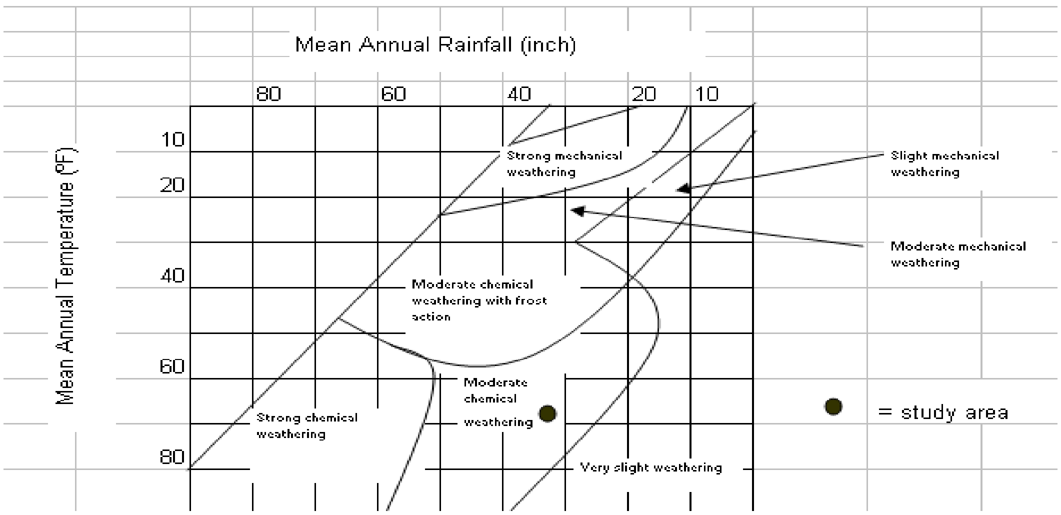


Fig 2.4 the relative importance of various types of weathering under diffrent temperature and rainfall conditions for the study area based on Pelier (1950) as cited in Ollier (1975)

B. Erosion:- is the detachment and removal of soil and rock by the action of running water, wind, flowing ice, and mass movement and the relationships between the factors which influence erosion is extremely complex (Selby, 1993).

Pelier (1950), as cited in Ollier (1975) indicated relation of climate to landforms also called climatomorphic regions and has also showed the importance of various types of weathering under various temperature and rainfall conditions (fig 2.4).

Erosion in general is a function of erosivity (potential ability to cause erosion) and erodibility (vulnerability of a geologic material to erosion). The magnitude of erosion processes in the Ethiopian highlands finds its cause in the combination of erosive rains, steep slopes due to the quick tectonic uplift during Pliocene and Pleistocene, and impact by deforestation, an agricultural system where the open field dominates, impoverishment of the farmers and stagnation of agricultural techniques (Stahl, 1974, 1990; as cited in Leuven, 2001).

The main causes of erosion in the study area are steep slopes, rain erosivity, material erodibility and human impact (deforestation and landegradation). As it can be seen from the slope map (fig.2.1), 88.46% of the total area of the catchment area is with slope of greater than 15% favoring high erosion.

High rain erosivity is an important factor in the highlands as in the case of Oda catchment. For example, data of automatic recorders installed in central Tigray during one year indicates that 65% to 77% of rain has intensity greater than 25 mm/hr (Hunting, 1976b). Also, Kraver (1988), (as cited in Leuven, 2001), obtained (from the rain data of six soil conservation research programs of Ethiopia): erosivity due to hailstorm is 2.5 times more important than erosivity due to rain. The other factors are the erodibility of the catchment geologic materials (soils and rocks) and the human impact such as deforestation. The basaltic materials that compose the catchment of the area of interest are (especially the alkali olivine basalt) easily detachable, fractured, jointed and vulnerable to erosion.

Wash erosion, rill erosion and gully erosions are the major erosional processes that are caused by the running water at the catchment of the study area. Wash erosions are those erosions that are caused by the overland flow. The quantity and size of the particles that can be transported by runoff are a function of velocity and turbulence; and these increases as slope steepness and depth of the flow increases. Most of the soil covers found with in the micro intermontane basins are formed by the wash erosion.

Rills are small channels with cross sectional dimensions of a few centimeters to a few tens of centimeters. They are usually discontinuous and may have no connection to a stream channel system (Selby, 1993). Most research on soil erosion in Ethiopia deals with sheet and rill erosion (Leuven, 2001). These rill erosions are one of the major agents for sediment transport on the sloppy and deforested catchment area of Oda. When master rill becomes deepened and widened it is called gully. Gullies are erosional features found in several part of the world and are most common in materials as deep loess, volcanic ejecta, alluvium, colluvium, gravels partly consolidated sands (Blong, 1970; Stocking, 1980), as cited in Selby (1993). Gully systems in Ethiopia can often be considered as discontinuous ephemeral streams (Bull, 1997) comprising a hill slope gully, an alluvial - colluvial cone at the foot of the hill and renewed incision with gully head formation further down slope in the valley vertisol (as cited in Leuven, 2001). This is the common features of Oda catchment

(Plate 1). Some of the gullies of Oda catchment are formed following the nearby E-W trending faults and lineaments.

C. Mass Wasting: - are the other common geomorphic process that have dissected steep slopes and produced high relief in the study area. These processes are common near the rift margin, which is tectonically and seismically very active.

So many varieties of earth materials and processes involve in mass movement and mostly result in different types of movements. Some of the major masses wasting processes in Oda dam catchment include rock falls, debris slide, soil fall (refer chapter six).

D. Volcanism (dykes) and Faulting: -Volcanic activity is one of the main processes that created the landform of the area which later was modified by younger processes such as faulting and the above mentioned geomorphological processes. As part of the Ethiopian rift margin, the topography of the area is affected by the NNW-SSE and NNE-SSW running fault sets and other minor fractures and joints, which are responsible for the formation of the different landforms, especially for the escarpment.

2.4 Soil

Soil is the end product of the processes of decay and decomposition of rocks on the surface under the influence of certain natural processes (Singh, 1997). At present several classification systems are available, each system serving to a particular objective i.e. for example, soil definition for engineering use is different from that of agricultural definition. Only the agricultural and hydrological definitions and use of soil will be dealt with here while the geotechnical aspect of soil will be discussed later in the respective chapters.

Soil type, texture, thickness and moisture content are some of the factors that can affect the hydrological (runoff, infiltration, evaporation, erosion condition) and vegetation of the catchment area. Based on the aerial photo interpretation and field survey, soil map for the study area is prepared so that it will be helpful in computing runoff, soil water holding capacity, and the actual evapotranspiration using the soil-water balance approach.

Generally speaking the catchment of Oda dam project is characterized by thin soil cover and most of them are residual soils (saprolite). Slope classes of greater than 35% have negligible soil cover, especially those lie between 40%-60% slopes are rocky exposure. Those parts of the catchment with slope classes less than 30% have thin cover (residual soils) to relatively thicker minor slope and river deposits at places just near the junctions of stream plains.

Gradation analysis of the soils is done in the laboratory and soils of the study area are classified using the textural classification chart (fig 2.6).

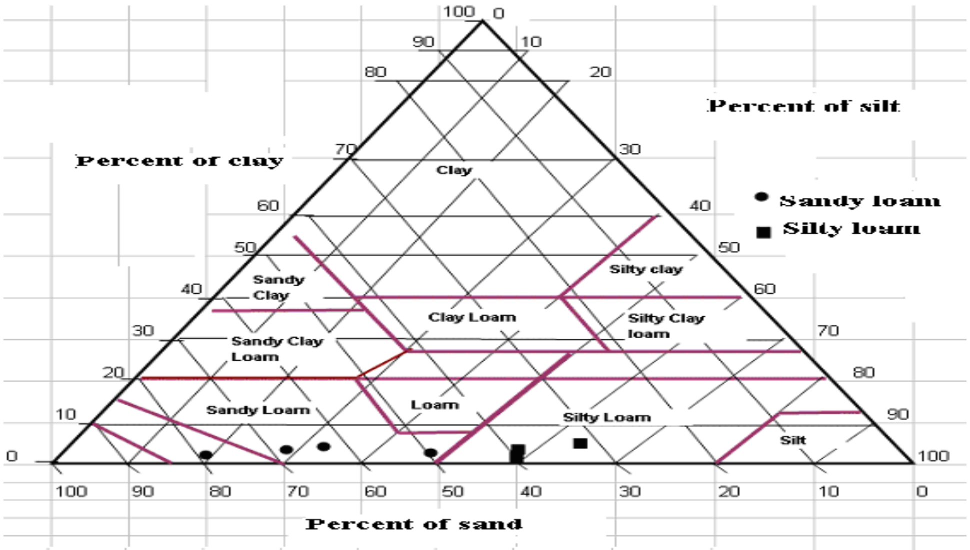


Fig 2.6 Textural classification of some of the Oda catchment

Generally, the soils of the Oda catchment can be grouped into two main groups, viz. silty loam, sandy loam, with a rock exposure at the relatively steep slopes (Map 2.5). The sandy loam covers most of the catchment area and is part of the residual while the silty loam covers the smallest area of the river flank and foot slopes.

Table 2.2 Summary of soils at Catchment

Soil Type	Averaget Soil depth
Sandy loam	25-50 cm
Silty loam	> 150 cm

2.5 Present Land Use and Land Cover

The assessment of land use of a specific project is essential to bring about an understanding of the relationships between given areas of land and specified land use. The main purpose of investigating land use here is to describe the existing hydrological processes (runoff, sedimentation, etc) that have an association with the reservoir area of the Oda dam. The main present land uses identified in the Oda watershed area are grazing land, shrub land, homestead and others (rock out crops, gullies, foot paths etc). Grazing land, categorized under different slope classes, is the major land use in the catchment covering nearly 5456.5 ha (83.9%) of the total land (Fig 2.3). However, this does not mean that this land is covered by grass only.

Fig 2.5 Soil map of the study area

It rather is covered by a mixture of grass and shrubs although grass is the dominant one especially at the lower class slopes.

The rest 16% is covered by shrubs (4.4%), Homestead (5.19%), cultivated land (1.83%) and miscellaneous (4.6%). The soil thickness at most of the shrub lands and some of the grazing lands is less or equal to 25 cm and the majority of the grazing land is with a soil thickness between 25 and 50 cm. Maximum soil thickness in the catchment, is observed at the flood plain, which includes both cultivated and grazing land (reservoir site).The different land uses with their respective slope classes are summarized in table 2. 3.

Table 2.3 the present land use classification of the Oda Catchment

No.	Land Use	Area (ha)	% Proportion	Slopes (%)					
				0-3	3-8	8-15	15-30	30-50	>50
1	Cultivated land	118.75	1.83	-	-	-	118.8	-	-
2	Grazing land	5456.5	83.9	25	50	525	4014	842.5	-
3	Shrub land	287.5	4.4	-	-	-	-	287.5	-
4	Homestead	337.5	5.2	-	-	-	312.5	25	-
5	Miscellaneous lands(dominantly rock outcrop)	300	4.6	-	-	-	-	-	300
	Total	6500	100						

2.6 Drainage Pattern and Vegetation Cover

The study area drains eastward from the northwest plateau to the depression as part of the Danakil area. The main Oda River meanders at the relatively gentler slopes while it possesses a dendritic type of drainage pattern at the higher slopes where the catchment is characterized by irregular landform.

Vegetation cover in the area in general is scarce as a result of intense human and livestock intervention. Scattered remnants of natural trees, shrubs, and grasses were observed on steep slopes of mountains, hills, gorges, gully sides and valley bottoms. Acacia is one of the dominant vegetation in the area. Structurally high and low shrubs invade and dominate the study area with few scattered trees both in the lowlands and highlands.

Fig 2.3 Present land use of the study area

CHAPTER THREE

GEOLOGY

3.1 Regional Geological Setting

The Oda catchment is situated in the plateau region of the northwestern Ethiopia, which is mainly covered by different volcanic rocks. Considerable geological works have been done on the Ethiopian volcanism by different workers, which mainly focus on the volcanic succession and tectonic events. Geochemical researches were also conducted more recently in the Ethiopian plateau volcanics. Some of the previous workers to be mentioned here are: Just in - Visentin and Zanetin (1974); Kazmin (1975, 1979); Zanetin et al (1978); Mohr (1983); Zanetin (1992); REST (1996); Pike et al (1998, 1999) and Dereje (2002).

Most of the Ethiopian plateau (including the study area) and the rift valley terrains are underlain by volcanic rocks. In Ethiopia, there is a huge volume of lava (about 350,000 km3) which forms a pile up to 2,000 m thick, and covers more than 600,000 km2 (Mohr and Zanetin, 1988, as cited in Pike et al, 1998).

The Ethiopian volcanics are divided in to two main series: (1) Trap (Plateau) series; and (2) Rift series (Zanetin, 1992). The term trap series is a collective name traditionally used for the pre-rift extrusive rocks. Although predominantly basaltic, they include major units of trachy-basalt, trachyte, some phonolite and quite large amount of rhyolite. The stratigraphy and other brief geological descriptions are given below.

3.1.1 Regional Stratigraphy

As part of the NW highlands, the type area and its vicinity is regionally mapped with in the geological map of Ethiopia (Scale: 1:2,000,000) compiled by Mengesha et al (1996). According to Zanetin et al [1978); Kazmin (1979) and Mohr (1983], the main formations that cover the type area in stratigraphic order are: Ashange formation, Aiba formation, Alaje formation and various quaternary sediments (fig**.** 3.1) for its simplified geological map and for its simplified stratigraphy.

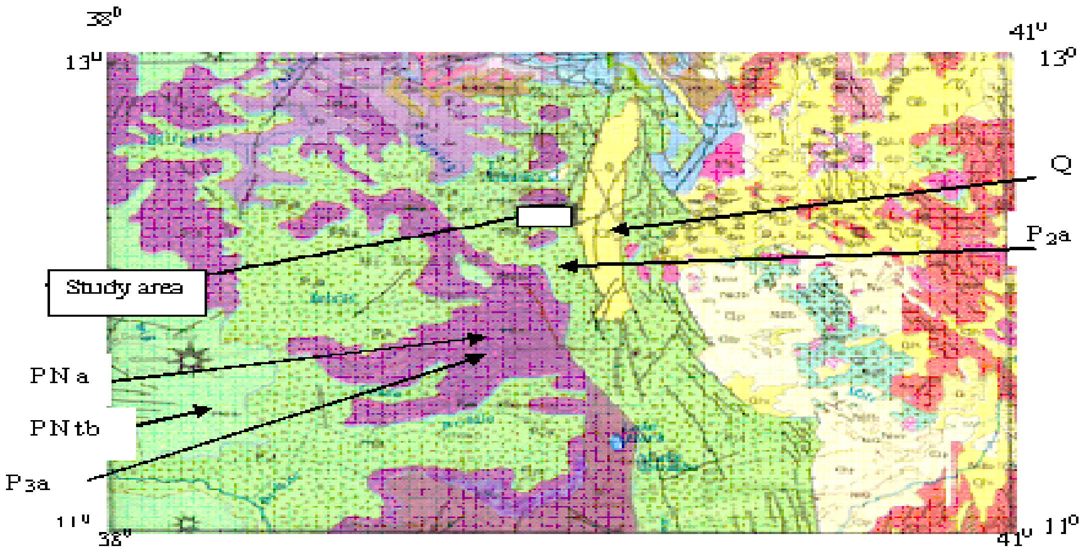


Fig 3.1 Simplified regional geological map of the study area and its vicinity(taken from the geological map of Ethiopia: Scale 1:2000,000).

LEGEND:

Q— Alluvial and lacustrine deposit
PNtb= TarmaberGussa formation: Alkaline to transitional basalt often forming shield volcanoes, trachyte and phenolite
PNa=Alaje formation: rhyolite; trachyte transitional and sub alkaline basalts
P3a= Aiba basalts: flood basalts with rare basic tuff
P2a=Ashengie formation: Deeply weathered alkaline and trasitional flows with rare intercalations of tuff, often tilted (includes Akobo basalts of SW Ethiopia.

A. Ashange Formations: - are the oldest basalts of Ethiopian plateau and are strongly weathered and are without clear stratification (Kazmin, 1979). They underlie the rest of the volcanic pile with the pre-Oligocene unconformity (Zanetin and Justine-Visentin 1973, 1974a, c and others as cited in Kazmin, 1979). These formations are basalts with transitional tholeitic affinities and/or alkaline basalts of low Al_2O_3 and high TiO2 emitted during the pre-Oligocene stage (Zanetin et al, 1978). Kazmin (1975) also states that the Ashange group is composed of predominantly alkaline basalt with interbeded pyroclasts. This is broadly classified into alkali olivine basalt and tuffs, rare rhyolites and dolerite sills. Their age is assumed to be in between 50(?) -35 Ma (Zanetin, 1992).

B. Aiba Formation: - represent the greater part of the flood basalt Pile over the northern part of the western plateau (Mohr, 1983). They are produced by fissure eruptions having a thickness range of 200 m-600 m and are compacted showing some stratification at places (Kazmin, 1979). The Aiba basalts, with 32-25 Ma age, are typical basalts, with very homogenous in composition (Zanetin 1992).

C. The Alaje Formations: - represent the inter-layered silicic rocks and transitional basalts, but some times only the silicic rock, mostly peralkaline rhyolites (Zanetin, 1992). These rocks are inter-bedded with lavas and agglomerates of basaltic composition and Oligocene in age.

D. Quaternary Deposits: - are those deposited during most recent geological time on top of the stratigraphic succession. According to the Ethiopian geological map and Kazmine (1975), Holocene undifferentiated alluvial, lacustrine are found at the Alamata - Kobo graben and on top of plateau of Lake Hashenge catchment. The sediments of the graben (valley) vary between gravelly silty sand to cobbles toward the foot of slopes and fine alluvium (silts, find sands, clays) at the central part of the valley.

3.1.2 Volcanism, Tectonic and Structure

The most important of the tectonic stages noted in the Ethiopian plateau have been tentatively correlated with the main episodes of the evolution of the Red sea and the Gulf of Aden (Zanetin and Justin-Visentin, 1975, in Zanetin et al, 1978).

According to Zanetin (1978), the information, which has been collected, would seem to indicate that the general evolution of the area studied has been controlled above all by the process of uplifting and up warping (Merla, 1963; Azzaroli, 1968, as cited in Zanetin et al 1978). At the beginning of each stage the volcanism occurred with in a large, elongated basin. Then, the outer part of the basin was uplifted and the volcanism died out on the uplifted area. In this way the escarpments formed and the volcanism was confined to the rifts. After wards, strips of the escarpments and the outer most zones of the rift were in their turn lifted up forming the intervening marginal gravens, and narrowing again the rift. One of these grabens is the Raya valley where the type area is situated. When termination of volcanism and tectonic events occurred, the plateau and escarpment underwent deep erosion.s to the geological structures of the study area are concerned, its over all picture is similar to the step fault scheme of western Afar margin (Zanetin et al 1992).

3.2 Geology of the Study Area and Its Vicinity

3.2.1 Lithology

According to the geological map of Ethiopia compiled by Mengesha et al (1996), the whole catchment area and its vicinity of Oda dam site is mapped as Ashangi formation, which is a deeply weathered alkaline and transitional basalt flow with rare intercalation of tuffs.

No geological map at a scale of 1:50,000 or more is produced for Oda catchment and its vicinity so far. Thus, in mapping the catchment area at a scale of 1:50,000, aerial photo and computer aided image interpretation, many field traverses across and along lithologies, following river and ridge exposures are made. Accordingly, four lithologic units and many lineaments (faults, dykes) are identified and mapped (fig.3.2). In the oda catchment and its vicinity the types of rock units identified and mapped are basaltic rock unit (dominant one), welded tuff, granodiorific intrusion (very small out crop), and Quaternary deposits. The catchment area is dominantly covered by the basaltic rock units followed by the welded tuff while the Quaternary deposits are found below the Oda dam axis covering the flat topography. Brief lithological descriptions of the units with in and around the Oda catchment are given below from top to bottom.

A. Quaternary Deposits: - these are recent deposits in the area and are largely located below the dam axis forming the plain areas. These Quaternary deposits are largely derived from the basaltic mountain ranges that are standing high on the shoulder of the valley and consist of piedmont deposit, young alluvium and channel deposits. As indicated in the hydrogeological report of the Raya Valley (REST, 1997), the geophysical and geological log of wells sunk in the basin depict that these sediments are composed of intercalating layers of gravel, gravely sands, silty sands, clay, silty and clay. The thickness of the sediments ranges from few meters to more than 250 m. The minimum thickness is found towards the foot of the slopes where as the maximum thickness is obtained at the central part of the valley. Coarser materials are found at and near the flank of the slope and decrease towards the center.

B. The Dioritic Units: - it outcrops in a small part of the central part of the Oda River (not mappable) and to the north of the reservoir area just on the water divides of Oda - Tengago catchments. This unit is negligible in terms of aerial coverage. It is slightly to medium weathered, jointed, and coarse grained in texture.

C. Welded Tuff: - Ash tuff is one of the pyroclastic materials that are consolidated. Pyroclastic material is classified primarily according to particle size. Particle size fragments between 2 to 64 mm in diameter are called lapilli while particles less than 2 mm are called ash and if greater than 64 mm, and if partly or wholly molten known as bombs otherwise we call them blocks if angular. Volcanic rocks that consist of ash and lapilli are known as tuff, ash tuff if they consist largely of ash and lapilli tuff if lapilli pre dominate (Williams et al, 1985).

These welded tuffs overlie the basaltic units of the study area and are found at the upper part of the catchment. This welded tuff is characterized by sparsely and scattered small sized lapilli (2 mm to 4 mm in diameter) through out the matrix of ash. It is silicic in composition, grey fresh color, compacted, hard and seems acidic lava flow. However, the vitroclastic texture and its transitions from firmly welded tuff in to less compacted porous tuff at its top and bottom part make it obvious pyroclastic origin. That is, the ash tuff is compacted and hard at its central part forming cliff topography and less compacted at the two ends forming a relatively gentler topography. It is horizontally bedded with a bed thickness of 2-4 m and is affected by widely spaced vertical joints besides bedding plane [See plate 13].

D. Basaltic Rock Units:-are the most abundant rock types found at the oda catchment and they exhibit different types of textures such as aphanitic, amygdaloidal and scoraceous. Generally these basaltic rock units can be grouped into alkali olivine basalts (medium to fine grained) and aphanitic basalts (fine grained basalts).

i. The alkaline olivine basalts are part of the Ashangi formation and are the dominant lithologic units with in the catchment of the study area. When they are examined on the outcrop and in hand specimen, they are medium to coarse-grained, easily friable and susceptible to weathering. They are medium to highly weathered and are also variably altered. As observed from the outcrops of the less weathered portion or at the insitu remnant boulders, phenocrysts of plagioclase and olivine are present in the black matrices.

These alkali olivine basalts are also affected by a number of systematic and non-systematic joints, which are filled by calcites. They have variegated color depending on the degree of weathering and contain some interintercations of agglomeratic or basic tuffs.

ii. The Aphanitic basalts - are fine grained basalts and occur as dikes, sills, cap rocks and the have variable trends. These types of basalts cover a minor part of the catchment and are highly jointed but less affected by weathering as compared to the alkaline olivine basalt in general. They are found capping or overlying the hills of the older and weathered alkali olivine basalt.The chemical and petrological composition of those alkaline olivine basalts (dominant part of Ashengie formation) have been studied by researchers. For example, few Oligocene samples from eastern border of the northwest (NW) Ethiopian plateau, in which the Oda dam project is situated, have been studied (Piccirillo et al, 1979; Mohr and Zanetin, 1988; Hart et al, 1989; as cited in pike et al, (1998). Basalts from eastern part of the northwest Ethiopian Plateau (Pike et al, 1998), in which the Oda catchment and its vicinity is located, consist of sub alkaline olivine-clino pyroxene porphyritic basalts with a microlitic texture (Olivine, clinopyroxene, Fe-Ti-oxides, plagioclase and scarce K-fieldspars).

3.2.2 Geological Structures

The engineering behavior of rock masses is highly influenced by the presence and nature of the geological structures. Structures make the rocks weak and unstable on one hand and permeable on the other hand. Thus, it is very vital to consider and study the nature and type of geological structures in any civil engineering projects. The geological structures of the study area are identified both from desk study using aerial photographs and followed by later field checks. Most of the larger geological structures traced from the aerial photographs are lineaments which could include dykes, fault scarps, straight streams etc but the smaller structures such as joints are described and measured during the fieldwork. The common geologic structures found in the study area are brittle type including faults and joints.

A. Joints

Joints are fractures along which little or no displacement has occurred and are present with in all types of rocks. At the surface, joints may open as a consequence of denudation, especially weathering (Bell, 1983). It has been observed that cuboidal, rectangular and columnar joints are more common in the igneous rocks. Further, there is more number of joints trending in several directions and these do not bear any systematic angular relation with each other [Gokhale, 1996].

The catchment, reservoir area and foundation area of the study area is covered by the volcanic rocks (basaltic and some tuffs) of variable degree of joints and weathering. The joints are both systematic and non-systematic types. The joints found with in the older and weathered alkali olivine rock are clearly identified at all places due to the intense weathering except at the less weathered outcrop while those joints found at the younger and fresh aphanitic basalts are clearly observable. Some columnar joints are also observed at the E-W trending basaltic dykes [Plate 14]. Many joint measurements are taken at the reservoir, foundation and other parts of the study area for the regularly oriented joint systems (table 3.2). The nature of the joint spacing in the basalt is not uniform everywhere. That is, the basaltic rock units are locally massive and affected by very widely spaced systematic joints while at places they are affected by closely to very closely spaced joints.

Fig 3.2 Geological map of the Oda catchment and its vicinity area

In this work more focus is given to the concentrated joints as engineering property of rocks (strength, deformation and permeability) are affected by these joints. Most of the joint sets on both the relatively fresh aphanitic basalts and alkali olivine basalts are very closely to closely spaced and narrow to very narrow while those joint sets on the felsic welded tuff vary between closely to widely spaced and very narrow to moderately narrow. However, joints sets found on the alkali olivine basalts are mostly filled by calcite filling while those joints on the aphanitic and felsic welded tuffs are mostly opened except that they are filled by loose sediments.

B. Faults

The study area is situated in the periphery of the NW part of the rift escarpment where it is affected by a series of faulting and other associated geological structures. In the study area it is too difficult to find fault kinematics indicators, slicken sides, crushed or sheared materials fault scarps etc as the area, is characterized by the intense weathering and erosion which is responsible for the rapid re-shaping of the fault indicators and transport the crushed materials down to the valley floor. However, some faults and/or lineaments are inferred and identified by the help of aerial photo, satellite image interpretation, field topographic and some remnant fault scarps (Fig 3.2). These inferred and identified faults variable trends but majority of them trend to the N-S, ENE, WSW and E-W (Table 3.2).

Table 3.2shows some of the measured orientation of the faults

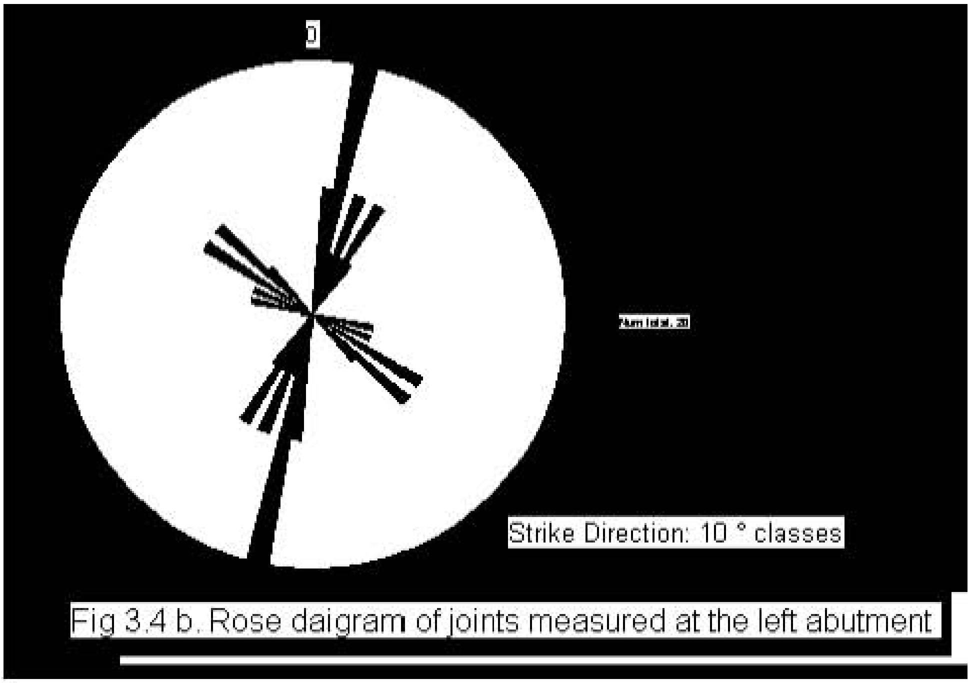
S/N	Location		Strike	Dip Amount
	Easting	Northing		
1	555086	1366642	N50E	Steeply dipping
2	557415	1367238	S40W	Steeply dipping
3	557415	1367238	S85W or W	Steeply dipping
4	557415	1367238	N80W or W	Steeply dipping
5	557415	1367238	N10E	Steeply dipping
6	557415	1367238	N-S	Steeply dipping
7	557544	1367354	N75^{0}E	Steeply dipping

Fig.3.3 Geological map of the reservoir and foundation area

Table 3.1 Joint Data Measured at Different Parts of the Study area

Location	Joint Set	Strike in Range	Dip Amount in Range	Dip Direction in Range	Spacing in Range	Opening in Range	Filling Materials	Description	Lithology
Right abetment (557826E 1366634N)	J1	290^0 to 350^0	75^0 to 90^0	20^0 to 80^0(NE)	2.5cm to 20cm	0.5mm to 10mm	Most of them are open	Very closely to closely spaced and moderately narrow to narrow	Aphanitic basalt
	J2	N10^0E to N40^0E	70^0 to 90^0	100^0 to 350^0 (SE)	5mm to 20cm	2mm to 10mm	Most of them opened	Very closely spaced to closely spaced, moderately narrow to narrow	
	J3	N45^0E to N80^0E	24^0 to 50^0	315^0 to 360^0 (NW)	3cm to 26cm	0.5mm to 4mm	Most of them opened	Very closely to closely spaced and narrow to very narrow	
Left abutment (557918E 1366828N)	J1	280^0 to 315^0	65^0 to 85^0	10^0 to 40^0 (NE)	4cm to 15cm	0.5mm to 2mm	Filled by calcite	Very closely to closely spaced and very narrow	Mediumly weathered alkaline basalt
	J2	N05^0E to 30^0E	60^0 to 90^0	275^0 to 300^0 (WNW)	3cm to 45cm	0.5mm to 5mm	Partially filled by calcite	Very closely spaced to medium spaced and narrow to very narrow	
Upper part of catchment (547602E 1368409N)	J1	N 200^0 to N 220^0	80^0 to 900^0	(SE)	5cm to 75cm	1mm to 1cm	Opened	Closely to widely spaced and very narrow to moderately narrow	Welded tuff
Left Side of Catchment (553889E 1369793N)	J1	305^0 to N-5 (360^0)	70^0 to 80^0	(215^0 to 270^0) (SE)	1cm to 25cm	0.1mm to 0.2mm	Opened	Very closely to moderately spaced and very narrow	Aphanitic basalt
	J2	N20^0E to N40^0E	38^0 to 45^0	120 to130^0 (SE)	1cm to 13cm	0.1 to 0.8mm	Opened	Very closely to closely spaced and very narrow	
Catchment area (557442E 1366394N)	J1	310 to 360^0 (N-S)	45^0 to 65^0	(WSW)	1mm to 3mm	0.1mm to 0.5mm	Filled by calcite	Very closely spaced and very narrow	Medium weathered alkaline olivine basalt
	J2	N40 to N75^0E	85^0 to 90^0	(NW)	1cm to 15cm	0.1mm to 0.5mm	Filled by calcite	Very closely to very closely and very narrow	

Fig 3.5 Rose diagram representation of joint measurements at the study area



3.3 Reservoir and Foundation Geology

The geological condition of the reservoir and foundation area is not different from that of the catchment area. The main litho logies found at the reservoir and dam foundation are the alkali olivine basalt the aphanitic basalt pediment deposits and colluvial and old and young river deposit starting from the oldest to the youngest. The bed rocks are well exposed at the two abutments of the dam foundation and reservoir area as well as at the central river channel at places and for this reason the locally available pediment and colluvial deposits

are not considered in the geological mapping of the reservoir and foundation area. Thus, only the alkali basalt and the aphanitic are mapped (Fig.3.3) at the geological map of the reservoir and foundation area.

The alkali olivine basalt are mainly exposed at the central part of the reservoir, dam foundation and reservoir rims while the aphanitic basalt are found at the right abutment where option-1 and option-2 of the dam axis begins,; at the left abutment where option-1 dam axis ends, as well as at the up stream part of the reservoir rims acting as cape rock. The pediment and colluvial deposits are found at depositional side of the meandering Oda river bank and the active river deposit which mostly are gravels and sands are found at central river channel. The se pediment and river deposit are described and mapped at the engineering geological map of the reservoir and foundation.

CHAPTER FOUR

HYDRO-METROLOGY

4.1 Hydro-metrology

Any water resource projects are influenced by the meteorological variables of the project area such as rainfall, temperature, humidity, etc. and these data are collected from the nearby stations of the study area and are analyzed and interpreted in relation to the surface and groundwater of the study area which all together affect the geo-technical and geological behavior of the study area. The locations of the metrological stations around the study area are given below.

Class	Station	Altitude (m asl)	Location	
			Latitude	Longitude
4	Alamata	1600	12^{0}31'	39^{0}39'
4	Korem	2460	12^{0}31'	39^{0}31'
1	Maichew	2410	12^{0}48'	39^{0}32'

Table 4.1 Adjacent meteorological stations of the study area.

4.2.1 Precipitation

Precipitation can be defined as the total amount of water falling from the atmosphere in the form of rain, snow, etc. on the earth and is measured in the form of depth of water occurred on horizontal land surface due to precipitation in a particular day, month or year (Suresh, 1997). The available rainfalls of the three nearby stations namely the Alamata, Korem and Maichew are compared with the location of the study area. Although the Maichew station is a class1 station and has a complete data it will not be considered directly here as it is far away from the study area. The mean monthly rainfall for the three stations is given below in *Table 4.2.*

Stations	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
Alamata	35.6	38.4	76.2	88.6	53.2	8.2	114	190.7	51.5	25.7	26.5	36.6	738.1
Korem	43.5	34.8	84.3	88.6	120.8	21.8	165.4	233.6	73.9	74.9	21.1	38.7	1002
AM	39.6	36.2	80.4	85.1	8.7	121.8	139.1	212.1	62.7	50.3	23.8	37.7	869.1

Table 4.2 mean monthly rainfall values of the Alamata and Korem stations (in mm). *AM - Arithmetic Mean

Here only the Korem (high land station) and the Alamata station (low land station) are considered, since the study area is located in between the two stations. An isohyetal map was produced for the whole Raya valley in 1996 by the project and this is used to calculate the mean areal rainfall of the Oda catchment (Table4:3) in comparison with the mean annual rainfall of the stations.

Zone	Isohyet (mm)	Mean Isohyet (p) (mm)	Area Enclosed between Isohyets (A) (Km^2)	P*a (mm km^2)
a_1	<800	750	0.735	551.3
a_2	800-900	850	13.72	11662
a_3	900-1000	950	30.62	29089
a_4	>1000	1000	19.9	19925
Total			65	61227.3

Table 4.3 *computation of mean areal rainfall of the Oda catchment from isohyetal maps*

From this table, the mean areal rainfall for the 65km^2 area is 942mm. This value is between what is calculated for the Korem station, from which Oda catchment is situated, and the arithmetic mean of the two stations. The rainfall pattern of the area is bimodal with small rainy season in the months of February to April and heavy rainy season in the months of July to September (Fig 4.1).

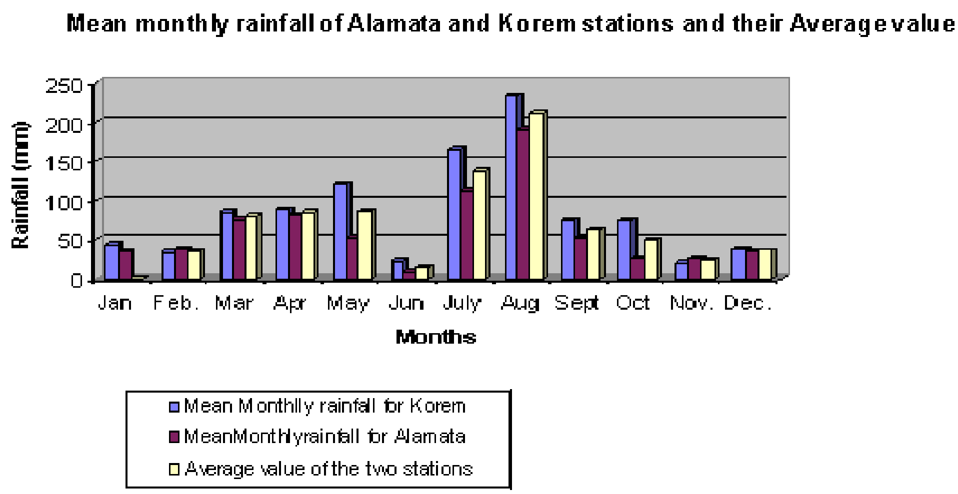


Fig 4.1Comparison of mean monthly rainfall value of both Alamata and Korem stations and their Arithmetic mean

As we can see from fig 4.1, the mean precipitation of the three months (March - May) and four months (July - October) covers 26% and 60% of the mean annual total precipitation of the Korem station while 32.3% and 52% of the mean annual precipitation is covered in the months of Feb - May and July to September respectively in the Alamata station. The peak mean monthly precipitation is recorded in the months of August in both stations while the mean minimum value is recorded at June and November for Alamata and Korem stations respectively (Table 4.2, and

Fig 4.1). Inter annual rain fall variation is also compared using the annual sum of each year and mean annual values for the two stations). The inter- annual rain fall variation in both stations are quite large i.e. the maximum values are 1421 mm in 1977 and 1067 mm in 2000 in Korem and Alamata stations respectively. While the minimum values are 366 mm in 1983 for Korem and 262.4 mm in 1984 for Alamata(see annex A).

4.2.2 Temperature, humidity, wind speed, and sunshine hours

Except rainfall and temperature data, there is no recorded data for other climatic data such as relative humidity, wind speed, sunshine hours in the mentioned two nearby stations. Thus, the data of these climatic parameters are taken from Maichew and other sources that are described in their respective topics.

A. Temperature:-highlands have lower temperature than lowlands. Although not a continuous record, 31 and 19 years of temperature data are available for the Alamata and Korem stations respectively. The temperature data recorded at both Korem and Alamata (Table 4.4) depicts that the Alamata station (lowland) has higher temperature record than Korem station (highland). The highest mean maximum temperature occurs in the months of May to July (31.89^{0}C - 34.3^{0}C) and the lowest mean minimum value occur in the months of November to January (8.4-^{0}C -9.1^{0}C) in the Alamata station. In the same manner, the Korem station has highest mean maximum temperature in the months of April to June (23.75^{0}C - 24.46^{0}C) and lowest values in the December to February (6.78^{0}C - 8^{0}C)

Station	**Temp**	**Months**											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
	MM Max. (^{0}C)	23.8	26.5	28.4	30	32.2	34.3	32	30.3	30.6	30.1	28.7	27.5
	MM Min. (^{0}C)	9	11.7	13.7	14.8	14.8	14.1	14.5	12.7	12.3	10.1	8.4	9.1
Alamata	Average	16.4	19	21.1	22.4	22.4	24.3	23.2	22.5	20	20.1	18.6	18.3
	MM Max. (0C)	20.6	27.9	22.3	23.9	23.8	24.5	21.9	22.6	23.2	22	20.1	20.6
	MM Min. (0C)	8	7.13	8.4	10.1	10.8	11	12.28	118	9.92	8.5	6.91	6.8
Korem	Aver-age	14.3	17.6	15.4	16.5	17.3	17.7	17.1	17.2	16.6	15.3	13.5	13.2
Average monthly temp. of the two stations		15.3	18.3	18.2	19.5	20.3	21.	20.15	19.85	18.3	17.7	16.1	15.8

MM Max.= Mean monthly maximum; MM Min. =mean monthly minimum

Table 4.4 Mean monthly maximum and average monthly temperature of the study area.

B. Relative Humidity: - A 7 years recorded data of relative humidity is found in the Maichew station. The mean monthly relative humidity varies from 45% to 65.9%

(Annex A). February and June are the driest months while March, April, July and August are most humid months of the year in the area.

C. Wind Speed: - is a very influential factor in several hydro-meteorological processes and it also affects the stability of engineering structures.A 9 years wind speed is recorded at the Maichew station. Analysis of these data shows that the mean monthly wind speed varies from 1.14m/sec to 3.45m/sec. According to the data, the months June, July and August are windy while November, December and January are less windy (Annex A).

D. Sunshine Hours: - monthly sunshine hours per day (Annex A) at the Maichew station ranges from 3.9 to 10.2 hours and its mean monthly values ranges from 4 to 7.86hrs. The months July to September have highest cloud cover while the rest months have more or less similar cloud cover and with the minimum cover occurring in the month of April**.**

4.2.3 Potential Evapotranspiration (PET)

PET has several importances such as calculating of the hydrologic losses, planning and design of irrigation schemes, determination of crop water requirement and irrigation scheduling, etc. Penman *(1955)* defined potential evapotranpiration (PET) as the amount of water transpired in unit time by a short green crop completely shading the ground of uniform height and never short of water.

The potential evapotranspiration of the study area is calculated using both Thornthwaite and Mather *(1957)* as cited in Dune and Leopold *(1978)* and using the modified Penman methods using wind speed, sunshine hours of both Korem and Alamata stations to compare the result with the actual site condition. The PET values of Thornthwaite are very much underestimated (table 4.5) and cannot represent the actual site condition and for this reason the modified Penman values are used to calculate the related parameters useful in the water balance of the Oda catchment. The monthly average values for the Penman PET are calculated using FAO (1995) CROPWAT software.

Method	Jan	Feb	Mar	Apr	May	Jun	Jul.	Aug	Sep	Oct	Nov	Dec	Annual
Thornthwait & Mather (1957) (mm)	46	65	65.9	78	85	92	84	81	68	50	50	48	824
Modified Penman (mm)	124	98	121	129	133	150	127	112	114	101	93	90	1392

Table 4.5 calculated potential evapotranspiration of the study area.

4.2.4 Actual Evapotranspiration

Actual Evapotranspiration (AET) is actual quantity of water evaporated by soil and transpired by plants and is usually equal or less than the potential evapotranspiration. In areas where no direct measurement of AET is possible, it can be calculated from the water balance equation of a system provided by other hydro-meteorological data that are available. In the Oda catchment case AET is calculated using a water balance model that requires the input of data such as precipitation, direct run off, crop coefficient, available capacity of root zone which in turn is related to the vegetation type (or root depth) and soil texture of the study area. The parameters vital for this purpose are taken from the land use and soil map of the study area (chapter - 2) in relation to the long term soil-water balance approach of Thornthwaith and Mather *(1957)* as cited in Dune and Leopold *(1978)* (Table 4.6).

Vegetation	Soil Texture	Available Water capacity (%)	Rooting Depth (m)	Available Capacity of Root Zone (mm)	Area Proportion	AET (mm)	Surplus (mm)
moderately Deep Rooted Cereals	Silty loam	20	1	200	0.02	566	144
Deep rooted Pasture Grain	Fine Sandy Loam	15	1	150	0.839	500	210
Deep Rooted Shrubs	Fine Sand loam	15	1	150	0.044	490	228
Deep Rooted Shrubs	Fine Sand	10	1	100	0.098	267	443
Weighted Average Value						478.6	232.5

Table 4.6 *Weight average values of AET and surplus in relation to the land use and soil texture, root depth etc. of the Oda catchment area.*

Table 4.7 *Summary of the weighted average long term monthly water balance of the study area.**all measurements are in (mm)

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
P	40	36	80	85	87	15	139	212	63	50	24	37	868
DRO	0	2	7	10	2	0	34	79	4	14	2	4	158
RPET	124	98	121	129	133	150	124	112	114	101	93	90	1392
CPET	25.	20.1		48.7	62.1	64.2	38.8	34	52.2	47.1	39.6	23.6	489.7
AET	25.	20.1	34.1	48.7	62.	56.9	38.5	34	52.2	46.6	36.8	23.4	478.5
S	1.7	8.1	37.9	26	23.	0	27.1	98	6.2	1.7	0.39	1.6	232.5
D	0	0	0	0	0	7.6	0.36	0	0	0.88	2.8	0.22	11.8
TAFR	6.1	10.9	6.1	47.4	46.3	23.1	11.2	112	62.1	32.3	16.5	9.9	420.4
RO	3.5	5.9	3.5	24.1	23.6	11.8	14.5	56	31.5	16.1	8.3	2.1	219.2

P-Precipitation DRO - Direct Run Off, REPT - Reference Potential Evapotranspiration, CEPT - Crop Potential Evapotranspiration, AET - Actual Evapotranspiration, D - Soil Moisture Deficit, S - Moisture Surplus, TAFR - Total Water Available for run off.

4.2.5 Surface Water Condition and Surface Runoff

Rainfall is the primary source of water for runoff generation over the land surface. Runoff is a collective name of water that drains across the basin into a stream channel as over land flow and ground water flow to a stream as base flow.

In the Oda catchment case there is no continuous base flow as the river is seasonal one, and for this reason only the surface runoff is considered. Surface runoff is that portion of rainfall, which enters the stream channels directly after the rainfall. The type of runoff and its volume resulting from a basin are mainly influenced by the climatic and physiographic factors (Suresh, 1997), which in turn includes several factors with in them and because of its dependency on several factors; it is quite difficult to determine the accurate runoff rate or volume from watershed area.

In the absence of a gauged station, a number of common methods are used to estimate the catchment field. The rational method is the commonly used method, which considers the runoff coefficient based on the characterization of the catchment by its land use, a slope and soil type (Suresh, 1997). That is:

$$R=C*A*P \qquad 4.1$$

Where R – catchment yield

P - 75% dependable rainfall

A - catchment area

C - runoff coefficient

And $$C=\sum_{i=1}^{n}\frac{c_i a_i}{A} \qquad 4.2$$

a_i = sub-area of catchment

c_i = runoff coefficient for each sub-area

A = total area of the catchment

Runoff coefficient is the ratio of peak runoff rate to rainfall intensity and its value varies from 0.05 for flat sandy areas to 0.95 for impervious urban areas. The land use, slope and soil types of the Oda catchment are provided on their respective chapters (Fig 2.2 and Fig 2.1). Based on this, the weighted average of the runoff coefficient of the study area is determined to be 0.3 (Table4.8).

Land Use	Class	Slope (%)	Area (a_i) (ha)	Dominant Soil texture	C	ci * ai
Cultivable Land	C_4	15-30	118.75	Silty Loom	0.7	83.
Grazing Land	G_1	0-3	25	Sandy Loom	0.1	2.5
	G_2	3-8	50	Sandy Loom	0.15	7.5
	G_3	8-15	525	Sandy Loom	0.5	262.5
	G_4	15-30	4014	Sandy Loom	0.22	883.1
	G_5	30-50	842.5	Sandy Loom	0.33	278.
Shrub	SL_5	30-50	287.5	Sandy Loom	0.35	100.7
Home Stead	H_4	15-30	312.5	Sandy Loom	0.4	125
	H_5	30-50	25	Sandy Loom	0.5	12.5
Rock Out Crop		>50	275	Hard Rock	0.85	233.8
Miscellaneous			25	Silty loom	0.2	5
Sum			6500			1993.6

Table 4.8 *runoff coefficient computation of the study area using the land use, soil texture and slope of the catchment*

The other variable to calculate the surface runoff of the study area is the 75% dependable rainfall. Dependable rainfall can be obtained by estimating respective rainfall data for dry years of 75% probable year by plotting probabilities from the annual rainfall records and fitting a long normal distribution of them. According to Suresh (1997), the frequency of a rainfall of a specified period is expressed in terms of recurrence interval, and is defined as the value, which is equal to or greater than the specified magnitude occurred in T years. That is,

$T = 1/P$ 4.3

Where, T = Recurrent Interval

P = is Probability of Events

If rainfall for few years is available, then the probability of the same condition for any particular year can be calculated as:

$P (\%) = m/n+1$ 4.4

Where m = rank of the event, arranged in descending order of their magnitude.

n = the total number of the years of rainfall record.

The amount of the rainfall corresponding to the 75% probability of exceedence is selected and the value of 75% dependable rainfall is used in place of historical mean rainfall to generate the surface catchment runoff.

The calculated 75% dependable rainfall (Table 4.8) of the Oda catchment is therefore 727mm. Thus, the catchment yield is computed using the equation (4.1) and is found to be 14 million cubic meter (MCM).

Year	Mean annual sum of the two stations	Descending Order	Rank(m)	P=m/(n+1)*100	T=1/p*100
1968	772.6	1421	1	3.7	27.00
1969	702	1170.7	2	7.4	13.50
1976	843.5	1143.5	3	11.11	9.00
1977	1421	1127.5	4	14.8	6.8
1978	6.39	1104.7	5	18.5	5.4
1979	940.5	1056.5	6	22.2	4.5
1980	927.5	1045.3	7	25.9	3.9
1981	1143.5	1012.8	8	29.6	3.4
1982	931.3	940.5	9	33.3	3.0
1983	476.9	931.3	10	37.0	2.7
1984	377	927.5	11	40.7	2.5
1985	511.8	876.6	12	44.4	2.3
1986	876	876	13	48.2	2.1
1987	807	867.1	14	51.9	1.9
1988	1127.5	858.8	15	55.6	1.8
1989	627.5	851	16	59.3	1.7
1992	1012.8	843.5	17	63	1.6
1993	851	807	18	66.7	1.5
1994	736	772.6	19	70.4	1.4
1995	1056.5	736	20	74.1	1.4
1996	1045.3	702	21	77.8	1.3
1997	858.8	639	22	81.5	1.2
1998	1170.7	627.5	23	85.2	1.2
1999	876.6	511.8	24	88.9	1.1
2000	1104.7	476.9	25	92.6	1.1
2001	867.1	377	26	96.3	1.0

Table 4.9 Computation of dependable rainfall of the study area using the least square method. The 75% dependable rainfall = 727mm; recurrent interval (T) for the 75% is dependable 1.34 years.

4.4 Ground Water

4.4.1 General

Hydrogeological conditions affect land use, planning, site selection and cost, durability and even the safety of structures (UNESCO, 1976). The term ground water is usually refers to water that occurs beneath the water table in soils and geologic formations that are fully saturated. The study of ground water must rest on an understanding of the subsurface water regime in a broader sense i.e. it also encompass the near surface, unsaturated soil moisture regime that plays such an important role in hydrologic cycle, and have important influence on many geologic process (Freeze and Cherry, 1979).

Hydro-geological study was conducted by REST (1997) on the Raya Valley to assess the ground water potential of the valley for irrigation purpose. This study mainly focuses on valley floor as it is filled by loos Quaternary deposits of good aquifer. The frame of the valley, in which the Oda catchment is found, is composed of volcanic rocks of negligible aquifer.

In this study, a simplified hydrogeological maps of the Oda catchment and its vicinity is prepared (Fig 4.3) from the regional hydrogeological map of the valley by making some simple modification as relevant to the study area. Broadly speaking the hydrogeological units of the valley can be grouped as alluvial aquifers (basin fill) and extremely low permeability volcanic rocks. According to REST (1997) the valley fills (alluvial aquifers) are further subdivided into three based on the water bearing characteristics of the geological units. These are given below.

4.4.2 Alluvial (valley fill) Aquifers

These alluvial aquifers are found at the flat area of the valley just down stream of the Oda dam axis. As observed from geological log boreholes sunk in the valley, these alluvial deposits are composed of inter calatating layers of gravel, gravelly sands, silty sands, silt clay, with increasing coarser materials towards the top (REST, 1997). Geophysical investigation done by the Ethiopian Geological Survey (1996) and German Consult (1976) in connection with the groundwater study indicates that the thickness of these sediments range from few meters to more than 250 m. The main hydrogeological units of the study area include the following.

(A) Colluvial and River Deposits (Qcol and Al)

(B) These are high productive aquifers and high ground water recharge zones. These units are mostly composed of coarser sediments ranging from silt gravel to pebbles and cobbles (REST, 1997).

The colluvial deposits (Qcol) are dominantly found at the foot of the scarps while the alluvial sediments (Al) occur at any section of the longitudinal profile of the stream and are also composed of coarser materials. Both zones are covered with these colluvial and alluvial sediments and are assumed to be high ground water recharge.

(B) Inter-fluvial, Fan foot plains and valley bottom (QSMS), intermediate ground water recharge zone

The QSMS unit is dominantly composed of sandy silty clay and mostly covers valley bottom of the major streams, and foot hills, adjacent to the colluvial and river deposits (REST, 1997). This is assumed to be intermediate recharge zone and relatively with a lower transmissivity zone.

The third units of this valley fill, which is not included in the hydro-geological map of the study area, are generally low recharge area.

4.4.3 Extremely low Permeability Volcanic

This unit is the major unit that constitutes the catchment area of the study area. Litho-logically, these units are composed of alkaline olivine basalts, aphanitic basalts and welded tuffs, and are characterized as follows:

Generally, knowledge of hard rock hydrogeology such as for the study area is vital to study the ground water conditions of the volcanic rocks. Hard rock is a very general and vague term for all igneous and metamorphic rocks (UNESCO, 1984). The common features of hard rock environment, designated as hydro-geological massifs, are vertical sequences of three zones, termed upper weathered, middle fractured, and lower massive (Krasny, 1996a) *as* sited in Trop and Roberts (2001). The transition zone between weathered layer and underlying fresh rock can function as a secondary good aquifer depending on the porosity of the zone (UNESCO). However, the areal extent and thickness of this transition zone (middle fractured) of the hard rock.

The thickness of weathered layers and the presence of permeable zone in it depend on the interplay of a number of factors, among which are climate, topographic positions, mineralogical composition and lithologic texture and the distribution and spacing of the fracture system in the host rock (UNESCO, 1984).

Although the upper weathered and middle fractured zones are present in the sections of the litho-logic units of the Oda catchment, their thickness and areal extent is very limited and less significant from hydrological point of view. This is due to the high local relief and high erosion rate prevailing in the study area. Weathered layers are commonly most extensive and thickest in erosional peneplains of low relief at or near base level where local relief is only a few meters and slope of land surface is less than 10% (UNESCO, 1984). However, the local relief of the study area ranges between 1600 m - 3076 m and has moderate steep to very steep slope which does not favor the formation of thick aquifer.

The other relevant factor with respect to the hydro-geological condition of the Oda catchment is the presence of fractures and joints. Joints opening, spacing, orientation and infilling materials are among the important joint parameters that determine the permeability of unweathered hard rock and hence many measured joint data at different parts of the catchment area are plotted on the rose diagram (chapter 3).

Joints found on the alkaline olivine basalts are mostly filled by calcite and these found on the aphanitic are dominantly open and closely spaced while those joints on the welded tuffs are widely spaced and open. Nevertheless, the areal extent and topographic position of the aphanitic, which acts as dikes, cape rocks, and the welded tuffs which are cliff forming are not suitable areas for the groundwater. In general, the above-mentioned conditions of the volcanics of the study area made them low permeability units. Therefore ground water in the Oda catchment is restricted to the local fracture zones (faults) and other lineaments.

Fig 4.3 Hydro geological map of the Oda catchment and its vicinity

4.4.4 Water Quality Analysis

The study of water chemistry is important not only from hydro-geological point of view but also from engineering point of view. Generally speaking water quality analysis can be done either in the view of practical use such as irrigation, portable water, industrial use and its effect on the decay of engineering materials, or it can be studied in the view of scientific use in the determination of sources of recharge, direction of flow and the presence of boundaries.

Water, be it on surface or underground of the study area are studied for their chemical and physical aspects focusing on their impact on the engineering structure (dam in this case), and other irrigation and portable suitability. With this in mind nine samples from the stream Oda, springs of the catchment area and boreholes are collected and analyzed in the central laboratory of the Geological survey of Ethiopia. Some parameters such as EC, TDS, and SO_4 are measured in the field to support and cross-check the laboratory result. Some physical data are taken from the studies made on the Raya valley previously.

A. The Physical Analysis: - comprise temperature, color, turbidity and taste. As the results of these physical tastes depicts all the water source found at or at the vicinity of Oda dam and the valley are with in the recommended limits when compared with the Ethiopian Standards(Table 4.10).

Criteria	Recommended Limits	Raya Valley (including Study Area Ground Water)
Color	20	Nil-35
Odour and taste	Non-objectionable	-
Turbidity	5	
Temperature	20^0c -25^0c	18^0c-28^0c

Table 4.10 Comparison of physical characteristic of Raya valley (including the study area) ground water with the recommended limits for drinking water (REST, 1997*)*.

B. Hydro Chemical Analysis

A laboratory hydro chemical analysis of major cations, electrical conductivity, Silica and PH, has been conducted for both the surface and ground water of the study area (table 4.11 and Fig 4.2). The main cations include Ca^{2+} and Mg^{2+} in which their concentration varies from42 mg/lit for Oda river (rain water) and 110 mg/lit for the Germile fracture spring of negligible discharge for Ca^{2+} and that of Mg^{2+} varies between 24 - 80 mg/lit for the same Oda river and same spring respectively. The next are Na^{+} (22-121mg/lit) for the same spring also, and the K^{+} (0.6 - 2.3mg/lit) for the boreholes found at the alluvial deposit of Alamata town and Oda river respectively. The dominant anions are the HCO3 whose value varies between 288mg/lit for Oda River and 694mg/lit for the Germile fracture spring, and SO4 with the value ranges between 13 to 68mg/lit for the same river and spring respectively.

From the table 4.11, the surface water and the spring that ooze from the alluvial soils of bank of Oda River have lower values as they are characterized by replenishment by rain water and are more or less with similar chemical variations. In the fracture springs (SS-2 and SS-3) the cations are in the order of Na>Ca>Mg>K and that of anions are HCO_3>SO_4>Cl>F (for SS-2) and HCO_3 >Cl>SO_4>NO_3>F (SS-3). Spring SS-2 has very low discharge (about 4-5 jars per day in the month of February) and the water is stagnated a hand dug pit with a negligible replenishment. This is why it has a little bit higher SO4, Cl etc than in other cases and the relatively higher (Na) in the group could most likely due to small clay development due to different weathering (cation exchange) at the fracture zones along which the spring originates and the alkali olivine basalt. In the case of the boreholes, the cation ranges in the order of Ca>Mg>Na>K and that of anions are HCO_3>Cl>SO_4>NO_3>F. The boreholes at the alluvial zones have higher Ca^{+2} and HCO_3 due to the dissociation of the calcite coatings present on the boulders and cobbles.

Therefore, the weathered basalt is the main sources for the SO_4 and Na ions in the area and the calcite precipitates from the fracture are the sources of the HCO_3 and Ca^{+2} ions in the area.

The NO_3 in the Germile fracture spring is a little bit high due to most probably the waste disposal of domestic animals around the spring.

Generally, all the results show that all the geometrical results are below the maximum permissible level according to the Ethiopian standard for drinking purpose.

Code	Sample Location	mg/l												Conductivity (ms/cm)
		Na	K	Ca	Mg	F	Cl	HCO_3	NO_3	SO_4	CO_2	SiO_2	TDS	
SS-1	Spring (alluvial)	31	2	43	26	0.43	18	317	2.66	16	26	39	456.1	532
SS-2	Spring (on basalt)	121	1.4	110	80	0.42	56	694	62.02	68	84	42	1193	1767
SS-3	Spring (basalt)	79	0.9	78	65	0.5	49	594	13.73	36	42	47	916	1048
SR-1	Oda Stream	23	2.1	49	24	0.33	11	289	2.66	15	18	34	416.1	484
SR-2	Oda Stream	22	2.3	45	23	0.36	12	288	2.66	13	11	36	408.3	484
SR-3	Oda Stream	31	1.4	42	24	0.37	10	268	3.1	16		41	206.9	456
BH-1	Airport Borehole	70	2	95	85	0.39	135	499	18.61	58	50	66	963	1209
BH-2	Kajima Borehole	27	1.1	62	33	0.28	26	356	20.04	24	80	56	529.7	647
BH-3	Alamata town Borehole	33	0.6	82	34	0.29	16	410	11.52	13	48	56	600.4	663

Table 4.11 (a) *summary of major cations and anions analysis of surface and ground water in the study area*

The analysis of the laboratory works are represented graphically (Fig 4.2) using the piper diagram.

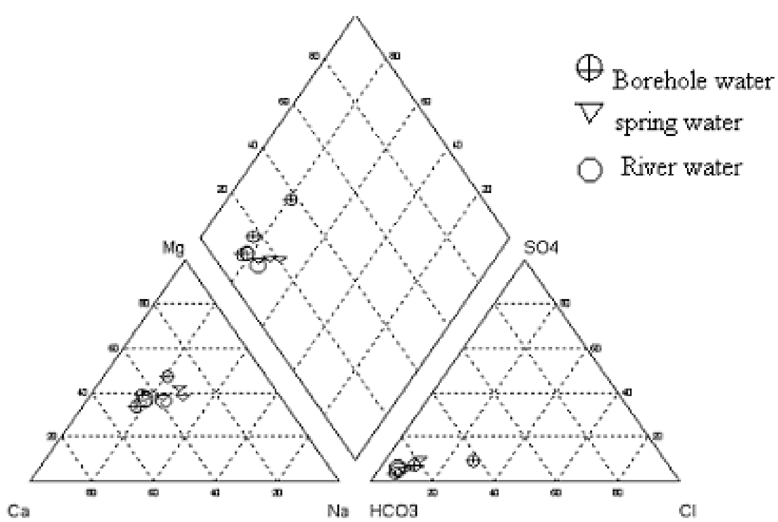


Fig 4. 2 piper diagram of water samples of the area

Code	%Na	SAR (meg/lit)	PH	Total Hardness $CaCO_3$ (mg/lit)	Water Type
SS-1	26	0.92	7.65	214.2	Ca-Mg-Na-HCO_3
SS-2	35.5	2.14	7.53	603	Ca-Mg-Na-HCO_3
SS-3	27	1.6	7.78	462	Mg-Ca-Na-HCO_3
SR-1	19.3	0.67	7.81	221	Ca-Mg -HCO_3
SR-2	19.7	0.67	7.71	207	Ca-Mg -HCO_3
SR-3	25.3	0.95	8.29	203.5	Ca-Mg-Na-HCO_3
BH-1	20.8	1.26	7.58	586.7	Ca-Mg-Na-HCO_3
BH-2	17	0.69	7.13	290.4	Ca-Mg -HCO_3
BH-3	17	0.77	7.49	344.5	Ca-Mg -HCO_3

Table 4.11 (b) *summary of the result % Na, SAR, Total hardness, PH and determination of the water type of the study area.*

4.4.2 Suitability of Water for Different Purposes

Conceptually water quality refers to the characteristics of water supply that will influence its stability for specific use *(JAICA, 2002).* For instance water that is suitably used for irrigation may, because of its sediment load, be unacceptable for domestic use without treatment to remove the sediment; and similarly fresh ground water of good quality can be appropriate for domestic use but may be either corrosive for industrial use without treatment to reduce its undesired effects. Thus, the quality required for water supply depends on its purpose.

Water can have two general impacts on engineering structures and materials. That is either it reduces its strength by decaying, corrosion, etc. or it affects its stability by exerting forces on the engineering structure. The geo-technical decaying of materials by water is mainly caused by the chemistry of water. Thus, the theme of the discussion here is, only the chemistry of water pertinent to the decaying effect of the geo-technical materials (concrete, mortar, steel, etc.) that could be used in construction of the dam body, canals, spill ways, etc.

Acidic water (PH<7), in organic acids and their solutions), acidic salts and their solutions, water containing alkaline bases (if PH>9), and salts that leach out or dissolve, causes decomposition *(Rethati, 1983),* which finally will result in the failure of the engineering structure. Water that possess excess of PH, hardness, TDS, Chlorine (Cl) causes corrosion, scale deposition, staining, etc. on water pipes and other structures.

For example, the limit of the pH and CO_2 attacks on concrete is given in Table 4.11.

Degree of Attack	Sulfate in Water (Mg/Lit)
Negligible	0-150
Positive	150-1000
Considerable	1000-2000
Severe	>2000

Table4.12 (a) *Effects of sulphate on concrete (Hunt, 1984).*

Degree of Aggressiveness	pH	Aggressive CO_2 (mg/lit)
Neutral	6.5	>15
Week	6.5-5.5	15-30
Strong	5.5-4.5	30-60
Very Strong	<4.5	>60

Table4. 12 (b) *Effects of aggressive CO_2 on concrete (Hunt, 1984).*

Hardness, mg/l as $CaCO_3$	*Water class*
0-75	*Soft*
75-150	*Moderately hard*
150-300	*Hard*
Over 300	*Very hard*

Table4.12 (c) Hardness classification of water (after Sawyer and McCarty) as cited in Todd (1980)

According to the hydro-chemical analysis (Table 4.11a) conducted on both the surface and ground water of the area, most of the chemicals are with in the acceptable limits except hardness which may cause corrosion to water pipes. Therefore, if there is a need to use steel pipes for canal, care should be taken in designing and selecting of the pipes. The CO_2 values of all the boreholes and springs are with in the strong aggressive nature indicating a careful design analysis should be carried out.

The other thing that is considered in this hydro-chemical analysis is to check the suitability of the waters for irrigation as well as drinking purpose. The suitability of water for irrigation is contingent on the effects of the mineral constituents of the water on both the plant and the soil. Effects of salts on soils, causing changes in soil structure, permeability, aeration, indirect affect on plant growth *(Todd, 1980).* It is so difficult to put exact limits of permissible salt concentrations for irrigation water as various crops have different salinity tolerances. Another factor that affects irrigation water salinity is the soil chemistry and drainage condition. Although the water to be supplied for the irrigable land is of good quality, salinity problem may prevail in the irrigation field if no proper drainage and/or if the soils at the command area have saline nature.

In assessing and classifying water for irrigation suitability, specific condition (expressed in TDS) and sodium contents are the most important factors that should be considered. Excess sodium in irrigation water relative to calcium and magnesium or relative to the total soluble salt content can adversely affect soil structure and reduce the rate at which water moves into and through the soil (infiltration, permeability), as well as reduce soil aeration *(JAICA, 2002).* The magnitude of the effect of excess sodium can be related to the relative proportion of sodium ions and calcium plus magnesium ions in the irrigation water. According to the U.S. Department of Agriculture, the above relationship can be expressed by the sodium absorption ratio (SAR).

$$SAR = \frac{Na}{\sqrt{0.5(Ca + Mg)}} \qquad 4.1$$

where the concentration of the components are expressed in Meq/lit.

The classification of SAR in terms of suitability is tabulated below (REST, 1997).

SAR	Class
<10	Excellent
10-18	Good
18-26	Fair
>26	Poor

Table 4.13 Classification of SAR values in terms of suitability for irrigation. (After Todd, 1980)

When the results of analyzed results, (Table 4.11 (b)) are compared based onTable 4.13**,** the waters of the study area are excellently suitable for irrigation. However, it is hard water and therefore needs treatment (softening) as it can cause corrosion or encrustation for water pipes.

CHAPTER FIVE

ESTIMATION OF CATCHMENT SOIL LOSS AND RESERVOIR SEDIMENTATION

5.1General

For design of reservoirs and channels, the knowledge of sediment yield of the catchment area associated is most essential, as deposition of sediments in storage area of the reservoir and over the channel bed, reduces their net capacity, as a result the life of the structure gets reduced (Suresh, 1997). This in turn is related to the economic life of the project.

The various sources of sediments such as erosion from catchment area, soil movements by mass wasting processes are considered in chapter 2. The watershed characteristics of the study area that include catchment size, soil type, slope, land use, geology, etc (refer chapter 2) and climatic characteristics like rainfall, temperature, etc (chapter 4) which can affect soil loss and sedimentation processes are described. The best way to estimate soil loss and sedimentation of a watershed is to conduct field measurement during the various rainy seasons which in fact could not be done here due to the limit of time and nature of the work itself. Thus the approach followed here is to characterize the catchment of the study area in terms of the above mentioned factors and to correlate with different sedimentation studies carried out in the highland of Ethiopia, though limited, and other developed conventional methods.

Sedimentation fluctuates widely from nearly zero during the dry season to extremely large quantity during major floods. The flash floods carry with them the bulk of annual sediment load composed of bed and suspended loads (REST, 1997).

Sediment concentration is not available for Oda stream in particular and other streams in the Raya Valley in general as is the case in most part of Ethiopia. In such cases, as also mentioned in REST (1997), the total sediment transport of a stream could be estimated from similar watersheds whose sediment transports have been previously determined from suspended sediment load data or from studies of reservoir sediment accumulation. Some of the important computed sediment budgets in different parts of Ethiopia by different workers are given below.

1. Hunting (1976), as also stated in NEDECO (1998); REST (1997); Leuven (2001); executes the specific suspended sediment yield for Mesanu river near May Dollo (catchment area of 139 km^2) and for Belt Creek (with catchment area of 14.2 km^2)

which both are located near Mekelle, found to be 1700 t/km²/yr and 3000 t/km²/yr respectively based on the study conducted from June to September 1975.

2. NEDCO (1998) estimated the average specific sediment yield of Tekeze basin (includes Tekeze, Angereb & Guang river catchments) as deduced from the Khasm el Girba reservoir area. Higher sediment yield is expected up stream with in the Tekeze basin itself. For example Hamphreys et al (1996) calculated the yield to be 1,200 t/km²/yr; NEDECO (1998): also found the sediment yield in the order of 1,081 t/km²/yr based on the measurements in Tekeze at Embamadre in 1996. The following is a table that shows the sediment yield estimated for the proposed dam sites at the different tributaries of Tekeze basin.

Table 5.1 Estimated Sediment Yield for the Proposed Dam Sites

Dam Sites	River	Town Nearby	CA (Km²)	Altitude of bed (m)	Highest Altitude (m)	Altitude Diff. (m)	Length of Main river (m)	Slope	Annual Sediment Yield		
									Sus. Ld (t/km²)	Sus. Bed Ld (t/km²)	Annual Vol. (Mm³)
1	Mariam Shewito	Adua	60	2000	2350	350	12.5	2.80	1300	1625	0.07
3	Tekeze	Sokota	10236	1250	3500	2250	219	1.03	1200	1500	10.59
4	Tekeze	Sekota	19555	1150	4000	2850	294	0.97	1200	1500	20.23
5	Tekeze	Yechila	29693	990	4000	3010	319	0.94	1100	1375	28.16
6	Tekeze	Yechila	36891	980	4000	3020	366	0.83	1100	1375	34.98
7	Tekeze	E/madre	47723	830	4000	3170	449	0.71	1000	1250	41.14
12	Tserare	Sokota	2474	1350	3500	2150	64	3.36	1400	1750	2.99
16	Guang	Shedi	1532	950	2000	1050	80	1.31	1000	1250	1.32
21	Angereb	Abdurafi	4318	740	2950	2210	146	1.51	1000	1250	3.72
23	Mesanu	Mekelle	143	2080	2500	420	15	2.80	1500	1875	0.18
25	Giba	Mekelle	1729	1750	2750	1000	70	1.43	1400	1750	2.09

Note: Sus. Ld= Suspended load; Sus. Bed Ld=Suspended bed load

3. Humphreys et al (1996), estimated the specific sediment yield of Abay basin just where the Abay passes the Ethiopian border, it was found in the order of 680t/km²/year which is less than that of Tekeze, and this calculation is based on Roseires dam measurements. According to NEDECO (1998), the reason why the specific sediment yield of Abay basin is less than that of Tekeze is due to the existing of more vegetation cover in the Abay basin and the different geological coverage of the two basins.

4. As stated in REST (1997), the sediment load rates of the existing Koka dam (catchment area of 4050 km2) and Legedadi reservoirs from their catchments were

estimated to be in the range of 2000 to 2200 $t/km^2/yr$. Related studies show that sediment inflow to the existing reservoir in the country ranges between 1200$t/km^2/yr$ and 2400 $t/km^2/yr$.

It is difficult to compare the Oda catchment with other catchment areas unless all variables that affects the catchement areas known. However, it is possible to correlate with any of the catchment areas mentioned in table 5.1, if the characteristics of the catchments are known. The other option to correlate them is using the empirical relationship that considers only the area-sediment yield relationship.

5.2 Estimation of Catchment Soil Loss Using the Universal Soil Loss Equation Approach

Early estimates of soil loss were primarily qualitative and were supported by a single variable equation. Through time multiple factor equations were developed as researchers came with more and reliable data. These analyses cumulated in the equation most widely used today for soil loss prediction - the sediment budgets, i.e. detailed account of the sources and deposition as it travels from its point of origin to its eventual exit from a drainage basin (Reid and Dunn, 1996), were never established for the Ethiopian Highlands (Cited in Leuven, 2001).

One of the recently and widely used methods developed to estimate the long term average annual loss of soil from a catchment is the universal soil loss equation (USLE) which includes the watershed parameters that affect soil loss such as soil erodibility, rainfall erosivity, scope length and gradient, cropping management and the erosion control practices. All the above soil loss parameters of the Oda catchment area is characterized and determined in their respective chapters. The values for each factor are computed. Tables 5.3 & 5.4 using the equation:

$$A = RKLSCP \qquad (5.1)$$

Where A = the soil loss, t/ha/yr

R = rainfall erosivity factor

K = the soil erodiability factor

L = the slope length factor

S = the slope gradient factor

C = the cropping management factor, and

P = the erosion control practice factor

The brief description of the terms used in USLE based on Kirkby and Morgan (1980) is given is given as follows:

- The rainfall erosivity Factor (R) - is the product of two rainstorm characteristics namely the kinetic energy and the maximum intensity.
- The soil erodibility Factor (K) - is the quantitative description of inherent erodibilty of particular soil. This factor reflects the fact that different soils erode at different rates when other factors that affect erosion are the same.
- The slope length factor (L) and the slope gradient factor (S) – the slope length is the distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur or to the point where runoff enters defined channel whereas the slope gradient (S) is the effect of slope steepness or gradient.
- The cropping management factor(C)- represents the ratio of soil loss from a specific cropping or cover condition to the soil loss from a tilled, continuous fallow condition for the same soil and slo[p and for the same rain fall.
- The erosion control practice (P) – is the ratio of soil loss using the specific practice compared with the soil loss using up and down hill culture.

Some of the limitations of the USLE are:

- Its application to specific year or storm is not appropriate because it only estimates the longterm average annual soil loss.
- It does not consider gully erosion

Although it has the above limitations the USLE can be adopted for soil loss estimation in many parts of the world with certain local modifications. For example, the following is developed for Ethiopian cases.

Table 5.2 The USLE adapted for Ethiopia (Hurni, 1985) (R in Jem $m^{-2}ha^{-1}y^{-1}$, k also in SI-units, following the Wischmeier & Smith's (1978) conversion coefficients.

THE UNIVERSAL SOIL LOSS EQUATION (USLE) ADAPTED FOR ETHIOPIA

EQUATION: A=R*K*L*S*C*P (TONS PER HA PER YEAR)

1. R: RAINFALL EROSIVITY

ANNUAL RAINFALL (mm)	100	200	400	800	1200	1600	2000	2400
ANNUAL FACTOR R	48	104	217	441	666	890	1115	1340

2. K:SOIL ERODIBILITY

SOIL COLOUR	BLACK	BROWN	RED	YELLOW
FACTOR	0.15	0.20	0.25	0.30

3. L: SLOPE LENGTH

LENGTH (m)	5	10	20	40	80	16	240	320
FACTOR	0.5	0.7	1.0	1.4	1.9	2.7	3.2	3.8

4. S: SLOPE GRADIENT

SLOPE (%)		5	10	15	20	30	40	50	60
FACTOR	0.4	1.0	1.6	2.2	3.00	3.8	4.3	4.8	

5. C: LAND COVER

DENSE FOREST:	0.001	DENSE GRASS:	0.01
OTHER FOREST:	SEE GRASS	DEGRADEDGRASS:	0.05
BADLANDS HARD:	0.05	FALLOW HARD:	0.05
BADLAND SOFT:	0.40	FALLOW PLOUGHED:	0.06
SORGHUM, MAIZE:	0.10	ETHIOPIAN TEFF:	0.25
CEREAL S/PULSES:	0.15	CONTINOUS FALLOW:	1.00

6. P.MANAGEMENT FACTOR

PLOUGHING UP AND DOWN:	1.00		
STRIP CROPPING:	0.80	PLOUGHING ON CONTOUR:	0.90
APPLYING MULCH:	0.60	INTERCROPPING	0.80
STONE COVER 80%:	0.50	DENSE INTERCROPPING:	0.70
STONE COVER 40%:	0.40		

Source: Leuven (2001)

Table 5.3 Calculated values for the parameters used in soil loss equation.

Land Use	Rainfall (mm)	Soil color	Slope Length (m)	Slope (%)	Land Cover	Land Management
C_4	869	Brow	250	15	Sorghum and Maize	Ploughing on contour
G_1a	869	Brow	500	3	Degraded grass	40% stone cover
G_2	869	Brow	250	6	Degraded grass	40% stone cover
G_3a	869	Brow	900	10	Degraded grass	40% stone cover
G_3b	869	Red	200	10	Degraded grass	80% stone cover
G_4	869	Red	1600	25	Degraded grass	40% stone cover
G_5a	869	Red	2000	35	Degraded grass	40% stone cover
G_5b	869	Red	713	35	Degraded grass	40% stone cover
SL_5a	869	Red	625	35	Dense forest	40% stone cover
SL_5a	869	Red	500	35	Dense forest	40% stone cover
H_4a	869	Brown	500	20	-	80% stone cover
H_4b	869	Red	550	20	-	80% stone cover
H_5a	869	Red	150	10	-	80% stone cover
M_6	869	Red	750	55	-	-

As indicated in table 5.5, the total annual soil loss from the Oda catchment is 634,294.30 tons and out of this 75.9% (475,720.70 tons) is lost from the grazing land, and 23% (145,887.7 tons) is lost from the homestead while the remaining is lost from the cultivated and shrub lands.

However, the USLE only considers for the sheet and rill erosions but not gully erosion, which is a common feature in the oda catchment. That is, the drainage ways, which come through the slope deposites of the oda catchment, are highly affected by active gully (plate 1) erosion which is 4-6m deep. Therefore, from the actual observation of catchment condition, the soil loss is expected to be more than the computed value.

Land Use	Area (ha)	Slope (%)	Factor						Soil loss Per (ha)	Total (Tons)
			R	K	L	S	C	P		
C4	118.75	15	479.8	0.2	3.27	1.6	0.1	0.9	45.19	5,365.80
G1	25	3	479.8	0.2	5.15	0.36	0.05	0.4	3.56	88.95
G2	50	6	479.8	0.2	3.27	0.48	0.05	0.4	3.01	150.62
G3a	350	10	479.8	0.2	8.15	1	0.05	0.4	15.64	5,474.52
G3b	175	10	479.8	0.25	2.95	1	0.05	0.5	8.85	1,548.10
G4	4014	25	479.8	0.25	12.8	2.6	0.05	0.4	79.84	320,472.62
G5a	125	35	479.8	0.25	15.8	3.4	0.05	0.4	128.87	16,109.29
G5b	717.5	35	479.8	0.25	6.15	3.4	0.05	0.4	50.16	35,992.02
SL5a	150	35	479.8	0.25	5.5	3.4	0.001	0.4	0.90	134.58
SL5b	137.5	35	479.8	0.2	4.6	3.4	0.001	0.4	0.60	82.54
H4a	175	25	479.8	0.2	4.6	2.6	1	0.5	573.84	100,422.14
H4b	112.5	25	479.8	0.25	4.9	2.6	1	0.5	764.08	85,959.17
H5a	50	35	479.8	0.25	2.6	3.4	1	0.5	530.18	26,508.95
M6	300	55	479.8	0.25	1	1	1	1	119.95	35,985.00
TOTAL										634,294.30

Table 5.4 Computed soil loss values from Oda catchment using the USLE

5.3 ESTIMATION OF RESERVOIR SEDIMENTATION

The construction of reservoir plays a great role in the development of river basin by mainly tackling the problems of irrigation, power scarcity, flood control, etc. When we select a reservoir site, a due consideration should be taken for sedimentation problem expected to face in the reservoir.

Sediment yield is the total sediment out flow from a watershed or drainage basin during any given time (Kirkby and Morgan, 1980). That is to say sediment yield is the sum of suspended sediment and bed load and mostly only the former is measured. However, the bed load is estimated as percentage of the suspended lead (in the order of 25%), (NEDECO, 1998). All of the sediment loss is not delivered to the stream system as it is deposited at various locations in the watershed. The material that is carried to the reservoir then, is the sediment yield.

The best method for obtaining sediment yield values is direct measurement of the suspended and bed load for the point of interest in the watershed. This procedure is costly and needs a long-term effort. Therefore, it is necessary to estimate sediment yield using predictive methods and data available for the project area (Kirkby and Morgan, 1980).

As already depicted in section 5.1, various values of soil loss and sediment yields are obtained by different workers and at different parts of the Ethiopian high land. These differences could be due to the catchment nature (geology, geomorphology, vegetation, etc.) and various climatic factors (Rainfall, Temperature, etc).

To get a reasonable suspended load estimate, it would be more rational to consider the influence of flow magnitude and catchment area. However, in the study area, there is no measured stream discharge data. Thus, it will be wise to adopt the different approaches. In this work, two approaches are used to estimate the reservoir sedimentation i.e. the USLE approach and the other empirical options that relate catchment area by taking into consideration the experience of the country.

5.3.1 Using the U.S.L.E and Sediment Delivery Ratio

The USLE has a positive side in that it allows extensive tabulations of individual factors mentioned above incorporating the results of vast experience. But it does not allow estimating the gully erosion.

All of the soil loss from the catchment area is not delivered to the stream system or reservoir area because it is deposited at various locations of the watershed. Soil erosion , soil loss and sediment yield are terms with different meanings in soil erosion technology i.e. soil erosion is the gross amount of soil moved by drop detachment or run off, soil loss is the soil moved of a particular slope or field, and sediment yield is the soil loss delivered to a point under evaluation.

The total soil loss from the Oda catchment without considering the gully erosion is 634,294.3 t/year (table 5.4). As mentioned in the technical hand book prepared by ESRDF (1997), the total soil loss and the sediment yield to the reservoir is related by:

$$D=Y/T \qquad (5.2)$$

Where $D=34.4A^{-0.18}$

D= sediment delivery ratio (%of soil loss).

T=total soil loss from the catchment (tone /Km2/year)

Y =sediment yield measured at the inlet in to the reservoir (tone /Km^2/year)

A = catchment area, for the area less or equal to 60 km2.

Depending on the information given above, the sediment delivery ratio of the oda catchment area is calculated to be 16.23% and the estimated sediment that enters the reservoir only from the sheet and rill erosion is 1,583.80 tones/km^2/year.

5.3.2 Using Other Empirical Relations

The other empirical options used here are those formulas that relate catchment area and its annual siltation rate by considering the countries experience. Some of these include the following.

1. Joglekar's Method

Joglekar (1960) as cited in Suresh (1997) developed an enveloping curve for computing the annual silting rate of reservoirs having 100 km^2 watershed area. The curve indicates that the silt rate falls down as the catchment area increases.This methode can be applied everywhere as it only relates area silt rate with area of catchment. The annual rate of silting envelope curve has the following form:

$$S = 0.597/ A^{0.24} \quad (5.3)$$

Where S = Annual siltation rates (Mm^3 per 100 km^2)

A = Catchment area (km^2)

Table 5.5 Computed Suspended Load for the Study area Based on Joglekar's Curve

Catchment Area	Annual Siltation Rate (Mm^3 per 100 km^2)	Annual Siltation Rate in (m^3)	Siltation Rate in $m^3/km^2/yr$
65 Km^2	0.220	143000	2200

2. Awash River Basin study conducted by Halcrow (1989), as cited in REST (1997)

Halcrow (1989) sediment yield - area graph consists of an upper envelope and best-fit curve. The water balance analysis was conducted at Legedadi dam for record period of 13 years (1979 - 1992) as stated in REST (1997). The results showed that the rate of sediment load to the reservoir is about 2230 t/km^2/yr and out of which about 1786 t/km^2/yr is suspended load. They plot this result on the Halcrow sediment yield - area graph and the following relationship is obtained.

$$S = 6207A^{-0.23} \quad (5.4)$$

Where, S = Suspended sediment yield in t/km^2/yr

A = Catchment area (km^2)

3. Hunting Study

Based on the results obtained by Hunting Technical Services Limited (1975) conducted on the rivers of Mesanu at May Dollo and Bellet near Quiha (Mekele), REST (1997) developed the following relationship between suspended sediment yield and catchment area.

$$S = 4600A^{-0.19} \quad (5.5)$$

Where, S = Suspended load in $t/km^2/yr$

A = Catchment area (km^2)

Hence, the estimated sediment load for Oda reservoir depending on the various approaches above is summarized below in table 5.6.

Table 5.6 Estimated Sediment Load for the Reservoir of the Study Area

Catch Area (km^2)	Approach	Suspended Load ($t/km^2/yr$)	% Bed Load ($t/km^2/yr$)	Total Sediment Loads ($t/km^2/yr$)
65	Equation 5.2	1583.8	15	1821.4
	Equation 5.3	3190	15	3668.5
	Equation 5.4	2376	15	2732.4
	Equation 5.5	2081	15	2393.2
	Average	2307.7	15	2653.9

N.B. 1. The bed load percentage is taken to be 15% based on the actual site condition and information given in section 5.3.

2. The conversion from tone to volume is adopted to be 1.45 by assuming the specific weight of sediments as adopted in REST (1997) and NEDECO (1998).

As you can see from table 5.6, the sediment yield value is minimal for the USLE as it does not include the gully erosion and the maximum value is that of Joglekar's method indicating a little exaggeration. Thus, to balance these two extremes, it is better to take the average value of the four equations which is 2653.9tone/km2/yr i.e the average annual segment yield of the catchment to the reservoir is 172503.5t/year and this accounts 27.2 % of the total soil loss calculated by the USLE. Thus, the delivery ratio (D) for the Oda catchment is estimated to be 27.2% according to the result obtained and is quite reasonable if we compare with the actual site condition [plate 11]. However, if the catchment is properly treated with biological, physical conservation measures and change the present land use, the mentioned siltation rate will significantly be reduced.

5.4 Mitigation Mechanisms of Reservoirs Sedimentation

Sediment inflow amount relies on the rate of gross erosion in the catchment and the energy of the stream system to transport the eroded material to the reservoir. This in turn depends on climatic condition, nature of the soils, slopes, topography and land use, flow velocity and the physical condition of the basin.

Many of the rivers in the Raya Valley including Oda that are flowing from the highland to the low land (flatter areas) destroy a considerable farmland due to high siltation from the steep slopped mountains. Besides, most of the rivers are braided type and deposit their sediment load in their course and subsequently, expansion of river course and stream bank erosion is aggravated which in turn results in diminishing of the farm lands [Plate 11].Various control measures, adopted for reservoir's sedimentation involve (I) Design aspects, (II) Reservoir operation technique, (III) Soil erosion control and (IV) Sedimentation removal (Suresh, 1997).

Complete control of reservoirs siltation is not possible, but can be mitigated in different extents by applying various design aspects of reservoir areas such as proper position of outlet, put options of possibilities for raising the height of dam when capacity of the reservoir is filled by silt deposition.

Reservoir operation is another means of reservoir silt reduction. This is for instance the sluice gates provided in the dam should be situated at different levels in order to be able to use the reservoir water at various water levels. The other silt mitigating technique is to reduce intense erosion of the Oda catchment by applying the various methods of soil and water conservation methods. These methods, among others, are the physical and biological measures which play significant role in trapping the sediment from the various drainage systems of the watershed area. Some of these methods and structures involve construction of check dams, terracing, afforestation, and changing the land use of the catchment area. Among all, covering the area with vegetation could be effective means of silt reduction in the Oda drainage basin because vegetation reduces not only erosion rate and velocity of run off but also the impact of rainfall drop let on the soil.

The last but not the least post deposition technique to reduce siltation impact of Oda dam reservoir is to apply the different methods of sediment removal from reservoir area. The common means that could be useful for removing silts or sediments from reservoir incorporates Flushing excavation, dredging etc. However, these types of methods may be expensive in terms of cost.

CHAPTER 6

SEISMICITY AND LAND SLIDE

6.1 General

Quite large number of geologic process that affect environment and engineering structures are known all over the world today. Earthquake, landslide, sedimentation, erosion, flooding are some of the geologic and related processes observed in the study area. Erosion, sedimentation hazards in relation to the reservoir of Oda are already discussed in the previous chapter while the earthquake and land slide in general will be discussed in this chapter in relation to the dam project.

Indeed, in the Raya valley as a whole flooding and erosion are potential dangers for the agricultural lands, towns and villages of Alamata, Waja, etc. as they are located at the flood plain. Although there is no recorded data, the Alamata town was flooded in 1981 and many properties and lives were affected (personal communications), and since then some protection measures such as retaining walls have been constructed around the town (Plate 12). Similarly, dwellers of the Waja town have always suffered from flood and at presently there is a plan to shift the village to relatively safe site known as Tumuga and some actions are already started. The storm floods that come from the mountainous and very steep slopes of the high lands also lose many farmlands. For example, the Oda River has 5km length from the dam axis down to the Addis Ababa - Mekelle main road and with a measured average width of 80m for the 2.2km length and 150m for the rest of 2.80 km length (Plate 11). About 600,000 m^2 or 60 hectare arable land is lost only from the active river channel of Oda. In fact, there are a number of similar streams /rivers having similar damage both on the lowland and towns and villages and farmlands. This is simply to mention the problems; otherwise it needs its own work that should come up with solutions.

6.2 Seismic Activity

Geophysical data are essential elements in determination of site seismicity. The important step in geological assessment of seismicity is the location and mapping of all facts that may affect the engineering structures and ascertainment of whether they are active. Regional geological structures (Fig.3.1) and minor structures (Fig.3.2 and Fig.3.3) are identified and mapped. The study area is located in the western margin of the tectonically active Afar rift system and hence the faults in the study area are assumed to be active requiring due attention when evaluating seismicity. The most fundamental information of the faults in association with the length, dip direction, etc. and these data are given in chapter three.

Plainly speaking, with the present state of knowledge, earthquakes can never be predicted accurately and hence to develop a system for fore warming and eliminating the risks of loss to life is yet a distant dream (Singh, 1997*)*. However, structures in many earthquake prone countries are now being designed more safely. Technical studies assess the consequences of the historical seismicity and activities of any local faults, the soil condition and likelihood of landslides, subsidence, and liquefaction (Bolt, 1988).

From the basic geological and seismological information, seismic zoning maps can be constructed by classifying the area in to zones of varying earthquake incidence by taking into account the qualitative and quantitative records of the past earthquake and also geological setting of the area. Based on such information, (Gouin, 1976*)* produced the first seismic zoning map of Ethiopia. We cannot directly measure seismic activity at the site level except describing it by relating the geological structures, engineering geological properties of the site material with the past seismic records of the region.

Various types of maps such as seismotectonic maps (compilation of seismic, geodetic and geological information) and seismic zoning (compilation of seismic and earthquake engineering information) can be produced to characterize the seismicity and evaluate their hazard on life and properties.

Recently a probabilistic seismic hazard analysis was carried out by Fekadu Kebede and Laike Mariam Asfaw (1996*)* to obtain the hazard maps for Ethiopia and the neighboring countries. In their work, the hazard maps were produced for 0.01, 0.005 and 0.0033 annual probabilities of exceedence, and eight seismic source zones were identified on the base of seismicity and tectonic (Fig 6.1) which are considered as the main contributor of damaging earthquakes for the seismic hazard assessment in the region.

Each seismic source zones is identified by some homogeneity in its observed seismicity (earthquake epicenters) and tectonic characteristics (Fekadu Kebede and Laike Mariam Asfaw, 1996) and the tectonic features are:

1- The Awsa Shear zone (ASZ) in southern zone (Zone-1), the southern most rifts (SMR) of Ethiopia and the main Ethiopian rift (MER) (Zone-2), the western margin of Afar depression (Zone-3), the Afar depression including the Djibouti (DJI) area (Zone-4), the proposed transform fault (PTF) connecting northern Afar to axial trough of the Red Sea (Zone-5), the southern part of axial trough of the Red Sea (Zone-6), the western Gulf of Aden (Zone-7) and the region characterized by an extensional tectonics in Yemen (Zone-8).

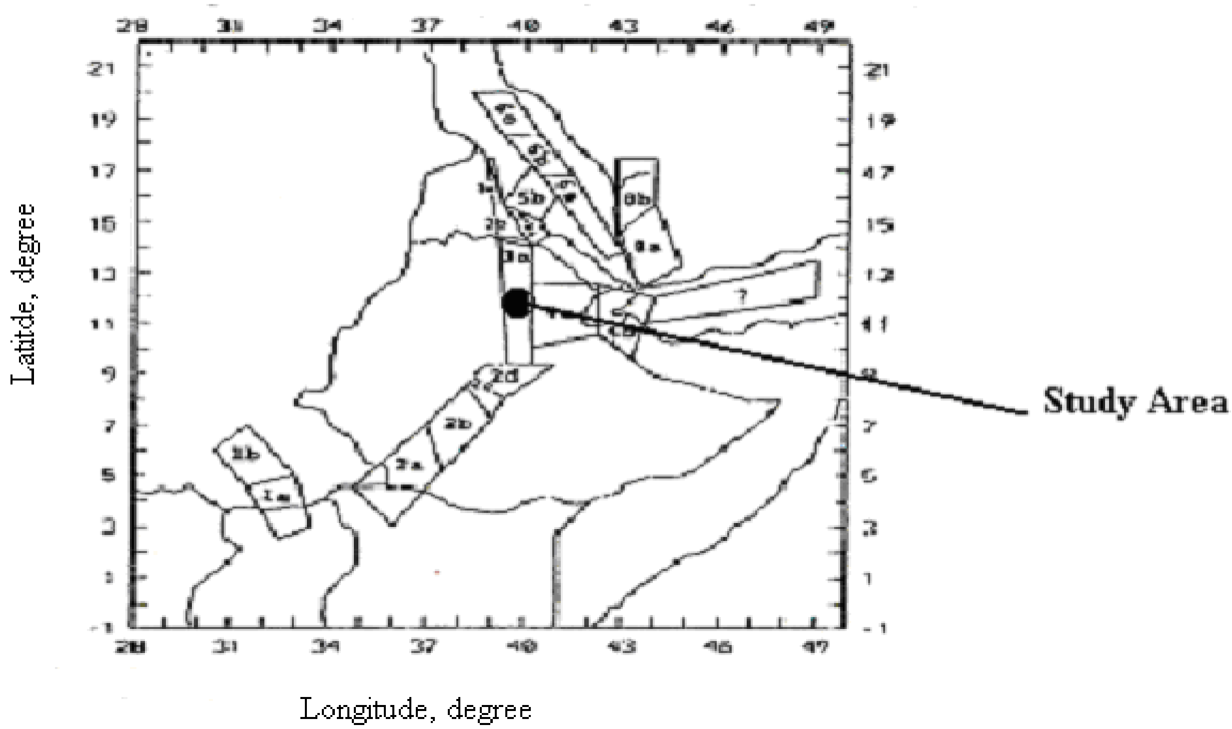


Fig 6.1 Seismotechtonic source zones contributing to hazard evaluation in Ethiopia and the neighbouring countries. Numbers 1 to 8 in the figure show seismic source zones while alphabets (a,b c etc) are intended to indicate the sources with in each group source (after Fekadu Kebede and Laikemariam Asfaw,1996)

The main interest here is not to discuss all the eight seismic source zones, but Zone-3 (western margin of Afar depression in which the Oda Dam site is situated. Surface geology and focal mechanisms of recent earthquakes depict that the western margin of Afar depression is dominated by normal faulting. Damaging earthquake has occurred in this region since instrumental recording started in Ethiopia (kebede & Laike Mariam 1996). Examples are the 1961 Kara Kore earthquake sequences with the largest magnitude being Mp=6.6 further more; this zone is characterized by marginal graven (e.g. The Raya, Kobo, Kara Kore, Borkona, and etc grabens), which are the sites of active continental fracturing.

Table 6.1 Parameters used for seismic source zones. M_0 and M_1 denote the lower and upper threshold magnitudes respectively; b-values represent the seismicity, and give the relative abundance of small and large earthquakes for a given region, (After Fekadu Kebede and Laike Mariam Asfaw, 1996).

Seismic Source Zones	M_0	M_1	b-Value	Rate/Year
1	4.0	7.2	0.61	1.63
2	4.0	6.9	0.75	1.08
3	4.0	6.7	0.75	1.30
4	4.0	6.4	0.71	2.50
5	4.0	6.7	0.71	0.94
6	4.0	6.8	0.88	1.53
7	4.0	6.1	0.87	1.58
8	4.0	6.4	0.50	0.30

The horizontal peak ground acceleration (PGA) value, which is important parameter for the dam design, found for the western of the Afar depression (around 10.5^0 N and 40.0^0E) is 0.13g for 0.01 annual probabilities of exceedence.

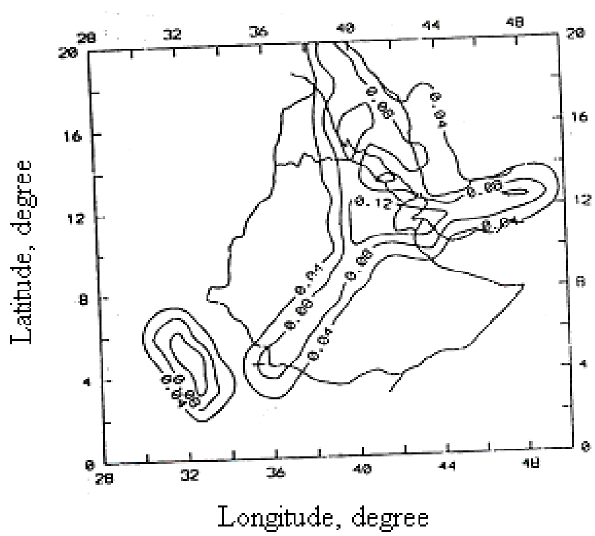


Fig 6.2. Seismic hazard map of the Ethiopia and the neighbouring countries. The hazard is for an annual probablity of exceedence of 0.01. Contours indicate horizontal peak ground accelerationas a fraction of g. (After Fekadu Kebede and Laikemariam Asfaw, 1996)

The dam axis of the study is located at latitudes of 120 21' 53" N and 39^0 32' E longitudes within the western part of the Afar depression which requires seismic resistant design.

The other alternative method of the seismic hazard map is the one produced by the state building codes standard which recommends the engineering precaution to be taken in each rank of hazard in the maps. According to the building standard of Ethiopia (1995) the country is divided in to zones of approximately equal seismic risks depending on the known distribution of the past damaging earth quake ranging from less damaging zones (zones 1 and zone 2) to zones of major damaging (zone 4). The study area is located in zone 4 of the seismic hazard map of the Ethiopian building standard (Fig 6.3). The design ground acceleration chosen in fig 6.3 for each seismic zone corresponds to a reference of return period of 100 years. According to building code, the ground acceleration ratio depends on the seismic zone (table6.2) and hence the ground acceleration value for zone 4 is considered to be 0.1g for 100 year return period.

Table 6.2 bed rock acceleration ratio: α_o = the bed rock acceleration ratio for the site and depends on the seismic zone

zone	4	3	2	1
α_o	0.10	0.07	0.05	0.03

Thus, the ground acceleration value for the Oda dam can vary from 0.1g to 0.13g for 100 year return period depending on the two alternatives mentioned above.

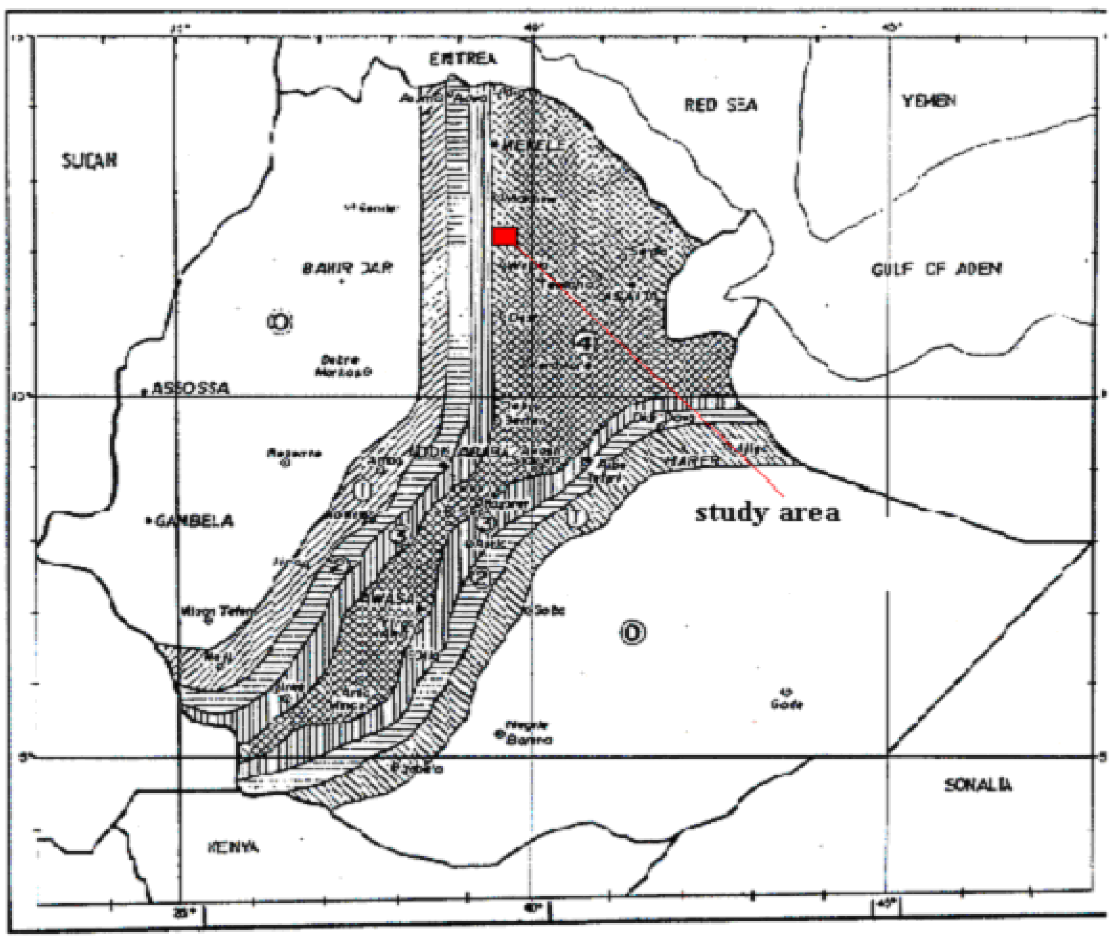


Fig 6.3. Seismic hazard map of Ethiopia (source: Ethiopian Building standards 1995)

Therefore, the design of the Oda dam should meet all necessary seismic resistant design parameters before its construction as the site is located in one of the important regions with respect to seismic hazard by correlating the important seismic parameters and the designed life span the dam.

6.3 Landslide

6.3.1 General

Landslide involves the vertical and horizontal movements of soil, rock, or a combination of the two under the influence of gravity (Schuster, 1978), as cited in Johnson and DeGreff (1988), and its size can range from detachments of a few cubic meter to movements of hundreds of millions of cubic meter. In some regions landslides are so frequent that they represent an important factor in the modeling of the landscape forms (Bell, 19987) and they can cause a great damage to farmlands, forest stands, communications and other civil engineering structures (roads, dams, buildings etc) resulting in serious economic problems. The aim of this topic is not to describe and classify landslide into detail but to mention some of the existence of landslide and its effect on the dam project. Otherwise landslide study is a vast subject requiring its own work.

6.3.2 Classification of Landslides

Several landslide classifications based on both their genetic and many authors have proposed morphology features but because of the wide variability of this phenomena and the contemporaneous occurrence of few basic process, none of them are complete. However, for this purpose, the landslide classification of (Varnes 1958) is the adopted. Varness (1958) as cited in Bell (1983) classifies landslide according to the type of movement undergone and the type of materials involved. The types of movement were grouped into falls, slides and flows where as the materials involved can be grouped as rocks and soils. According to this classification scheme the following types of landslides are identified on the study area:

A. Rock falls is abrupt movement of blocks or complexes of solid rocks loosened by weathering (Bell, 1987) and are very rapid as a result of free fall. In the study area these type of landslide are commonly steep to very steep slopes when the moderately to highly weathered alkali olivine basalt is overlying it. Movement of the material is extremely high and fallen blocks are found at the foot of the cliff of the catchment area unless they are washed away by erosion. These easily identified by their curved hallow and wedge shaped hollows of relict scars.

B- Soil falls in the area are is not as important as rock falls and is limited to river banks where relatively thick soils have. It is triggered by river under cut of the banks and is mostly common down stream of the Oda dam axis.

C-Rockslide is a translational movement of rock, which occurs along a more or less planar or gently undulating surface (Varnes, 1978*)* as cited in Dikau et al (1996). It commonly occurs in mountainous environment rock exposures where slope angle is close to or parallel to, the dip of the rock. In the study area these type of landslide occur along the banks of the slopes and near to the banks of the river as well, where jointing is very important. That is, the form and mode is controlled by planar structural discontinuities such as the ones identified in the area (refer diagrams), especially by NNW - SSE trending and NE - SW trending planar structures with dip direction towards NE and SE respectively. The movement can range from very slow to extremely rapid rockslides.

1- **Debris Slide** is failures of unconsolidated materials that break up into smaller and smaller parts as the slide advances down slope (Varnes, 1978). According to Hutchinson (1988), as sited in Dikau et al (1996), the geometry of the failure area is characterized by low depth to length ratio (D/L often < 0.05) and high length to breadth ratio (L/B typically 5 -10 m or more).

Debris slide is also common in the Oda catchment areas, where high differential weathering prevailing following intense fracturing of the rock mass and their failure surface, usually develops at the contact between the Regolith cover and the underlying bedrock. The thickness of the soil (regolith) in catchment is very thin, less one meter owing to the steep slope and high erosion and for this reason most of the debris slide have shallow thickness (usually less than 2 m). Failure usually takes place on a wide range of slope angles from 18^0 to 50^0 (Clark, 1988; Corominas and Alonso, 1990), although most of them are restricted to slope ranging from 25^0 to 45^0, as cited in Dikau (1996). In the study area, failure occurrence is most commonly found to be in between 30^0 to 46^0 as measured in some places, although some scars are also observed at less than 30^0 slopes which are situated at 558221E and 1367074N, near streams when there is undercutting (Plate 7). As shown on the plate, it has got a semi-circular shape because this debris slide occurs along the intersection of the pre-existing sets of joints where forms a wedge failure, which its sharp edge is modified to semi-circular due to the intense weathering along the intersection. Velocity of materials is very slow to rapid.

6.3.3 Possible Causes of Landslide in the Study Area

Here, the possible causes and triggering factors of the types landslides identified in the study are briefly described below.

The causes for Rock Falls of the Oda catchment are briefly:

- Undercutting of the toe or face of a slope by a river.
- By the existence of facilitators such as weathering and opening of features near to a cliff top.

And the main causes for the rockslides are similar to the rock falls except their failure plane relatively gentler than rock fall and are:

- Steep rock slopes, jointing with a dip toward the open slope face are preparatory pre requests.
- Development of pore pressure during rainy season, undercutting of the toe support, earthquake etc.

And debris slides are caused by

- Land degradation (destruction of vegetation cover).
- Rainfall i.e. the mean annual areal depth of the rainfall is 869mm and maximum of Korem is 1421mm
- Human interference and cattle grazing
- Differential weathering along fractures along the slope class L_2 to L_5 (Fig.2.1).
- Earthquake, for example, a recent debris slide has happened between the beginning of September 2002 and February 2003, which is caused due to the earthquake. Occurrence (about 5 rector scale according to the news released from the Addis Ababa University Geophysical Observatory) in around beginning of September 2002 according to the information obtained from the local farmers (PLATE-7).

6.3.4 Landslide Hazard Class

Landslide hazard refers to the natural conditions of an area potentially subject to slope movements and is defined as the probability of occurrence of landslide of a given magnitude, in a pre-defined period of time and in a given area (Varnes and IAEG, 1984) as sited in Cardinali et al (2002). Landslide risk expresses the economic and social dimension of slope failure. Landslide risk is usually defined as the product of landslide hazard and vulnerability. The latter ranges from zero (meaning no damage) to one (representing complete destruction).

The slope of the Oda catchment is prone to weathering, jointing, storm and earthquake that can easily be liable to landslide. Although three are some old small and shallow landslide scars on the catchment on the dam site, their effect on the dam stability is not as such problematic because they can be mitigated by engineering design. However their contribution to the catchment sediment yield and forest destruction is considerable as observed from the site condition.

Regarding to the landslide hazard classes of the study area, the steep valleys directly connected to the effect of river action (bank erosion) are in a very high landslide. Fig 3.3 and Fig 7.2) while the next slope class L_4 to L_6, (Fig 2.1), which has very large areal coverage of the catchment, are with a next higher land hazard. The potential hazards in the steep river valleys and slope classes L_4 to L_6 are characterized by their presence of undercut, open cracks close to the slope faces. The slope classes L_1 to L_2, are safer, but with very small areal coverage, and the L_3 is moderate. Therefore, the steep slopes with a direct attachment of the river action and the L_4 to L_6, slope classes are hazardous area that may cause damage to the dwellers of the catchment, forest destruction, and to the dam reservoir area requiring a special attention during the dam design.

6.3.5 Landslide Mitigation Measures

It is difficult to propose a uniform and efficient type of mitigation measures for landslides since they are complex in nature that involve various materials and nature of movements together with the existence of unpredictable triggering factors such as earthquakes and storm rainfall.

Location of failure depends on variation of shear strength with depth which in turn depends on a number of factors such as nature and composition of the material, jointing systems, degree of weathering, presence or absence of water, slope nature and so on. For instance, nature of jointing systems and their relation with slope face are major factors in rock mass failure where as in soils and/or debris, regolith depth and slope angle are important as these determine the critical depth at which the failure takes place. In order to make an assessment of the necessary treatment of landslide in upland areas, parameters like classification of landslide, type and thickness of soils, type of bedrock and their geotechnical properties are very essential (Moser, 1978) as cited in Bell (1983). These parameters are discussed in the previous chapter so that the design engineers can design appropriate stable slope.

In here the only methods, which may be adopted, to reduce or control the effects of landslides are briefed as follows.

The main land use of the catchment area is grazing land. No complex infrastructure concentrated dwellers are present in the area. Most local villages found with in the catchment are located at the top flat part of the hills which more or less safe of landslide hazard. Hence, no much and direct impact of landslide is expected on the area on life and property. Thus, the following landslide measures are mainly focused the landslides that have contribution on siltation hazard to the reservoir, destruction of deforestation, and stability problems to the dam project and accordingly the measures are given below.

A. Afforestation practice: - the destruction of forests in an area facilitates landslide (Seby, 1993). As discussed in chapter two the vegetation covers of the area is sparse due to intense land degradation mainly caused by uncontrolled cutting of trees and high cattle grazing. From the field evidences show that most of the landslide scars seen at the area commonly occur at the places where relatively less vegetation cover has. Trees increase the resisting forces by their rooting network. Large closely spaced trees on low angle slopes (up to 34^0) can increase the normal stress by 5Kpa while increasing the shearing stress by about half of that (Bishop and Steven 1964) as stated in Selby (1993) therefore, reafforestaion and changing of the land use from grazing to area enclosure will be significantly reduce not only the land slide but also the siltation problem.

B. Drainage: - in mitigating landslide hazard, the application appropriate drainage is the most effective and regardless of the type of land slides .the seasonal ground water seepages and surface water has a sound impact on triggering the landslide in the area. Besides, when the reservoir fills water, there will inevitably exist allowable seepage at down stream of the dam axis. These conditions are favorable to landslide by reducing the shear strength of the weathered basaltic rocks of the area. Many of the land slide of Oda caused by gully undercutting of their banks. Thus, proper drainage design that that protects the draining of water to the potentially instable area is vital to mitigate the landslide in the study area.

C. Surface slope protection: - includes methods that reduce infiltration of water in to the slopes and maintain them nearly dry. These include the application of shotcrete and masonry blocks. Shotcrete is a form of concrete that can be sprayed on to the face of an excavation where it builds up to form a lining, usually a few centimeters thick (Blyth and Freitas, 1974) while masonry bocks is simply the application of masonry works using blocks of strong stones. These methods, especially the use of shotcrete at the reservoir rims foundation can be essential for three purposes i.e. for landslide protection, decrease the reservoir water loss, and to increase the strength of the foundation materials.

D. Gully treatment by check dams and gabions:-Check dams are one of the known methods to protect undercutting of gullies if properly design with appropriate drainage (spill way) and good foundation of less scouring effect. In the Oda area the thickness of the soils is thin and a sound rock for foundation is found at very shallow depth favoring the check dam construction. Stone useful for the construction is also available locally at nearby distances. Hence the construction of cheek dams with help of gabions can considerably reduce the further gully undercutting that cause landslide.

E. Avoiding human uncontrolled human intervention: - One of the main factors for the existence of degraded land in the Oda area is human intervention. People simply cut or set fire to intensify arable lands and destroy trees from the catcment area. They are also excavating canals along the side slope to divert the flood to their lands with out proper design. These cause minor landslide at the bank slopes of the Oda River as seen during the fieldwork. These uncontrolled and unplanned human activities have to be stopped to minimize the landslides in the area.

HAPTER 7

ENGINEERING GEOLOGICAL AND GEOTECHNICAL CHARACTERIZATION AND MAPPING OF SOIL OF THE STUDY AREA

7.1 General

There is no universally accepted definition of what is meant by the terms 'rock' and 'soil' and the definition is dependent up on the interest of the user. Geologists define soil as a sub surface layer of rock waste in which the physical and chemical process of rock weathering and cooperates intimately with organic processes (Singh, 1997). An engineer clearly considers any mineral material that lacks high strength being a soil (Johnson & Degreff, 1988) or comprises all material found in the surface layer of the earth crust that are loose enough to be moved by spade or shovel (Winter Korn, 1975). The distinction between soil and soft rock is not easily made. The simplest distinction is that of strength (Selby, 1993) i.e. material with a uniaxial (unconfined) compressive strength less than 1.25 Mpa is normally taken to be soil (Geological Society of London, 1977 as cited in USDA (2001). In describing (both in the field and laboratory), classifying and mapping of the soils and rocks of the study area, the world wide accepted methods and procedures such as the American Society for Testing of Materials (ASTM), International Association of Engineering Geology, or British standards are used.

7.2 Geotechnical and Related Surveys Conducted in the Study Area

The proper design of civil engineering structures require adequate information on the engineering-geological and/or geotechnical behavior of the earth materials (soils and rocks) which in turn depends on the geology, hydrology, climate, land use, slope, etc. as these affect the engineering properties of the rocks and soils of the study area over time. Engineering geological research and mapping are therefore mainly directed towards understanding of the interrelationships between the geological environment and the engineering situation; the nature and relationships of the individual geological components; the active geodynamic processes (UNESCO, 1976).

Thus, to investigate and make geotechnical characterization of the soils and rocks of the study area, many field and laboratory works have been conducted.

That is, geological maps, land use maps, slopes, relief and land form, hydrogeological maps engineering-geological maps of scale 1:50,000 for the catchment area; and geological and engineering geological maps (scale 1:1000) are produced for the reservoir and dam foundations. Some previously collected raw data either on the dam site or other nearby projects are collected or incorporated in addition to the many primary data collected on the site (table7.1):

Table 7.1 Main Geotechnical and related works conducted on the Study area

S/N	Major Tasks	Items Produced
1	Collecting engineering geological and geotechnical raw data from previous works	Some data are collected
2	Field Works Mapping Of catchment (1:50,000) and reservoir and dam site (1:1000)	Geological, slope, land use, hydro geological map, relief and land forms engineering geological maps for the catchment and geology and engineering geology are produced
3	Rock joint measurement	At 20 selected out crops
4	Schmidt hammer rebound measurements	At 19 out crops; 15 measurement on each out crop
5	Field permeability tests on soils	9 measurements
6	Pocket penetrometer	16 measurements
7	Disturbed soil samples collection	15 samples for different laboratory analysis
8	Rock samples	10 samples for various aggregate and strength tests
9	Water samples for quality analysis	9 samples
Laboratory test on soils		
1	Gradation analysis	11 tests
2	Atterburg limits	8 tests
3	Direct shear	4 tests
4	Specific gravity	8 tests
5	Shrinkage limit	6 tests
6	Free swell	8 tests
7	Consolidation	1 sample
8	PH and EC	8 tests
On Rocks (Aggregates)		
10	ACV (Aggregate at Crushing Value)	2 tests
11	Water absorption	3 tests
12	Unit weight	2 tests
13	Density	2 tests
14	Soundness for fine aggregates (taken from REST, 1997)	1 test
15	Gradation analysis for the aggregates	1 test

7.3 Origins and Description of Soils

Classification of rocks and soils for engineering geological mapping should be based on the principle that the physical or engineering geological properties of a rock in its present state are dependent on the combined effects of mode of origin, subsequent digenetic, metamorphic and tectonic history and on weathering processes (UNESCO-IAEG, 1976).

Rocks and soils are extremely variable materials, which may be classified in many ways, and for many purposes and thus, a material, which is strong enough for one purpose may be too weak for other purpose. Hence, soils and rocks have to be described and classified carefully not only by their laboratory results but also by their actual field conditions. That is laboratory tests could not be a substitute for the field description rather the former strengthens the later. Moreover, some soil parameters such as origin, thickness, aerial extent other engineering properties cannot be partially or fully studied by a laboratory works as we cannot represent exactly the actual nature of the site and for this reason field visual inspection and examination is quite vital. Thus, the combination of descriptive and determinative procedures allows a prediction of the likely behavior of the materials to be made.

The origin of soils is related to a complex combination of conditions and processes and is the result of continuous. Soil development is controlled by a number of factors which often work in very close cooperation to change an original material into a soil and to mention some of these factors are climate, nature of parent material, vegetation, topography and time which are already presented in the respective chapters. Thus, the soils of the study area are originated from the weathering products of the rocks as a result of the various factors mentioned above. The resulting soil depends on the stability of minerals that make up the parent material and its texture (grain size) (Birkeland, 1984) as cited in Johnson and Degraff (1988).

Soils of the study area are thus described, classified and mapped based on field visual inspection, using some limited field equipments such as pocket penetrometer, gulph permiameter, and laboratory analysis.

Geologically, the soils of Oda area can be broadly categorized into residual and transported soils. Residual soils are those soils that remain in position at the place of origin while transported soils are soils moved from their place of origin by various agencies such as water and gravity. The transported soils can be further divided into alluvial, colluvial depending on their transporting agent and hence the first two are common types of transported soils in the study area.

This type of classification is very crucial or pre-hand to the other types of engineering classification because the engineering properties of soils are the reflection of their mode of formation. Soil displays considerable variability in its characteristics and properties owing to a variety of geologic factors. The physical characteristics and engineering properties of a soil is derived from the parent material and geologic processes that produced it (Johnson and Degreff, 1988).

Soils of the Oda catchment area are mapped at the engineering geological map of catchment (1:50,000 scale) and that of the reservoir and dam site soils are re-mapped at more detail scale (1:1000) of the engineering geological map of these sites. All description and classification of the soils refers to soils found in the catchment, reservoir, and foundation, as they are formed under more or less the same factors and geologic processes. However, more detail engineering descriptions and classifications is carried out at the reservoir and dam site where the reservoir and foundation are situated. In case if there exists an important difference between those soils found at the dam site and catcment area it will be explained at each sections.

7.3.1 Residual Soils

Residual soils of the catchment area have more aerial coverage but with insignificant thickness although some pockets of thick residual soils are observed at plots of flat area and in areas affected by differential weathering.

In the field of engineering-geology a soil unit is mappable if its thickness is greater than one meter. As explained by Price and Rengers (1982), the reason why one meter thickness is taken is that surface morphology of the underlying bed rock is usually recognizable if the overlying soil is less than one meter thick and not recognizable when the thickness exceeds one meter; and the engineering geological importance of a soil cover is limited if its thickness is less than one meter. For this reason the residual soils of the Oda catchment are not included at the engineering geological map of a scale of 1:50,000 because their thickness is less than one meter. However, they are included in the engineering-geological map of the reservoir and dam foundation (1:1,000). Samples have been collected and analyzed in the laboratory besides to the field description to characterize them in comparison with the degree of weathering of their parent rocks.

The thin coverage of this residual soil of the study area indicates that the rate at which weathering advances into the rock is less than the rate of removal of the products of weathering by erosion as the result of the steep slope nature of the catchment area.

Residual soils can have characteristics that are distinctively different from those of transported soils. Particles of residual soil often consist of aggregates or crystals of weathered mineral matter that break down and become progressively finer if the soil is manipulated. What appears in situ to be coarse sandy gravel may change to fine sandy silt during excavation, mixing and compaction (Blight, 1997).

The study area is dominantly covered by the weathered basalts whose degree of weathering varies between fresh (I) to residual soils (VI) and of these weathered basalts, the medium (III) to highly (IV) weathered ones have greater percentage of coverage while the weathered part of grades I; II and V and VI have smaller aerial coverage (Fig7.1 and Fig 7.2). Boulders sound parent rocks (basalt) are very often found enclosed with in the profile of the weathered rock of the study area. The transition from grade I to grade VI is gradual and without clearly defined point at which the material changes from rock to soil.

There is difference in opinion on defining the term residual soils and which parts of the weathering grades are considered to be part of residual soil. For example Blight (1997) stated that from the weathering profile, the term residual soil is applied to upper three categories of weathering grade (IV, V, VI). However, according to the weathering classification of rocks given in (Bell, 1983; Dearman, 1991), the term residual is given upper most of the weathering grade (VI). On the other hand, any material whose unconfined compressive strength (UCS) is below 1.25 Mpa is taken as soil and if its UCS is above 1.25 Mpa it is considered to be rock (Johnson and Degreff, 1988; Selby, 1993).From the Schmidt hammer hardness test taken, larger portion of the study area the grade IV have greater than 1.25 Mpa of UCS. Moreover, the grade IV and V have a clearly observable relicts of joints and fractures while not in the grade VI.

Figure7.1 Engineering map of Oda catchment

Thus, the engineering behavior of the grades IV and V will be determined not by the soil property but by the relict structures they possess similar to the rock mass and for this reason they cannot be analyzed and classified as soils using the usual soil classification methods such as the Unified Soil Classification system. Rather the word saprolite could be given to them.

In this work, therefore, the term residual soil is given only to the VI grade of weathering and these soils can be classified using the usual methods of engineering soil classification methods although there could still exist some limitation.

The residual soil in the catchment falls with in the silty sand (SM) and Sandy lean clay (CL) (Fig.7.2) but restricted to small area of the reservoir.

The silty sand (SM) soil covers almost the whole catchment area but thin and it is not mappable. Laboratory gradation analysis shows that the sand, silt and clay content of the silty sand soils vary between 62-80%, 19-28% and 1-2% respectively. They have a liquid limit range of 44-46% and plastic index of 14.05% to 15.14% values. This value shows that they are medium plastic soil (Table 7.2).

Table 7.2 Range plasticity index values used for qualitative description

(After Burmister, 1949, as cited in Das, 1998)

PI	Description
0	Non plastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
>40	Very high plasticity

These residual silty sand soils are found in the catchment, reservoir and abutments of the dam site. Their color is dominantly yellowish brown and light red with some local yellowish type. The sandy lean clay types of the residual soils have a very limited and localized aerial coverage. They are thicker than the silty sand and are found at lower topography including the reservoir rims. Grain and Atterburg limit analysis of these soils show that they have 36% sand, 59% silt and 5.1% clay content and are with a liquid limit and plastic limits of 40.3% and 26% respectively and this shows that they are in the medium plasticity range.

7.3.2 Transported Soils

Transported soils are those soils, which are removed from their place of origin and re-deposited somewhere else. Depending on their means of transporting agent, they can be alluvial, colluvial, loess etc. Alluvial and colluvials are the main types of transported soils present in the study area. They are called alluvial if their transporting agent is water and, colluvial if their transporting agent is gravity. Both the catchment and the reservoir area are highly incisted and characterized by local ups and flats. A relatively thick soil cover is found at the foot of the gentler slopes, at the bank of gullies, streams etc following the trend of the drainage system. These soils are the combination of both alluvial and colluvial deposits and it is very difficult to differentiate these deposits and put where their exact boundary is for the reason they are found intermixed. From the field soil description and classification, such deposits are categorized as pediment deposits. Pediment deposits are those soil deposits, which are consequences of gravity, slope wash and fluvial action. The pediment deposit shows both lateral and vertical variation as observed from the gully/stream cut exposures. They range from clayey silty sand to gravel. However, there are some pockets of colluvium deposits at places where the fluvial action is not important and they are composed of silts, sands, gravels and some bounders and cobbles.

The other types of transported soils identified in the field are the old and active river channel deposits. Their major components are sands, gravels, boulders and cobbles. The older river deposits are cemented by calcareous precipitates (plate 5). After the field description, classification and mapping of these units (Fig.7.2), samples are collected for laboratory analysis from the top part of the pediment deposit, where the thickness of the fines varies from 2m to 8m. The laboratory results analyzed in the Tigray Bureau of Water Resource (TBWR) geotechnical laboratory and the description and analysis of these soils shows that the main soil groups of this unit are sandy lean clay/lean clay with sands and sandy silt.

A. Sandy Lean Clay/Lean Clay with Sand

This type of soil group of the pediment deposit is found near the depositional side of the meandering streams where the colluvium is dominated by the alluvium. It overlies the sandy and gravelly river deposits and this is clearly seen at the banks of the Oda River. These are the dominant soil group from the pediment deposits than the other type of fine soils. The analyzed samples show that this group consists of clay fraction (1.5-6%), silt (32-60%) and sand (40-60%). Its liquid limit and plastic limit varies between 37-41% and 23-27% respectively. According to its plastic index (14.06-14.37%), the sandy lean clay soil type falls at the medium plastic type.

B. Sandy silt

This soil type is also part of the top layer of fine soils of the pediment deposit. They are found near the slopes of hills overlying either the gravelly soil or the residual soil. Their aerial coverage is small and becomes thin towards the slope. This group of soil has 35-50% sand, 48-60% and 2-5% clay fractions. Their liquid limit and plastic index is similar to the sandy lean clay varying between 37.9 to 41.4% and 10.8 to 14.8% respectively. For the rest of the information refer table 7.3 below.

7.4 Classifications of Soils of the Study Area for Engineering Purposes

Engineering classification of soils in short means the arrangement of soils into different groups and subgroups according to their engineering behavior. This is very crucial because it is more convenient to study the engineering properties of soil groups than that of individual soils.

There are several types of engineering classification of soils depending on the nature of soils existed and type of the engineering project. To mention some of the common ones are textural soil classification, the American Association of State Highway and Transport Officials (AASHTO) and the Unified Soil Classification System (USCS). Textural classification incorporates only texture but not plasticity and for this reason it is not important for engineering classification. Although AASHTO considers both texture and plasticity, it is more useful for classifying soils for highways. USCS considers textures and plasticity as AASHTO in classifying soils and is the most vital all purposes. The USCS is adopted in describing and characterizing soils of the area, as it is more descriptive and considers the organic soils and gives more attention for the fine soils description which is vital for the hydraulic properties of the soils.

Table 7.3 Laboratory analyses results for some of soils of the study area

S/N	Location	Depth (m)	Soil		Shear Parameters		Gs	Natural Moisture (%) Content	Shrinkage Limit (%)	Atterburg Limits (%)		Free Swell
			Type	Symbol	C (Kg/cm^2)	ϕ (degree)				LL	PI	
1	TP1		Silty sand	SM	0.6	24.37	2.62	10.11		50	14.35	40
2	TP2	0-0.9	Sandy silty	ML	-	-	2.58	53	24.52	41.52	14.37	50
3	TP4	0-2.15	"	ML	-	-	2.68	14.72	18.76	37	14.06	20
4	TP5	0-2.6	Sandy silt	ML	-	-	2.5	-	16.66	37.9	10.8	30
5	TP7 (residual)	0-1.9	Sandy lean clay	CL	-	-	2.62	-	30.76	40.3	14.3	30
6	TP8 (residual)	0.4-2.4	Silty sand	SM	-	-	2.67	-	-	46.5	15.14	20
7	TP9	0.2-0.4	Sandy lean clay	CL	-	-	2.76	-	-	-	-	30
8	RS (residual)	-	Silty sand	SM								
9	DA	-	Lean clay	CL	0.05	32.41	-	24.4	23.4	41.4	14.8	-
10	RSL1 (residual)	-	Silty sand	SM	0.25	30.73	-	12.5	20.37	44.5	14.05	
11	RSL2 (residual)	-	Silty sand	SM	0.25	33.09	-	-	-	-	-	-

C=cohesion; ϕ=angle of internal friction

Figure7.2 Engineering map of reservoir and dam foundation

7.4.3 Unified Soil Classification System (USCS)

The USCS was first developed by Casagrande in 1948 and later, in 1952, was modified by the Bureau of Reclamation and Corps of Engineers of the U.S.A. The system has also adopted by the American Society for Testing Materials (ASTM). The system is the most popular system for use in all types of engineering problems involving soils (Arora, 1997). This system classifies soils into two broad categories:

This classification system is the most widely used method in the classification of soils in dam site.

According to this classification, soils of the project area falls into silty sand (SM) sandy silt (ML) and lean clay with sand (CL) (Fig. 7.3).

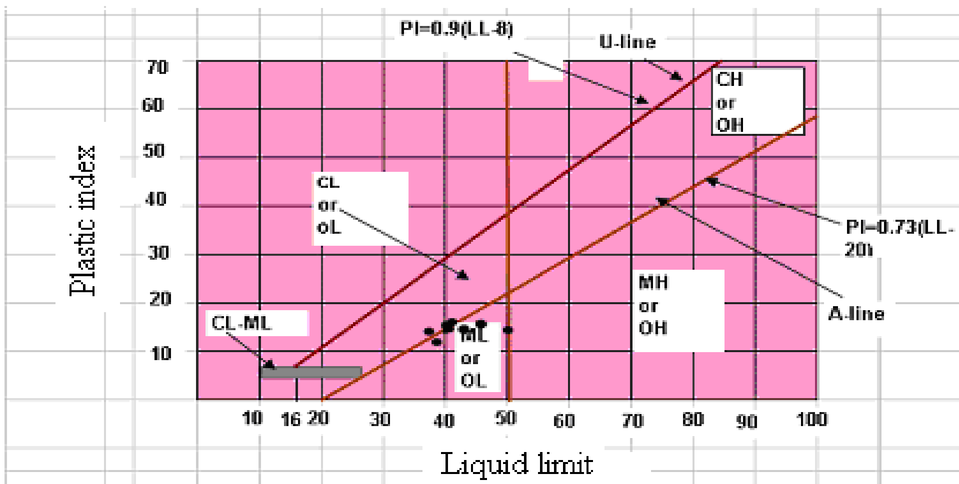


Fig. 7.3. Plots of plasticity of the soils Of the study area based on USCS

Table 7.4 Classification of soils of the study area based on USCS

Test pit (TP)	Depth (m)	Sand (%)	Silt (%)	Clay (%)	LL	PI	USCS	
1		66	30	4	50	14.35	SM	Silty sand
2	0-0.9	40	58.5	1.5	41.4	14.37	ML	Sandy silt
4	0-2.15	40	59.5	0.5	37	14.06	ML	Sandy silt
5	0-2.6	35	60	5	37.9	10.8	ML	Lean clay with sandy silt
7	0-1.9	36	59	5.1	40.3	14.3	CL	Sandy lean clay
8	0.4-2.4	70	28	2	46.5	15.14	SM	Sandy silt
Dam Axis		50	48	2	41.4	14.8	CL	Lean clay
RSL1		80	19	1	44.5	14.05	SM	Silty sand

7.5 Physical and Index Properties of the Study Area

For a proper evaluation of the suitability of the soils for use as a foundation or construction materials, information on its properties, besides to classification, is frequently necessary. Some of the physical properties of soils that may relate to the state of soil or the type of soil are grain size, specific gravity, consistency, water content, unit weight, etc.

After the field categorization of soils in to similar zones is accomplished, representative samples were collected for laboratory analysis to determine some of the above mentioned physical and index properties of soils such as specific gravity, gradation, Atterburg limits, shear parameters, consolidation, natural moisture content, compaction, free swell and some chemical analysis such as pH and electrical conductivities.

7.5.1 Specific Gravity

In soil engineering a factor called specific gravity is important in correlating the weight-volume relationship of soils. Specific gravity is the ratio of mass of a given volume of solids to mass of an equal volume of water at 4^0C (USDI, 1974). The knowledge of specific gravity of soil particles is necessary not only for sedimentation analysis but also for assessing the volumetric contribution of the different size fractions to a soil system (Winterkorn, 1975). Specific gravity is also vital parameter used to determine the void ratio and particle size. The specific gravity of solids for most natural soils falls in general range of 2.65 to 2.80 the smaller values are for the coarse-grained soils that is for sands that consist wholly or mainly of quartz unless they contain organic matter (Arora, 1997). The laboratory analysis of the soils of Oda dam shows that their specific gravity values range between 2.5 for the sandy silt to 2.76 for the lean clay with sand soil and this indirectly indicates that their they are with a limited organic mater whose specific gravity is usually as low as 2.2 (Singh, 1994).

7.5.2 Moisture Content

Moisture content is the most influential factor affecting the engineering properties of soils. The control of moisture in soil used either as a construction material or as encountered in a foundation often represents an important part of the cost of structure and may exert a considerable influence on the construction procedures used (USDI, 1974). Thus, it is quite essential that the water content of a soil be recorded and reported in conjunction with all investigations, tests and construction works. In general, water content in civil engineering works has a direct bearing on the soils strength and stability of all earth works and foundation, in compaction controls, and in determining consistency limits. Natural moisture content for some representative soil samples are conducted at the geotechnical laboratory of the Tigray Water Resource Bureau (TWRB) and the results vary from 10.1% to 53% (Table 7.3). This shows that most soils are in their dry state except one sample. Although there is an increasing trend of moisture content with depth, the variation is not significant. This implies that the moisture holding capacity of the soils of the study area is low.

7.5.3 Grain Size Analysis

Grain size analysis is one of the vital soil index properties used to determine the engineering behavior of soils. It is a descriptive term, which refers to the distribution and size of grains in a soil.

Particle size distribution is found in two stages:

1. Sieve analysis, for the coarse fraction that retain No. 200 sieve (0.075mm) in diameter and
2. Sedimentation (hydrometer) analysis or wet analysis for the fine fraction (particles with less than 0.075mm in diameter).

The laboratory particle size analysis, for that matter including also other tests, is performed according ASTM standards. The sieve analysis used to separate the coarser soils (retain No. 200 sieve) and the fine soils (pass No. 200 sieve) while the sedimentation (wet analysis) or hydrometer analysis is to separate the silt fraction from the clay fraction.

The results of grain size analysis are then represented on a graph called the gradation curve, where by using the diameter of particles on horizontal logarithmic scale and the percentage (by weight) of size smaller than a particle sieve aperture as ordinate in a natural scale.

The gradation curve then is used to determine parameters termed and designed as effective size (D_{10}), uniformity coefficient (C_u), and coefficient of curvature (C_c). The effective size (D_{10}) is important to estimate the hydraulic conductivity and drainage through a soil and C_u and C_c are useful in determining the uniformity of grains and shape of gradation curve respectively.

$$K=CD_{10}^2 \qquad (7.1)$$

where C = constant that depends on the uniformity of soils

$Cu = D_{60}/D_{10}$ (7.2)

where D_{60} = diameter (mm) corresponding to 60% fine

D_{10} = diameter (mm) corresponding to 10% fine

$Cc = D_{30}^2/(D_{60}*D_{10})$ (7.3)

where D_{30} = diameter (in mm) corresponding to 30% fine

The hydraulic conductivity (equation 7.1) is applied only if the soils are loose sand soil and thus it cannot be applied here. However the 'Cu' and 'Cc' values of the soils of the area is calculated (Table 7.5) to express the uniformity quantitatively.

Table 7.5Computed Uniformity Coefficients

Soil Group	C_u Values in Range	C_c Values in Range	Remark
Lean clay with sand (CL)	3.75-5	1.1 - 1.63	The soil type varies between very uniform medium uniformity
Sandy silt (ML)	7-11.9	0.61-2	This type of soil is medium uniformity
Silty sand (SM)	12-23.6	0.65-0.78	This soil type varies between medium to non uniform soil

$C_{u=}$ Uniformity coefficient

$C_{c=}$ Coefficient of curvature

N.B. 1. $C_u < 5 \rightarrow$ Very uniform soil

C_u = 5 to 15 $\rightarrow$ Medium uniform

$C_u > 15 \rightarrow$ Very non uniform soil or well graded (Venkatramalah, 1993).

2. The value of C_c for well-graded soils range between 1 and 3. However, non uniform soils cannot be detected by Cc values only (Arora, 1997). Thus, the C_c values are not considered in describing the uniformity since the soils are not well graded.

The uniformity coefficient (C_u) values for the lean clay soils varies between 3.75 (in TP_4) to 5 (in TP_2), and that of the sandy silt soil (ML) varies between 7 (in TP_5) to 11.9 (in DA) while the silty sand has a Cu value between 12 (in TP_8) to 23.6 (in TP_1).

More uniform soil is more compressible than well graded soil (Arora, 1997) and thus the lean clay with sand (CL), soils are very uniform than the silty sand soil indicating that the former is more compressible than the later.

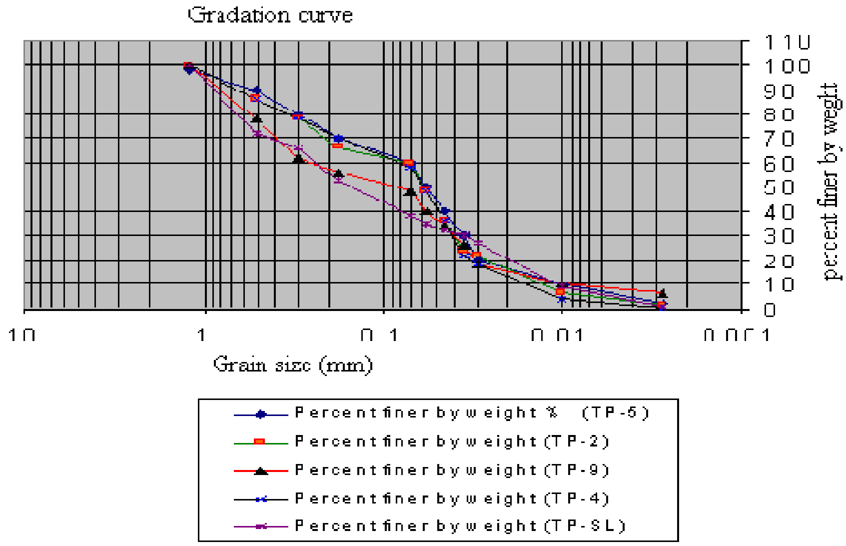


Fig. 7.4 Gradation curves for some of the soils of the study area.

7.5.4 Atterburg Limits and Index Values

A. Atterburg Limits

The water contents at which the soil passes from one state to the next are known as consistency limits or Atterburg limits. Consistency limits are mainly used for identifying and classifying fine soils. Plasticity is the ability of a soil to be deformed without fracture or cracking and is important index property for fine soils (USID, 1975). The liquid and plastic limits give a measure of plasticity of soil and the shrinkage limit is useful in identifying expansive soils. The liquid and plastic limits are both dependent on the amount and type of clay in a soil, but the plasticity index is generally only dependent on the amount of clay in a soil and thus, plasticity index (PI) is a rough measure of the amount of clay in a soil, while the study of PI in combination with liquid limit gives information about the type and nature of clay (Singh, 1994). Clays with high value of liquid limit (LL) and PI are known as highly plastic or fat clays and those with low values are called slightly plastic or lean clays and the later types of soils are common in our study area.

Depending on the moisture content the following four stages, or states of consistency are used for describing the consistency of a soil i.e. the liquid state, the plastic state, the semi-solid and solid states.

Liquid limit (LL) is the water content at a point of transition of the clay sample from a liquid state to plastic state, whereby it acquires a certain shearing strength (ASTM D-423) and the plastic limit (PL) is the smallest water content at which the soil begins to crumble when rolled out into thin threads approximately 3mm in diameter (ASTM D-424) (Cernica, 1995).

The liquid limit is determined in the laboratory either by Casagrande's apparatus or by cone penetration method. However, in our case the Casagrande is used. The liquid limit is the water content at which the soil is sufficiently fluid to flow when the device is given 25 blows i.e. LL is the moisture content determined at N= 25 from the flow curve. As it is difficult to get exactly 25 blows for the sample to flow, the test is conducted at different water contents in order to get blows in the range of 10 to 40 (Arora, 1997). Then a plot known as flow curve is made using water content as ordinate and number of blows on log scale as abscissa and is approximately straight line. Some of the flow curves made for the soils of the study area are given below in (fig. 7.5). Though all soils have relatively low LL, the silty sand soil has higher value than the other types soil. This is due to the nature of residual soils. Coarse crystals of residual soil that is classified as coarse soil (retain on No.200) during sieve analysis can be changed into progressively finer soils during the LL determination processes. This in terms of the dam site implies that the behavior residual soils (SM) of the will be changed into clayey nature when water is stagnated in the reservoir which in turn implies a promising future for water tightness of the reservoir area. The laboratory procedures for determining the liquid limit is inconvenient and time-consuming because it requires the test to be repeated at least 3-5 times at different water content and plotting the results. There is another method known as one-point method that approximates the value of liquid limit by conducting only one test, provided the number of blows is in the limited range.

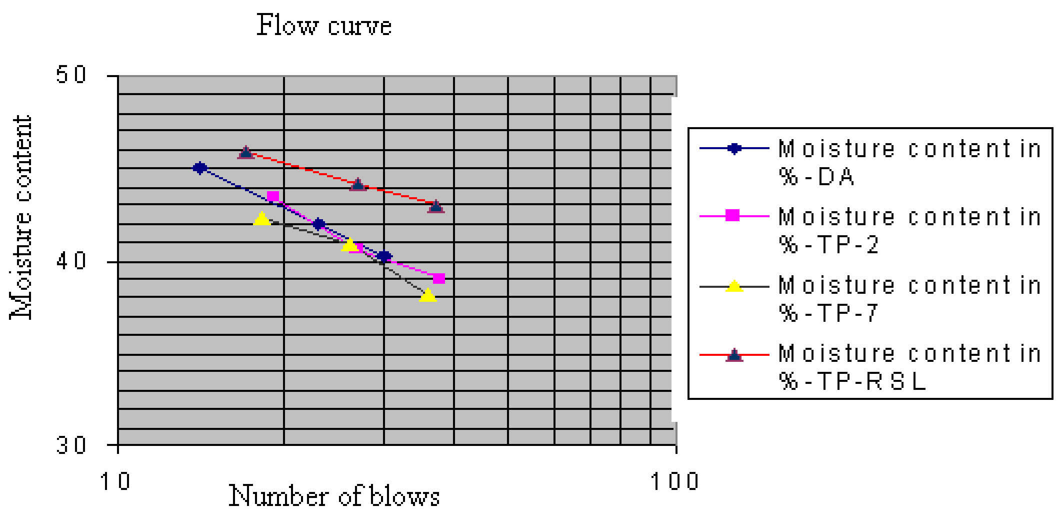


Fig. 7.5 flow curve chart of some of the soils of the study area**.**

The liquid limit is given by equation 7.4 based on the assumption that the flow curve is a straight line.

$$LL = W_N\ (N/25)^n \qquad (7.4)$$

where n = index as given below

n = 0.092 for soils with liquid limit less than 50%, and n = 0.12 for soils with liquid limit is greater than 50%.

The accepted range for N is 15 to 35 for soils of LL < 50% and 20 to 30 for soils with LL > 50% according to the Indian standard.

The laboratory (3-point method) results are compared with one-point method (table 7.6) and they both have very similar result. All the soils of Oda area have liquid limits less than 50% except one sample. Thus, the adopted value of 'n' is 0.092 and the value N (table 7.6) is taken one of the three blows that fall with in the 15 to 35 range while the value W_N (is the water content that corresponds to the value N as used in the laboratory tests. The values of the liquid limit of the soils are all below 50% indicating the soil is low plastic and low compressively.

Table 7.6 Comparison of laboratory (three-point) method and one-point method of liquid limit of the soils of the study area.

Test Pit	Soil type	Laboratory (three-point) LL-Values	Value of 'n'	Computed One-point LL at a Given N and W_N Values					
				N_1	W_{N1}	LL1	N_2	W_{N2}	LL2
DA	Lean clay with sand (CL)	45.5	0.092	30	40.3	40.98	23	42	41.7
TP_7		40.3	0.092	26	40.9	41.05	18	42.23	40.97
TP_1	Silty sand soil (SM)	50	0.092	26	49.69	49.87	16	52.6	50.5
TP_8		46.5	0.092	26	46	46.2	19	48.1	46.9
RSL_1		44.5	0.092	27	44.2	44.5	17	45.9	44.3
TP_4	Sandy silt (ML)	37	0.092	31	34.65	35.3	18	40.88	39.7
TP_5		37.9	0.092	26	37.58	37.7	16	38.97	37.4
TP_2		41.4	0.092	27	40.6	40.9	19	43.4	42.3

B. Index Values Associated with Consistency Limits

The most common indexes associated to these Atterburg limits include the plasticity index (PI), liquidity index (LI) and consistency index (CI). Plastic Index (PI) of a soil is the range of water content over which the soil remains in the plastic state (Arora, 1997) and its numerical values are obtained by subtracting a plastic limit from the liquid limits. When plastic limit is greater than the liquid limit, the PI value is taken to be zero (not negative) and when LL and PL cannot be determined, the soil is non-plastic. The PI values for the soils of study area are given in table 7.3.

The liquidity index (LI) is the nearness of a soil's water content to its liquid. That is, when the soil is at its liquid limit, its LI value is 100% and soil behaves as liquid and if it is at its plastic limit, the value of LI is zero. If the value of LI is negative, it indicates that the natural moisture content is less than the plastic limit and the state of soil is in hard) state.

$$LI = \frac{W - PL \times 100}{PI} \qquad (7.5)$$

where w = natural moisture content

The Consistency Index (CI) of a soil depicts its firmness (consistency). It can be calculated as:

$$CI = \frac{LL - W}{PI} \qquad (7.6)$$

Where symbols are same as above

The value of CI indicates in opposite direction to the values of LI. That is, CI means the nearness of water content to its plastic limit. A zero value of CI indicates that the soil is at its liquid limit and this, therefore, is soft soil and with negligible shear strength. A soil is relatively firm if the CI is 100% and this happens when the water content is at its plastic limit.

However, note that the total sum of LI and CI is always 100% showing that a soil having a high value of CI has a lower value of LI and vise versa. Therefore, it is important to take either of the two indexes to describe and classify the soil and mostly CI is used. Analysis of the CI values of the soil of the study area show that **(**table 7.7**)** they are in very stiff to hard consistency (IAEG, 1981) (Annex C7**)** except in TP2 which of course we encountered water at 2m depth during pitting as it is located near the Oda river bank.

Table 7.7 Classification of the Oda soils based on consistency index

Test Pits	Consistency Index (CI)	Term
TP1	2.78	Very stiff or hard
TP2	-0.80	-
TP4	1.6	Very stiff or hard
RSL1	2.28	Very stiff or hard
DA	1.15	Very stiff or hard

7.5.5 Shrinkage Limit (SL)

Shrinkage limit is the limit found between the solid and semi-solid states of soil. Shrinkage limit is the smallest water content at which the soil is saturated. Laboratory analysis for shrinkage limits of the study area is carried out and the results are presented in table 7.8.

Table 7.8.Shrinkage Limits, Free Swell and Specific Gravity results.

Test Pit	Depth (m)	Shrinkage Limits (SL) (%)	Free Swell (%)	Specific Gravity
TP_1		-	40	2.62
TP_2	0-0.9	24.52	50	2.58
TP_4	0-2.15	18.76	20	2.68
TP_5	0-2.6	16.66	30	2.5
TP_7	0-1.9	30.76	30	2.62
TP_8	0.4-2.4	-	20	2.67
TP_9	0.2-0.4	-	30	2.76
RSL_1		20.37	20	2.57
DA		23.4	-	-

The shrinkage limit of the soils of the study area varies from16 to 31% (table 7.8) this according to Altmeyer (1955) as cited in Chen (1980) implies that the soils are with non-critical degree of expansiveness.

Table 7.9 comparison of degree of expansiveness of soils (After Altmeyer, 1955).

Shrinkage limits	Degree of expansiveness
Less than 10	Critical
10-12	Marginal
>12	Non critical

7.5.6 Free Swell

Free swell of a soil is determined as the ratio of the change in volume to the initial volume, expressed as percentage and is one of the tests used in the assessment of swelling potential of soils. According to Holtz and Gibbs (1956), as cited in Nelson and Miller (1992), soils having free swell values as low as 100% may exhibit considerable expansion in the field when wetted under light loading, and even soils having free swell value below 50% seldom exhibit considerable volume change even under very light loading. The free swell values of the soils of the area vary from 20 to 50% (table 7.8) and are with in the acceptable limit.

7. 5.7 Swelling Potential of Soils and Estimation of types Clay Mineral

The swelling potential of soils of the study area is assessed using the above-mentioned simple tests such as Atterburg limits, clay contents, shrinkage limits and free swelling potential. Comparison of the entire laboratory results of the soils with the corresponding guides to swelling potential places the soil of the study area as low swelling potential soils indicating that they are not problematic soils for engineering application.

Table7. 10. Classification of swelling potential

Ola (1982) PI	Ramana (1993) LL	Potential expansiveness
0-15	>50	Low
15-25	50-70	Medium
25-35	71-90	High
>35	>90	Very high

To estimate the type clay minerals in the area the soils are plotted on the liquid limit-plastic index chart and accordingly the clay minerals are found to be Kaolinite (Fig7.6) and this is characterized by relatively low swelling potential.

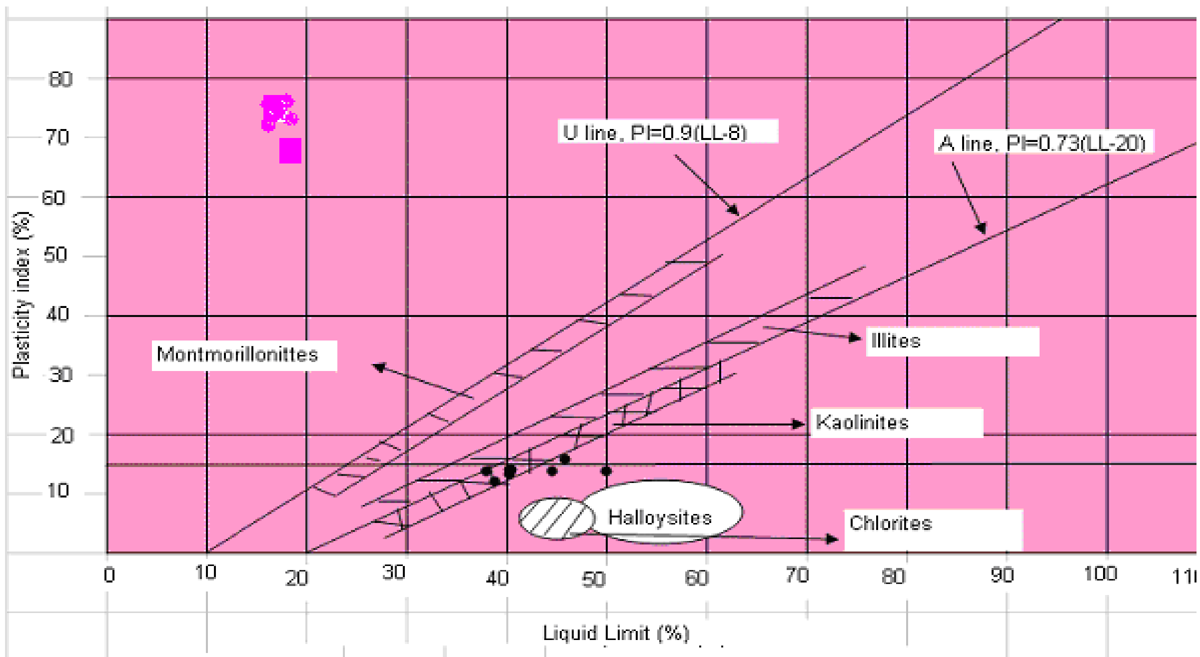


Fig 7.6 Plot of soils of Oda dam to determine the type of clay mineral

7.6 Electrical Conductivity (EC) and pH of Soils of the Study Area

The knowledge of chemistry of soil and water of a particular site is essential to permit selection of suitable type of cement to provide protection for the concrete attack and select a suitable crop type for that area. To know this some chemical test such as pH and EC are conducted on the soils. EC is the property of a material to permit an electric current and it indicates the concentration of ions in the soil and for this reason it helps us to determine the aggressiveness of the soil to the engineering structure or plant growth. pH refers to the effective concentration hydrogen ion in a solution. An acidic soil or an alkaline soil can corrode the pipe or concrete of engineering structure.

From the table 7.11 the pH of the soil varies from 7.1 (neutral) (TP4) to 7.8 (about alkaline) (TP7, TP5, TP2, TP9) and this shows that the soil of the study area is more or less with in the acceptable limit (Table 7.11) of PH value for the intended dam structure and crops to grown on the irrigable land. The EC value of soils of the study area varies from 180 (in TP4) to 1700 in (TP1). The SM type of soil group has high value of EC because they are residual soils with higher concentration of elements while the transported soils (CL and ML) have relatively lower values because some of the elements could be depleted during transportation.

Table 7.11 The pH and EC values of soils of the study area.

Test pit	Soil type	pH	EC (µs/cm)
TP7	Lean clay with sand (CL)	7.8	540
TP1	Silty sand soil (SM)	7.4	1700
TP8		7.4	1320
RSL1		7.6	280
TP4	Sandy silt (ML)	7.1	180
TP5		7.8	310
TP2		7.8	270

7.7 Engineering Properties of Soils

The knowledge of the determination of soil physical and index properties is crucial and those properties are pre-requests to the determination of the engineering properties of soils. The principal distinction between index and engineering properties is that the determination of index properties is simple and may be accomplished by personnel with comparatively little training, where as the determination of engineering properties requires considerable knowledge and skill if reliable information is to be developed (USDI, 1974). The main engineering properties include shear strength, compressibility and permeability.

7.7.1 Shear Strength

The shear strength of a soil is its maximum resistance to shearing stresses and the engineering computations concerned with the strength of a soil deals primarily with its shear strength (Arora, 1998). It is represented as composed of internal friction (ϕ) and cohesion (c). Angle of internal friction is the resistance due to interlocking of a particles and friction between individual particles at their contact points and cohesion is the resistance due to inter particle forces which tend to hold the particles together in a soil mass. The shear strength (s), can be represented as

$$\tau_f = C + \delta \tan\phi \qquad (7.7)$$

where C = cohesion

ϕ = Angle of internal friction

δ = Total normal stress on the failure

τ_f = Shear strength

The shear failure of a soil mass occurs when the shear stresses induced due to the applied compressive loads exceed the shear strength of the soil. Shear strength is the main engineering property, which affects the stability of soil mass under loads. That is, it governs the stability of slopes, bearing capacity of soils, the earth pressure against retaining structures and other problems.

In the soils of the study area, a direct shear tests on four samples (TP1, RSL1, RSR2 and DA) is determined and the results of the shear parameters (C andϕ) are given in table 7.3 and their graphical representations are given fig. 7.7 below. The factors that affect the shear strength of cohesionless soils are shape, gradation, and denseness of particles (Arora, 1997).

The gradation of sandy silt (ML) is uniform and that of (SM) is medium to nonuniform (table 7.5). The angle of internal friction (ϕ) of these types of soil varies 27^0 (for loose condition or uniform) to 34^0 (for dense condition or well graded) (Arora, 1997). That is, the laboratory ϕ values of these soils vary from 24.4^0 to 33^0 showing that that the soils vary from loose (uniform) to nonuniform (well graded) or dense state. In terms of shear parameters, dense sand and over consolidated clays have similar property and the high strength at the peak point in an over consolidated clay is due to structural strength while that of dense sand is due to interlocking of grains (Das, 1998). The lean clay (CL) soils of the study area have a ϕ value of 32^0 (table 7:12), which is similar with that of the dense sand. Besides, the clay type of the area is determined to be kaolinite type clay, which has a strong structural bond. Therefore, the clay is over consolidated clay. Over consolidated clay means a soil which has been subjected to an effective pressure greater than the present over burden pressure and some of the various cases is that the existence of a greater overburden in the past which has been eroded or excavated (Singh, 1994). This is also true with actual site condition because these CL soil group are found as pockets at the riverbank of the meandering Oda River, which is usually exposed to such over burden removal due to the meandering nature of the river.

Table 7.12Results of shear parameters for some of the soil of the study area

Location	C (Kg/Cm^2)	ϕ (Degree)
TP1	0.6	33.09
RSL1	0.25	24.37
RSL2	0.25	30.73
DA	0.05	32.41

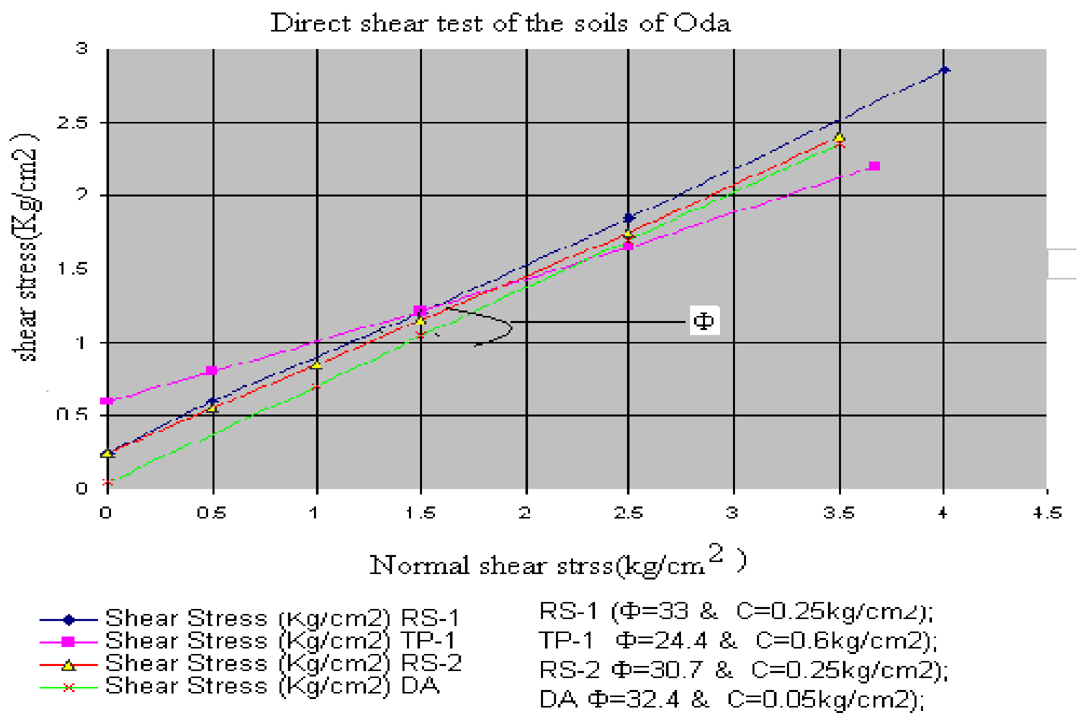


Fig 7..7 Plots of direct shear for soils of Oda dam

These shear parameters are determined from the disturbed samples (remold) because it was not possible to collect undisturbed samples for the reason that the soils have sandy character and dry nature.

In performing the test, three tests are carried out for the same soil type under different normal stresses. Then, the shear stress at failure for each normal stress is calculated as the ratio of resisting shear forces to the cross-sectional area of the specimen under test. The results are plotted graphically with the shear stress on the vertical scale and the normal stress on the horizontal scale (Fig. 7.7). The value of the angle of internal friction (ϕ) is determined from the slope of the line through the plotted points, and the intersection of this line to the shear stress axis (vertical axis) is the cohesion value of the soil.

The shear strength of soils is determined in the laboratory by direct shear tests, unconfined (Uniaxial) compression tests and triaxial compression tests. A number of methods are also available for determination of shear strength of soils in the field such as the vane-shear test, penetrometers etc.

The unconfined compression strength test is a special case of triaxial compressive test in which the specimen is failed under axial compressive stress only with zero lateral stresses (δ3 = 0) assuming that no moisture is lost from the specimen during the test. Unconfined compressive strength can be tested using pocket penetrometer besides to the laboratory test (table 7.13**).**

The value of the unconfined compressive strength decrease with depth for the transported fine soils as the soil becomes moist with depth while it increases with depth in the case of the residual soils as the soil becomes more intact and rocky nature.

Table 7.13 some of the results of Unconfined Compression Strength test of soils done in the field using Penetrometre.

Test pit	Soil group	Depth(m)	UCS(Kg/cm^2)	Remark
TP1,TP8,RSL1	Silty sand (SM)	Surface	2.5	Dry
		0- 0.4	3.5	Moist but rocky
		0.4-1	4.2	More intact
TP2 and TP4	Lean clay with sand (CL)	Surface	>4	Dry
		0- 0.6	2.5-3	Little bit moist
		0.6-1.20	2.5-3	Little bit moist
DA	Sandy silt (ML)	3.5-4		Dry
		3.5-4		dry

7.7.2 Compressibility of Soils

The property of a soil (dry, wet or saturated) pertaining to its susceptibility to decrease in a volume under pressure is known as compressibility and it is indicated by the change in volume of a soil per unit increase of pressure (Singh, 1994).

A stress increase caused by the construction of foundations or other loads compresses soil layers. The compression is caused by deformation of soil particles, relocation soil particles and expulsion of water or air from the void spaces.

Settlement characteristics of a soil can be determined by mechanisms such as laboratory or field measurements and by developed relationships of compressibility to that of soil index properties.

To investigate the compressibility of the soils, a laboratory based analysis done for consolidation and other index tests, which are discussed earlier.

Construction often involves the use of soils to make a structure or the placement of a structure made of other materials on a soil foundation. In either case, the compressibility of the soil used is an important consideration. The decrease in volume (compressibility) of a soil mass can be a consequence of either natural or artificial factors (Johnson & DeGreff, 1988). That is, compressibility can be done either by artificial means (compaction) or natural (consolidation) and both of these are determined in the geotechnical laboratory of TWRB.

A. Compaction: - is an artificial densification of soils (Johnson and DeGreff, 1988). It is the process by which soil particles are artificially rearranged and packed together in to the state of closer contact by mechanical means so as to decrease its porosity and thereby increase its dry density. It is a consideration whenever soil is used as a construction material. Soils are extensively used as a basic material of construction of earth structures such as dams, highways, air fields and others. In a dam projects soils can be used either as embankment for dam body or as blanketing materials for pervious reservoir areas.

The factors that affect compaction are the moisture content, the amount of compactive efforts (energy), and nature of soil and method of compaction. Soils of the area are tested under the same energy and the methods (proctor test) in the Laboratory and they cannot be a factor for this analysis. Water content and soil type are the main factors that affect the results of the compaction. Laboratory analysis for some of the soils in the study area (especially those found on the reservoir) is done to evaluate their compaction nature.

The dry density of the soil increases with an increase in water content until the optimum water content is achieved. Field description and consistency analysis shows that all the soils are dry and stiff and thus, the impact of the moisture content is more or less the same for soils of the area.

Soil type is the other factor that affects compaction. Coarse-grained soils can be compacted to a higher dry density than fine soils (Arora, 1997). As you can observe from table 7.14 and fig.7.8, the silty sand (which is coarser) has the highest dry density than the lean clay (which is finer). Even the same silty sand soil exhibits different dry density owing to their clay content i.e. silty sand soil with less clay content (RSL1 and RSL2) has attained higher dry density than those with relatively higher clay (TP1) (table 7.14). The hydraulic properties of the reservoir soils can be improved by some mechanical compaction while they are in their place. The analyzed results of compaction i.e. maximum dry density (MDD) and natural moisture content (NMC) are represented graphically (Fig.7.8**)** and is given in table 7.14 below.

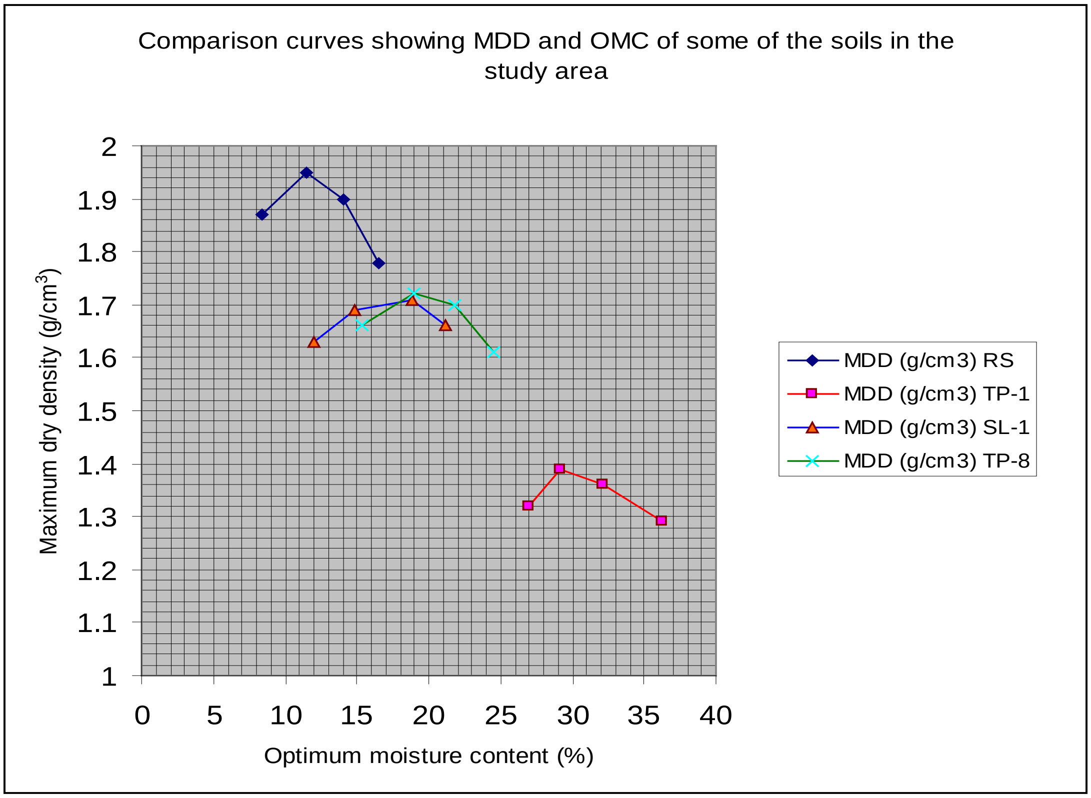


Fig.7.8 Compaction curve for soils of the Oda dam

Compaction mainly removes air from void spaces. As can be seen the MDD Vs OMC graph above and table 7.14, the dry density of the soils increases with the addition of more water and reaches maximum at the optimum moisture content and decreases again because the extra water starts occupying the space which the soil could have occupied.

Table 7.14Shows Results of MDD and O.M.C of Standard Compaction for Area of Interest

Location	Sol Type	Compaction Result	
		MDD/g/cm3	O.M.C (%)
TP1	Silty Sand (SM)	1.39	29
RS		1.95	11.5
RSL1		1.71	18
TP8		1.72	19.5
RSL2		2.02	14.5
DS	Sandy silt (ML)	1.83	15

B. Consolidation

There are several ways in which data from a laboratory compression test may be presented and analyzed. The consolidation is rapid at first, but its rate gradually decreases. After a time the dial reading becomes steady, and the soil sample may be assumed to have reached condition of equilibrium (Venkatramaiah, 1994).

The consolidation tests done in the laboratory are used to determine.

- Calculation of void ratio
- Coefficient of volume change
- Coefficient of consolidation
- Coefficient of permeability

A. Void Ratio (e):- is the ratio of the volume of voids to the volume of solids. The final void ratio corresponding to each pressure increment is calculated from either the height of solids method or change in voids ratio. For each pressure increment in a consolidation test, the change of void ratio (Δe) can be determined using the equation 7.7.

$$\frac{\Delta e}{1+e} = \frac{\Delta H}{H_o} \Rightarrow \Delta e = \frac{(1+e)\Delta H}{H} \qquad (7.8)$$

where $\triangle e$ = change in void ratio

$\triangle H$= change in specimen height

H_O = initial specimen height

The value of the void ratio is then calculated (table 7.15)

Table 7.15 Summary of Consolidation Test Results

Pressure	Cumulative $\triangle H$(mm)	Cumu-lative $\triangle e$	$e=e_o-\triangle e$	Incremental		$1+e_o$	MV m^2/MN	T_{50} (Min)	H (mm)	Hmean (H1+H2)/2 (mm)	($Hmean^2$) (mm)	$C_V = \frac{0.026(H_{mean})^2}{t_{50}}$	a_v m^2/MN
				$\triangle P(KN/m^2)$	$\triangle e$								
0	0.00	0.00	0.9016						20				
20	0.542	0.0515	0.8501	20	0.0515	1.8501	1.391	6.76	19.46	19.73	389.27	1.49	2.573
40	1.334	.1268	.7748	20	0.0753	1.7748	2.121	11.56	18.67	19.07	363.66	.817	3.764
80	1.794	.1705	.7311	40	0.0437	1.7311	.631	5.76	18.21	18.44	340.0	1.53	1.092
160	2.474	.2352	.6664	80	0.0647	1.6664	.485	7.84	17.54	17.87	319.33	1.05	0.808
320	3.258	.3097	.5919	160	0.0745	1.5919	.292	4.84	16.74	17.14	293.77	1.57	0.465
640	4.112	.3909	.5107	320	0.0812	1.5107	.167	4.84	15.89	16.32	266.17	1.42	0.252

$\triangle H$ = settlement; $\triangle e$=change in void ratio; M_v= Coefficient of volume compressibility;

C_v =Coefficient of consolidation; T_{50} =time at 50% consolidation; a_v = coefficient of compressibility;

H_{mean} = average specimen thickness; H_O =initial height of specimen 20 mm;

e_o =initial void ratio = 0.9016

Table 7.16 Suggested Correlations by Various Authors for Cc and LL (After Das 1998)

S/N	Suggested Correlation	Suggested for	Cc for Sample of Oda (DA)	Suggested by
1	Cc = 0.009 (11-10)	Undisturbed clay	0.320	Skempton (1944)
2	Cc = 1.15 (e_o - 0.27)	All clays	0.723	Nishida (1956)
3	Cc = 0.3 (e_o - 0.27)	In organic cohesive soils	0.189	Hough (1957
4	Cc = 0.156 e_o + 0.01	All clay	0.151	Rendo - Herrero (1980)
5	Cc = 0.141Gs 1.2 (1e_o/Gs)	Natural clay	0.236	"
6	Cc = 0.2343 (11/100)Gs	All clays	0.274	Negaraje & Murthy (1985)

NB. Dam axis soils of Oda have LL = 45.5; Gs = 2.57, & e_o = 0.9016.

$$C_c = \frac{e-e_o}{Log\left(\frac{\delta_1}{\delta_0}\right)} \quad (7.9)$$

where Cc = compression index

e = final void ratio

e_o = initial void ratio

δ_0 = initial effective stress

δ_1 = final effective stress

Compression index is vital element in computing settlement caused by consolidation. A relationship has been developed between the compressibility of a soil, as indicated by compression index and a liquid limit and is linear relationship. The relation developed between liquid limit and compression index is given in table 7.17 as forwarded by several authors.

(b) Coefficient of volume change or volume (compressibility (M_V):- is calculated for a given pressure in a consolidation test and can be computed simply by voids ratio method or change in the thickness method.

$$MV = \frac{\Delta e}{1+e_0} \times \Delta\delta \quad (7.10)$$

Coefficient of volume compressibility (M_v) for the tested sample varies from 1.4 m^2/MN to 0.17m^2/MN for the pressures 20 KPa and 320KPa respectively.

The other parameter known as the compression index (Cc) representing the linear portion of the void ratio versus logδ plot and is negative in view of the decreasing void ratio for increasing pressure.

c) Determination of coefficient of consolidation (Cv):- consolidation test is conducted in a laboratory to study the compressibility of a soil. The coefficient of

consolidation (C_v) can be determined by adopting some of the characteristics of theoretical relationship between time factor T_v and degree of consolidation (U) to the relationship between elapsed time t and degree of consolidation of a specimen obtained in the laboratory for any pressure increment (Singh, 1994). Coefficient of consolidation decreases with the increasing liquid limit of soil. For a given load increment on a specimen, two graphic methods are commonly used for determining C_v from laboratory one-dimensional consolidation tests. These are the square root-time and the logarithm-of-time methods. In the square root of time method, a plot of deformation against the square root of time is made for incremental loading and similarly specimen deformation against logarithm-of-time plot is made to determine the values of C_v.
Coefficient of the tested sample varies from o.87m/year to 1.57m2/year **(**table 7.16)

d) Coefficient of Permeability:-can be determined during the consolidation test by attaching a standpipe to a fixed ring consolidometer and performing the falling head permeability test (Singh, 1994). The permeability test is conducted when consolidation of specimen is complete under a particular pressure increment. It can be also estimated indirectly by using equation (7.9) when the values of M_v, C_v have been calculated.

$$K = CvM_v\gamma_w \qquad (7.11)$$

where C_v = Coefficient of consolidation

M_v = Coefficient of volume change

γ_w = Unit weight of water

7.7.3 Field Permeability of Soils

A soil material is porous if it contains interstices and this porous soil material is permeable if the interstices are inter-connected or continuous. Permeability is the ease with which water can flow through it and it is a very important engineering property of soils (Arora, 1997). Knowledge of permeability is vital in several soil engineering problems, such as seepage through and below earth structures (e.g. dams), settlement of buildings, yield of wells, etc. The permeability of soils is also useful in design of filters used to prevent piping in hydraulic structures.

The coefficient of permeability for soils can be determined either in the field or laboratory test using the constant or variable head permeability tests, or indirectly from consolidation test as discussed above. In the study area the permeability coefficient of the fine soils of the reservoir area is determined in the field using the constant-head-method (table 7.17**).** Field permeability tests are often more reliable than the laboratory tests because field tests are performed on soil in-situ that are not affected and covers larger area of influence of the test that considers local variations. As shown in the table 7.17, the permeability of the reservoir soils varies between $1.5*10^{-1}$ cm/sec in the sand soil to $9.7*10^{-4}$ cm/sec. As we can observe from the table below there is a variation of permeability for the same soil group because the clay content varies even with the same soil group.

Table 7.17 Permeability Field Test Results of the Soils of Reservoir Area

Location	Soil Type	Thickness (m)	Permeability (cm/sec^2)
TP1	Silty sand (SM	2.5	8.36×10^{-4}
TP_2 (Kf_2)	Sandy silt (ML)	2	1.87×10^{-4}
Kf_3	Sandy silt (ML)	3	9.7×10^{-4}
Kf_4 (TP_5)	Sandy silt	2.5	7.63×10^{-4}
Kf_5	Sand		1.5×10^{-1}
Kf_6	Sandy silt	3	1.23×10^{-3}
Kf_7	Sandy silt	3	4.36×10^{-3}
Kf_8		2.5	8.360×10^{-4}
Kf_9	Lean clay (CL)	3	8.9×10^{-4}

7.8 Engineering Uses of Soils of the Area

So far some of the Physical and Engineering properties of the various soil groups are discussed in the previous section. In this section their engineering uses and applications will be discussed by comparing the results of the Oda soil with standard values.

Based on soil USCS made above the soil groups of the study area includes the sandy silt (ML), the silty sand (SM) and the lean clay (CL). Their relative desirability for various purposes are given below depending maximum dry density, optimum moisture content, shear parameter (C & ϕ), compressibility, permeability, etc. as mentioned above in comparison with the numerical rating intended as guide line (AnnexC7) . When the engineering suitability of the soils are compared in terms of the shear strength and compressibility, SM soil group is better than the other soil group while the CL soil group is better in terms of the permeability and workability (Table7.18). Therefore the CL soil group can be used for blanketing of the reservoir in the area where the aphanitic basalt is exposed.

Table7.18 Comparative Engineering Properties of Soils of the study area.

Group symbol	Value when compacted	Shear strength when compacted	Compressibility when compacted	Workability as construction material
SM	Semi-pervious to impervious	Good	Low	Fair
ML	Semi pervious to impervious	Fair	Medium	Fair
CL	Impervious	Fair	medium	Good to fair

CHAPTER 8

ENGINEERING GEOLOGICAL AND GEOTECHNICAL CHARACTERIZATION AND MAPPING OF ROCK

8.1 Description of Rocks for Engineering Purposes

8.1.1 General

Rocks, like soils, are very important in many civil engineering projects. Rocks are also the parent materials of the soil that we see on the surface of the earth. The most challenging surface structure with respect to rock mechanics are large dams, especially arch and buttress types that impose high stress on rock foundations or abutments, simultaneously with the force and attraction of water (Goodman, 1989). The proposed Oda dam is going to be concrete dam that requires rock engineering.

The engineering behavioral distinction between soils and rocks can be made for instance, based on the basis of hardness or strength (Piteau, 1970), porosity and density (Duncan, 1996), permeability and compressibility, all of which are important engineering properties, as cited in Dearman (1991). That is, rocks are stronger, denser, with lower primary porosity, and less compressible than soils in general. In engineering geology rocks can be based on their engineering properties and engineering uses. Intact rock or rock material is the smallest unit of rock that is free of large-scale discontinuities where rock mass is affected by discontinuities, i.e. rock mass is the combination of intact rock and discontinuities (geologic structures). In many civil engineering works the challenge lies on the rock mass properties than the intact rock properties. Rock mass means a large volume of rock on which, or in which, some engineering work is to be carried out (Beaves, 1985). The intensity and nature of geologic structures (discontinuities) such as joints, bedding separation surfaces, some hydro-thermal veins, dykes, sills, schistosity, cleavage and likes, depend on the origin, nature, homogeneity and geological history of the rock mass. Discontinuities in an initially homogenous rock mass not only contribute to the destruction of continuity, in a reduction in homogeneity since it is along fractures that dykes and sills are intruded, and that weathering is more active (Beaves, 1985). In general, a full engineering-geological understanding of site covered by rocks is obtained by detail qualitative and quantitative description of lithologic and physical properties of both intact and rock mass. To have a common understanding among concerned professionals, the rock description methods developed by the International Association of Engineering

Geologists (IAEG, 1981) and the International Society of Rock Mechanics (ISRM, 1981) are adopted to describe the rocks.

According to Dearman (1991) the description of rock involves the following steps:

- Determination of the rock names i.e. the lithological rock name.
- Description of the properties of the rock material
- Description of the additional properties necessary to describe the features of the rock mass.

All the steps mentioned above provide a descriptive rock name from which engineering properties may more readily be inferred than from lithological rock name.

Having this in mind, rocks of the study area can be described as follows: the main lithologic units found with in the catchment, reservoir and dam foundations are welded tuff, basaltic units and dioritic units. Intact rock description such as strength, weathering, etc. and rock mass description (mainly discontinuities and degree of weathering) which affects the engineering characteristics of the rocks of the study area is given as follows. Some of the description of rocks on color, texture, composition, etc are already given in chapter 3 and will not be repeated here.

8.1.2 Welded Tuff

The state of weathering of the welded tuff varies between slightly to medium weathering. It is affected by one set of vertical joint set that varies from closely to widely space. The joints are undulating and slightly rough in nature and are open. The other type of discontinuity present in this unit is the bedding plane, which has nearly horizontal orientation. These discontinuities (the vertical joint set and horizontal bedding) are slightly to moderately weathered and are in a dry condition. The mediumly weathered part of the welded tuff has some variegated colors of yellowish and reddish color indicating the existence of slight decomposition (alternation). The unconfined compressive strength of the welded tuff, the wall strength of the vertical joint sets is more or less similar and varies between moderately strong to strong as estimated from the Schmidt hammer field tests in combination with manual hammer blow test. This welded tuff is only found in the upper part of the catchment.

8.1.3 Basaltic Rock Units

The rock description given under this category includes the alkaline olivine basalt, the aphanitic basalt and the recent basaltic dykes intruding the older basalt. From engineering point of view these basaltic rocks do not posses similar engineering property due to the difference in degree of weathering and joint conditions and orientations. Therefore, these rock units can be grouped into two engineering-geological groups, namely the fresh to slightly weathered group and the medium to highly weathered group.

The fresh to slightly weathered group includes the aphantic basalt, the recent dykes and some pocket of slightly weathered out crops of the alkali olivine basalt. Two joint sets are common ones in these units except there are three sets in some localities of the aphantic basalt. The spacing of these joint sets vary from very closely spaced and with moderately narrow to narrow opening having no infilling materials (Table 3.2). The rock units are not much affected by weathering and have high strength for the rock while the joint wall has low strength as estimated from the Schmidt hammer field tests. These differences in strength between joint wall and the rock material indicates that there is more weathering effect along the joints than on free face of the rock units. These types of rocks are found on the catchment, (Fig 7.1) reservoir and dam foundation (Fig 7.2).

The medium to highly weathered rocks includes the alkali olivine basalt, which covers most of the catchment, reservoir and foundation. This group show different degree of weathering. Locally, this unit is completely weathered and changed into residual soils. This lithologic unit is also affected by series of oriented and non-oriented joints. However, all the joints found within them are filled with calcite minerals. Two dominant joints (NW-SE and NE-SW) are dominant and the NW-SE joint sets are more steep (85^0-90^0) than the NE-SW joint sets having a dip amount of 45^0-60^0. The opening of these joints becomes relatively wider as compared with the fresh or slightly weathered basalt groups. The unconfined compressive strength of these rocks, as obtained from Schmidt hammer and laboratory test (TCDE, 1996) varies between 26 to 60 MPa i.e. it is moderately strong to strong.

8.1.4 The Dioritic Intrusion

This litologic unit occurs as dyke intrusion and negligibly out crops at certain places of Oda River and certain jointing streams, especially at the upper rims of the reservoir and left side of the catchment (Fig 3.3 and 7.2). It is fresh to slightly weathered and its strength as determined from the Schmidt hammer and other simple semi-qualitative tests (hammer blow), is found to fall in the strong category according to IAEG (1981) recommendation.

8.2 Engineering Geological Classification of Rocks

8.2.1 Classification of Rocks Based on Strength and Degree of Weathering

The genetic based geological classification of rocks may have less significant relations to engineering properties of rocks concerned. Different rock units can be grouped into the same engineering category regardless of their origin.Typical engineering problems that require rock classification include assessment of slope stability, exactions, for construction material (Bell, 1983).

Weathering has a profound effect on the physical and mechanical properties of rocks and generally strength of rocks decreases with increasing of deree of weathering. Rocks of the study area, which are dominantly basalt, are considerably affected by weathering. Weathering in the area of interest is facilitated by the presence of high temperature, high rainfall, composition of the rock (composed of ferromagnesian elements) and the presence of small and large geological structures owing to the rift system.

In places like Oda where weathering has vital role in modifying the engineering properties of rocks, it is misleading to use rock name alone as indicator of geo-mechanical and engineering properties. A classification of weathered rocks for engineering purposes requires as its bases, characteristics of the rock which can be determined in the field or laboratory. Classification range from those based purely on visual inspection (subjective) to those based on the results of precise results and detail tests (Beavis, 1985). The present work involves field inspection and description, Schmidt hammer based strength determination at field, some laboratory tests such as water absorption, unit weight, aggregate crushing value (ACV), and Los Angeles abrasion and unconfined compressive. Strength test results which were obtained from the Transport Construction and Design Enterprise (TCDE) and REST (1997) are also used. Gradation tests such as the Aggregate Crushing Value (ACV), (LAA) gradation will be more explained in Chapter 9.

Fig 8.1 Engineering geological zoning of reservoir and foundation materials depending on permeability

In classifying the weathered rocks for engineering purposes, part or all of the following should be used (Beavis, 1985):

- Description of rock material or rock mass
- Strength index
- Fracture spacing (if mass)
- Rock quality designation (RQD)
- Rock; soil ratio
- Porosity

In the Oda dam case the first four criteria have been used to classify the rocks of the study area as there is no data for the last two. The description of the rock is already given in section 8.1. Field Schmidt hammer reading are converted in to the unconfined compressive strength using the following equations and relationships:

1. Graphical correlation that relates dry density, unconfined compressive strength values and Schmidt hammer (SHV).
2. Empirical formula proposed by Barton add Choubey (1977) as cited in Bell (1983):

$$\text{Log USC} = 0.00088\gamma_d \text{ SHV } (KN/m^3) \qquad (8.1)$$

where SHV = Schmidit Hammer Value

UCS = Unconfined Compressive Strength (MPa)

γ_d= Dry Rock Density (KN/m^3)

A. Strong to Very Strong Rock Units

These basalts are fresh to slightly f weathered. As already mentioned above it is affected by two to three sets open joints. The degree of weathering is relatively higher in out crops of these units where it is affected by closely spaced Joints and is less affected when massive. Degree of weathering increases as the fractures becomes so close to each other.

The other parameter used in describing degree of weathering of rock material and rock mass is the Rock: Soil Ratio (RSR) that indicates the weathering grade in the field. Some of the fractures of the strong to very strong basalt have some loose soil fill and this according to Beavis (1985) means these basaltic units fall with in the 90-100 Rock: Soil Ratio (RSR). The average unconfined strength of these basaltic units varies from 101 to 185 Mpa (table 8.1). These types of rock units outcrop as isolated hills with in the catchment, reservoir and dam foundations (Fig 7.1 and 7.2).

B. Moderately Strong to Strong Rock Mass

The moderately strong to strong rock units of the study area include the medium weathered basalt, the slightly to medium weathered dioritic intrusion and the welded tuff. The medium weathered basalt is the major constituent of the central, left and right side of the catchment, and the reservoir and dam foundation while the slightly to medium weathered welded tuffs are limited only to the upper part of the catchment area. The slightly weathered dioritic intrusion out crops in some localities of the Oda River and the right side of the Oda catchment area (Fig 7.1 and 7.2)

Lithology	Degree of Weathering Class	SHV unit	Computed Unconfined Compressive Strength (MPa)			Description	Density of Rock (KN/m³)
			Using Graphical method	Using Barton and Choubey (1997)	Average Value in Range		
Basalt	I-II	40-50	93-170	109.6-199	101-185	Strong to very strong	29.3
	III	16-32	26-55	26.4-68.4	26.2-62	Moderately strong to strong	
	IV-V	<16	<26	<26.4	26.2	Low strong	
Welded Tuff	I-II	46-48	60-65	63.1-68.87	62-67	Strong	19.6
	III	18-32	18-33	20.9-36.3	19.5-35		
Dioritic Dyke	I-II	32-44	55-80	58-89	56.5-84.5	Strong	26.8

Table 8.1Classification of rocks of the study area based on strength and degree of weathering.

Note: SHV = Schmidt Hammer Value

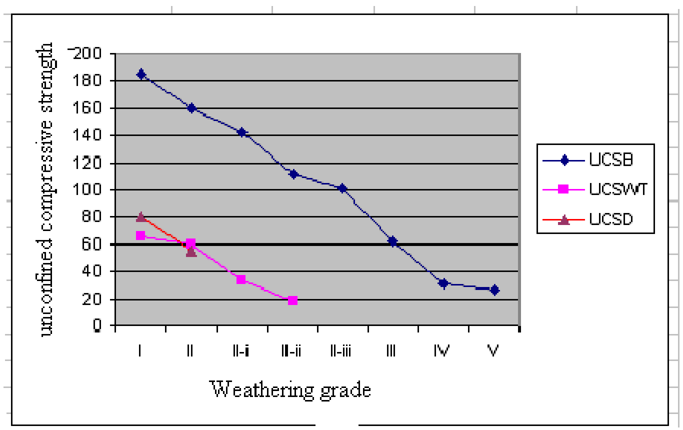
According to IAEG (1981) moderately weathered rock mass means when less than 35% of the rock material is decomposed to soil and fresh to discolored rock is present either as a continuos frame work as or a core stone. The core stones of the medium weathered basalts of the study area are large, and advanced weathering on all weak zones exists. This shows the rock: Soil Ratio (RSR) to be from 60% to 90%. Joints found on this unit are filled by calcite and these are identified using diluted hydrochloric acid during the fieldwork. The average unconfined compressive strength of this basalt (Table 8.1) varies from 20MPa to 62MPa. This shows that 74 to 123MPa of strength reduction exist when weathering progresses from the fresh to the medium basalt.

The welded tuff is less affected by jointing and hence less weathered as compared to the basalt. The strength of the welded tuff varies from 62-67 MPa for slightly weathered and 19.5 to 35MPa the medium weathered. That is, 32 to 42.5MPa strength reduction exist when weathering progress from slightly weathered to medium welded tuff. While the dioritic affected by non-systematic joints and is slightly weathered. It has strength of 58-89MPa (Fig 8.2).

From the relationship given above we can say that the loss of strength in the rock mass is greater than that in the intact rock, since tests on the intact rock at grades III and IV are made on core stone, and the rock mass of these weathering grades consists large amount of soil which has little or no strength as compared to the rock material.

WeatheringGrade	UCSB	UCSWT	UCSD
I	185	65	80
II	160	60	55
II-i	143	33	-
II-ii	111.5	18	
II-iii	101	-	-
III	62	-	-
IV	31.3	-	-
V	26	-	-

Table8.2 Variation in unconfined compressive strength with weathering grade of the rocks of the study area



UCSB= unconfinrd compressive strenght of basalt
UCSWT = unconfinrd compressive strenght of welded tuff
UCSD = unconfinrd compressive strenght of diorite

Fig 8.2 Variation in unconfined compressive strength with weathering grade of rocks

Saturation moisture content and saturated density of the basaltic rocks of the study area indicates also that when degree of weathering increases water absorption rate increase and saturated density decreases (Fig 8.2). Therefore, determination and characterization of degree of weathering is quite important when we study a site for engineering purposes.

Table8.3 moisture content variation rocks

Weathering Grade	Moisture Content
I	0.479
II	1.1
III	1.172
IV	2.083
V	2.1

Table 8.3 Water absorption Variation of basalt with weathering grade

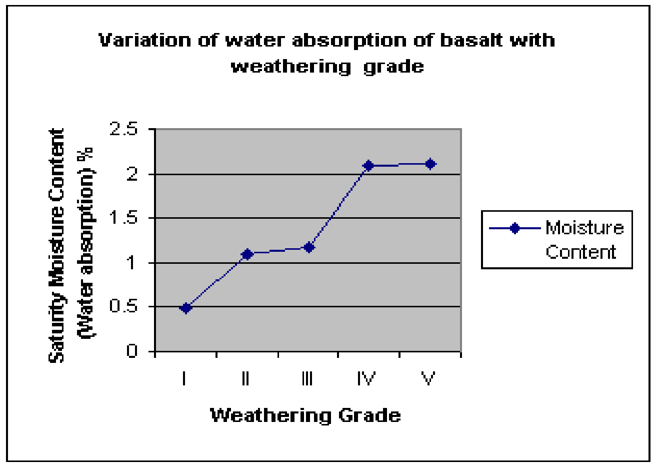


Fig 8.3 Variation in saturated moisture content with weathering

8.2.2 Geomechanical Classification of rocks

The engineering-geological properties of a rock mass have paramount importance than that of rock material properties and hence the need of rock mass classification becomes increasing from time to time because this rock mass classification and characterization more or less representation the actual site condition under consideration.

Several geo-mechanical classifications of rocks were used and are still in use to classify rocks for different engineering purposes. Among these, Bieniawski's geo-mechanical classification system considers parameters such as unconfined compressive strength of intact rock, Rock Quality Designation (RQD), spacing of discontinuities, orientation of discontinuities, condition of discontinuities and group water condition. The total number of weighted points, the rock mass rating (RMR), is the basis for classifying the rock mass into one of the new classes from very good to very poor (Johnson and DeGreff, 1988). This method is important in determining the shear and deformation parameters of rock by relating them with RMR values (see Annex C8).

In this work, joint collection (orientation, spacing, opening conditions, etc) was performed in the field using compass and meter tapes. Unconfined compressive strength and groundwater conditions were determined using Schmidt hammer and filled assessment respectively. The RQD values are also estimated using the empirical relation of Priest and Hudson (1976) as cited in Bell (1983) and Sharma et al (1999). The empirical relation of Priest and Hudson is given by the equation 8.2.

$$RQD = 100e^{-0.1\mu} (0.1\mu + 1.01) \quad (8.2)$$

where μ = number of discontinuities per meter.

The field joint measurement was mainly taken from the fresh to slightly weathered basalt (both aphantic and alkali olivine basalt) as these lithologic units constitute the main area of focus (reservoir foundation). Some joint measurement was taken also from the welded tuff and dioritic rocks to characterize their rock mass behavior. However, joint measurement on the highly weathered basalt was not possible as there is no good exposure for discontinuity measurement due to weathering effect.

The RMR classification of the dam site rock units is shown in Table 8.4. According to the RMR values shown in this table, all the basaltic rocks (aphantic and alkali olivine basalt) are classified in the range of fair quality (class III) while the welded tuff is classified in the range of poor rock quality (class IV). However, no information is available to show the quality of these rocks as no borehole data was available in the area although there is a general experience that degree of weathering and fracturing decreases with depth. In fact, the obtained result (Table 8:4) more or less fits with the surface condition of the dam site.

Table 8.4*The RMR Classification of the Dam Site and Catchment Area Rock Units* (refer annex: C8)

I. Aphanitic Basalt

S/N	Parameter	Average Value for Aphantic Basalt	Rating	Remark
R_1	USC of intact rock	101-185 (Average: 140)	12	
R_2	RQD value (%)	78-91 (Average: 89)	17	
R_3	Spacing of joints	2.66-12.3 (Average 7.3)	10	
R_4	Orientation of joints (strike and dip)	Slightly rough; 1mm average opening	-4	One joint set is favorable and other is fair
R_5	Condition of joints	Dry	7	
R_6	Ground water condition	Most joints are steeply dipping	10	
Total $RMR=R_1+R_2...+R_6$			52	
Class Description			III/F	

NOTE: III/F = Fair Rock Quality; UCS= unconfined compressive strength

NOTE: 1- Average of RQD for slightly weathered basalt based on equation 8.2 = 88+85+91+91/4 = 88.75 = 89

2 - Average RQD for medium weathered basalt = 84

II - Alkali Olivine Basalt

S/N	Parameter	Average Value for Alkali Olivine Basalt	Rating	Remark
R_1	USC of intact rock	62-143 (Average 104)	8	
R_2	RQD value (%)	77-91 (Average: 84)	17	
R_3	Spacing of joints	0.2-60cm (Average: 19cm)	10	
R_4	Orientation of joints (strike and dip)	Slightly rough: with average opening of 1.5mm	-4	One joint set is favorable while other is fair
R_5	Condition of joints	Dry	9	
R_6	Ground water condition	Steep to very Steeply	10	
Total RMR=R_1+R_2…+R_6			50	
Class Description			III/F	

III/F = Fair Rock Quality

III - Welded Tuff

S/N	Parameter	Average Value for Welded Tuff	Rating	Remark
R_1	USC of intact rock	33-65 (Average: 53)	6	
R_2	RQD value (%)	97	20	
R_3	Spacing of joints	30cm	10	
R_4	Orientation of joints (strike and dip)	With 1.2cm opening: continuous	-7	Fairly Favorable
R_5	Condition of joints	Dry	0	
R_6	Ground water condition	Steeply dipping	10	
Total RMR=R_1+R_2…+R_6			40	
Class description			IV/P	

NB: IV/p Poor Quality Rock

8.4 Engineering Properties of Rocks

The main engineering parameters of rocks of the dam site include modulus of deformation; shear strength and permeability properties of the rock types exposed at the dam site. The dam design begins from the estimation of ground strength, permeability and other factors with the required level of accuracy. In doing so geological factors play a major role, and from the various natural factors that influence the design of dams none are more important than geological ones (Lashkaripour and Ghafuoori, 2002).

The geomechanical classification of Bieniawski (1989) as cited in sharma et al (1999) was used to obtain the engineering properties (modulus of deformation and shear parameter) of the rocks exposed within the dam foundation. Similarly, the permeability of the rock mass is estimated using the empirical formula that relate joint opening and spacing with permeability as of Hoek and Bray (1981) and Serafim (1968) as cited in Bell (1983).

8.4.1 Determination of In-situ Deformation of Modulus from RMR (Deformation of Rock Masses)

The determination of deformation of rocks at the foundation of civil engineering structures is so important. Rock mass deformation results primarily from the closure of discontinuities and the deformation of intact rock that comprises the rock mass (Johnson and DeGreff, 1988). The in-situ deformation modulus of rock mass is vital parameter in the evaluation of deformation at dam site.

In-situ deformation modulus can be estimated from the final RMR of the geo-mechanical classification. The following equations from Serafim and Periera (1983) as cited in Akin (2002) for equation 8.3. and the same equation but modified by Hoek et al (1995), as cited in El-Naqu et al (2002) for equation 8.4 are used to calculate the in-situ deformation modulus of the Rock mass of the study area.

1. $E_m = 10^{(RMR-10)/40}$ (8.3)

   where E_m = in-situ deformation modulus (GPa) for 20<RMR<85

2. $E_m = 10^{(GSI-10)/40}$ (8.4)

   where GSI > 25

   E_m = in-situ deformation modulus in (GPa)

The geological strength index (GSI) of the rock mass can be estimated from RMR of Bieniawski (1989) as RMR-5 for RMR>18 (El-Naqa, and Kuisi, 2002). The RMR values (table 8.4) of the rock masses of the Oda dam are all greater than18 and hence their GSI value is greater than 25. The in-situ deformation modulus of dam foundation rock was estimated based on the above equations 8.3 and 8. 4. The estimated E_m values for the aphanitic basalt varies from 8.4 GPa (using equation 8.4) to 11.22 GPa (equation 8.3) and similarly the E_m values of alkaline olivine basalt and welded tuff varies from 7.5 Gpa (equation 8.4) to 10 GPa (equation 8.3) and 4.22 Gpa (equation 8.4) to 5.62 Gpa (equation 8.3) respectively. The dam foundation is to be situated on the alkaline olivine basalt. Thus, the average value of the in-situ deformation ($E_{rockmass}$) of 8.8 GPa can be adopted as design value for dam foundation.

8.4.2 Estimation of Shear Strength Parameters of Rock Masses

Shear strength of rocks is also one of the essential parameters in engineering design of structures. In this study the shear parameters of the rock masses of the study area have been calculated using the relation of Bieniawski (1989) as cited in Sharma (2002) that is given as follows:

$\Phi = 0.5\ RMR + 5$ (8.5)

$$C = 0.05\ RMR \tag{8.6}$$

where Φ= angle of internal friction (in degree)

C =cohesion (Kg/cm^2)

Depending on the equations 8.5 and 8.6, the angle of internal friction and cohesion of the aphanites basalt of the study are respectively 31^0 and $255kn/m^2$ while that of the alkaline olivine basalt are 30^0 and $245kn/m^2$. The welded tuff rock mass has an internal angle of friction (Φ) value 25^0 and cohesion value of $196kn/m^2$.

Once the shear parameters (C and Φ) are determined, the rock mass strength can be calculated using the most common empirical failure criteria proposed by Hock and Brown (1980, 1988) as stated in El-Naqa and Alkuisi (2002) as:

$$UCS_{rock\ mass} = \frac{2 \times C \times \cos\phi}{1 - \sin\phi} \tag{8.7}$$

Thus, the unconfined compressive strengths of the aphanitic basalt, alkali olivine basalt and welded tuff rock masses are 0.92MPa, 0.87 MPa and 0.62 Mpa respectively. The order of this value at least indicates the fairness of the analysis that the rock mass strength of aphanitic basalt is higher and that of the tuff is minimal while the strength of the alkaline olivine basalt is in between and is in agreement with the site condition.

8.4.3 Rock Mass Permeability

The changes in porosity which occur as weathering proceeds will certainly result in changes to permeability of rock material and rock mass but, later at the more advanced stages of weathering the development of some clay minerals and deposition of certain cementing material may act to reduce the permeability (Beavis, 1985).

No field permeability test has been conducted at the rock mass of the study area as there was no such an instrument and boreholes in the study area. Alkali olivine basalt and the aphanite basalts rock masses constitute the reservoir and dam foundation. Where there is no available instrument for field test of the rock mass, the permeability of rock mass can be estimated using the fracture analysis data.

The permeability of a jointed rock mass is usually several orders higher than that of intact rock. The rock mass permeability of the reservoir and dam foundation materials of the study area estimated using the Serafini (1968) as cited in Bell (1981) for opened fractures of the aphanitic basalt (equation 8.8) and that of the Hock and Bray (1981) as in equation 8.9.

$$1.K = \frac{e^3 \times \gamma_w}{12 \times d \times \mu} \quad (8.8)$$

$$2.K = \frac{e}{d} \times K_f + K_r \quad (8.9)$$

where:

e = Joint opening

d= joint spacing

γ_w = Unit weight of water (1g/cm^3 = 1000 kg/m^3)

μ = Viscosity of water

K_f = permeability coefficient of infilling material

K_r = permeability of intact rock

The results of equation 8.8 give the highest permeability coefficient for open fractures while equation 8.9 gives the lowest permeability coefficient for in filled joint systems.

In estimating the rock mass permeability, joints sets parallel or nearly parallel to the flow direction or perpendicular to dam axis are considered. Many joint measurements have been taken at 20 selected outcrops of the study area to characterize the water tightness and stability analysis of the area and about half of the mentioned numbers of out crop joint measurements are concentrated at the dam site (reservoir and foundation).

For the rock-mass permeability analysis of the reservoir and dam foundation materials (aphanitic and alkali olivine basalts), part of Joint set-1 (J-1) that trends 290 to 300^0 NW joint set - 2 (J2) that trends N10^{0}E to N40^{0}E and Joint set 3 (J3) that trend N45^{0}E to N80^{0}E are considered. That is, joint sets that are trending 450 from east (flow direction) either toward NE or SE word are taken into account for the permeability analysis. The weighted average opening and spacing values of the joint sets are summarized in table 8.6.

	Right abutment/reservoir			Left abutment/reservoir		Remark
Joint set	J1	J2	J3	J1	J2	
Average spacing (cm)	5	6	6	8	10	
Average opening (cm)	0.18	0.56	0.15	0.12	0.15	
Permeability value for AB (m/sec)	5.6×10^{-4}	3.4×10^{-2}	6.5×10^{-4}	2.5×10^{-4}	3.9×10^{-4}	Joints are open
Permeability value for A.O.B (m/sec)	4.6×10^{-8}	1×10^{-7}	3.5×10^{-8}	2.5×10^{-8}	2.5×10^{-8}	Joints are filled by calcite

Table 8.5 Summary of Joint data and rock-mass permeability calculation for the reservoir and foundation part of the study area.

N.B: AB = Aphanitic basalt 2 A.O.B = alkaline olivine basalts

The joint trend, spacing and operating measured for the aphatic and alkaline basalt fall more or less in the same category and hence the opening (e) and the spacing (d) values used to calculate the permeability values are found in the same. However, joints that are found in the aphanitic basalt are relatively fresh and open while those joints in the alkali olivine basalt are old and filled by calcite. In calculating the rock-mass permeability of the alkali olivine basalt the minimum coefficient of intact rock permeability (basalt in this case) adopted are 10^{-6}cm/sec and 10^{-4}cm/sec respectively (Bell, 1983; Brassingtone, 1988; Freeze and Cherry, 1979; Hock and Bray, 1981).

Therefore, the estimated rock-mass permeability of the aphantic basalt vary from $3.4*10^{-2}$m/sec in the abutment (J_2) to $6.5*10^{-4}$m/sec of the same abutment (J_3) while that of the alkaline olivine basalt varies between $1*10^{-7}$m/sec (in J_2) of the same abutment $4.6*10^{-8}$m/sec (in J_1) of the same abutment. This indicates that the right abutment is not watertight. This rock-mass permeability result is compared with that of Anon (1977) and is a comparable result. Thus, the alkaline olivine basalt falls with in the slightly permeable value while the aphantic basalt falls with in the moderately to highly permeable rock mass (Table 8.5). This way of figurative expression of permeability is good in estimating rock mass permeability. However, such estimated result must be treated with caution and it has to be supported by at least few field permeability tests during the design of the dam.

By the help of rock mass permeability estimation from this continuity analysis (for the rocks) and field tests (for soils, and field description, the reservoir and foundation materials have characterized and zoned (Fig 8.1).

Rock mass description	Term	Permeability (m/s)
Very closely to extremely spaced discontinuities	Highly permeable	10^{-2}-10^{-1}
Closely to moderately widely spaced discontinuities	Moderately permeable	10^{-5}-10^{-2}
Widely to very widely spaced discontinuities	Slightly permeable	10^{-9}-10^{-5}
No discontinuities	Effectively permeable	Less than 10^{-9}

Table 8.6 Estimation of secondary permeability from discontinuity frequency (Anon, 1977)

8.5 Reservoir and Foundation Conditions

As indicated in the engineering and geotechnical report(REST, 1997), the maximum capacity of the dam is $6.5*10^6$ m^3 water with about 265m crest length and 46.5 m maximum dam height and is expected to irrigate 457ha.

So far it has been tied to describe, classify and discuss about the hydrological, geomorphologic geological and engineering-geological characterization of the soils and rocks of the dam project which in turn help us to understand the engineering geological and geo-technical suitability of the site for the intended dam type.

Dam feasibility and viability is infact determined from technical and economical point of view. For instance, if we take the technical aspect only it involves the input of many disciplines such as engineering, geology, watershed expert, hydrologist, irrigation agronomy, economist, sociologist, pedologist, etc. Here only the engineering geological and geotechnical aspect of the dam is considered. Thus, from engineering geological point of view factors such as topographic conditions, foundation condition, availability of construction materials, spillway conditions are taken into consideration in determining the dam type. Depending on the above factors and other economic considerations, the recommended dam type could be either masonry dam or composite dam of concrete and rockfill dam. The concrete part of the composite could be useful construct the overtopping type of spillway while that of the rock fill part is recommended for cost minimization. The rockfill part of the dam could also either with upstream concrete slab or with central clay core to protect the seepage along the dam body.

Topographically, the dam site has a U-shaped valley and the abutments are steeper having a fractured rock outcrop. A site with steeper abutment and rock exposure is not much convenient for earthdam type of dam because such a steeper abutment do not easily form a coherent bondage with the dam body. Besides, the steep slope and high relief of the catchments area leads to the strong and high flooding that may affect the stability of the dam body as it is situated at the foot of the mountains and hills. The foundation material is dominated by the mediumly weathered basalt.

A suitable location of spill way is another important factor in determining size. In the study area this is the main factor that determines the type of dam. That is, there is no saddle area suitable for spillway along the sides of the two dam abutments that require less exaction. In this situation, it is not possible to construct earthdam only because no suitable spillway site exists along the abutments. However, for the masonry concrete dam or its combination with rockfill, it is possible to construct a spillway across the dam body, which overtops it.

The other important factor for the determination of dam type in the study area is the availability of construction materials with in reasonable distance. The soils vital for the core and shell of the dam body of an earth dam are found at about four to five km down stream of the dam site. Moreover, a very considerable arable land will be lost for this purpose. For these reasons the type of dam proposed is the Masonry dam.

8.5.1 Geophysical Investigation and Dam Axes Options Proposed

A - Dam Axes Options

Three-dam axis was proposed at Oda dam site by REST (1997). These dam axes are named as down stream option (DOP), middle stream option (MOP) and upstream option (UOP). Abutment favorability and reservoir capacity were taken into consideration in selecting the three variant dam axes. Geophysical investigations were carried out (both vertical electrical sounding and profiling) along the down stream and the upstream-proposed axes.

The two abutments of the down stream dam axis are characterized by the steep slope and slightly weathered aphanatic basalt. Both abutments are not suitable in terms of water tightness (Fig. 8.1) and stability due intense fracturing and weathering effect. Besides, this dam axis doesn’t have a good reservoir site topographically.

Moreover, according to the geological survey (EGS, 1996); a relatively thick overburden and fault that cross the dam axis are identified. Therefore, this dam axis is not recommended.

The middle dam axis has a relatively the shortest dam axis. The down stream and the middle dam axis options share a common right abutment composed of aphantic basalt dyke which is not watertight due to the open closely spaced joints. The two abutments, especially the left abutment are pervaded by old land slide showing they are not stable.

The upstream dam axis option is located at upstream side of the other options and it is better in terms of watertightness, stability and reservoir condition. Comparatively the right abutment is less weathered and relatively free of landslide than the left although both fall on medium weathered basalt category. The right end of the upstream dam axis should be located upstream side of the existing landslide (Fig.7.2). This rock unit is also relatively watertight as the fractures are filled by calcite. The previously proposed option of this axis can be shifted a little bit 10 meters down stream to increase the suitable reservoir and to some extent decrease axis length. The approximate location of the current position of this axis is indicated on the engineering geological maps (Fig 7.2 and 8.1).

B- Geophysical Investigation along dam axes

Geophysical methods are usually used at the initial stage of geotechnical investigation to loosely estimate zone of discontinuities, thickness of overburden and lithological contact. Resistivity profiling and vertical electrical sounding (VES) were applied at the Raya Valley dam sites (including Oda dam) proposed by REST in (1996).

Raw VES data (for the two dam axis options) and one profiling data were collected from the Ethiopian Geological Surveys (EGS) geophysical team and are incorporated in this work. However, the VES data are very noisy and difficult to interpret them. According to the geophysical report of EGS (1996) the noisiness of the VES data is due to the rugged nature of the terrain, which deviates quite considerably from the applicability of the electrical methods that are based on certain theoretical assumption with a certain degree of tolerance. With this limitation, preliminary interpretation of the VES and profiling data is attempted as follows because it can give us some clues.

Six VES readings (3 on the upstream axis and 3 on the down stream axis) and 2 profiling have been made on the proposed dam axis by the geophysics team of EGS

(1996). The team tried prepared a geo-electric section for the two axes although it is very difficult and unreliable to prepare such a section using noisy data and with no controlling point data such as borehole

From the data obtained raw data pseudo section (for the two axes) and one profiling curve are prepared using sulfur software compares the results (Fig.8.4 a. and b). According to the results there are some inconveniences on the upstream axis.

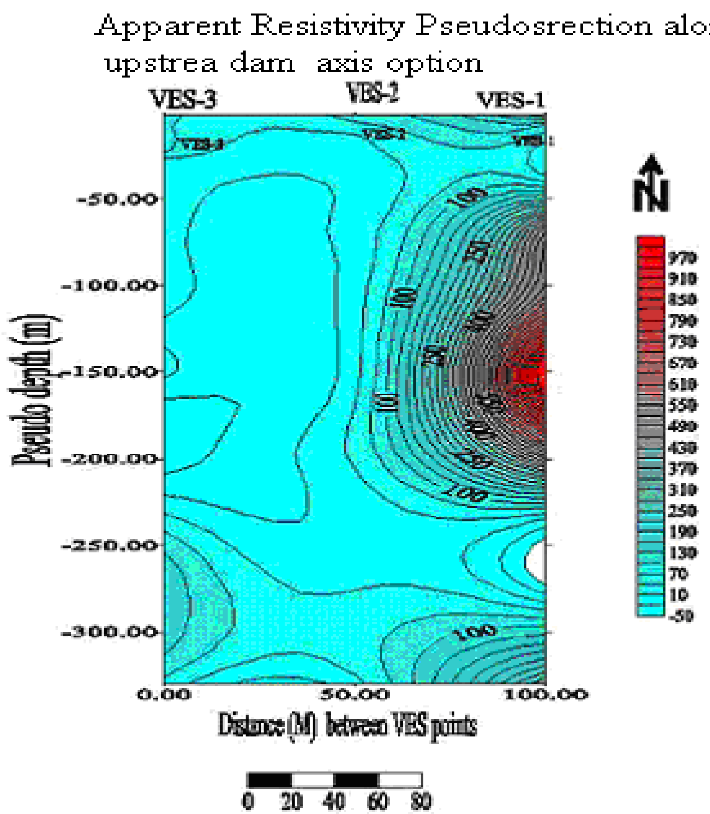
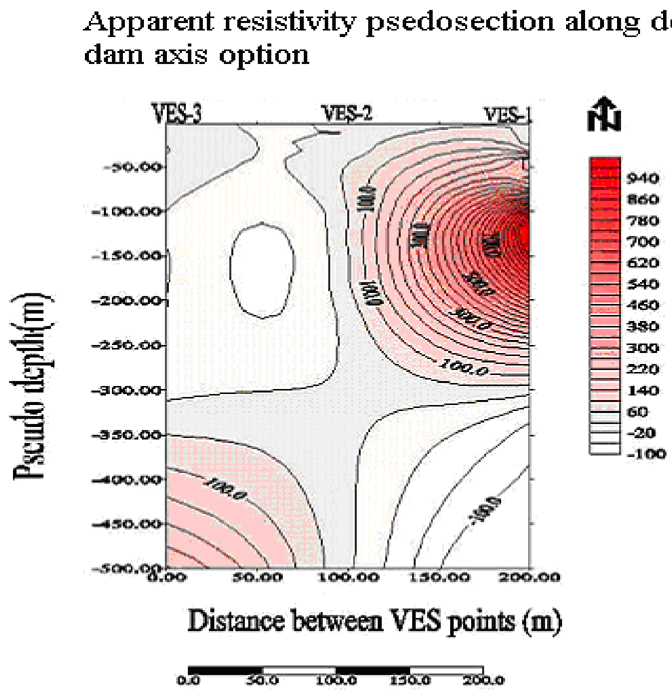


Fig 8.4a Apparent resistivity pseudosection along dam



axes

Fig 8.4b Apparent resistivity pseudosection along dam axes

(1) The second layer (table 8.7) (sand and gravels) should have not been continue up to the sides of the basaltic hills and rather it should be restricted to the river channel. (2) The naming of all the low resistivity materials as sands and gravels is only not fair. It also has the possibility to be other material such as ash, weathered scoraceous basic tuffs with or without having water because from actual site condition observed at the surface the basalt are intercalated by these materials. Any way one thing is true for all in that the low resistivity and high resistivity materials in general can be estimated. Low resistivity, which ever it is, indicates that the material is weak and requires some careful engineering design that incorporates treatment to improve the strength and/or permeability of the weak rock mass unit. The summary of interpretations for the VES results along the up stream axis is given below.

i. VES interpretation

The vertical electrical sounding (VES) survey, the apparent resistivities are entered into the computer for determining the resistivity and thickness of each layer, using the resist software package of ITC, Netherlands. The interpretation of VES results was made and the fitting accuracy with root mean square (RMS) error of 3.4% to 27.2%. The successive layers are described from top to bottom as given below along upstream dam axis.

Table 8.7(a) OD1VES- 3 (RMS = 4.1%

	Resistivity	Thickness	Depth
1	108.7	1.2	1.2
2	14.4	3.2	4.4
3	247.1	7.4	11.8
4	3.5	30.3	42.1
5	1021.5	-	-

Od1VES-3= Oda1 vertical electrical sounding

VES- 3 is nicely fitted by five layers models with RMS error of 4.1%. The first layer is characterized by high resistivity value of 108.7 ohm-m and with thickness of 1.2m. The response of this layer seems to be due to highly weathered and fractured basalt as checked from river channel exposure. The second layer with relatively low resistivity of 14.4 ohm-m and 3.2m thicknesses is supposed to be due to sand and gravel or intercalation of the acidic or basic tuff. The third layer, which is characterized by high resistivity is most likely due to more or less massive basalt. The fourth layer with low resistivity value of 3.5 ohm-m and with a thickness of 30.3m is assumed to be due to water saturated sand /gravel or the weathered tuff. The fifth layer with a very high resistivity value of 1021.5 ohm-m and unknown thickness is supposed to be due to basaltic bedrock.

Table 8.7(b) OD1VES-2 (RMS=4.4%)

	Resistivity	Thickness	Depth
1	66.4	1.4	1.4
2	16.4	8.0	9.4
3	240.7	14.6	24.0
4	3.7	32.6	56.6
5	300	-	-

Od1VES-2= Oda1 vertical electrical sounding

VES-2 has five layers with RMS error 4.4%. The top layer covers the upper most layers and is characterized by relatively higher resistivity of 66.4 ohm-m and 1.4m thicknesses. This response could be due highly weathered and fractured basalt. The second layer with low resistivity value of 16.4 ohm-m and 8m thicknesses is assumed to be due the response of sand and gravel or the weathered tuff. The third layer, with high resistivity value of 240.7 ohm-m and 14.6m thicknesses is likely due to massive basalt. The fourth layer with very low resistivity value of 3.7 ohm-m and 32.6m thickness is assumed to be a response of saturated fractures and pore cavities or sand.

The bottom layer with high resistivity of 300 ohm-m and infinite thickness is due to fresh basaltic bedrock.

Table 8.7(c) OD1VES -1(RMS=19.1%)

Resistivity	Thickness	Depth (m)	
1	94.6	1.8	1.8
2	19.0	4.6	6.4
3	22003.9	189.1	195.5
4	15.2	15.5	211
5	535.7	-	-

Od1VES-1= Oda1 vertical electrical sounding

VES-1 consists of five layers, with fitting accuracy of 19.1%, which is very high. Its interpretation is given very roughly due the maximum error. Similar to the other VES mentioned above the top layer is with a relatively high resistivity of 94.6 ohm-m and 1.8m thickness is due highly weathered and fractured basalt. While second layer has a resistivity value of 19.0 ohm-m and 4.6m thickness and it likely outlines the response of sand and gravel the weak tuff. The third layer with very high resistivity (22003.9 ohm-m and a thickness of 189.1 m is most probably a fresh and dry basalt while the less resistive (15.2 ohm-m) having a thickness of 15.5m is represents most probably similar to the second layer. Lastly, the relatively massive basal reappears again.

8.5.2 Engineering-geological suitability of Reservoir and Foundation Materials for the Proposed Dam

The engineering geological suitability of the reservoir and foundation can be evaluated in terms of stability and water tightness conditions. To assess the suitability of the site for the proposed dam, the engineering properties of both soiles and rocks are already given in chapter 7 and chapter 8. The engineering- geological characterization of the soils and rocks is based on the detail field description, classification using Schmidt hammer test, fracture analysis, test pits, penetrometer, permeability test, and geo-physical, permeability test, and geophysical (VES and profiling along the dam axis options. Although no borehole data on the dam axis, we can categorize and group the reservoir and foundation in terms of their engineering suitability for the masonry dam or its combination with rockfill dam.

A dam to be engineering- geologically and geodetically feasible and viable it should have a reasonably sound foundation, water tight reservoir and the construction materials required for dam should be with in the reasonable economical distance in enough quantity and quality. For instance, according to Atewell and farmer (1976) a gravity or mass concrete dam is suitable:

- Where there is rock foundation with in soft to 30 ft (or 6-10m) of the surface.
- The bearing capacity of the rock should be 8.68-10.85kg/cm^2 or0.855-1.069 Mpa.
- When the length of the crest of the dam would be five-times or more the height from the foundation
- As an additional requirement, there must be plentiful supplies of suitable sand and gravel or crushed aggregate with in a few km of the dam site.

The geo-technical parameters of rock mass of the study area important for the dam design such as the strength RMR values, in situ deformation and shear parameters and rock mass permeability of calculated values are given in tables 8.1 to table 8.4 According to these mentioned values and table 8.5. The qualitative evaluation of the field application and engineering use of the rocks found at the foundation and reservoir are given below. Soils at the dam foundation are thin besides to their limited use for masonry dam or its combination with rockfill foundation although they could have some importance in terms of reservoir permeability (water tightness).

The main rock units found at the reservoir and dam foundation are the aphetic basalt and alkali olivine basalt. The former is stronger but with high permeability value while the later is with relatively lower strength and with a semi-permeable to impermeable nature. According to the criteria (table 8.5), the aphanite basalt falls in good range and that of the alkaline olivine basalt falls with in the fair range for foundation usage.

According to the information given chapter 7 and (annex C7) the permeability of silty sand sail (SM) and ML varies from semi-pervious to impervious when compacted where as the CL soil group are impervious. This indicates that the lean clay (CL) group can be used for blanketing of part of the reservoir where the highly permeable aphanitic basalt is exposed at the reservoir and its rims.

Table 8.8 Classification of foundation conditions

Foundation Index	Description	Rock Class	Compressive Strength of Rock (M P A)	Deformation Modulus (10^3M P A)	Orientation of Main discontinuity Joints To Axis	Groundwater Table / Permeability (CM/S)	Overburden Weathered Rock Thickness (M)
1	VERY GOOD	1	$\geq$ 200	$\geq$ 50	Parallel, Dip 45^0- 90^0 U/S	BELOW $K<10^{-0}$	NONE
2	GOOD	2	100 - 200	10 - 50	Parallel, Dip Toward Upstream 20^0-45^0	BELOW $K<10^{-0}$	<3
3	FAIR	3	50 - 100	5 - 10	Parallel, Dip Toward D/S 45^0 - 95^0 Perpendicular Or Near Perpendicular ($\leq \pm 45^0$) Dip 20^0- 90^0	ABOVE $K=5\text{-}10^{-4}\text{-}10^{-3}$	3 - 5
4	POOR	4	25 - 50	2-5	Parallel, Dip Towards D/S 20^0 - 45^0 Dip 0^0-2^0 Irrespective Of Strike	ABOVE $K=5\text{-}10^{-4}\text{-}10^{-3}$	5 - 10
5	VERY POOR	5 / 6	$\geq$ 25	2	Parallel, Dip Towards D/S O^0-20^0	ABOVE K>5.10-3	>10

SOURCE: EELPA et al CONSULTINGANGINEERS (1994).

CHAPTER 9

ASSESSMENT OF NATURAL CONSTRUCTION MATERIAL FOR THE PROPOSED DAM

9.1. General

Construction materials can be natural or man made. Natural construction materials such as sand, gravel, crushed rock aggregates, dimension stone and clay that may be produced in their raw state for construction where as artificial or man made are those produced in a factory and includes concrete blocket, bricks, different metal sheets, etc. In this study, it is only the natural or geologic construction materials that are important for the proposed dam type will be discussed. The availability and proximity of the geologic construction materials are one of the factors that determine the type of dam to be constructed. As mentioned above, the type of proposed dam is masonry dam, which requires large amount of aggregates in combination with cement. There are several types of natural construction materials useful in the construction industry and it is difficult to discuss all types of natural construction materials. For this reason only the aggregates and stones for masonry works will be considered in this study. Aggregates can be used for concrete production for road construction. Although there are common properties of the aggregates used for concrete and road, the main focus still is on these aggregate useful for concrete production.

Aggregates are defined as particles of rock which, when brought together, form part of or the whole of an engineering structure (Smith and Collies, 1993). The demands of aggregates become higher and higher in the world today as most civil engineering structure requires aggregate.

The description and classification of aggregates in a way appropriate to their use in the construction industry is essential. The purpose of description and classification is to class things sharing similar behavior.

In the study area the construction materials, (aggregates), are identified and some physical tests such as unit weight and water absorption tests; mechanical tests (strength tests from laboratory Schmidt hammer tests), aggregate crushing value (ACV), Los Angeles Abrasion Value (LAA) and chemical tests such as sulphate and chlorite contents are conducted to assess their suitability for the dam construction.

9.2 Aggregate for Concrete

Concrete is defined as a mixture of cement, water or binder and aggregates where the binder (water and cement) forms the paste and aggregate forms the inert filler and hence concrete is composite material. In absolute volume terms the aggregate amounts to 60-80% of the volume of concrete and is, therefore the major constituents

(Smith and Collies, 1993). For this reason the aggregate type and volume have a significant influence on the nature and engineering properties of the concrete. One of the essential requirements of aggregate is that it should remain stable with in the concrete in a given environment through out the design life of the concrete. Aggregates are divided in to coarse and fine varieties, the course usually consists of rock material that passes the 37mm sieve and is retained on the 4.8mm sieve. Fine that passes through this sieve not exceeding 10% by weight of the aggregate.

Therefore, to produce a workable, durable, strong and watertight concrete it is quite essential to study the type, nature (quality) and quantity of the aggregates which are the major components of the concrete

9.2.1 Coarse Aggregate

Concrete aggregate usually consists of natural sand and gravel, crushed rock, or mixtures of these materials. Coarse aggregates can be obtained from naturally occurring gravels or crushed rocks. In the study area, the aphanitic basalts are selected to be the sources of the crushed rock coarse aggregate. These basalts outcropped at the reservoir rims starting from the dam abutments to the up stream of the reservoirs. Some of the possible quarry sites are located on the engineering geological map (Fig 7.2). The surfacial quantity of the quarry sites indicated (Fig 7.2) only are calculated to be greater than 340,000 m^3 as estimated using the hill or cliff exposures and located at the upper end of the reservoir with in the 500 m to 1000 m from the dam axis. There are also another similar potential quarry sites for the crushed aggregate both at Oda reservoir and neighboring catchments boundary with in the radius of one km to six km. Another possible source of the coarse aggregates are the river deposited gravels, cobbles, boulders with or with out further crushing of them. However, this needs careful selection as some of alkali basalts have still some stains of weathered position, which may affect the concrete.

The quality and suitability of the aphanites basalts are also confirmed using the laboratory tests and some existed data such as physical tests (aggregate grading, unit weight specific gravity water absorption), mechanical tests like strength tests (chlorite and sulphate content) and briefly described below.

A. Gradation, Unit weight and Specific gravity

i. Gradation- of aggregate is the particle size distribution of aggregate as determined by separation with standard screens (USDI, 1981). Gradation of coarse aggregate is determined by means of screens having openings according to specifications or requirements for the job. Some crushed coarse aggregates are tested for gradation at the ERA laboratory as per the requirement and the mix design can be done based on the result of the laboratory.

ii. **Unit weight** -the definition of unit weight of rocks is the same as that of soils that is given in chapter-7. Three tests of unit weights on the coarse aggregate are conducted in Korem material testing laboratory of ERA. The values varies from 1436 kg/m^3 as 1488 kg/ m^3 and the unit of the same rock as tested in the laboratory of civil engineering department of the Addis Ababa university (REST, 1997) is 1678 kg/ m^3 and therefore, the unit weight of the coarse aggregates lies with in the allowable limit. Unit weight together with the specific gravity of an aggregate are essential in the concrete production as it provides a helpful base for computing unit cement, water content, and volume of concrete per batch.

iii. Specific gravity-is another important physical property of aggregate that has a direct importance when the design or structural considerations require that the concrete have minimum or maximum weight. The design consideration of masonry or concrete dam requires a maximum weight as its stability depends on its weight. The suitability of an aggregate can be quickly and easily indicated by its specific gravity.

The specific gravity of the mixed crushed coarse aggregate of the area varies from 2.93 to 2.97 as tested in the laboratories of Transport Construction and Design Share Company (TCDSC) and Ethiopian Road Authority (ERA) respectively. The third specific gravity value that is tested at the geotechnical laboratory of china WAMBAO is 2.95, which lies between the two.

The laboratory results done at the TCDSC and ERA laboratories at different times from different localities of the aggregate source are quite similar and this shows that the sample was more or less representative. The specific gravity of each aggregate varies from 2.86 (for the aggregate size of half inch) to 3.03 (in the aggregate size of one inch) (table 9.1). According to Grim (1967) minerals (aggregate in this case) are considered as heavy if their specific gravity is greater than 2.8 and for this reason the aggregate is suitable for the dam construction. Generally, low specific gravity often indicates porous, weak and absorptive materials and high specific gravity often shows higher quality.

Table 9.1 Summary of specific gravity results for coarse aggregate.

Institutions	Specific gravity of indicial Aggregate				Specific gravity of mixed Aggregate
	1 ½” Pass	1” pass	½” pass	3/8” pass	
ERA	3.01	3.03	2.86	2.94	2.97
TCDSC	-	-	-	-	2.93
China WAMBAO	-	-	-	-	2.95

B. Water Absorption and Strength properties

i. Water absorption- is an indirect measure of the permeability of an aggregate, which, in turn, can relate to other physical characteristics such as mechanical strength, shrinkage, soundness and to its general durability potential (Smith and Collis, 1993). Three samples were tested at the laboratories of TCDSC, ERA and China WAMBAO and the obtained results are 2.1%, 1.1% and 2.08% some water absorption tests were also conducted by REST (1897) on the same rock and the results are found to be less than 0.5%. These variations in the water absorption shows that the slight difference of the samples from fresh to slightly weathering grade i.e. water absorption increases with increasing degree of weathering. According to the British standard, from which Ethiopian aggregate standards are derived, the acceptable water absorption value should be less than 3% (Bell, 1980). Thus, water absorption values of the coarse aggregate selected for the Oda dam construction falls with in the acceptable limit. Lightweight aggregates generally have higher water absorption values ranging from 5 to 20% (smith and collis, 1993) and this also strengthen the idea that the coarse aggregate of Oda are heavy aggregates.

ii. Strength- is another essential property of coarse aggregate for concrete production. Compressive strength of the potential source rock for the crushed coarse aggregate is determined both in the field (using Schmidt hammer) and in the laboratory. From the Schmidt hammer results the compressive strength of the fresh to slightly weathered aphanitic basalt varies from 101 to 185 MPa, and, the wet and average compressive strength (REST, 1997) of the same aggregate have 152 MPa and 161.6 MPA respectively as determined from laboratory while the dry compressive strength is greater than the average values. The field and laboratory results are compatible which is greater than 100mpa. According to the Ethiopian Electric Light and Power Authority (EELPA) et al (1994), Aggregates (rocks) with greater than 100 MPa are good quantity aggregates for concrete work. Hence, the coarse aggregates of the area are of good quality from strength point of view.

iii. Aggregate crushing value (ACV) -Aggregate crushing value measures the resistance to static load. In this test sample of nearly 2 kg is subjected to a continuous total load of 400 KN transmitted through a piston, in a compression test machine and is achieved in 10 minute. The percentage of fines passing sieve British standard (BS) 2.36 mm is calculated to be the aggregate crushing value. Two hand crushed aggregate samples were tested in the geotechnical laboratory of the China WAMBAO located in Kobo town. The result of the analysis shows that the ACV of the coarse aggregate is found to be 12% that falls with in the acceptable limits. This result is in fact a little bit lower when we compare with actual field observations and some hammer blow and Schmidt hammer tests. The reason for this is that the manual crushing does not attain the appropriate shape of aggregates. That is, most of the hand-crushed aggregates were elongated and flaky which can easily crushed than the rounded shape. Thus, had it been for the larger percentage of the thin and elongated shape of the aggregate, the ACV values would have been higher than 12%. An aggregate crushing value below 10% indicates a very strong aggregate and a rock with a value greater than 35% would normally be considered too weak for any engineering use (Attewell and Farmer, 1975). Generally the higher value of ACV shows the weaker material and vise versa.

iv. **Los Angeles Abrasion value (LAA**) - Los Angeles Abrasion (L.A.A) value is one of the abrasion tests useful for the evaluation of aggregate for engineering use. L.A.A is the resistance to abrasion and measures the percentage loss of weight in comparison with the original weight. Values for L.A.A test are numerical similar to ACV of similar sized charges for values up to about 30 (smith and collis, 1993). According to the TCDSC geotechnical laboratory analysis, the L.A.A value of the course is found to be 13% that is in the acceptable limit.

C. Chemical (chloride and sulphate) content and suitability of coarse aggregates

Chemical reactions of certain aggregate materials and the alkalis in cement is associated with expansion, cracking, and deterioration of concrete and is in turn can result in the total destruction of the engineering structures made of the concrete such as the masonry dam. For this reason chemical tests of chloride and sulphate are tested at the TCDSC geotechnical laboratory to assess the chemical suitability of the aggregate as a construction material for the dam body.

i. Chlorite- the presence of chlorides in concrete can present potential hazards with some cement in that it reduces the sulphate resistance, and can considerably increase the risk of corrosion of embedded metal (smith and Collis, 1993). A chloride test is conducted at the geotechnical laboratory of TCDSC and the obtained result is 50 mg/L depicting that it is not hazardous to concrete work.

ii. Sulphate- is the other chemical behavior of the aggregates that can affect the concrete if present above the allowable limit. When present in sufficient quantity, sulphates in aggregates can result in excessive expansion and ultimately, the disruption of hardened concrete in wet or damp conditions, owing to the reaction with cement compounds (Lea, 1970) as cited in Smith and Collis (1993).

As the case in Chloride, Sulphate content test for the coarse aggregate is determined at the TCDSC geotechnical laboratory. The result of the laboratory test shows that the coarse aggregate has no (or nil) sulphate content and this depicts that the aggregate is suitable for the dam construction. According to Smith and Collis (1993), the total acid soluble sulphate content of the concrete mix should not exceed 4% by mass of cement in the mix.

9.2.2 Sands for Fine Aggregate

The textural maturity of sands varies appreciably. The high degree of sorting coupled with a high degree of rounding characterizes mature sand (Bell, 1980). Enough amount of sand deposits (>90, 000m^3) are found within the Oda river channel at about two to three kilometers down stream of the dam axis (Fig. 3.2). The sand is clean, thick and is medium to coarse grained. Samples are taken from Oda river channel (in an area of 2000m length by 150 m width) to determine their gradation and the silt/clay fraction. Moreover, existed data on organic matter and unit weight of the sands are used in the analysis of the sands as construction materials for the dam body.

Fine aggregates (sands) are useful for construction purposes to prepare concrete, mortars, plasters and renderings (Bell, 1980). For instance, one of the functions of sand in concrete is to reduce the void space created by the coarser aggregate. Thus, well-graded sand gives a lower proportion of voids than one with poor graded (or uniform size) sand. Grading is, therefore, an essential property as far as the suitability of sand for concrete is concerned. Therefore, either very fine or very coarse sand, or coarse aggregate having a large deficiency or excess of any size fraction, is often undesirable.

A gradation analysis is conducted on the sands that are selected to be used in Oda dam construction and the result is summarized on Table 9.2)

The fineness or coarseness of the sand can be determined by a parameter known as fineness modulus (FM) which can be calculated by adding the cumulative percentage retained on the six standard screens (from No. 4 to No. 100 inclusive) and dividing the sum by 100 (table 9.2). According USDI (1980), a sand is categorized as coarse/medium if the value of FM ranges from 2.50 - 3.50; and we call it fine sand if its FM value is between 1.50 and 2.50 and very fine if its FM value is between 0.50 - 1.50. Depending on the information given (table 9.2), the fineness modulus of the sand of Oda dam is calculated to be 3.50 depicting the sand is coarser grained. Where very coarse sands are used, the concrete mixes can be harsh and suffer bleeding (Smith and Collis, 1991). Thus, a proper concrete mix design is required in the Oda case to reduce or avoid the bleeding effect of the concrete due to coarser nature of the sands.

Table 9.2 Dry Sieve analyses for sands of Oda dam and computation of fineness modulus

Sieve Size (ASTM)	% of Passing	Individual % of Retained	Cumulative % Retained	Recommended limits (retained percentage)(USDI,1981)
3/8"	100	-	-	-
No. 4 (4.76 mm)	90	10	10	0 to 5
No. 8 (2.38 mm)	77	13	23	5 to 15
No. 16 (1.19 mm)	51	26	49	10 to 15
No. 30 (0.595 mm)	23	28	77	10 to 30
No. 50 (0.297 mm)	7	16	93	15 to 35
No. 100 (0.149 mm)	2	5		12 to 20
No. 200 (0.074 mm)	1	2		3 to 7
Total		100	350	
Fineness Modulus=(350/100) = 3.5				

Allowable grading limits for sand depend to some extent on shape and surface characteristics of the particles (USDI, 1980). The grading conditions of the Oda sand are more or less with in the allowable range (table9.2)

Most of the sands used for concrete production or building purposes should also be as free from impurities as possible (table 9.3). They should contain no significant quantity of silt or clay i.e. less than 3% by weight (Bell, 1980). If the aggregate has a silt/clay content of more than the allowable value, they need a high water content to produce a workable concrete mix which in turn leads to shrinkage and cracking on drying. Moreover, the presence of more fines (clay and silt) in the fine aggregate retards setting and hardening forms a poor bondage with the cement and produces a weak and less durable concrete. According to the laboratory analysis of all the sands, the silt/clay fraction for most of the samples were less than 3% but in this work some of the samples (table9.3) have values greater than 3% showing that the **sand needs treatmen**t before using it. This variability of the silt/clay will continue even in the future due the nature of the river.

Table 9.3 Laboratory Results for Fine Aggregates (Sands)

Code	Silt/Clay (%) Fraction	Organic impurity	Unit Weight Range (Kg/m3)	Specific Gravity Range
1	3.83	0	2067	2.89
2	2.69			
3	5.19			
4*	1 to 2			

* is sample by REST(1997) from the same source

Allowable ASTM value for of silt/clay fraction = 0-3%

Allowable ASTM Value organic content = 0

The organic content of the Oda sand is zero showing that it is with in the allowable limit. However, some of the sample shows a silt/clay content above the allowable value indicating the requirement of washing before using them.

9.3 Stone for Masonry

Stone for the masonry work of the dam is also assessed and as the case in the coarse aggregate the main source of stone for masonry work is either to use aphanitic basalt from the proposed quarry site or the big boulders and cobbles that are found at the down stream of the dam axis with in the 0-1 km radius of the rock outcrop and river channel respectively. However, the river cobbles and boulders need to be washed prior to use because some of them are coated by calcareous material. Moreover, they are rounded shape and difficult to dress and shape them for the external masonry work although they can be used for the central zone of the dam body without any need of shaping them. Most of the river Cobbles and Boulders are of alkali olivine and aphanitic basalts in composition and are fresh as their weathered part is washed away by the river action.

The stones to be quarried from the aphanites basalt are the major source of masonry works of the dam. The masonry stones and the coarse aggregate have the same sources and the field and laboratory tests explained for the coarse aggregate above are also applicable to the masonry stones. As far as their workability is concerned they are better to be dressed than the river deposits although they can have some difficulty in dressing and shaping them due to their hardness and concoidal fractures formed when hammered.

9.4 Water

Any potable water is suitable for use as mixing for concrete. Two criteria should be considered in evaluating suitability of water for mixing concrete (USDI, 1981) and these are: (1) whether the impurities will affect the concrete quality, and (2) the degree of permissible impurities. To check the suitability of water, representative samples of water from streams, springs and boreholes are collected and chemically analyzed (chapter 4) and all are suitable for mix and curing of the concrete (table 4.11a and b) as they are suitable for drinking.

Most springs are located with in the catchment area (Fig. 7.1) and have very small discharge and are not important to be a source of water for the construction. The Oda River itself is also not perennial to be used as source of water for the dam construction although it can be used up to around the end of December after rainy season. The potential water sources for constructing the dam is thus the boreholes located down stream of the dam axis within the alluvial deposit (Fig. 4.3).

CHAPTER TEN

CONCLUSION AND RECOMMENDATION

Dam is one of the vital hydraulic structures that require the involvement of several disciplines during its study and design period. In an investigation of a potential dam site (reservoir and foundation) the climate, hydrology (rainfall, runoff, evapotranspiration,) geomorphologcal, geological and engineering geological aspects are some of the important factors to be considered. Although the hydrology and geomorphology are vast disciplines that require expertise for their detail study, their brief assessment is considered in this work in relation to their relevance to the engineering geological condition and characterization of the Oda area.

The climate of the study area varies between tropical (kolla) just near to the dam axis and temperate (dega) at its water divide, which is part of the Korem highlands.

Three land forms units namely the nearly flat to gently sloping (1.2%), slopping to moderately steep (Hilly land) (73.8%) and steep to very steep land (25%) dominate the area. the most common types of geomorphic processes prevailing in the area includes weathering, erosion, mass wasting, and faulting.

Soil and land use maps of the Oda catchment that are very important in the computation of the runoff, evaporation, infiltration, erosion condition and sediments yield of the catchment area are prepared. According to the textural classification, two main types of soil groups are identified namely silty loam and sandy loam. The main land use includes grazing land (dominant), shrub land, homestead and others (rock outcrop, gullies, foot paths etc).

Geological maps of the study area at the scales of 1:50,000 and 1:1,000 are prepared for catchment and reservoir and foundation respectively. Accordingly the main lithological units are Quaternary sediments, welded tuff aphanitic basalts and alkali olivine basalts. The Quaternary deposits are located down stream of the dam axis while the welded tuffs are restricted to the upper part of the catchement area. Most of the dam site (reservoir and foundation) is covered by the aphanitic basalt and alkali olivine basalt (dominant). Small outcrop of dioritic intrusions are also identified at very restricted localities such as stream and ridge exposures. The other important geological parameters with regard to civil engineering structures are the geological structures or discontinuities. Although the trend of faults is variable, the nearly N-S trending and nearly E-W fault system dominates over the other. Similarly two main joint sets namely the WNW-ESE and NNE-SSE are the dominant set although the

WNW-ESE can further be grouped in to WNW and NNW at places. The joints in the alkali olivine basalts are filled by calcite while those in the aphanitic basalts and welded tuff are open.

Analysis of hydrometrological data depicts that the mean annual rainfall and temperature of the study area are 869 mm and1 8.5c^{o} respectively. The potential evapotranspiration (PET) and the AET are also calculated using the modified penman method and the long-term water balance approach respectively. The mean annual PET is 1392mm while that of AET is 478.5mm. The surface runoff of catchment is calculated based on the rational method and is found to be 14 million cubic meter (MCM).

A simplified hydrogeological map of the Oda catchment and its vicinity is produced at 1: 50,000 scale from the regional hydrogeological map of the valley by making some simple modification as relevant to the study area. Generally, the hydrogeological condition of valley fills which are found down stream of the dam axis varies from intermediate to high productive aquifers while that of the catchment area is characterized by extremely low permeability formations due to steep slope and high erosion rate which are not favorable for the formation of thick and good aquifer. This can be strengthened by the absence and limitation of springs in the Oda catchment.

Chemical analysis of both the surface and ground water shows that the waters are suitable for drinking, irrigation and non corrosive (aggressive) to concrete except some of the spring and borehole data which show hardness may cause some corrosion and staining on water pipes.

The total annual soil loss from the Oda catchment and reservoir sedimentation are estimated to be 634,294 tones and 1725,503.5 tones respectively that is about 27.2% of the total soil loss enters into the reservoir. This indicates that the area is siltation prone areas which can significantly affect the design life of the reservoir unless the catchment is treated well.

The area is located within the seismically active part of the western margin of the Afar Depression (Zone-3) which is dominated by normal faulting. This means that it requires seismic resistant design parameters before construction.

The assessment of landslides in the area also shows that the area is affected by shallow landslides which involve the creep, rock fall, rockslide, debris slide depending on the nature of the materials and slopes of the area.

Engineering-geological maps of the study are also made at the scales of 1:50,000 for the catchment and 1:1000 for the reservoir and dam foundation based on the field description, laboratory and some field tests. Accordingly the soils and rocks are described and characterized based on the results obtained.

The catchment is dominantly covered by thin (less than one meter) residual soils. Relatively thick transported soils which include the alluvial and colluvial deposits are found at the foot of gentler slopes at the banks of gullies, streams, etc following the trend of the drainage system. The alluvial and colluvial deposits are found intermixed at the foot of slopes and are grouped together as the pediment deposits. The pediment deposits show both lateral and vertical variations and their composition ranges from clayey silt sand to gravel. The other type of transported soils identified in the field is river channel deposits which consist of sands, gravels, boulders, and cobbles. The older river deposits are calcareous cemented.

The results of the laboratory analysis show that the residual soils fall with in the silty sand (SM) and sandy lean clay (CL) soil groups while the pediment deposits dominantly consists of sandy silt (ML) and sandy lean clay (CL).

The gradational analysis shows that the clay content of the soils range from 0.5% to 6.5% and are being dominated by the fine sands and silt content. The computed uniformity coefficient (Cu) of the soils show that the CL soil group varies between very uniform to uniform while the ML is medium uniform and the SM is with a medium to non uniform (well graded) soil. This indicates that the CL soil group has relatively highest compressibility and low shear strength and the SM soil group least compressible and with high shear strength than the groups while the ML soil group are in between the two soil groups.

Based on the results consistency limit, all soils of the study area are characterized as low compressibility soil as all the analyzed samples have a liquid limit values less than 50%. The soils have also low to medium plasticity and they are of very stiff consistency with a consistency index value of 1.15 to 2.78.

The swelling potential of the soils of the study area is assessed using the simple tests of the Atterburg limits, shrinkage limits, tree swell and the clay content and are found to be no swelling soil indicating that they are not problematic soils in terms of expansiveness property. The type of clay mineral is estimated using plasticity chart and is the kaolinite type which is characterized by low swelling potential and relatively higher shear parameters as compared with other types of clay minerals. The important shear strength parameters of soils (cohesion, angle of internal friction) vary from 0.05 to 0.6 kg/cm^2 and 24.4^0 to 33.1^0 respectively. The values of the angle of internal friction of the silty sand (SM), sandy silt (ML) and the lean clay is more or less the same showing that the SM and ML soil group varies from uniform gradation (loose) to well graded soil (dense) and that of the CL soil is an over consolidated clay soil. The unconfined compressive strength (UCS) of the soils varies from 2.5 to greater than 4 kg/cm^2. The values of UCS decreases with depth for transported fine soils as the soil becomes moist with depth while it increases with depth in the case of the residual soils as the soils become more intact and rocky. The consolidation test of the lean clay soil varies 1.39 to 0.167 m^2/MN for the coefficient of volume compressibility, and from 1.49 to 1.42 m^2/year. The M_V determines the amount of compressibility that is likely to occur under a given load while the C_V shows the likely rate of settlement per annum under loading conditions. Field permeability of the reservoir soils and their values range from 1.5x10^{-1} for pure fine sand to 9.7 x 10^{-4} cm/sec soils are semi permeable. However, this value can be improved into impervious by proper compaction.

Rocks of the catchment, reservoir and foundation are also described and classified depending on their engineering behavior. Rocks of the study area depict variable engineering behavior depending on the degree of weathering and jointing. They are classified based on strength and degree of weathering in to strong to very strong rock units, and moderately strong to strong rocks. The strong to very strong includes the fresh to slightly weathered basalts. As measured from Schmidt Hammer test the average unconfined compressive strength of this unit varies from 101 to 185 MPa. The laboratory tested wet and dry compressive strength of these rock units varies from 152 MPa to 158 MPa respectively showing a good agreement with field Schmidt hammer test. The moderately strong to strong rock mass includes the medium weathered basalt, the welded tuff and the slightly to medium weathered diorite rocks vary from 62 to 67 MPa (fresh tuff) to 19.5 to 35 MPa (Mediumiy weathered tuff), and 58 to 89 MPa respectively. Geomechanical classification is also used to characterize the rock mass behavior of the rocks of the study area. Accordingly the basaltic rocks, the aphanitic and the alkali olivine basalts, fall in range of fair quality (class III) and that of the welded is classified as poor quality rock mass (class IV) based on the RMR values. The shear parameters of these rocks are also determined using the RMR relationship. The shear parameters, cohesion (C) and angle of internal friction (ϕ) of aphanitic basalts are

255 MPa and 31^0 for the aphanitic basalt, and 245 MPa and 30^0 for alkali olivine basalt respectively. The welded tuff has a C and ϕ of 196 MPa and 25^0 respectively. The in situ deformation modulus (E_m) of the aphanitic and alkali olivine basalt varies from 8.4 GPa to 11.2 GPa and from 7.5 to 10 GPa respectively while that of the E_m of the welded tuff varies from 4.2 to 5.6 GPa. Rock mass permeability of the reservoir and foundation materials is also estimated using the fracture analysis data. In estimating rock mass permeability, joint sets parallel or nearly parallel to the flow direction or perpendicular to the dam axis are considered. Thus, the estimated rock-mass permeability of the aphanitic basalt vary from 3.4×10^{-2} m/sec in the abutment (J_2) to 6.5×10^{-4} m/sec of the same abutment (J3) while that of the alkali olivine basalt varies between 1×10^{-7} m/sec (J_2) of the same abutment to 4.6×10^{-8} m/sec (J_1) of the same abutment.

Their presence of soils in the study area is only important either for reservoir water tightness or is overburden at the dam foundation. At the upper dam options (axis-1), the soil cover is thin depicting that the foundation at this section has less overburden to be excavated. The soils, especially the lean clay (CL) can be used for reservoir blanketing where the aphantic basalt is exposed in flatter topography. The engineering geological study indicates that the alkali olivine basalt are fairly suitable in terms of foundation for the concrete dam or its rockfill combination and water tightness of the reservoir while the aphantic basalt are also suitable in terms of foundation but pervious.

The quality, quantity and proximity of the construction materials are studied. As the engineering geological study shows, enough and good quality of rock sources for the course are available with the one km radius of the dam axis and at around three km down stream of the dam axis.

Based on the study performed so far, the following recommendations are forwarded:

- Dam, especially masonry dam requires detail engineering geological study and detail design. Although an attempt has been made to describe and characterize the dam site from engineering geological point of view, there are still uncertainties about the exact location of the overburden and the Variation of the rock mass permeability with depth. The geophysical survey conducted at the site is also not reliable showing large root mean square error although it can give some hints. Thus, drilling is recommended at the upstream dam axis option. Packer (Lugeon) permeability tests along the bore holes are also recommended before the dam construction.

- Depending on the result of the core drilling work, grouting may be important to improve the engineering properties, that is, to increase the strength and decrease permeability of the rocks.
- Since the area is located at the seismically active zone (Zone-3) according to Fekadu Kebede and Laikemariam(1996), and zone 4 according to the Ethiopian building code of practice (1995), due attention should be given to the seismic resistance design in the course of design analysis.
- Though not directly related with engineering geological problem, the other most potential hazard for Oda reservoir is the siltation problem, which is the common case in most Ethiopian highlands. Hence, before the construction of the dam siltation mitigation measures such as physical (check dams, trenches, terracing etc.) and biological measures (afforestation) should be done in the catchment area. To know the effect of the measures to be taken in siltation rate, it is better to conduct research work that could come up with a feasible solution.

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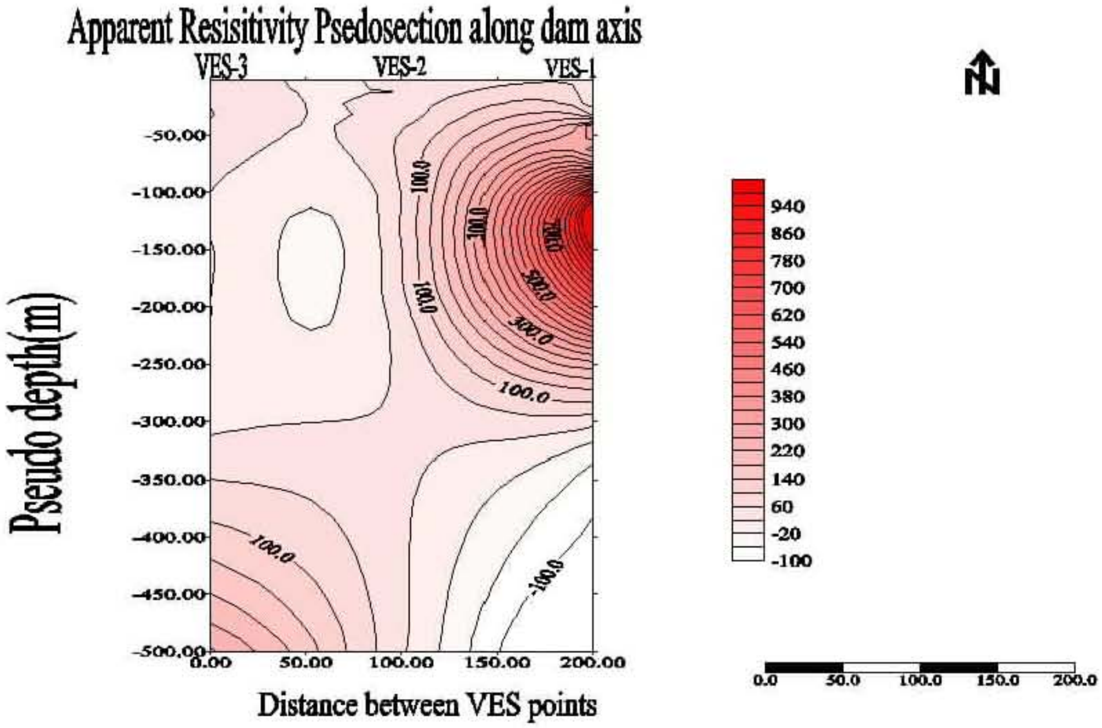

Distance between VES points (m)