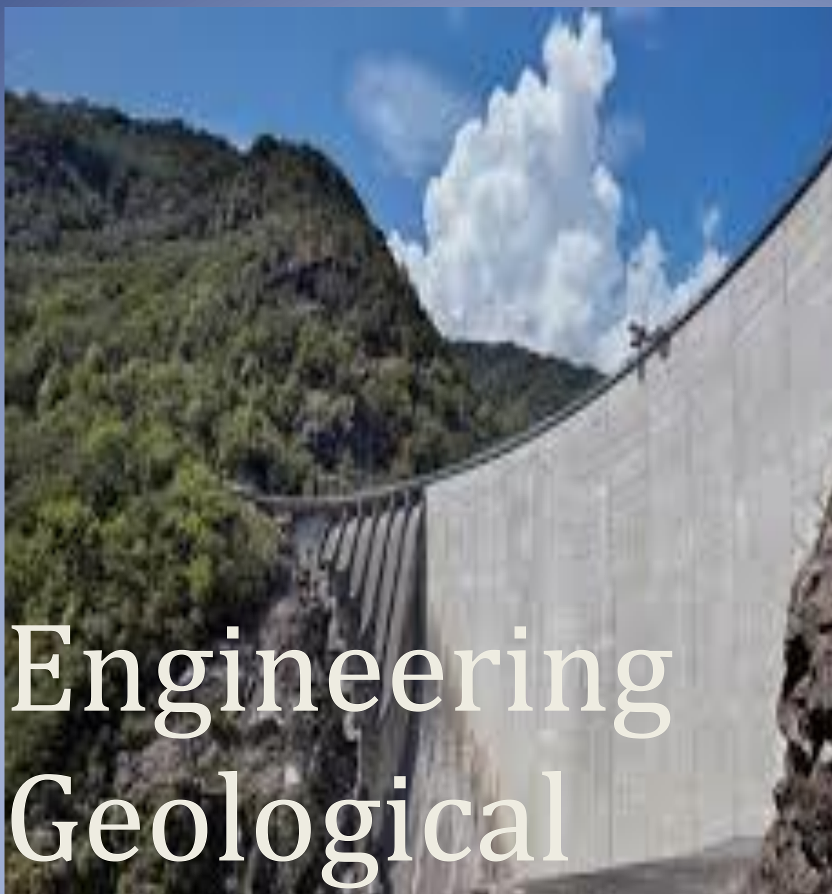

Engineering Geological Investigation of Dam Sites

By

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Engineering Geological Investigation of Dam Sites

Abstract

Dams are engineering structures constructed for different purposes. They are of different sizes, shapes and types. In all cases, many essential studies should be carried out before deciding the location, type and size of the dam. Among those studies is the geological investigations which should be carried out to deduce the geological conditions in the most relevant site, depth of the foundations and their types, cut-off depth, type of the available construction materials, and type of the expected geological hazards. Without proper geological investigations, the siting of a dam will cause serious hazards during construction and during commissioning of the dam. In this study, Mosul Dam case is considered as the consequences of inadequate geological investigations which were carried out by the contractor and supervised by Swiss Consultant. The location of the dam site and its foundations are built over a highly karstified area, where gypsum and limestone beds are exposed and exist deep under the ground surface, and even deeper than the foundations. Accordingly, grouting treatment was carried out and still on going, but all the attempts to have a safe and relevant dam were in vain. In this study we have provided the essential studies which should be included during the geological investigation to have a safe and sound dam.

Key words: **Dam sites, Geological investigation**

2.0 Introduction

Geological investigation for selecting and locating dam sites is one of the most significant studies which should be carried out in different scales and stages before deciding the best location for a dam. Therefore, an adequate assessment of site geologic and geotechnical conditions is one of the most significant aspects of a dam safety evaluation. Evaluation of the safety of a new dam requires, among other things, that its site, abutments, foundation and reservoir have been adequately examined, explored, and investigated so that the geological conditions are fully understood as much as possible. The geological investigations should include four main topics; these are:

1. The geology of the dam site including the foundation for the dam itself and the sites for other structures such as spillway, diversion tunnel and outlet works. To check whether the dam foundation has sufficient strength and durability to support the type of dam proposed, whether the foundation is watertight, especially, when karstified rocks occur in the site and in deeper horizons bellow the foundations.
2. The geology of the area to be occupied by the reservoir once the dam is completed. Whether the storage area is watertight or are there areas of cavernous limestone and/or gypsum which might lead to the dam not retaining water.
3. Stability of the slopes in the dam site and reservoir area whether landslides into the reservoir are possible which might cause a wave of water to be pushed over the top of the dam.
4. Finding sources of the construction materials which will be needed to build the dam in nearby areas of the dam site including all required types like: aggregates of different types and sizes, filling materials in the core and both surfaces (if the dam is of earth-fill type).

Literature Review

Winslow et. al, (1960) studied the engineering geology of the dam and spillways areas for the monroe reservoir, southern India, they referred in their study that the Salt Creek drainage basin in Monroe, Brown, and Jackson Counties, Ind., was studied to provide basic information for the planning of the Monroe Reservoir. This report principally concerns the dam site and spillway areas of the proposed reservoir. Four units, defined on the basis of engineering characteristics, are present in the reservoir area. Impermeable siltstones of the Borden Group form the valley walls along Salt Creek and will confine the reservoir. Rocks of a second unit, the Harrodsburg and Salem Limestones, cap the ridges high above flood-pool level (556 feet). The two remaining units consist of unconsolidated materials in the valley of Salt Creek. Terrace deposits above the flood plain are sandy to gravelly silts. Valley-fill deposits as much as 70 feet thick are present in the valley of Salt Creek. Clayey silts predominate in the valley fill and forma satisfactory foundation material of low permeability for the dam. Two spillway locations have been considered for the Monroe Reservoir. The first, a short distance from the dam site, would require a channel through about 90 feet of bedrock, the upper 50 feet of which would be the Harrodsburg Limestone. This site would be near the dam, and rock excavated from the spillway channel could be used as fill material in the dam. A second potential spillway site lies about 1 mile south of the dam. Here the spillway channel would cut through 40 feet of material, 20 to 30 feet of which are unconsolidated sediments and the remainder is siltstone belonging to the Borden Group.

- **Dam Site Description**

That mantle the siltstones of the Borden Group on that side of the valley, and the other abutment will lie directly against the siltstone that forms the southwest wall of the valley. The conduit will be founded on siltstone beneath the dam on the southwest side of the valley. Although the Borden siltstones are porous, they are not permeable, and thus leakage through these rocks will be negligible. The Borden contains a few thin limestone beds, but in the dam site area none are believed to be sufficiently thick or cavernous enough to present a leakage problem. During the exploratory drilling program of the U. S. Corps of Engineers along the centerline of the dam, circulation of drilling fluid was lost while the Borden siltstones of unit 1 were being cored in several test holes. The reason for this circulation loss is indeterminate because limestone was not encountered and the core was essentially continuous. Very thin crinoidal limestone layers and (or) horizontal joints (bedding planes) may have served, however, as an avenue for water escape while drilling in the Borden was taking place. Some seepage may occur through the valley-fill materials, especially where the silt is sandy to gravelly, but these materials are not sufficiently permeable to cause serious leakage problems. Fig.1 shows the variation of mechanical properties with depth for a hole on the northeast bank of the valley of Salt Creek. On the basis of tri axial compression tests Fig.1, most of the material is of medium consistency. The upper 25 feet is characterized by material with natural moisture contents between the liquid and plastic limits (upper and lower limits of plasticity). This means that the naturally occurring materials are in a plastic state. When liquid limits are between 30 and 50 percent moisture, soil-water suspensions are generally classified as medium plasticity clays Fig.1. The clay bed from 20 to 24 feet beneath the surface presents foundation problems that will influence the design of the dam. This high plasticity or “fat” clay has a liquidity index near 1.0 and has almost no strength. A middle “non plastic” zone was reported from about 30 to 45 feet. The Atterberg limits show that a sample of the material near the bottom is characterized by low plasticity and has low natural moisture content. These characteristics probably will not extend across the width of the valley of Salt Creek at the dam site. Colluvial materials are present in the upper and lower parts of the test-hole section described above, but these materials are generally confined to the valley fill nearest the bedrock surface. The silty clays in the upper part of the test hole probably are a result of reworking the valley-fill material by flood-plain processes. The materials lying below:

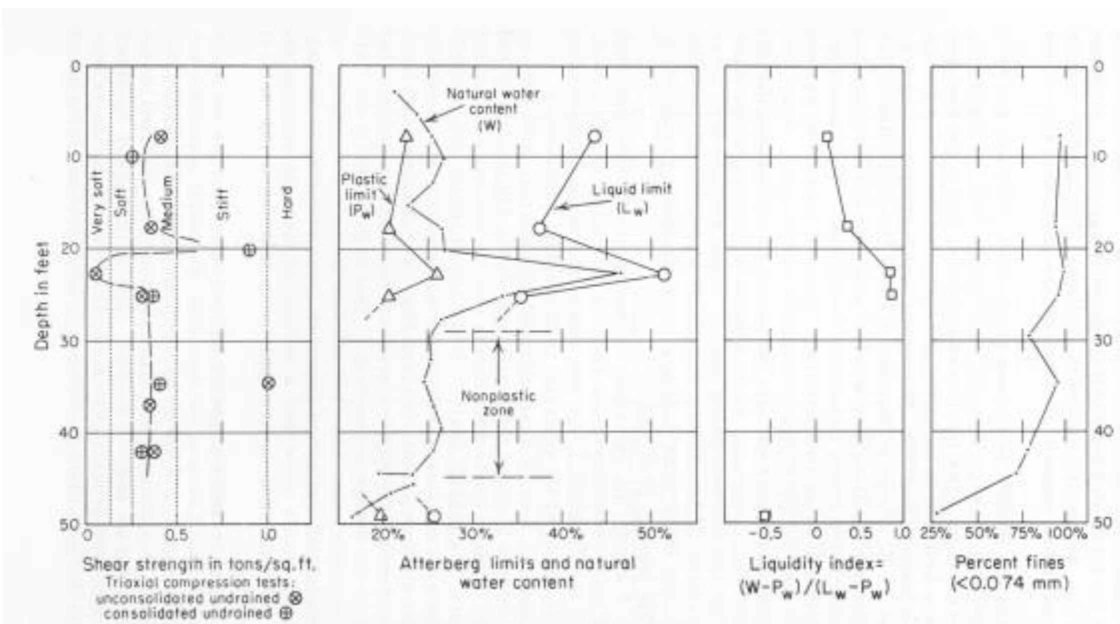

Figure 1 variation of engineering properties with depth for undisturbed of samples

The geologic investigation of the valley of Salt Creek indicates that it is a suitable area for construction of the Monroe Reservoir. The dam site, spillway sites, and the entire region of the reservoir are within the siltstones of the Borden Group. The Borden siltstones and the moderately thick (as much as 70 feet) valley-fill deposits have low permeability, and leakage through these materials should be minor. These materials will provide suitable foundations for dam and spillway construction.

Rogers et.al, (2010) presented in this study the investigation about Hoover Dam Fig.2a. Hoover Dam was a monumental accomplishment for its era which set new standards for feasibility studies, structural analysis and behavior, quality control during construction, and post-construction performance evaluations. One of the most important departures was the congressional mandate placed upon the U.S. Bureau of Reclamation (Reclamation) to employ an independent Colorado River Board to perform a detailed review of the agency’s design and issue recommendations that significantly affected the project’s eventual form and placement. Of its own accord Reclamation also employed an independent board of consultants which convened twice yearly several years prior to and during construction of the project, between 1928 and 1935. Reclamation also appointed a special board of consultants on mass concrete issues, which had never been previously convened. Many additional landmark studies were undertaken which shaped the future of dam building. Some of these included: the employment of terrestrial photogrammetry to map the dam site and validate material quantities; in situ instrumentation of the dam’s concrete; and consensus surveys of all previous high dams to compare their physical, geologic, and hydrologic features with those proposed at Hoover Dam. The project was also unique because the federal government provided of all materials, except the concrete aggregate, to minimize risk of construction claims and delays.

- **Back ground**

Investigations along the lower Colorado River which eventually led to the construction of Hoover Dam were initiated by the U.S. Geological Survey’s Hydrology Branch in 1901-02 when hydrologist J. B. Lippincott identified dozens of potential dam sites along the Colorado River, including the bedrock narrows in Black and Boulder Canyons. In 1904 the newly formed U.S. Reclamation Service began evaluating potential dam sites along the Colorado River. The seminal event that eventually led to the dam’s construction began with the unintentional flooding of the Imperial Valley that commenced in March 1905 when the headworks of a privately constructed diversion canal were overwhelmed along the lower Colorado River, about four miles south of the

Mexico-California border (Davis, 1907; Grunsky, 1907; Sykes, 1937). The Southern Pacific Railroad attacked the break throughout 1906, eventually closing off the channel at midnight on February 10/11, 1907, after the Colorado River had discharged its waters into the enclosed basin for just under two years, creating the Salton Sea, with a surface area of 500 square miles (Orsi, 2005).

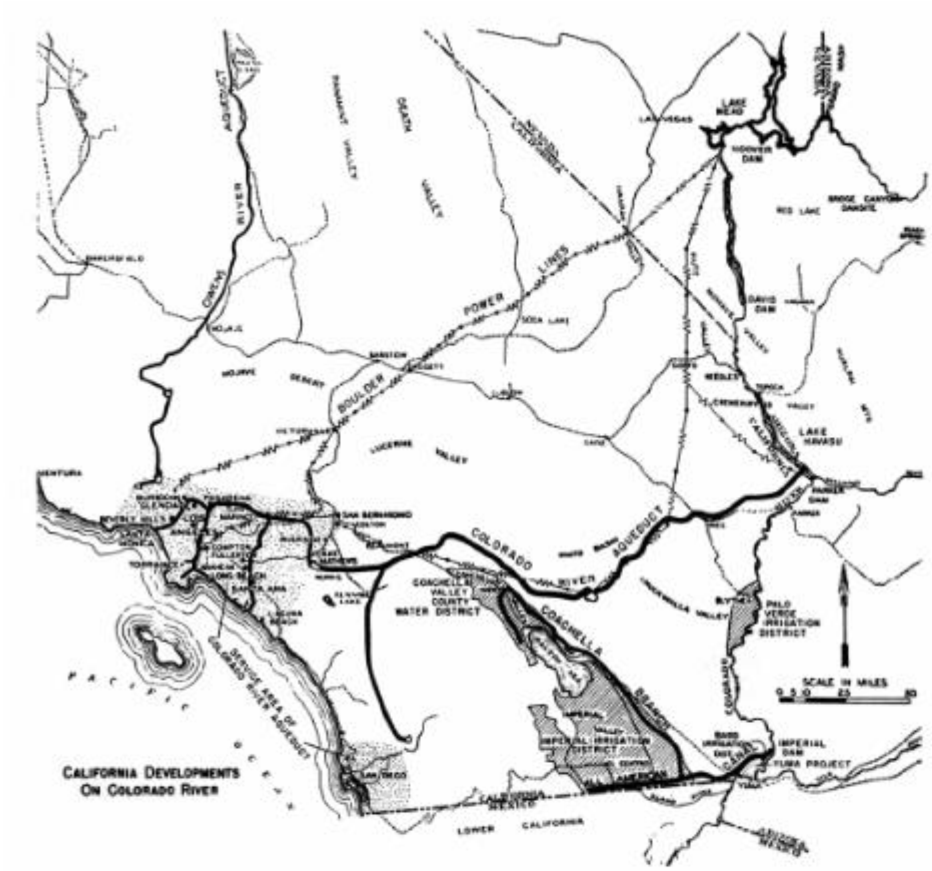

Figure 2a Location of Hoover Dam, agricultural areas that received irrigation water from the dam, the Colorado River Aqueduct, and the Boulder Canyon Project transmission lines serving southern California (USBR)

The disastrous flooding of the Imperial Valley bankrupted the massive commercial scheme for reclaiming this inland basin of southeastern California. During the winter of 1909-10 the Colorado River once again jumped its banks, this time filling Volcano Lake south of the border and, once again, threatening crops in the Imperial Valley. Congress appropriated $1 million to provide additional flood control along the lower Colorado River Fig.2b.

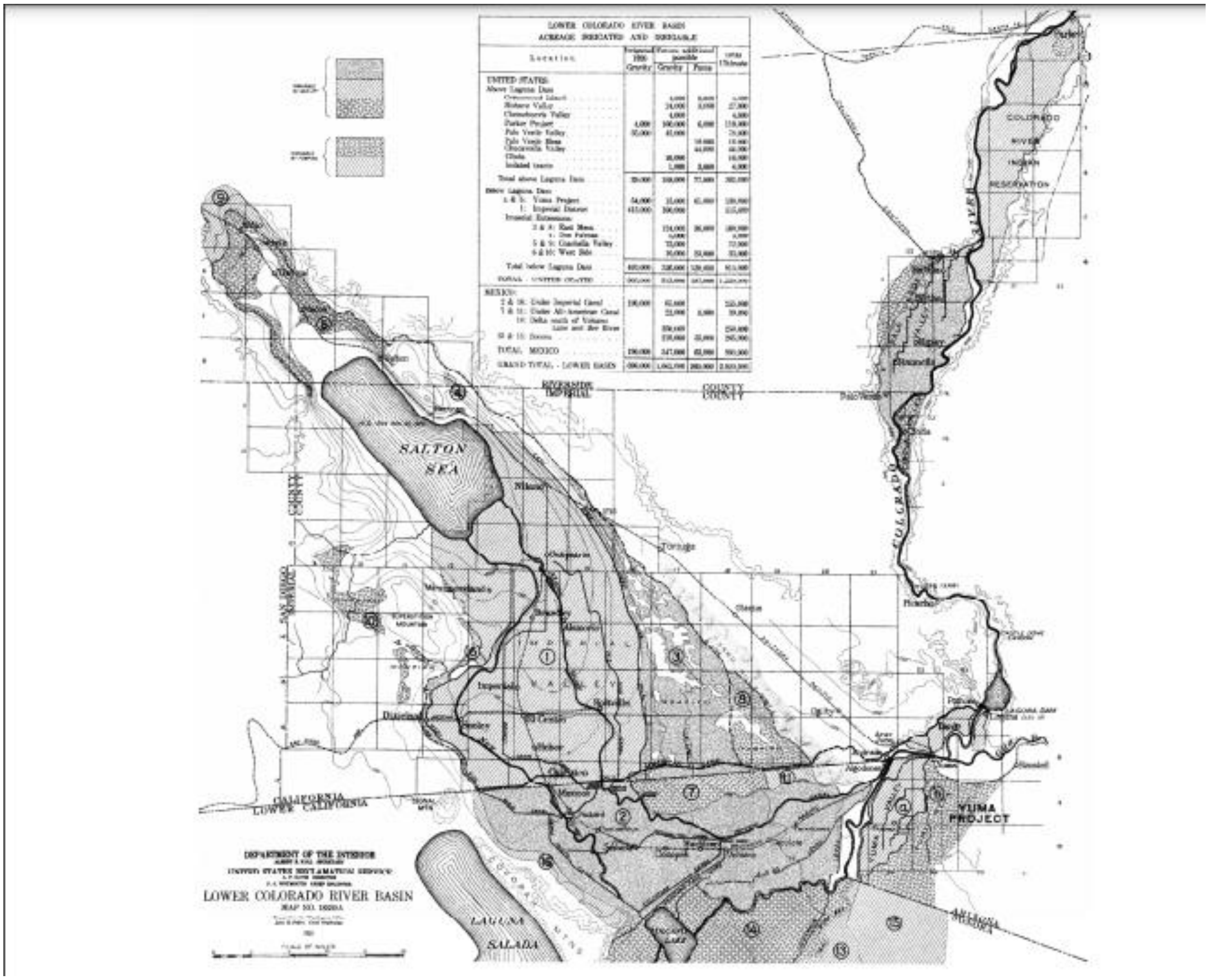

Figure 2b **Map from the 1922 Fall-Davis report showing the non-alkali valleys within and adjacent to the Lower Colorado River Basin that could be irrigated by a dam in Boulder Canyon. These included the Palo Verde, Yuma, Mexicali, Imperial, and Coachella Valleys. At that time about 700,000 acres were under cultivation using irrigation over an area farmed by almost 100,000 people. The reservoir in Boulder Canyon had the potential to bring 2,020,000 acres under irrigation, including areas irrigated by gravity flow and those that would require pumping. (USBR)**

Al-Ansari et.al, (2015) investigated about Mosul Dam. The dam is located on the River Tigris in northern Iraq, 60 km north-west of the city of Mosul. The project was designed to store 11.11 km³ with water surface area of about 380 km² at the maximum operation level 330 m a.s.l. Reservoir sedimentation is the main problem that directly affects the performance of dams due to the reduction in the storage capacity of their reservoirs. Monitoring the storage capacity of reservoirs is an important issue for the planners, designers and operators of the dams. Iraq mainly depends on the rivers Tigris and Euphrates for its water resources. Until the 1970s, Iraq was regarded as a rich country with regard to its water resources, due to the presence of the Tigris & Euphrates Rivers. Mosul Dam Reservoir is the biggest and one of the most important strategic projects in Iraq.

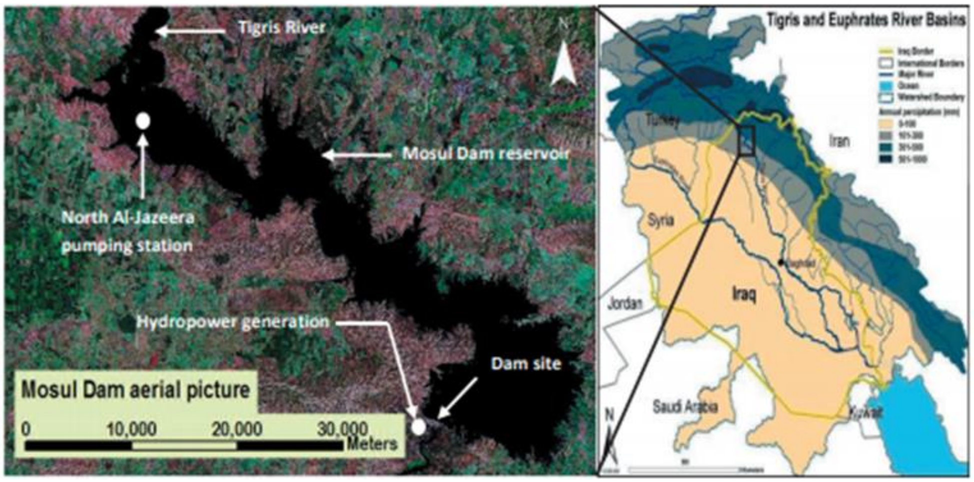

Figure 3 Location of Mosul dam with main facilities

- **Geology**

The oldest exposed formation within the vicinity of the reservoir is the Pilaspi Formation (L.Miocene). The exposures of this formation are confined to the hilly areas. It is composed of dolostone, limestone, marl and marly limestone. In the plain areas, Lower and Upper Fars (Lower–Upper Miocene) formations are exposed. The Lower Fars Formation (also referred to as the Fatha Formation) is composed of alternating beds of limestone, gypsum and siltstone whilst the Upper Fars Formation (also referred to as the Injana Formation) is composed of alternating beds of sandstone and siltstone. In the northern part of the reservoir near the inlet, the main geologic formations are Pilaspi and Ana which are composed of limestone, while the Fatha and Injana Formations dominate the plain area (Al-Sinjari, 2007; Sissakian, et al., 2014). In the vicinity of Mosul Dam, the exposed formation is Lower Fars. It is composed of alternating beds. In addition, fifty six sediment samples were collected from the bottom of its reservoir to study the nature of sediment deposited using the Van-Veen grab sampler. The samples were covering most of the reservoir area. The results revealed that the sediments were comprised of gravel, sand, silt and clay in the ratios 3.8%, 15%, 55.5% and 25.7% respectively. The distribution of these sediments (Fig.4) indicates that the silt portion represents the highest or 77% of the bottom sediment of this reservoir followed by clay 13.5% and then sand with gravel 9.5%. However, sand percentages are the highest in the northern zone of the reservoir where the River Tigris enters the reservoir and decrease gradually towards the dam site. In the meantime, silt percentage decreases towards the dam site whilst the finer fraction (i.e. clay) increases. The sediment is poorly sorted, nearly symmetrical in skewness and leptokurtic, very leptokurtic, to mesocratic.

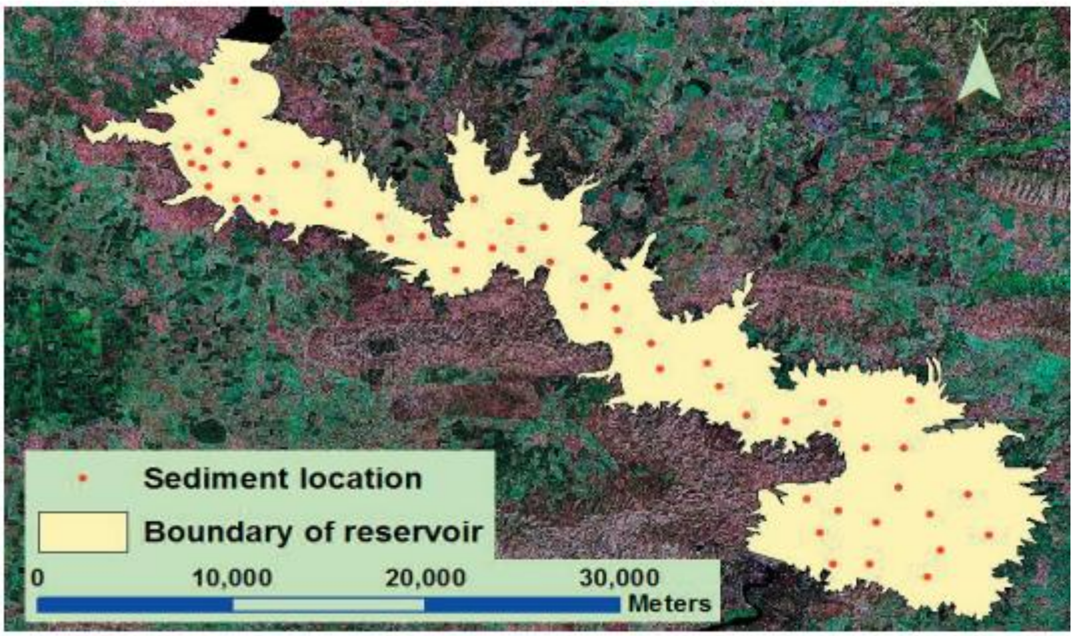

Figure 4 Locations of sediment samples in MDR.

- **Topographic Map**

A pre-impounding topographic map scale 1:50000 were obtained from the Remote Sensing Centre at Mosul University, Iraq. It was used to develop a TIN map for the reservoir before operation of the dam. The map was initially scanned and converted to (JPEG) format before further processing (Fig.5a). The topographic map was projected onto a satellite image and georeferenced to the Universal Transverse Mercator (UTM) projection, 'WGS-1984, Zone 38N' in the Arc/Info program within Arc/GIS software (ESRI, 2012) (Fig. 5b). Contour lines and spot locations of elevations (benchmarks and high-water marks) within the reservoir area on the map were manually digitized to determine x, y and z coordinates. Furthermore, stream path lines representing the River Tigris within the reservoir area were also digitized using water surface slope and contour lines. The total number of the digitized points within the reservoir area was 6,029 points (Fig.5c). The reservoir ‘Polygon Shapefile’ (hard clip) around the reservoir boundary was created from the satellite image using the Arc/map program within Arc/GIS software. The polygon was used during a TIN development to prevent interpolation outside the enclosed area (Issa, et al., 2013). All digitized points from the 1983 map and reservoir ‘Polygon Shapefile’ were used to develop a TIN for the reservoir area before the construction of the dam (Fig. 5d). The TIN was created by the tools ‘add XY data’ command in Arc/map program within Arc/GIS software. The ‘WGS-1984, Zone 38N’ projection information, linear unit meter for interpolation, and 0.9996 scale factor were used for the construction TIN in the Arc/GIS software. (Fig. 5d) was used to calculate the water surface area and storage capacity of MDR before impounding by ‘3D-analyst’ tools. The area and storage capacity of MDR as a function of pool elevation are listed at 2 m intervals in (Table1) of limestone, marl and gypsum (Al-Ansari, et al., 1981).

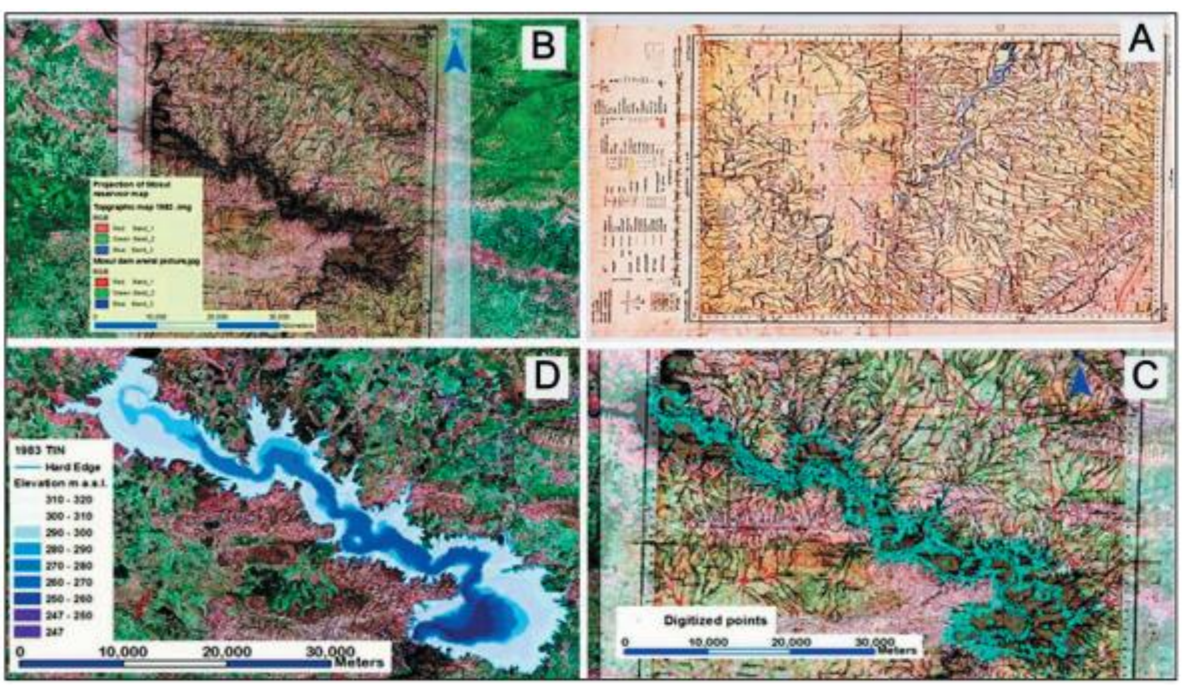

Figure 5 Projection processes of topographic map and formation TIN map for MDR before construction dam

Table 1 Water surface area and storage capacity of MDR at different water levels for 1983 survey

Pool elevation (m a.s.l)	Area (km²)	Storage capacity (km³)	Pool elevation (m a.s.l)	Area (km²)	Storage capacity (km³)
250	0.0331	0.0000375	**292**	104.93	1.787
252	0.0815	0.000148	**294**	111.35	2.003
254	0.4775	0.00686	**296**	122.66	2.237
256	2.341	0.00303	**298**	133.72	2.495
258	6.7995	0.0116	**300**	142.92	2.851
260	14.203	0.042	**302**	203.41	3.117
262	18.304	0.110	**304**	215.99	3.536
264	22.363	0.161	**306**	227.92	3.980
266	27.151	0.226	**308**	239.65	4.448
268	33.251	0.218	**310**	251.13	4.939
270	37.242	0.288	**312**	262.63	5.452
272	40.506	0.366	**314**	274.28	5.989
274	43.954	0.450	**316**	286.46	6.55
276	48.574	0.543	**318**	299.46	7.136
278	56.256	0.647	**320**	316.15	7.750
280	61.485	0.765	**322**	325.00	8.45
282	68.609	0.895	**324**	335.00	9.10
284	78.797	1.043	**326**	350.00	9.90
286	87.319	1.211	**328**	364.00	10.65
288	93.023	1.392	**330**	380.00	11.38
290	98.817	1.584			

Hassan et.al (January 2016) presented in this study the dukan dam reservoir. The dukan Dam Reservoir (DDR) in the Kurdistan Region of Iraq has been studied to determine the characteristics and nature of the reservoir and the deposited sediments on its bottom surface. This study was achieved by doing a field survey and grain size analyses of the collected sediment samples at 32 locations representing the whole reservoir area that had been created when the Lesser Zab River was dammed in 1959. The Dukan Dam, which is a multi-purpose concrete arch dam, was built on the Lesser Zab River for controlling its flood during high rainfall seasons, irrigation and power generation. The catchment area is 11,690 km2. The surface area of the reservoir is 270 square kilometers and the volume is 6.870 × 106 m3 at normal operation level (El. 511.00 m. a.s.l.). The minimum drawdown level is at elevation 469 m above sea level (a.s.l.). The live storage is 6.14 × 106 m3 while the remainder is dead storage. The reservoir has a surface area that reaches 270 square kilometers and is composed of two sub-reservoirs connected by a narrow channel that has a length of 5 kilometers. The relatively bigger reservoir is located in the north and has a triangular shape with a surface area approximately 250 square kilometers. The smaller sub-reservoir is located down south where the dam exists and it has irregular rectangular shape. Thirty-two sediment samples were collected from the bottom of Dukan reservoir. The bed of the reservoir is mainly composed of 15% gravel, 14% sand, 48% silt and 23% clay respectively. Most of the sediments are very fine grained, very poorly sorted, strongly coarse skewed and mesokurtic.In nature, most of the unconstrained rivers by dams are in an equilibrium state, which means that the sediment inflow and outflow are balanced. This balance is changed with time in dammed rivers because dams trap both water and sediment which cause increasing flow depth velocity (settling capacity) and decreasing flow velocity (transporting capacity) and finally lead to the deposition of the carried sediment by rivers in the reservoirs (Mooris, G.L. and Fan, J. 1998). Sedimentation is a natural complex process that consists of erosion, transportation and deposition (Mamma, C.N. and Okafor, F.O. 2011) Rivers have sufficient energy to do head ward, lateral and vertical erosion of the banks and the ground surfaces over the flow by hydraulic action, corrosion and corrosion processes. The eroded rocks are broken into smaller fragments by attrition process. The river sediments become smaller and more rounded towards the rivers downstream. Rivers transport the large-sized eroded materials such as boulders by pushing and rolling processes (traction), whilst the relatively smaller sized particles are transported by saltation process. The fine materials like silt and clay are lifted in rivers by the turbulence and transported as suspended load to further distances. The dissolved materials are transported by the solution load process. The energy loss of the rivers causes sinking and settling down of the carried sediments by the rivers. Sedimentation, in the reservoirs, is dependent on the nature of the rivers, geometry of the reservoirs and the dams operation. The dams cause slowing down flow velocity of the dammed rivers which feed the reservoirs and therefore reduce the rivers ability to transport the carried sediments which begin to settle down on the bottom of the reservoirs. The coarser sediments (pebbles and gravels) will be deposit first far away from the dam near to its upstream end forming a backwater delta that moves towards the dam body with time, whilst the finer suspended materials (silt and clay) deposit near to the dam body, in addition to passing the very finest colloidal particles through the outlet of the dam (Fig.6).

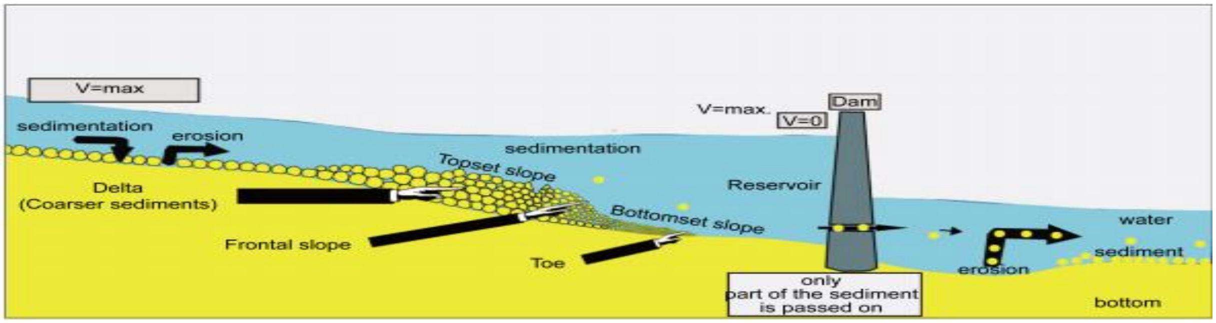

Figure 6 Schematic diagram shows the deposition of the carried sediments in the reservoirs

- **Methodology**

Thirty-two locations have been selected for taking the samples of the deposited sediments at the bottom surface of the Dukan Dam Reservoir (Fig. 7). A Van Veen Grab sampler was used for collecting these sediment samples because it is an easily used instrument for sampling sediments in water environments (Fig.8a). The absolute x, y, z coordinates of the sample locations were determined by using Echo Sounder Sea Charter 480DF (Fig.8b). The procedure of how the samples were taken at the bottom of the reservoir was shown in (Fig.8c). Sieve and hydrometer analyses were done for the collected sediment samples in both the Andria Technical Lab in Erbil governorate and the soil mechanic lab of the college of engineer/Sulaimani University in Sulaimani governorate (Figure 9). The graphical and statistical methods were utilized to classify and compare the sediments simply and rapidly. In the graphical technique, which is known, as (Folk classification), the sand, silt and clay percentages on an equilateral triangular diagram is used (Taha, Z.A. and Karim, K.H. 2009), (Folk, R.L. 1954).

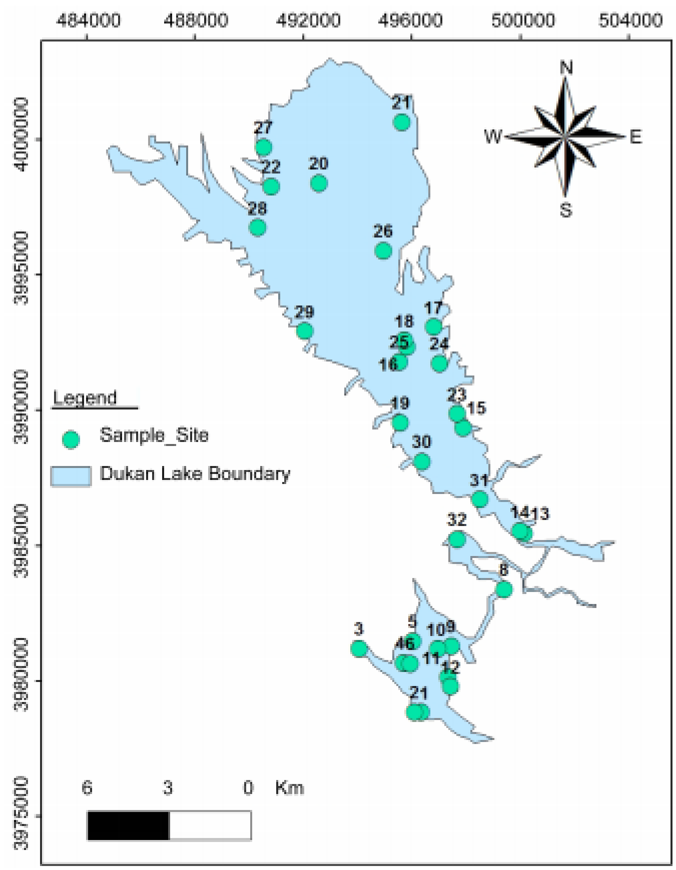

Figure 7 map shows the location of the samples taken at the bottom of the Dukan Dam Reservoir.

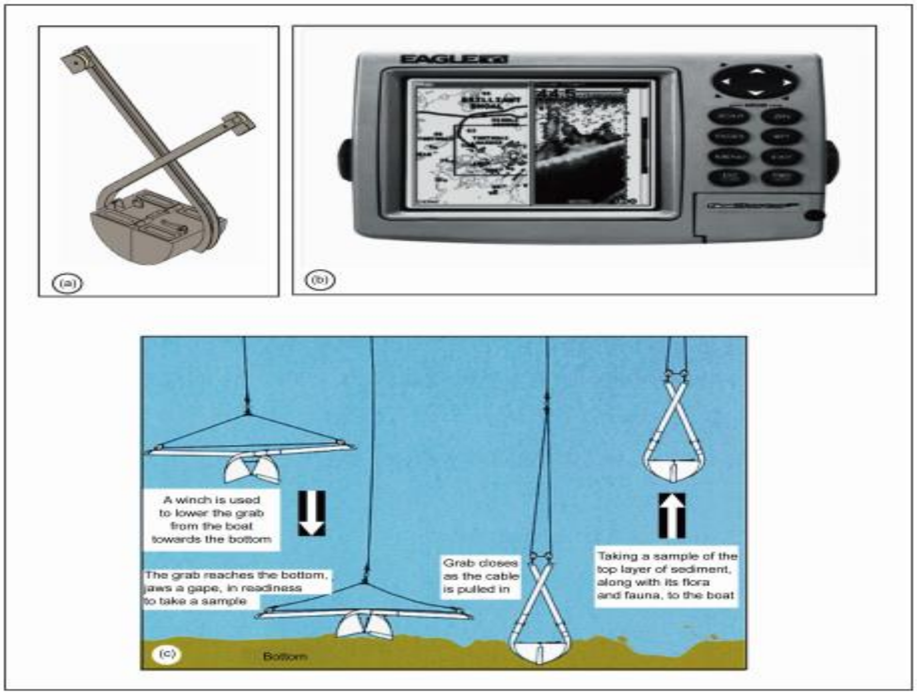

Figure 8 (a) A Van Veen Grab sampler. (b) Fish Elite 480 and Sea Charter 480DF echo sounder. (c) A steps of collecting samples by using van veer grab sampler

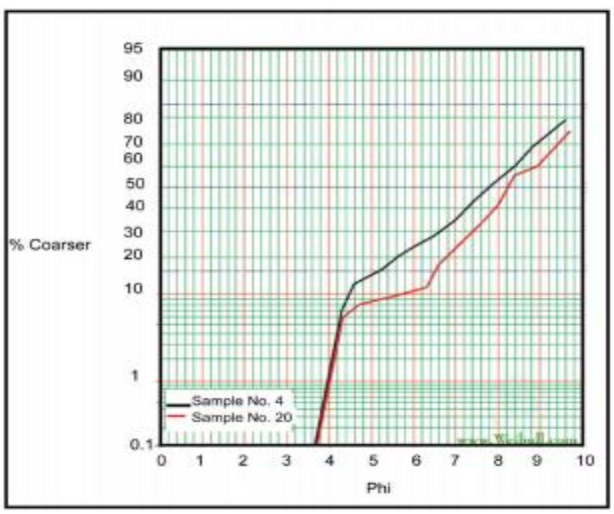

Figure 9 Grain size distribution of the bottom sediment in Dukan Reservoir

S.B. et.al, (October 2016) presented in this study the investigation about Axum Dam Site that dam is, almost always, a unique work, adapted to the morphology and the strength of the foundation, and also to the hydrological regime of the river. The dam, and the impounded water, interact with a great mass of terrain, very far away sometimes from the dam itself. The dam must retain water, have enough safety against sliding and adjust itself to the terrain deformations without too much cracking in service. As solution to these problems (Novak. P. 2009). stated that geological and geotechnical investigation of a dam site selected for detailed evaluation is directed to determination of geological structures, stratigraphy, and faulting, foliation and groundwater conditions at dam foundation and reservoir area, including the abutments. Previous experiences of dam construction in Tigray and other parts of Ethiopia show that many of the dams have defects related to several factors, among which are geological and geotechnical problems. This research deals with investigation of a newly planned dam to be constructed in Axum area (across the Maychew River) in Tigray, northern Ethiopia at approximately 40km south of Axum town.

Objectives of the study General Objective The major objective of this research were the water tightness, foundation condition and stability of the dam site and to recommend mitigation measures and the Specific Objectives:

- To map lithological distribution of rocks present in the area.
- To identify and describe structural defects such as faults, joints, solution channels in the rock.
- To determine and characterize the depth of groundwater.
- To determine the geotechnical properties of rocks and soils in the dam foundation and reservoir area.

And the methods that used to achieve the major objective and the specific objectives, the following methods and activities were used. These are review of previous works; geological method, drilling and geophysical methods (Fig.10).

1. **Geological method**

This method/activity is very important method to decide the purposed area is suitable to construct hydraulic structures. The shape of river valley and the geological formation of both abutments were well identified through this method. Based on this method different rock types are classified stand on their genetic type. The thickness of each lithology and the orientation of geological structures were measured in the field in different out crops.

Rock mass condition along the dam axis and abutments was based on geological mapping on rock outcrops.

2. Test pit and Core drilling method

Totally 19 test pits drilled on the reservoir area. These test pits were drilled by man power up to 0.7- 2.6m to take soil sample and measure the thickness of layered soil. In this stage the research work seriously observed and characterized the in situ setting or arrangement of different soil layers on the walls of drilled test pits. These test pits also used to analyze the weathered topography of rock beneath different soil layers. Finally, the permeability potential of the rock was characterized based on the freshness of fracture, type of infill material and aperture of discontinuities noted out from each test pit. Rotary core drilling rig selected to take rock sample different depth. The focused lines to drill for core samples were dam axis, abutments, downstream and reservoir area. The drilled samples were put in sampling box. In the graduated sample box simply measured to calculate RQD and to identify different parameters for RMR classification. The major parameters characterized during core drilling and from sample box were moisture conditions of rock, discontinuity spacing, discontinuity conditions and groundwater depth from different depth. The focused lines to drill for core samples were dam axis, abutments, downstream and reservoir area. The drilled samples were put in sampling box. In the graduated sample box simply measured to calculate RQD and to identify different parameters for RMR classification (Fig.10).

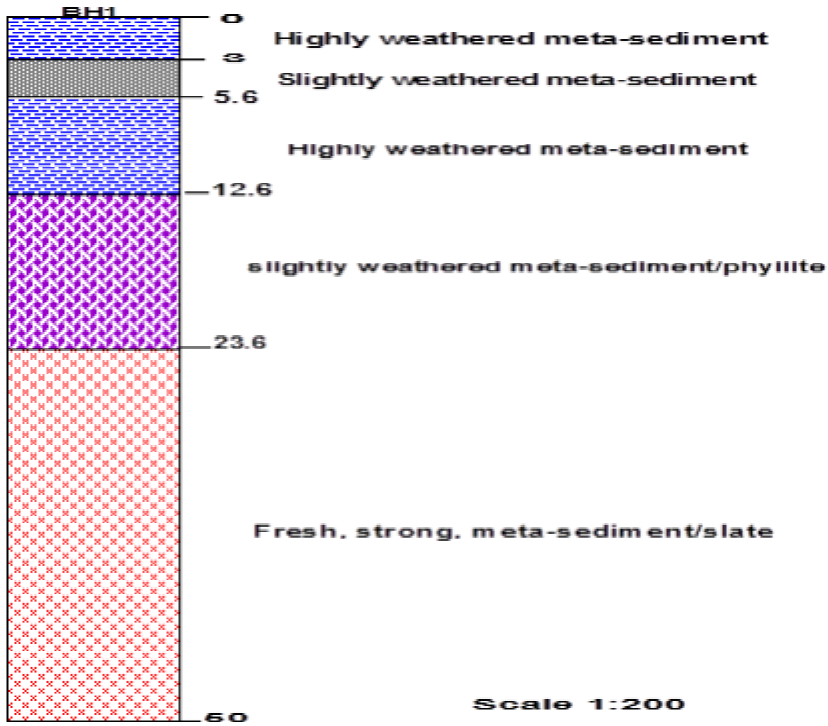

Figure 10 Core log from borehole one, (MA-BH1)

(Note: Log depth measured in meter)

3. Permeability measuring method

To characterize the soil permeability by using constant head and falling head methods. Constant head method used to characterize the permeability of coarse soil in the laboratory. Falling head method used for test the permeability of fine soil in the field. For laboratory test disturb and undisturbed soil samples collected from reservoir, abutments and around dam axis. Lugeon test used to characterize the permeability of weathered and fractured rock in the dam axis and abutments. By using this method, the research work characterized the average hydraulic properties of rock mass. The test conducted in five stages; with particular water pressure magnitude associated with each stage. A single stage consists of keeping a constant water pressure at the test interval for 10 minutes by pumping as much water as required. The first stage is held at a low water pressure, increasing the pressure in each subsequent stage until reaching PMAX. Once PMAX is reached, pressures are decreased following the same pressure stages used on the way up, thus describing a ―pressure loop.

4. Geophysical method

This special method is used to know the geological defects at very great depth and to know the lithological horizontal and vertical variation in the area as well as groundwater condition. The imaging and VES locations identified along dam axis, downstream, abutments and reservoir area. To measure vertical electrical sounding the selected method was Schlumberger electrode array. The Schlumberger array is particularly suited to this technique, because Schlumberger array has some specific advantages. This method basically to know the vertical succession of each lithology, the depth of ground water level, the presence of buried geological defects and to identify thin weak layer sandwiched between two lithological layers.

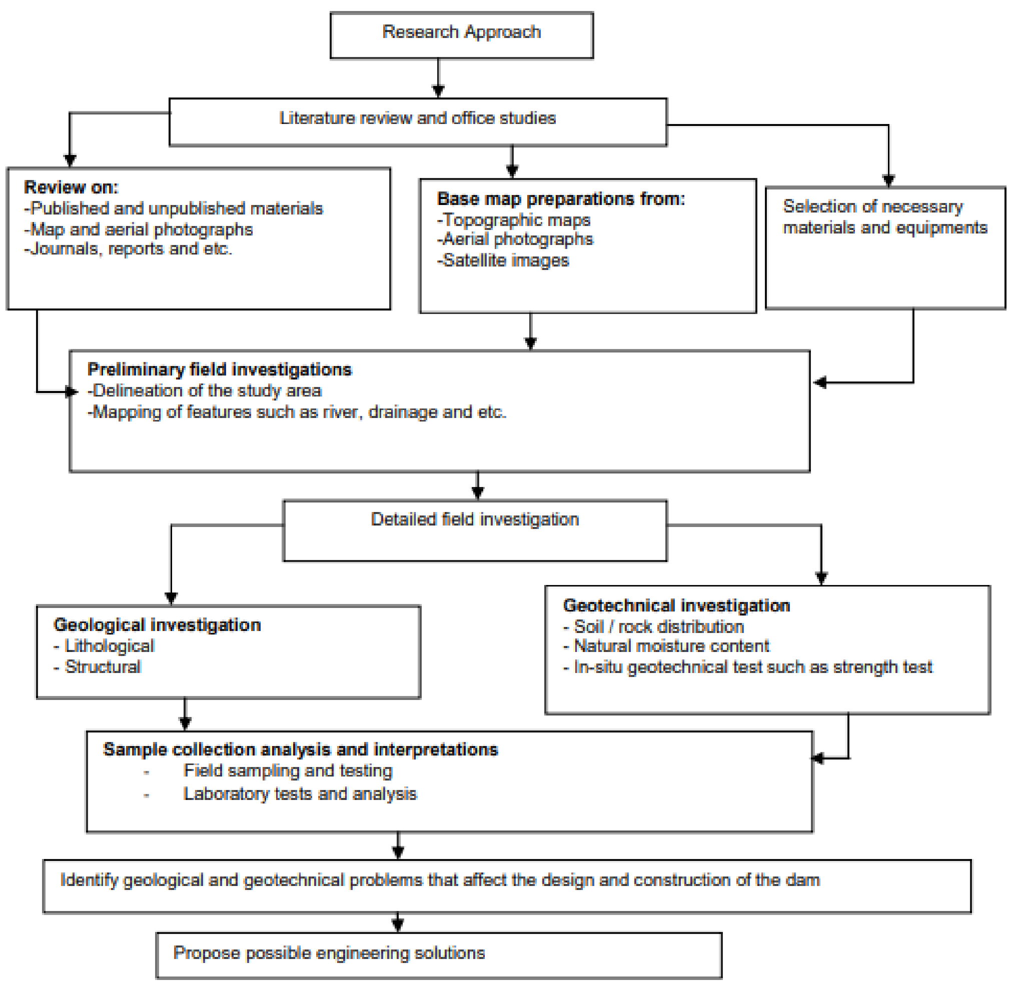

Figure 10a- Flow charts showing the research methodologies

- **General Characteristics of the Study Area**

The study area is located in northern Tigray, 248km Northwest of Mekelle, which is the capital of the regional state of Trigram. The project site (Maychew Dam) is situated in 'Nadir Adet' Woreda of 'central' zone, about 40km South-West of Axum town. Geographically, as indicated in (Fig.11), it is bounded between 460000mE to 469000mE and 1542000mN to 1564000 mN. The dam site can be accessed from Axum town by using two alternatives. One option is from Axum via 'Dego' and 'Seriha-bila' village to dam axis (30 km) i.e. about 25 km all weathered road and 5 km dry weathered road. The other option is about 32 km all weathered road along Axum-Adet and then about 8 km dry weathered road towards dam site.

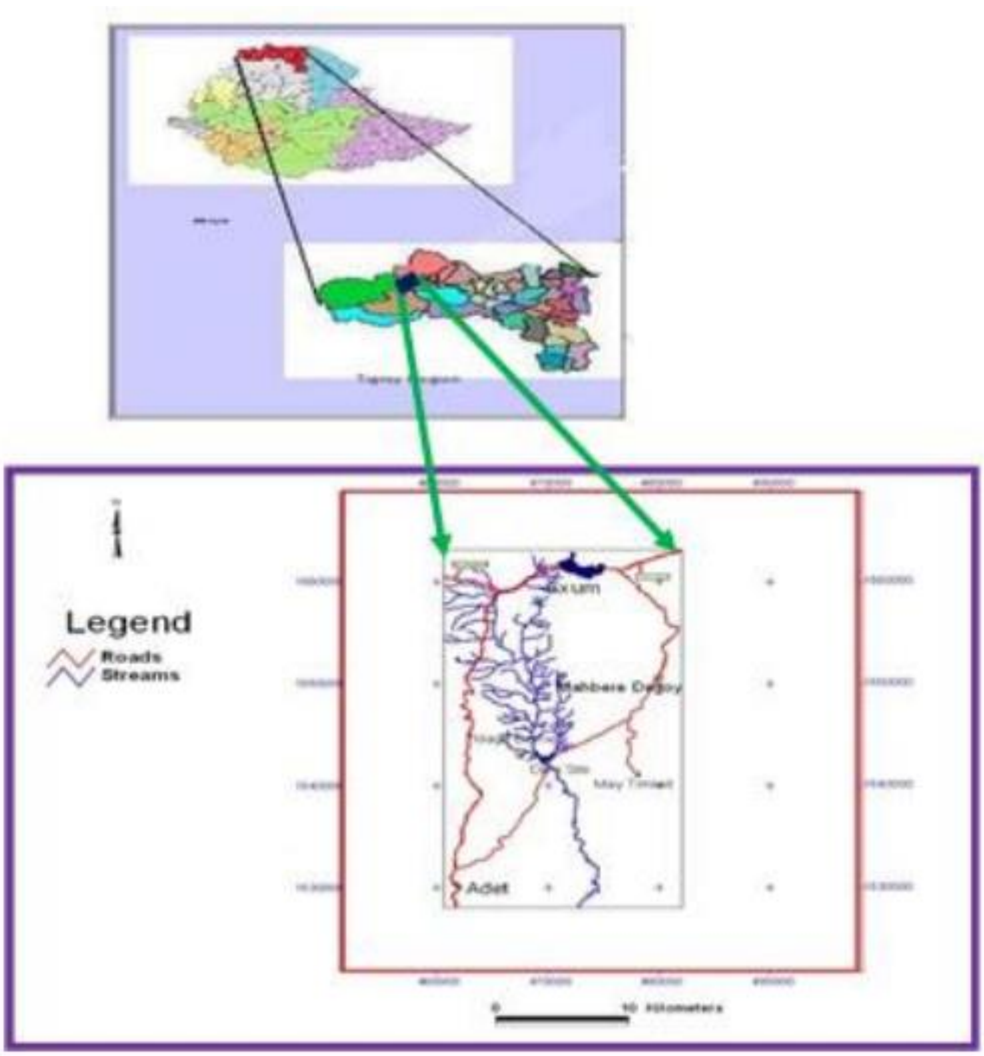

Figure 11 Location map

Results of the study indicate that the area is underlain by Quaternary sediments, metasedimentary and Meta volcanic rocks. Metasedimentary rocks are found covering the right abutment of the dam whereas at reservoir area it is found intercalating with Meta volcanic rocks. Meta volcanic rocks which are found covering the left abutment are strong, less permeable and fractured. Most of discontinuities such as fractures, bedding and foliation in the study area are oriented E-W, NNW-SSE and NNE-SSW. The VES, tomography and drilled core result revealed that the potential problems could occur due to presence of faults, joints, karstified black limestone, lithological variations, groundwater depth and topography at right abutment. Differential settlements may also occur because empirically estimated moduli of deformation of rock masses indicate that for right abutment much less than left abutment and different geological defects across the dam axis.

Adhikari1 et.al, (2019)presented in this study the dam site of proposed Sunkoshi-2 Hydropower Project and its surrounding mainly comprise the Tawa Khola Formation, which is the basal formation of the Bhimphedi Ground Hydroelectric power projects are pollution free and renewable source of energy. Most of these projects involve the construction of dams across a flowing river. Construction of dams requires stability analysis of the foundation at abutment, as well as the supporting rocks at the slopes of the reservoir area. Regarding the increasing demand of electricity in the country, the Government of Nepal, Department of Electricity Development has approved a program to conduct the feasibility study of two large hydropower projects in the Sapta Koshi Basin and has selected a number of sites that may be suitable for the construction of storage dams. Sunkoshi 2 Hydropower Project has been planned as a reservoir type hydropower project having dam height 166 m and capacity 1,110 MW. This study provides a basis for estimating deformation and strength properties of the rock mass for preliminary design calculation. The study area lies in parts of Sindhuli and Ramechhap districts positioned within the latitude 27° 14’00” to 27° 29’30” and longitude 85° 47’30” to 86° 10’20”. The area comprises the proposed site for Sunkoshi-2 Hydropower Project (Fig.12). Its dam site is near the Kudule Village at a distance of about twenty kilometers along the Pushpalal Highway (under construction) from its beginning at Khurkot. p.

Figure 12 Location map of the study area

The type and design of individual dams depends on factors such as volume of water to be stored, topography, geology, and type and amount of local material available for constructing the dam. In order for any structure to be safely built in a rock mass, an adequate understanding of the rock mass properties is essential. Achieving this understanding requires a sufficient amount of rock mass data to be collected. Study utilizing rock mass classification systems including RMR (Bieniawski, 1989) and DMR (Romana, 2004) have been applied. The gneiss is regional and contains large kyanite crystals (up to 2 cm length and 3 mm diameter), garnet (about 3 to 5 mm diameter), granite and pegmatite intrusions as well as parasitic folds and asymmetric augens. However, it was observed that some area contains rock exposure with dominating gneiss, whereas some sections contain mainly schists and quartzite Fig.13. Strength of rocks at outcrops varied greatly even when assessed in more or less fresh exposures at road-cuts and cliffs. Further classification of rock type and soil as 'engineering geological units' was made showing rock and soil assemblages of more or less uniform geotechnical properties (as estimated at the field). The rock exposures have been extrapolated at many places during mapping to provide information of complete outcrops, most of which include lesser than 1-meter (approximated) colluvial cover.

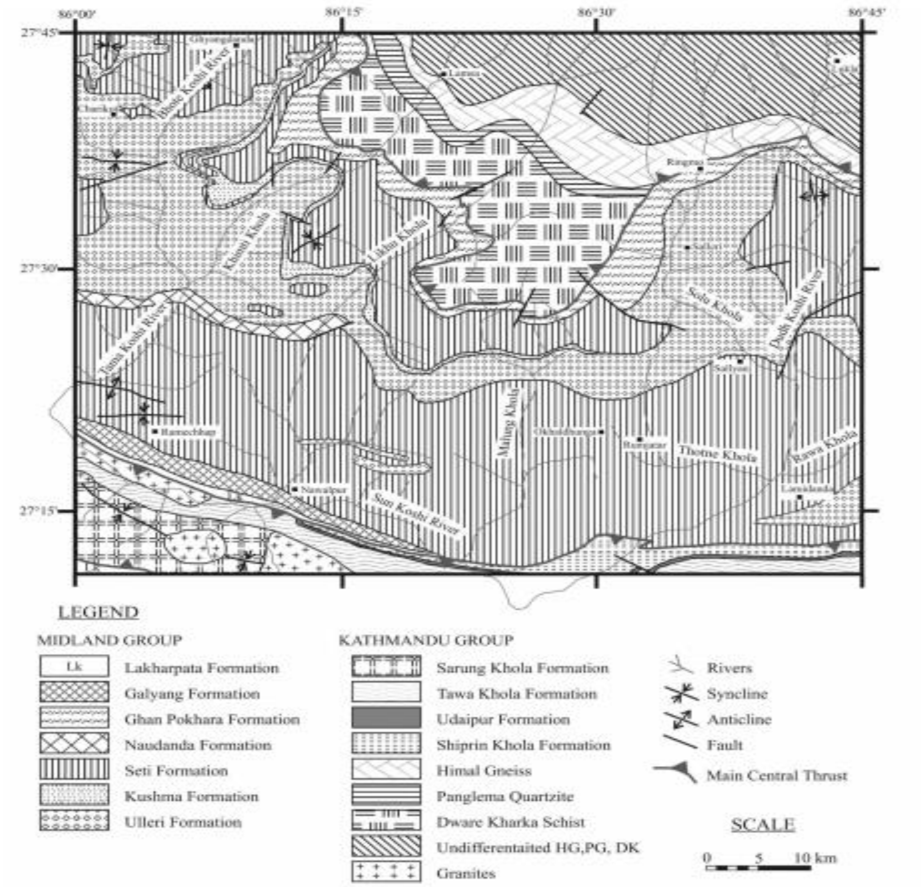

Figure 13 Geological map of the eastern Nepal (Modified from Shrestha et al., 1984)

The dam site of proposed Sunkoshi-2 Hydropower Project and its surrounding mainly comprise the Tawa Khola Formation, which is the basal formation of the Bhimphedi Group. Although garnet schist and micaceous quartzite bands are the main rock types; three rock units namely- Schist Unit, Quartzite Unit, and Gneiss Unit were identified. Since joint orientations were found to be consistent over fairly large areas, surface studies of joints were used in predicting subsurface orientations. Rock mass classification was made in line with the Rock Mass Rating System and the Dam Mass Rating classification for the dam foundation. The engineering geological map of the dam site shows several faults; however, their displacement is negligible. Some of the shears are important and would require special consideration if exposed near the foundation during preparation works; however, no surface evidence of these faults being active was seen.

Mebrahtu et.al,(june,2019)presented in this study electrical resistivity imaging and engineering geological investigations conducted at the Gereb Segen dam site and reservoir to evaluate water tightness and stability. The Gereb Segen dam is located 17 km southwest of Mekelle, capital city of Tigray regional state, northern Ethiopia and bounded by geographic coordinates 540,000 m to 545,000 m E and 1,479,700 m to 1,483,900 m N (UTM Zone: 37, Datum: Adindan) Fig.14. The embankment dam is 51 m high with a crest length of 850 m and reservoir capacity of 31 million m3 and is designed to provide water supply to Mekelle city. During the initial phase of construction, critical geological problems in relation to water tightness were identified. This research is aimed at addressing the geological challenges (water tightness and stability) of the dam site using geophysical and engineering geological investigations. The reservoir capacity of Gereb Segen dam is large compared to other micro dams around the study area. The variability in rainfall together with the extended duration of drought is threatening food and water security in Sub-Saharan Africa in general and East Africa in particular (De Hamer et al. 2008). Construction of dams in arid and semi-arid areas such as northern Ethiopia, where the main socioeconomic activity is rain-fed agriculture, is important and is directly linked to the erratic and variable rainfall (Yazew 2005; Walraevens et al. 2009). Northern Ethiopia, particularly the Tigray region, is often affected by drought largely as a result of uneven distribution of rainfall over many decades (Nedaw and Walraevens 2009; Berhane et al. 2013). One possible strategy for alleviating such a problem is through the use of various means of harvesting water for irrigation and drinking purposes. To this end, many water storage schemes have been undertaken by the Regional Water Bureau and Federal Ministry of Water Resources over the past 15 to 20 years through the construction of micro-dam reservoirs. However, many of the micro-dams have failed to store the expected amount of water. This is mainly due to lack of engineering geological, geophysical and geotechnical investigations prior to dam construction (Haregeweyn et al. 2005; Abdulkadir 2009; Berhane 2010a, b).

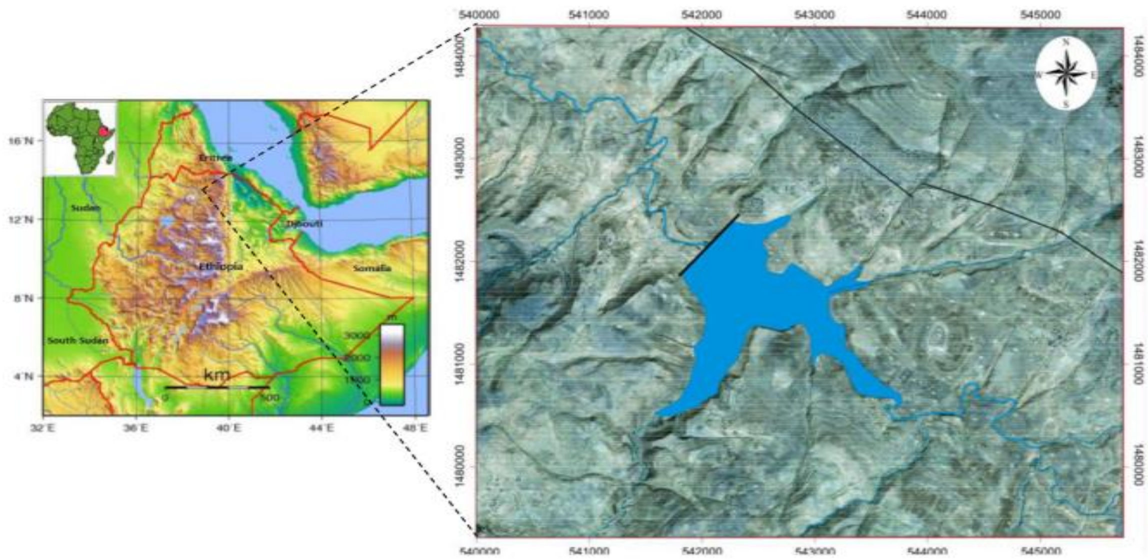

Figure 14 Location map of Gereb Segen dam site with reference to Ethiopia and Africa. The location map is extracted from SPOT imagery

- **Geology of the dam site:**

The dam site is covered by four geological units, namely alluvial deposits, dolerite, micrite limestone and marl limestone-shale intercalation units Fig.15 as outlined below. The local geological units are correlated with the regional geology of northern Ethiopia. The alluvial deposit is correlated with Quaternary deposit, dolerite with Mekelle dolerite, and micrite limestone and marl-limestone-shale intercalation with the Antalo limestone formation regionally. Alluvial deposits cover the central part of the dam site in the valley floors along the main river and its tributaries (Fig.15). This unit is composed of clay soil with units of gravel, with boulder-sized dolerite and limestone clasts. It has 10 m thickness at the center of the reservoir, but decreases towards the abutments. Dolerite is exposed as a sill in the right and left abutments, upstream and reservoir rim of the dam site. It is overlain by relatively jointed micrite limestone (Fig.15). The thickness of the sill varies from 40 m to 50 m in the study.

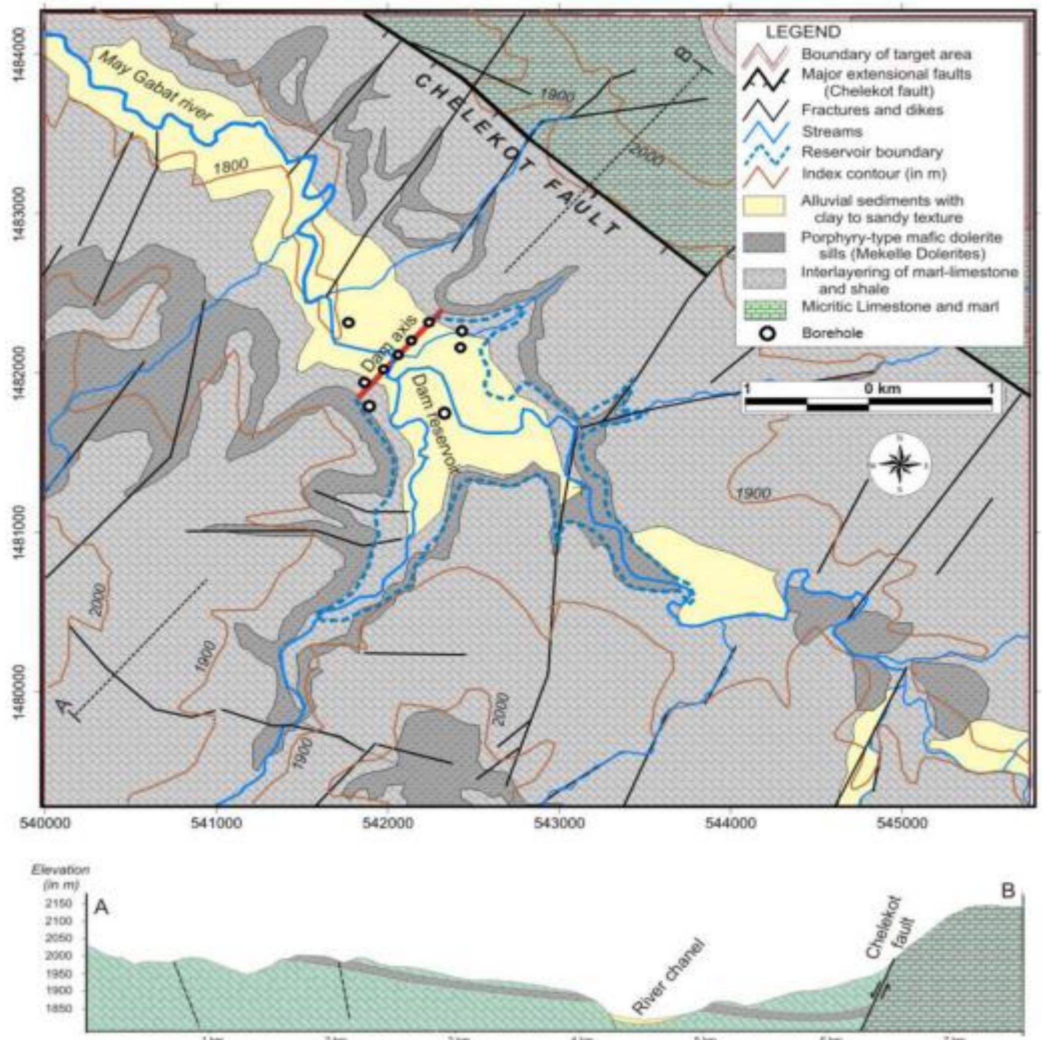

Figure 15 Geological maps of Gereb Segen dam site and its surrounding area. Lithologic contacts were extracted from SPOT imagery

area. The dolerite is highly weathered and shows exfoliation and spheroidal weathering (Fig. 16a). It shows dark-gray to black color and consists of medium- to fine-sized minerals. A micrite limestone unit is found at the upper part of the left and right abutments and along the upper face of the reservoir rim. The field investigation showed that it is moderately to highly jointed (Fig. 16b). The aperture of the joints varies from 2 to 15 cm with an average joint spacing ranging from 50 to 125 cm without filling materials. Karstification in limestone is common in the downstream of the proposed dam site. A highly weathered marl-limestone-shale intercalation unit is also observed in both right and left abutments and downstream of the dam.

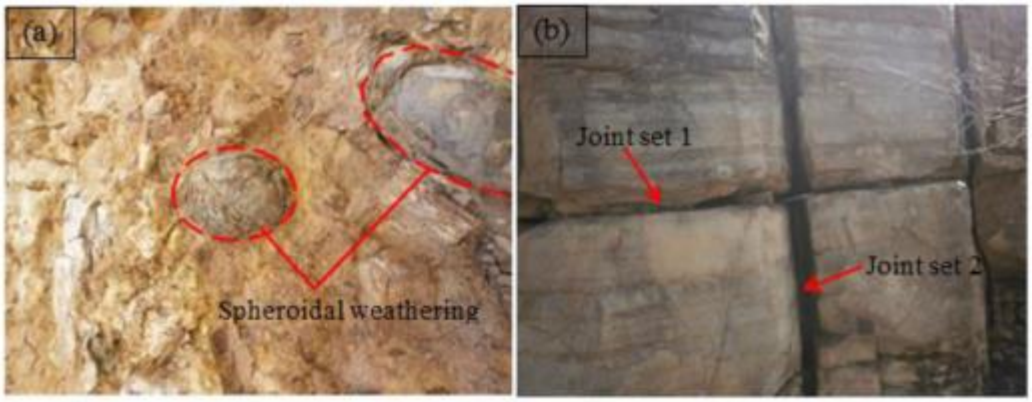

Figure 16 a Spheroidal weathering of dolerite at the right abutment, b limestone outcrops, jointed in two sets at the right abutment of the dam

The 2D electrical resistivity imaging and engineering geological investigations were conducted to examine the subsurface geological formations at the dam site. The site is underlain by alluvial deposits, dolerite, and micrite limestone and marl-limestone-shale intercalation units. Four cavities (two at the reservoir, one at the left abutment and one at the right central foundation) ranging in size from 0.8 m to 3 m were found at the dam site within the marly limestone layer, forming a karstified zone at the dam site. The presences of the karstified zone at the reservoir and dam foundation will likely lead to significant leakage for Gereb Segen dam. From this finding, it is possible to deduce that the marly limestone unit is expected to have similar cavities around the reservoir which could be the source of excessive water loss through the reservoir and foundation of the dam.

3.0 Result and Discussion

For dam investigation the geological method/activity is very important method to decide the purposed area is suitable to construct hydraulic structures. The shape of river valley and the geological formation of both abutments were well identified through this method. Based on this method different rock types are classified stand on their genetic type. The thickness of each lithology and the orientation of geological structures were measured in the field in different out crops. Rock mass condition along the dam axis and abutments was based on geological mapping on rock outcrops. The sediment management strategies increase the useful life of dams and decrease problems experienced downstream the dam by mitigating the sediment starvation phenomenon due to trapping sediment. In other words, the dam site is ideal in terms of water retention as rock type is supposed to have very low permeability as well as the direction of the discontinuities is nearly parallel to the axis of the dam and inclined upstream. As the lithology at the dam site area is quite complex with an assemblage of rock types with different susceptibilities to weathering, the grade of weathering is highly varying. This raises question about future weathering that would cause failure of slopes and adjacent structures during their engineering lifetime. Test pit and Core drilling method to take soil sample and measure the thickness of layered soil and also used to analyze the weathered topography of rock beneath different soil layers. Permeability measuring method used to characterize the soil permeability by using constant head and falling head methods. Geophysical method .This special method is used to know the geological defects at very great depth and to know the lithological horizontal and vertical variation in the area as well as groundwater condition.

4.0 Conclusions

The study of dam sites excites the interest of geologists because of the necessity for precise and detailed work and because funds are usually available for test pits and borings to gain information not obtainable by surface examination. The many devices available to the engineer to overcome difficulties at the site are each limited by various related conditions. Consequently the geologist must be scrupulous to set forth all the facts at his disposal. He should also realize that if adequate funds are available every difficulty can be overcome and that dam sites are abandoned only because the cost of the proposed dam exceeds its probable value. The economic changes of the future may change the ratio of value, and structures now unfeasible may someday be built. The feasibility of a dam is thus an economic problem, and statements as to feasibility are outside the province of a geologist's report, which should be confined to the physical conditions. The geology of dam sites may be considered under the following heads: Foundations; abutments (leakage); spillways; tunnels (by pass, discharge, etc.); materials for construction. This division is quite arbitrary, however, because the factors are so related that in the examination of any one site all must be considered. The cost of construction is also a part of the problem, and intelligent geologic work can be done only in conjunction with the engineer, in whose study of the problem this consideration is prominent.

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