Geological Investigation for Environmental Impact Assessment (EIA): Case Studies from Some of Mini Hydropower Projects in Sri Lanka

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Abstract— The geological investigation is a very important factor for the environmental impact assessment (EIA) study for any development project. The major objectives of this geological investigation are to identify existing surface and sub-surface geological conditions of selected locations for the main structures of the project, to describe stability condition of soil overburden and the bed rock, to analyze geological hazard situation of the area and to recommend appropriate precautionary measures to mitigate anticipated environmental impacts due to unfavorable geological conditions. At present study was focused to conduct the geological investigations for some of the mini-hydropower projects in Central Highlands of Sri Lanka. The mini hydropower project mainly consists of diversion weir, fore bay tank, penstock line and a power house. The locations of the above structures have been selected after the preliminary field and literature survey. For the purpose of this geological survey, the evaluation of general aspects of in-situ ground stability of the proposed location of the weir site, fore bay tank, penstock line connecting the fore bay tank, the power house have been investigated. On an appraisal of the analysis of data collected in the field and conclusion made based on the field observations, the proposed locations to construct the mini hydropower projects where moderate level of geological hazards and landslide risk exists can be recommended for the above projects only with the applications of location specific guidelines and precautionary measures for the prevention of future geologic hazards. It is advised to adhere to some recommendations for the sound construction and operation of the proposed mini hydropower projects.

Keywords— Geological Investigation, Environmental Impact Assessment, Mini Hydropower.

I. Introduction

The general objective of a geological investigation is to assess the suitability of a site for the proposed purpose. As such, it involves exploring the ground conditions at and below the surface [1]. It is a prerequisite for the successful and economic design of engineering structures and earthworks. Accordingly, a site investigation also should attempt to fore seen and provide against difficulties that may arise during construction because of ground and/or other local conditions [2, 3]. The complexity of a site investigation depends upon the nature of the ground conditions and the type of engineering structure [2-5]. For the purpose of this geological survey, the evaluation of general aspects of in-situ ground stability of the proposed location of the weir site, headrace channel path between the weir and the fore bay tank, location of the proposed fore bay tank, penstock line connecting the fore bay tank and the power house and location the power house of the project shall be considered.

The major objectives of this geological investigations are to identify existing surface and sub-surface geological conditions of selected locations for the main structures of the project, to describe stability condition of soil overburden and the bed rock, to analyze geological hazard situation of the area and to recommend appropriate precautionary measures to mitigate anticipated environmental impacts due to unfavorable geological conditions. At present study was focused to conduct the geological investigations for some of the mini-hydropower projects in the Central Highlands of Sri Lanka.

II. Location and Accessibility

The proposed mini hydro power projects is situated at Gammaduwa (07^{o} 42’ 0.13” N, 80^{o} 42’ 0.01” E) and Rajjammana (7 27’ 36” N, 80 39’ 05” E) in Matale district of the Central Highlands of Sri Lanka (Fig.1). Main structures of Gammaduwa mini hydropower project are to be set up on the right bank of the Kosgolla Oya which is a tributary of the Kalu Ganga, within a stretch of about 2 km. Main structures of Rajjammana mini hydropower project is located in downstream area of Sudu Ganga in Matale District. Sudu Ganga and Kalu Ganga originate from northern slopes of Hunnasgiriya mountain ranges in northern edge of the Central Highlands. The proposed mini-hydropower projects consist of diversion weir, open channel, fore bay tank and a power house. The estimated generation of power of electricity is about 1MW.

III. GEOMORPHOLOGY AROUND THE GAMMADUWA MINI HYDRO POWER PROJECT AREA

The project area is located in the North Western mountain range in Sri Lanka, namely the Gammaduwa and Karagahatanne mountains. It shows consequently a great diversity of geomorphologic features within a comparatively small area. The project area is mainly in the E-W Kosgolla Oya valley. This valley connects with several tributaries within Kosgolla Oya basins. Escarpments, deep slopes and narrow valleys are in fact a major landform in the massif, often reaching several small waterfalls flowing over them. The location at which diversion weir is proposed to construct, the stream flows in a relatively wide valley with U- strike shaped cross section having rather shallow river bottom. Some perennial tributaries can be observed upstream and downstream side of the weir.

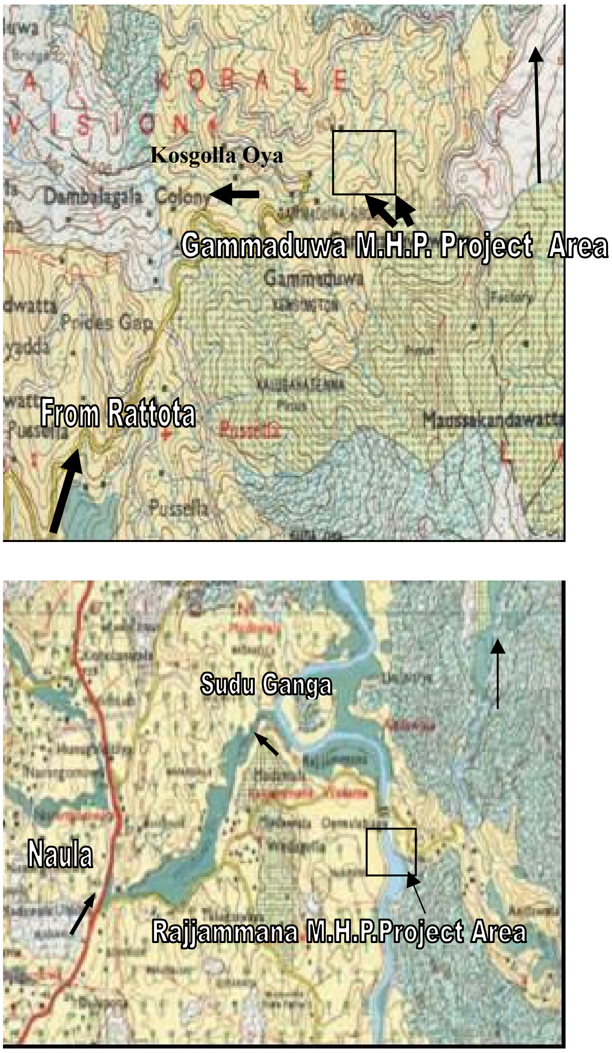

Fig. 1: Location Map of the project area (1:50,000; Matale Sheet)

The weir site, about 2m height and about 20m long, is proposed to cross the Kosgolla Oya. About 15m drop in the river was observed about 10 m from the weir site. The left and right bank of the river at the weir site and the pond areas show a gentle slope and average slope has an inclination varies from 25-35 degrees. The rock boulders were observed in the both side of the left and right banks of the weir site. The headrace channel is aligned along the SE-NW oriented mountain which is located at the right bank of the stream within a stretch of about 900m. This reinforced concrete channel has to pass initially a relatively gentle slope which is convex in shape and having an inclination ranging from 25-35 degrees.

The fore bay tank is proposed to be constructed on a more or less flat top of a convex slope having an inclination ranging from 10-30 degrees towards the N-E direction. The upper slope above the fore bay tank is straight showing an inclination of 20 degrees. The penstock is to be aligned along the NE directed slope which shows an inclination ranging from 20-45 degrees. The length of the penstock line is approximately 450 m. The power house is to be constructed on a slope which shows an inclination ranging from 10-15 degrees of the right bank close to Kosgolla Oya.

IV. GEOMORPHOLOGY AROUND THE RAJJAMMANA MINI HYDRO POWER PROJECT AREA

The project area is mainly located along the southerly to northerly strike valley of Sudu Ganga basin. There is an existing weir at the proposed project site which regulates and diverts Sudu Ganga water to irrigate existing agricultural lands located along both banks in Rajjammana and Lihinipitiya villages. Irrigation outlets are available at both ends of the weir to issue water quantifying amount maximum of 0.5 m^3/sec for irrigation purposes by each canal. This existing weir will be modified and raised by another 2 m, to have an additional water head for power generation (Photo 1). Length of the weir is 182 m and maximum height is 4 m at the centre part. Weir will be an ogee shape one without spillway gates.

The pool area will be approximately 16 Ha at fsl. The damage for the bank will be minimized when the pool area increases. The riverbanks will be submerged to an additional extent of 2 m and the river will be surged back to a length of approximately 107 m. There will be no substantial increase in the inundation area due to increase in weir height. The separate inlet channel will be constructed 30-40 m away from left side of the weir, under new phase of the proposal. This channel is aligned along the NE-SW oriented mountain which is located at the left bank of the stream.

Photo 1: Proposed weir site and pond area

A major portion of the headrace channel in both projects, cross concave type of slope having an inclination ranging from 45-60 degrees and the direction of the slope varies at different locations towards the power house to weir site. The headrace channel crosses several streams (or valleys) along the N-S direction, formed along the fracture erosion. In addition, several valleys can be observed along the channel trace formed due to gulley erosion and accumulation of colluvial deposits due to old landslide.

V. GEOLOGY AND STRUCTURE OF THE PROJECT AREA

Basic geologic analyses were carried out to obtain the overall geologic information. This area occupied high-grade lithologically and isotopically distinct, proterozoic metamorphic rocks, which belong to Highland Complex of Sri Lanka [6].

1:100,000 scale Geological map (Matale sheet) published by Geological Survey and Mines Bureau is used for the interpretation of Geological phenomenon in and around the project area. But general Geological data were collected during the field visit (Table 1 & 2) .General orientation of rock layers is aligned NE-SW direction. Major rock types are Garnet, biotite gneiss (+/- Hornblende), Biotite gneiss (+/- Hornblende), Crystalline Limestone (Marble), Quartzite, Khondalite, Charnockite and Undifferentiated metasediments (Fig. 2).

Garnet, biotite gneiss (+/- Hornblende) is the major rock type, striking along NE-SW direction and dipping southerly about 50º-70º. Quartz (40%), Feldspar (25%), Biotite mica (20%),Garnet (10%), and +/- Hornblende 5-8%, are the major mineral composition of these gneissic rocks.

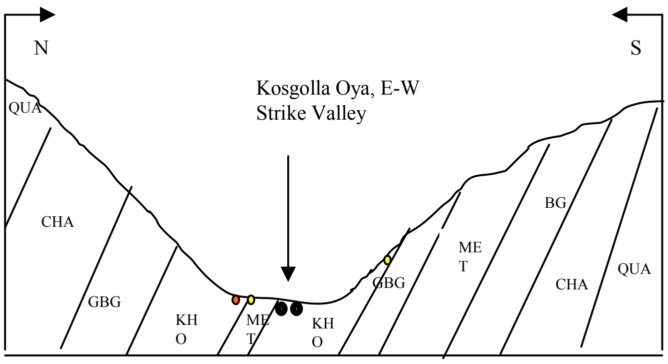

Fig.2: General Geology of Gammaduwa M.H.P. area, Length of Section , 1.5 km (approx.) along the weir location (A-B)

LEGEND:
CHA: Charnockite
GBG: Garnet Biotite Gneiss (+/- Hornblende)
BG: Biotite Gneiss
KHO: Khondalite
MET: Undifferentiated metasediments
● : Pegmatite- Cross cut the host rock along fractures
● : Quartzite- small bands

Table 1: The geological observations during the site inspection around the Gammaduwa Mini Hydro Power Project Area

Location	Strike/ Dip	Joints	Rock type	Characteristics	Weathering stage
L1:Left bank: near suspension bridge: downstream	N85^{0}E/ 40^{0}N	EW / 4m^{-1}	Charnockite	River flow along the major joint place	Fresh rock moderately Jointed
L2:Rightt bank: at the Power House : Downstream	N70^{0}E/ 30^{0}N	N10^{0}W / 5m^{-1}	Garnet-biotite gneiss (+/- Hbn): GBG	Boulders in both RB and LB.	Fresh rock moderately Jointed
L3: :Rightt bank: at the Power House : Downstream	Soil Profile: Red Latertic soil: boulders contained				highly Weathered: thick overburden
L4: Moderate valley: along the Penstock	Valley was formed along the joint: N45^{0}E / Landslide prone area			Perennial Streams flow	highly Weathered: thick overburden
L5: **Right bank : Downstream**	N10^{0}W / 40N	NS / 4m^{-1} And N40E Two set of joints	Garnet-biotite gneiss : GBG and Quartzo Felsdpathic Gneiss	Small water fall (Step fall of water): 15m height	Fresh rock highly Jointed
L6: Depression	N80^{0}E/ 30^{0}N	Valley was formed along the joint: N40^{0}W	Undifferentiated metasediments	Seasonal Streams flow: Soil erosion is possible along the depression (Photo)	highly Weathered: thick overburden
L7: Moderate valley	N/A	Valley was formed along the joint: N 50^{0}E	Khondalite and Undifferentiated metasediments	Head Trace channel should be protected: Soil erosion is possible along the depression Landslide prone area	highly Weathered: thick overburden
L8: Small depression	N15^{0}W /40^{0}N	N10^{0}W / 3m^{-1}	Garnet Biotite Gneiss	Seasonal Streams flow:	Slightly weathered
L9: Depression	Soil erosion is possible along the depression: Removing tree for home gardening Landslide prone area				Slightly weathered
L10: Near FB Tank: Small depression	N75^{0}E/ 25^{0}N	Stream flow along the joint of N20^{0}W	Garnet-biotite gneiss	Perennial stream flow	Fresh rock moderately Jointed
L11: At the FB Tank:	N80^{0}E/ 30^{0}N	NS / 3m^{-1}	Garnet-biotite gneiss	Thick soil overburden	Fresh rock moderately Jointed
L12:Along the channel trace	N70^{0}E/ 10^{0}N	NS / 4m^{-1}	Garnet-biotite gneiss		highly Weathered: thick overburden
L13: along the channel path	N55^{0}E/ 15^{0}N	N10^{0}W / 3m^{-1}	Biotite Gneiss	Small pegmatite extended along the foliation. The channel path runs along the narrow valley Stable slopes Thin overburden	Fresh rock moderately Jointed
L14: along the channel path	Old landslide area			Thick overburden	highly Weathered
L15: Weir site	N75^{0}E/ 10^{0}N	NS / 4m^{-1} And N10^{0}W / 3m^{-1}	Garnet-biotite gneiss Charnockite and Pegmatite	Pegmatite extended alon the NS joint palne	Fresh rock Highly Jointed
Weir site and river bed	N70^{0}E/ 45^{0}S	No	Khondalite		Slightly weathered
L16: Upstream	N75^{0}E/ 60^{0N}	N10^{0}W / 4m^{-1}	Garnet-biotite gneiss (+/- Hbn) And Quartzite	Quartzite: Tapering off	Moderately weathered

Table 2: The geological observations during the site inspection around the Rajjammana Mini Hydro Power Project Area

Location	Strike/ Dip	Joints	Rock type	Characteristics	Weathering stage
L1:Left bank: near new proposed power house	N20^{0}E/ 40^{0}W	N80^{0}W / 3m^{-1} *Weathering observed along the joint plane: Joint space about 1-2 feet*	Garnet-biotite gneiss (+/-Hbn): GBG	Perennial stream flows along dipping plane Boulders can be observed (1-2m) *Sudu ganga and Existing channel travel along the direction of strike*	Fresh rock moderately Jointed
L2:Left bank: 50 m from the L1	N30^{0}E/ 70^{0}W	4m^{-1}	Garnet-biotite gneiss (+/-Hbn): GBG	Same rock is extended and gully erosion might be occur along the joint plane Crystalline limestone as boulders	Fresh rock Highly Jointed
L3: Left bank: 50 m from the L1	N20^{0}E/ 20^{0}W	Highly Jointed *Weathering observed along the joint plane*	Biotite gneiss (+/-Hbn): BG		Fresh rock Highly Jointed
L4: Left bank: 200 m from the L1	Red Brown Earth Head Trace channel should be protected: Soil erosion is possible along the depression				highly Weathered: thick overburden
L5: : Left bank: 250 m from the L1	N10^{0}E/ 50^{0}W		Garnet-biotite gneiss : GBG		Fresh rock Highly Jointed
L6: Left bank: near earlier proposed power house	N15^{0}E/ 40^{0}W	N70^{0}W / 4m^{-1} Highly Jointed *Weathering observed along the joint plane*	Garnet-biotite gneiss (+/-Hbn): GBG		highly Weathered: thick overburden
L7:Left bank, Left side of the weir	N05^{0}E/ 50^{0}W	Highly Jointed *Weathering observed along the joint plane*	Garnet-biotite gneiss (+/-Hbn): GBG		Fresh rock Highly Jointed
L8: Weir Site	N10^{0}W /40^{0}W	N80^{0}W / 3m^{-1}	Garnet-biotite gneiss (+/-Hbn): GBG	Weir will be constructed one the solid rock of GBG	Fresh rock moderately Jointed
L9: along the left bank of the pool area	Alluvial Soil				
L10: near Intake	……	Tapering off	Quartzite	Residual Soil (Red Brown Earth) was formed wreathing of quartzite	highly Weathered: thick overburden
L11: along channel trace		as boulders	Crystalline limestone	Residual Soil (Red Brown Earth) was formed wreathing of quartzite	highly Weathered: thick overburden

The major rock types at the weir section of Rajjammana M.H.P., are predominantly consisting of fresh Garnet, biotite gneiss and Biotite gneiss which are highly foliated and jointed, Whereas at the bottom part of the left bank, slightly weathered khondalite rock layers was identified. Slightly to moderately weathered impure crystalline limestone (marble) isolated outcrops are exposed at the 10-15 m away from the pool are along channel trace. Isolated outcrops of marble are exposed along the channel trace up to power house. In addition, some weathered quartzite was observed along the channel trace.

Well foliated bedrock is exposed in the downstream section of the weir. There are major well-defined joints in Garnet biotite gneiss and Biotite gneiss below the channel trace, along the existing irrigation canal (Photo 2).

(a)

(b)

Photo 2: Well foliated-highly jointed rocks (a) along the channel trace: (b) At the downstream of Sudu ganga

VI. OVERBURDEN DEPOSITS

Major soil groups in the region are reddish and brown earth as residual and alluvial. The color of the surface *A* horizon is characteristics reddish/ yellowish brown with average thickness of 2-2.5m. The *B* horizon contains weathered rock particles in yellowish color with average thickness of 2m. The most of the soil profiles in the study area are in similar textural variations. The content of the organic matter in a soil is critical for retaining and cycling nutrients, for retaining moisture and for developing. Natural and human processes (eg. Land clearing, burning) which have low organic matter content and have a detrimental effects on the soil in its ability to sustain plant growth.

At the weir site of the Gammaduwa M.H.P., either side of the river bank, about 5-7m thick residual soil overburden resting on the highly weathered Garnet-Biotite Gneiss, Charnockite, Khondalite and slightly weathered undifferentiated metasediments and few meters thick pegmatite (intruded along the joint plane) were observed.

At the beginning of the channel trace of Rajjammana M.H.P., about 3-4m thick residual soil overburden resting on the highly weathered garnet-biotite Gneiss and quartzite. As well as, some in-situ boulders composed of crystalline limestone, garnet biotite gneiss and biotite gneiss are located on the slope at the left bank of the stream. About ninety percent of the slope across which the channel trace is to be constructed consists of 3-4m thick residual soil overburden. Some in-situ rock blocks are scattered on the slope, which is covered by the natural vegetation.

VII. GEOLOGICAL HAZARD SITUATION OF THE PROJECT AREA

Very old landslide or landslide prone areas were observed at the trace of the channel, weir site and power house. However, small slope failures were observed close to the power house and along the channel trace of left bank of the river. However, there is no landslide or slope failure occurred recently around the both locations according to the information gathered from the people who are living around the area.

VIII. SOIL EROSION AND SILTATION

The common problems associated with downstream hydrological changes, upstream flooding, sedimentation, water quality changes and adverse impact on plant and animal communities. Due to the formation of a small pond area upstream of the weir, submergence of river bank will be occurred. And also fluctuation of the water level of the pond area can be anticipated during the rainy seasons. As a result, minor scale river bank failures may be expected unless proper measures are taken.

Due to the cultivation activities above the pond area and upstream intermittent land clearing may cause considerable erosion followed by siltation problem [5]. During the construction of the headrace channel, expected cut slopes are minimal. Therefore, frequency for soil erosion may be negligible. Tributary channels of the upstream and downstream are small but they bring sediment from slope erosion start moving downstream in appreciable quantities. As stream bank become higher, more and deeper flow is constrained to the channel, thus increasing stream power and causing the banks to erode. Improving land use is one of the methods for recovery and prevention from the erosion and also there are some instructive hypothetical hydrological applications with the aggradations of the flood plain and commensurate rising of the banks [4].

Landfill is often necessary for construction roads, buildings and other diverse development activity. The problems of unplanned, hazard landfill, however causes serious problems be destroying natural functions including bio-diversity and flood detention. Landfill should be done using prevention measures (eg. retaining walls) to minimize the soil erosion.

IX. IMPACTS ON BEDROCK STABILITY

Although the bed rock exposures are well foliated and moderately jointed, the stability condition is favorable for the sound construction of the diversion weir. In-situ boulders and separated rock blocks may be encountered along the channel path. Several slope stability issues will be encountered when the proposed powerhouse will be excavated. Precautionary measures to be taken to stabilize the embankments of the area during excavation.

X. CONCLUSION

According to field observation, data collection and data analysis, following conclusion can be made subjected to the limitations mentioned above.

i. All the project area can be identified as moderately risk area of landslide hazard.
ii. Since the bedrock at the weir site is highly foliated and moderately jointed, uncontrolled blasting of this location may open those joints. This may lead to water leakage in the reservoir.
iii. Initiation of slope failures may be occurred due to the disturbances made by the construction activities of the project.
iv. Obstruction of natural water paths and dry galleys due to construction activities may also lead to future slope failures.
v. Unless vertical cuts having a height of more than 1.5m are properly retained, the loose nature of the overburden soil will lead cutting failures.
vi. Unless removed earth mass is dumped at proper sites it will lead sedimentation at lower lands and to occur debris flows along slopes.

In general the area across which the channel trace is proposed to construct different types of soil failures may be expected in unsupported slope cuts. Hence damages to the project elements may cause if adequate remedial measures could not be introduced at the very first stage of the construction works. Further these minor failures may lead to major failures in future with increasing ground instability in the project area.

According to the existing conditions, construction of these projects will not bring significant impacts to the natural slopes in the area if engineered and regulated constructions are to be performed and long term proper maintaining system persist. Also minor failures can be avoided or minimized by applying appropriate engineered measures and by minimizing ground disturbances during construction.

XI. RECOMMENDATIONS

On an appraisal of the analysis of data collected in the field and conclusion made based on the field observations, the proposed land area where moderate level of geological hazards and landslide risk exists can be recommended for the above project only with the applications of location specific guidelines and precautionary measures for the prevention of future geologic hazards.

It is advised to adhere to the following recommendations for the sound construction and operation of the proposed mini hydro power projects.

i) At the middle part of the headrace channel and the several valleys that are crossed by the penstock line at the Gammaduwa M.H.P., it is necessary to provide an aqueduct or large diameter pipe to minimize disturbances to the ground, where the old landslide and the debris deposit are located.

ii). A controlled blasting technique such as compressor drilling should be applied for constructions of the intake of headrace channel.

iii). Unstable slopes should be preserved by introducing deep rooted trees to mitigate future earth flows. It should not be used for any agricultural purposed.

iv). Natural water paths and dry gulley should be kept free from any obstruction by any kind of construction

v). Minimized the ground excavations during the construction phase to keep stability of slopes at maximum level.

vi). Earth retaining structures should be applied at every place where cuts will be encountered with a height more than 1.5m to prevent the initiation of local failures.

Building of excess hydrostatic pressure behind any type of gravity retaining wall may lead to collapse them and as a result, soil retained behind the wall will force in to failures. Therefore, prevention of building up of excess pore water pressure is the best tool rather than building a structure to sustain hydrostatic pressure. The following engineering applications should be provided to prevent building of excess pore water pressure during construction stage.

a). Draining out of water can be accomplished by providing weep holes

b). Weep holes should be provided in a Zigzag pattern.

c). Granular material should be placed behind the walls to facilitate free draining through weep holes.

vii). All types of water leakages and spills from open channel, location of fore bay tank and location of power house should be avoided by applying appropriate concrete paved drains to divert them back to the river.

viii). Existing surface drainage system in the tea lands should be properly maintained during operational phase.

ix). Removed earth masses should be dumped in a flat non-erosion area close to a valley bottom.

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