Geological Mapping Report

Detail engineering geological study of the Kokaha Khola Reservoir Project, Sunsari, Nepal

Central Campus of Tehnology
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Geological Mapping Report

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1. Introduction

The proposed Kokaha Khola reservoir project is located on the Bishnupaduka, Dharan Sub-Metropolitan city, ward no. 20, on the northern part of the Sunsari District of Koshi zone of the Eastern Development region (Figure 1). The project lies on the Kokaha Khola which originates from the Lesser Himalaya sequence. The components of the proposed project lie mainly on the Siwalik and the Lesser Himalaya sequence respectively.

This report describes the regional geology, engineering geology and the geotechnical study of the Kokaha Khola Reservoir Project.

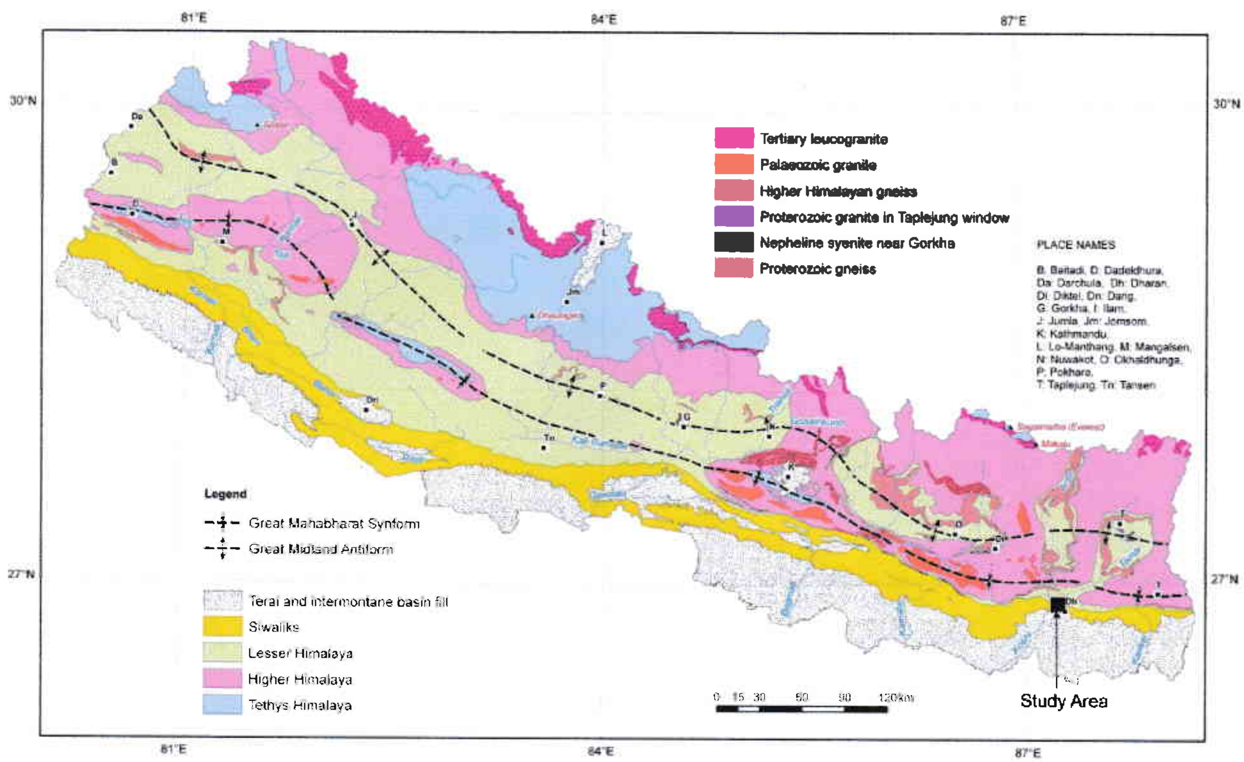

Figure 1: Geological Map of Nepal (after Dhital, 2015) with location of the area.

2. Regional Geology

Intracontinental collision between the Indian and the Eurasian plates since ~55 Ma gave rise to the rugged topography and dynamic geology of the Himalaya. Tectonomorphologically, the whole Himalaya can be divided into different longitudinal units having unique morphological, geological and evolutionary characteristics. From south to north, they are: Terai plain Indo-Gangetic Plain), Sub Himalaya (Siwalik); Lesser Himalaya; Higher Himalaya Crystallines (HHC); Tibetan-Tethys Himalaya and Indus Suture Zone, respectively. The Nepal Himalaya occupies approximately 800 km of the central part of the Himalayan belt extending along east-west direction (**Error! Reference source not found.**).

The Kokaha Khola Reservoir Project lies on the Siwalik and the Lesser Himalaya sequence of Eastern region of Nepal. Thus the Main Boundary Thrust (MBT) which separates the Siwalik from the Lesser Himalaya sequence passes through the project area. Regional geology shows the project area comprises of a rock units of Siwalik and the Lesser Himalaya Sequence. (Figure 2 & 3). The main rock units observed on the project area are medium to thick bedded Sandstone of the Siwalik and thin to medium foliated slate of the Lesser Himalaya Sequence. The general strike of the outcrop is NW-SE with dip towards NE at angles ranging from 45° to 86°.

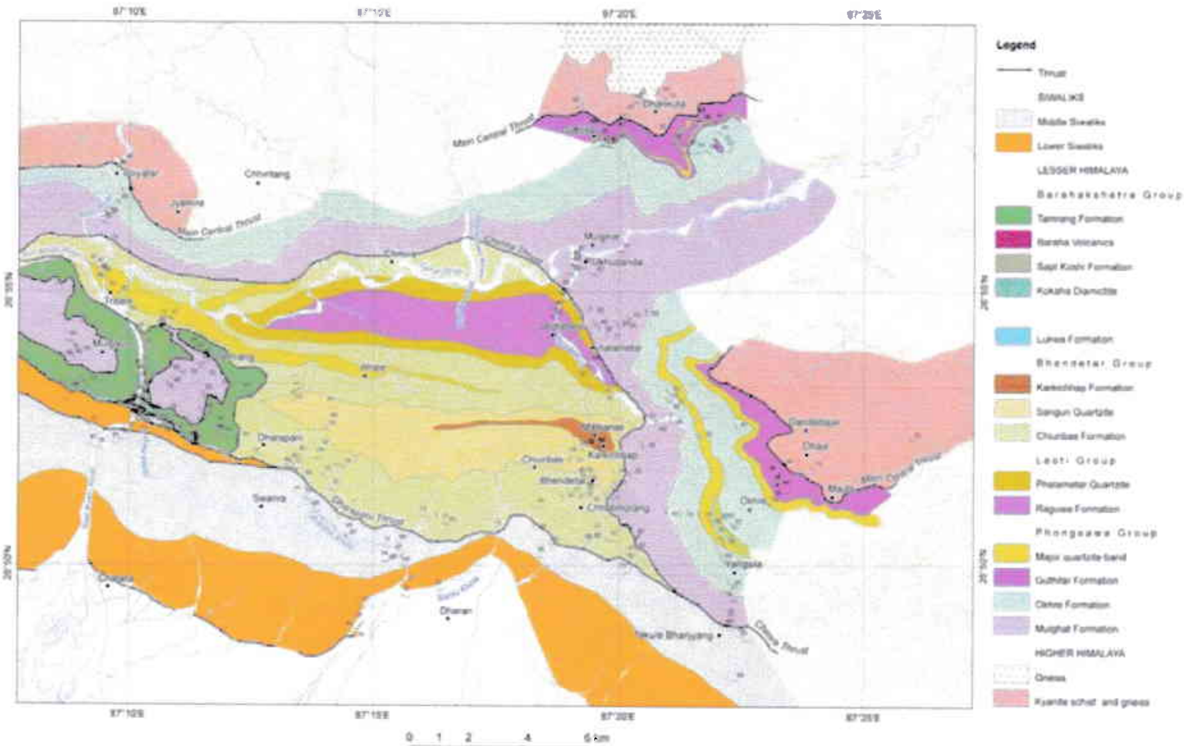

Figure 2: Geological Map of Tribeni-Dharan-Dhankuta area (after Dhital, 2015).

3. Geological and Engineering Geological Condition.

Geologically the proposed Kokaha Khola Reservoir Project lies on the Siwalik and the lesser Himalaya sequence respectively (Figure 3). The two units are separated by the MBT which is determined by the change in the lithology from sedimentary to metamorphic rocks around the project area.

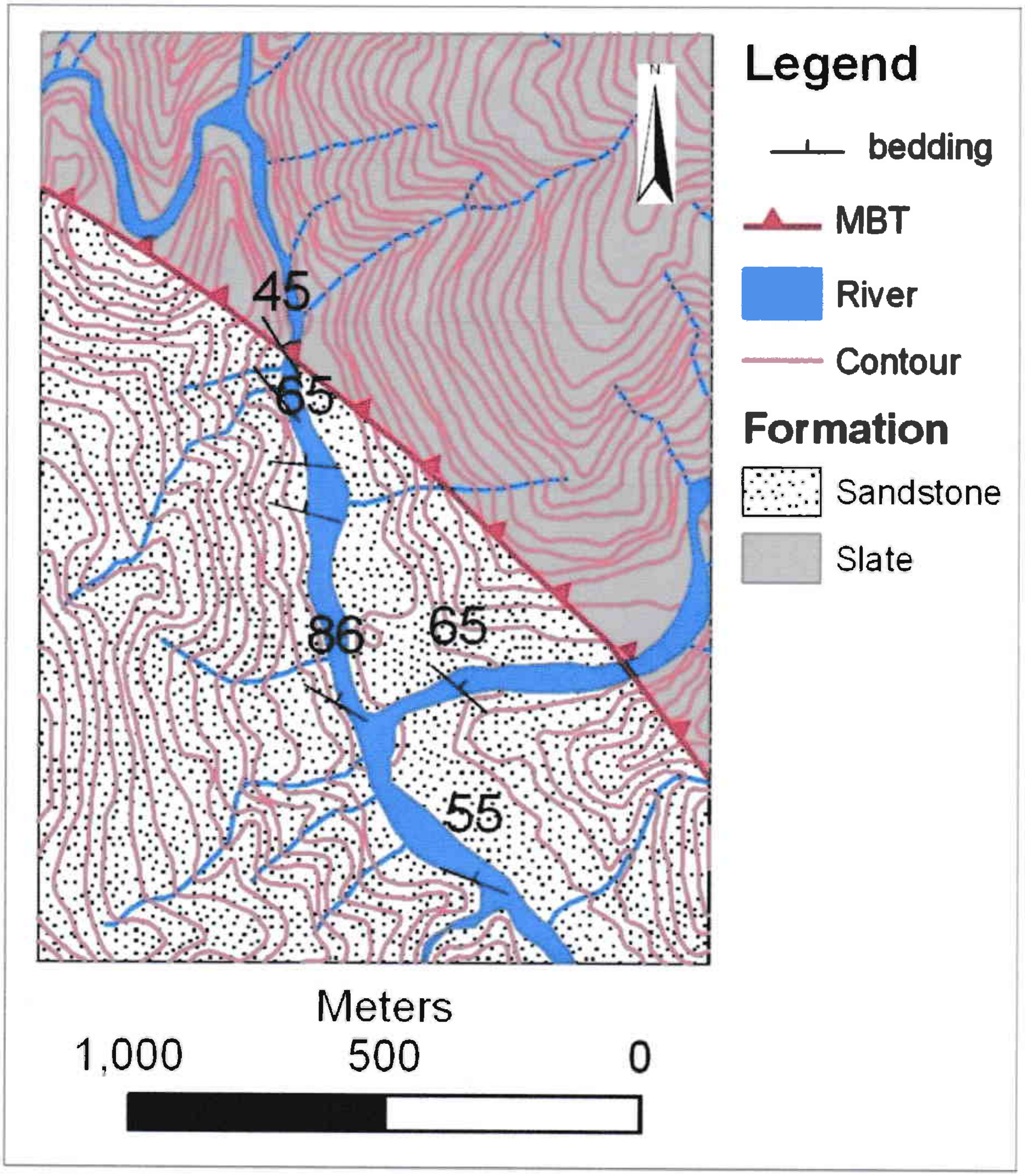

Figure 3: Geological Map of the Project area based on the present study.

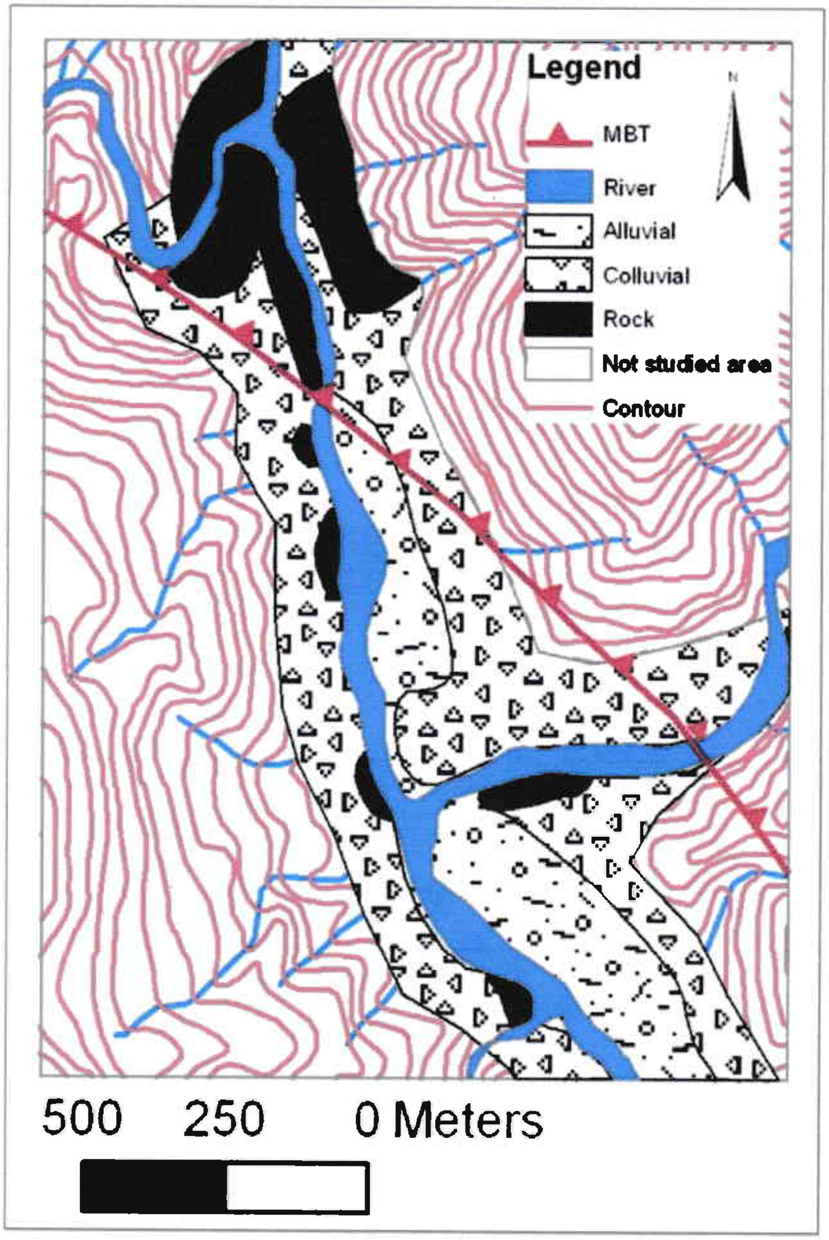

Figure 4: Engineering geological map of the Project area based on the present study.

3.1 Reservoir Area

The reservoir area of the project lies on the Bishnupaduka village. Lithologically whole reservoir area lies on the Siwalik. The area is mostly covered by the alluvial flood plain of the Kokaha Khola and has gentle hillslope on the either side. The hillslope is mostly covered by the colluviums developed due to the weathering and disintegration of rock mass. On the foot of the hill slope bed rocks are exposed. The main lithology is medium to thickly bedded medium grain sandstone whose general strike is NW-SE with dip towards NE. The mass wasting phenomenon is not significant throughout the reservoir area.

Figure 5: Upstream view of the reservoir area.

3.2 Weir

The proposed weir lies on the Lesser Himalaya sequence (Figure 3). The topography is rugged with moderate to steep valley slope on either side. The right bank is slightly covered by the colluviums and is moderately vegetated. The main lithology consists of thin to medium foliated dark grey slate sporadically showing pencil cleavage. Rocks are well exposed on the weir area whose general strike is NW-SE with dip towards NE and is oblique to the weir axis. The mass wasting phenomenon are observed around the weir area (Figure 6) which is discussed on the slope stability analysis chapter.

Figure 6: Plane failure observed at the left bank of Weir axis area.

4. Geotechnical Studies

Geotechnical studies include the stability analysis of surface slopes and rock mass classification.

4.1 Slope Stability

Slope stability analysis was carried out at various locations of the project area. For the analysis, discontinuity data were plotted at Schmidt's equal area net with lower hemispherical projection by using computer software Dips 5.1. Discontinuity planes were then analyzed with respect to the face slope (hill slope) and friction angle of the rock. Friction angle of rock can be assumed 33° for Sandstone and 21 ° for Slate (wet) (Barton and Choubey, 1977). Major discontinuity set measured around the project area is presented in Table 1. These values are useful for stability analysis in the project area.

Table 1 Attitudes of Major Rock Mass Discontinuity Planes (Dip Amount/Dip Direction) in the Project Area

Location	Hillslope	Foliation	Joint (J1)	Joint (J2)	Joint (J3)
Reservoir Area (left bank)	....	058/45	240/85	300/85	135/65
Reservoir Area (right bank)	....	040/65	030/81	309/69	110/62
Weir area (left bank)	062/75	058/45	200/45	310/60	125/87
Weir area (right bank)	265/62	060/45	215/66	310/85	175/45

4.1.1 Reservior area

The area has gentle to moderate topography resulting thick colluvial deposits on the either side of the Kokaha Khola hillslope. The bedrocks are exposure sporadically at left bank of the Kokaha khola and thick colluvial deposit covered by vegetation on the right bank. The rock exposed at left bank is slightly weathered, medium to thickly bedded and medium grained sandstone. The attitude of foliation and joints of the beds are listed on Table 1.

4.1.2 Weir

The area has moderate to steep topography resulting a good rock exposure on the either side of the Kokaha Khola. The weathering and disintegration of rock mass has developed colluvial deposits on the foot of hillslope on the right bank (Figure 7). The rock exposed on the weir axis is fresh to slightly weathered thin to medium foliated dark grey slate with sporadically pencil cleavage. The attitude of foliation and joints of the beds are listed on Table 1.

The slope stability analysis shows the plane failure due to Joint, J1 and wedge failure due to Joints J1 & J4; J1 & J5 on the left hillslope of the Kokaha Khola around weir area (Figure 8). The right hillslope shows the wedge failure due to joints J1 & J2; J3 & J5 and a possibility of toppling due to the Joint J1 depending upon the hillslope dip (Figure 9).

Figure 7: Rock exposure on right bank of weir axis.

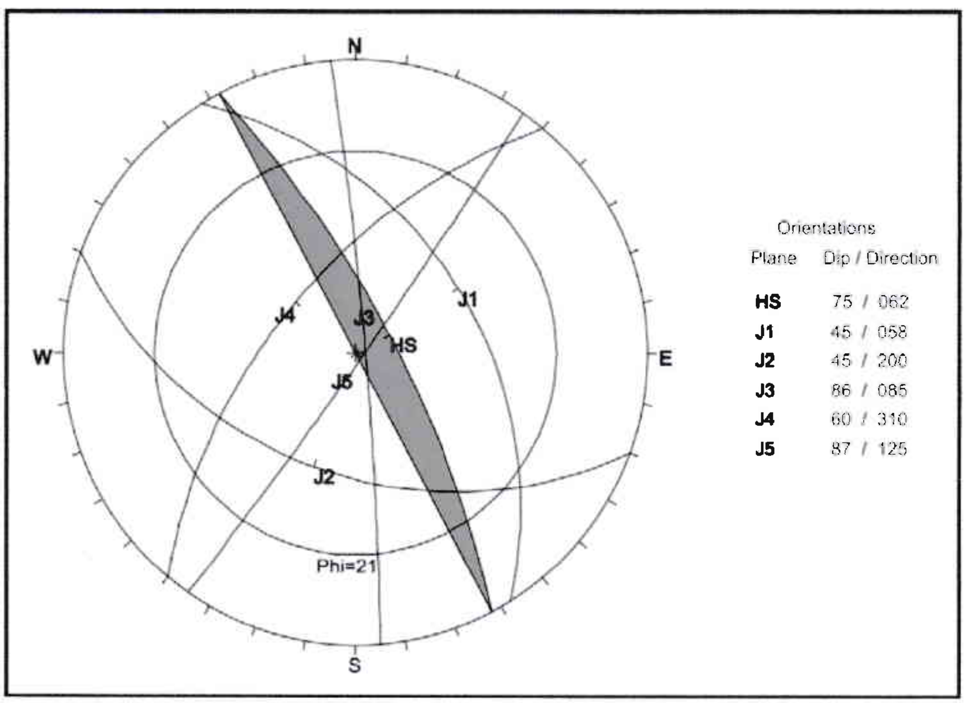

Figure 8: Slope stability analysis at the left bank of Weir axis area.

Note: J1, J2, J3, J4 and J5: Joint Planes, HS: Hill Slope (grey filled), phi: Friction Angle of bedrock.

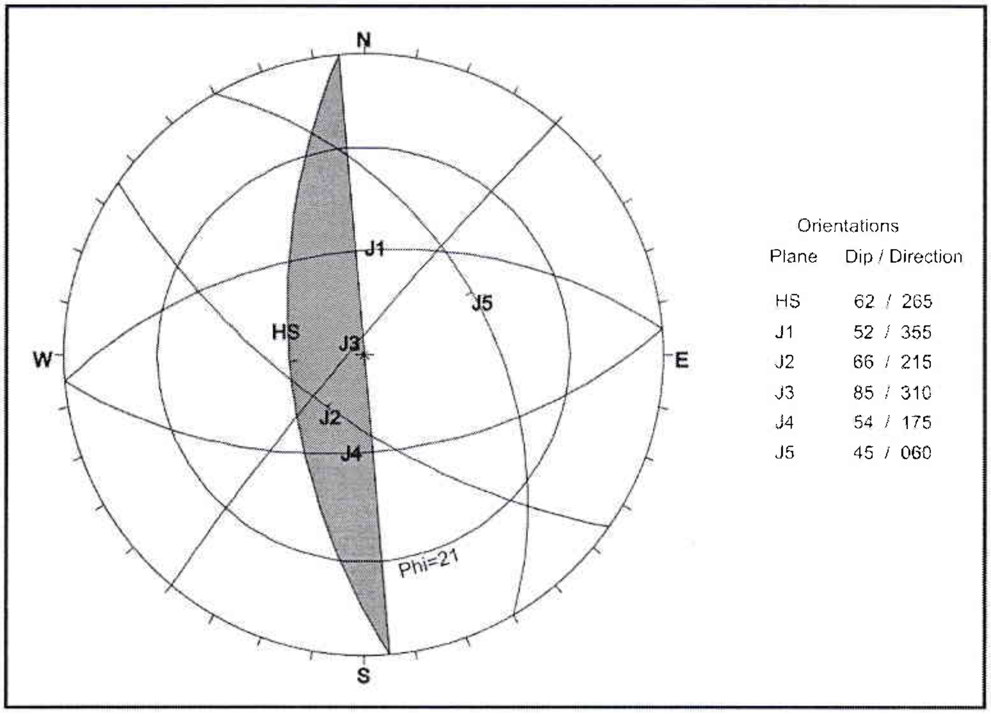

Figure 9: Slope stability analysis at the right bank of weir axis area.

Note: J1, J2, J3, J4 and J5: Joint Planes, HS: Hill Slope (grey filled), phi: Friction Angle of bedrock.

5. Seismicity of the Project Area

5.1 Regional Seismicity

The evolution of the great Himalayan arc is the result of collision between the Indian and the Eurasian tectonic plates. As the Himalaya lies in the plate boundary, the region is considered as one of the seismically active zone of the World as evidenced by many great earthquakes from the historical time. 1897 Assam earthquake, 1905 Kumaon earthquake, 1934 Nepal-Bihar earthquake, 1950 Assam earthquake, 2005 Kashmir earthquake, 2015 Gorkha earthquake are the great earthquakes (**Error! Reference source not found.**) that shocked the entire Himalayan region during the last century.

5.2 Seismicity in Nepal

As Nepal lies in the central part of the Himalaya, many great to strong earthquakes have occurred since the historical time. However, the seismic network was introduced in 1978 by the National Seismological Centre (NSC) under Government of Nepal evidences of strong to large historical earthquakes are recorded in monuments and other archaeological documents. In this regard the earthquake catalogue of the Nepal Himalaya is still incomplete so as to determine the nature of recurrent large earthquakes.

The tectonic features such as the Main Central Thrust, the Main Boundary Thrust, Himalayan Frontal Thrust and other active regional faults are the main sources of the earthquake in Nepal. Nepal has experienced several great and strong earthquakes over the past centuries that have resulted in substantial property damage and loss of life. Recent earthquakes of larger magnitude that have occurred in Nepal are summarized in Table .

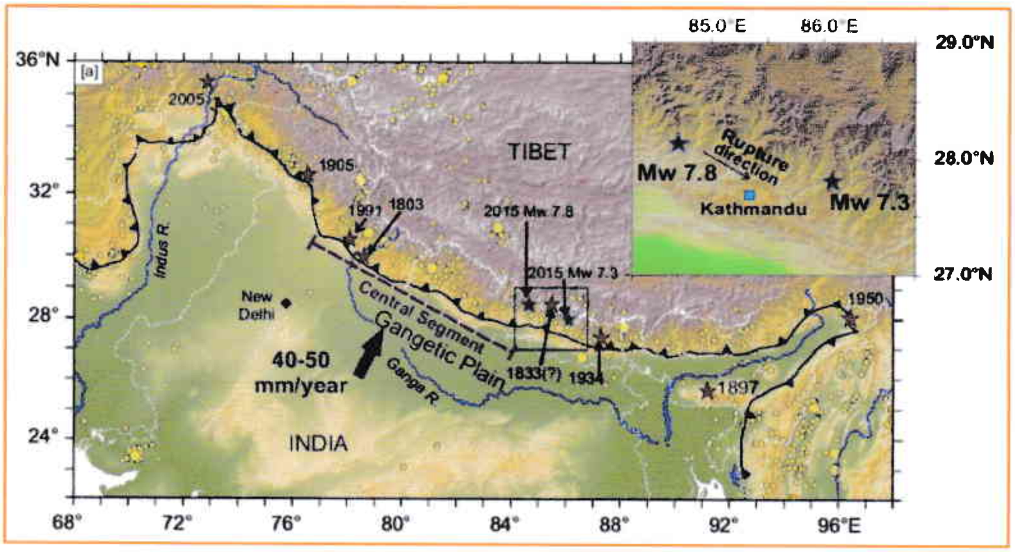

Figure 10: Regional seismicity map of the Himalaya (after Parameswaran et al, 2015)

Note: Red stars represent large historical earthquakes of the Himalaya. Blue stars represent 2015 events in Nepal Himalaya. Yellow circles represent background seismicity (size is proportional to magnitude). The inset map shows the rupture direction of the 2015 Gorkha earthquake.

1833 Sindhupalchowk earthquake (magnitude 8.0), 1916 Darchula earthquake (magnitude 7.3) are the large earthquakes occurred during preinstrumental time in Nepal. 1934 Nepal-Bihar earthquake epicentered at Chainpur of eastern Nepal severely devastated eastern part of Nepal including Kathmandu valley and Bihar. This earthquake with magnitude 8.3 is the largest earthquake in Nepal. However many strong earthquakes such as Darchula earthquake, Bajhang earthquake, Udayapur earthquake, Taplejung earthquake shook the Nepal Himalaya, 2015 Gorkha earthquake is the only large earthquake with magnitude 7.8 that severely devastated several parts of Nepal after the 1934 Nepal-Bihar earthquake (Table).

Table 2 Summary of Earthquakes of Nepal with M>6

S.N.	Location of epicenter	Year	Magnitudes
1.	Sindhupalchok, Central Nepal	1833	8.0
2.	Darchula, Far Western Nepal	1916	7.3
3.	Chainpur, Eastern Nepal	1934	8.3
4.	Dolakha, Central Nepal	1934	6.8

5.	Kaski, Western Nepal	1954	6.4
6.	Dharchula, Far Western Nepal	1966	6.3
7.	Dharchula, Far Western Nepal	1966	6.1
8.	Bajhang, Far Western Nepal	1980	6.5
9.	Udaypur, Eastern Nepal	1988	6.6
10.	Taplejung, Eastern Nepal	2011	6.9
11.	Gorkha, Central Nepal	2015	7.9
12.	Dolakha, Central Nepal	2015	7.3

At 11:56 am on 15thApril 2015, a large earthquake with magnitude 7.8 hit Barpak area of Gorkha district, Central Nepal. This earthquake is the repeat of 1833 Sindhupalchok earthquake indicating interseismic period of >180Yrs.The rupture of this earthquake propagated towards southeast (**Error! Reference source not found.**) severely devastating Gorkha, Dhading, Rasuwa, Sindhupalchowk and Dolakha districts of Nepal. The effect of this earthquake in the southern districts such as Nuwakot, Kathmandu, Bhaktapur, Lalitpur, Kabhrepalanchowk and Sindhuli districts was significant. The maximum peak ground acceleration (PGA) in Kathmandu valley was measured to 0.25g. The Gorkha earthquake was followed by thousands of aftershocks including 7.3 Dolakha earthquake on 12thMay 2015 (**Error! Reference source not found.**).

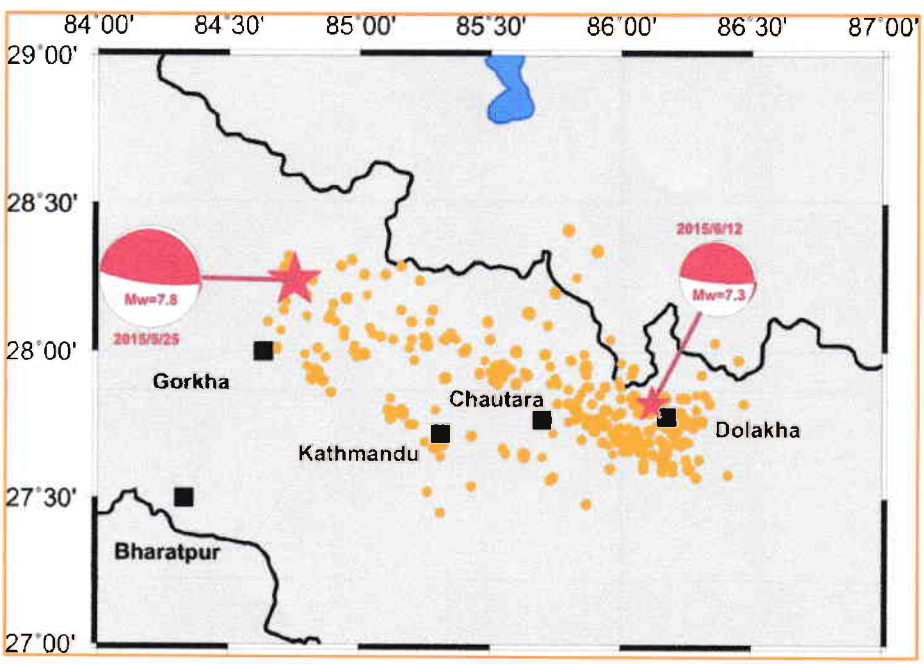

Figure 11: Aftershock Map of the 2015 Gorkha Earthquake.

Note: The red stars and associated beachballs represent earthquakes and their mechanism (with Mw >7.0) respectively. Solid orange circles represent aftershocks with magnitude more than 5.

5.3 Seismicity Evaluation

The NSC in 2002 prepared a PGA map of Nepal using probabilistic seismic hazard mapping technique (**Error! Reference source not found.**). It considered background seismicity, historical earthquakes and active faults in the area.

There are several methods to convert the probable PGA into the design seismic coefficient. Simplest method, empirical method and dynamic analysis using dynamic model are common methods to establish the seismic coefficient.

In order to determine seismic coefficient, a seismic design code for Nepal has been prepared.

By using Empirical method, the effective design coefficient according to seismic design code of Nepal is given by:

$\alpha_{eff} = R\ \alpha = R\ Amax/980$

Where,

α_{eff} = Effective design coefficient.

R = Reduction factor (empirical value, R = 0.5-0.65)

For maximum acceleration of 150 gal according to PGA map (**Error! Reference source not found.**) and the reduction factor 0.6, the calculated effective design seismic coefficient for the Kokaha Khola Reservoir Project is 0.091g.

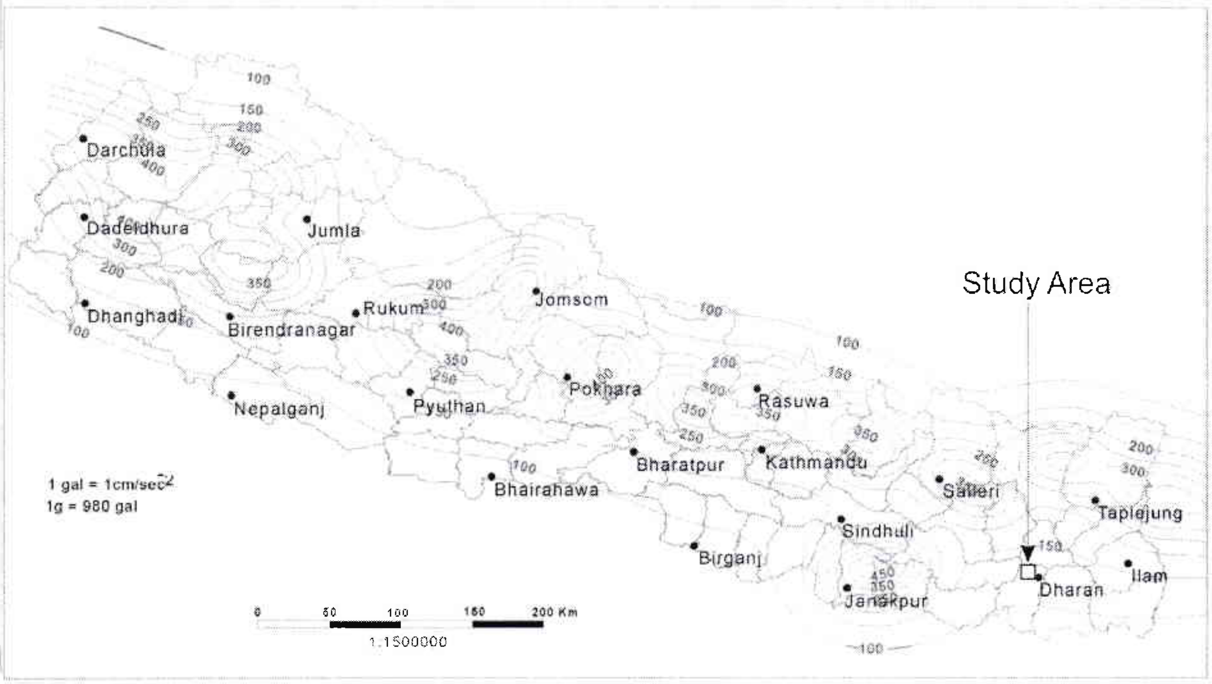

Figure 12: Seismic Hazard Map of Nepal (published by Department of Mines and Geology.

The PGA map published by NSC (**Error! Reference source not found.**) considers only rock type excluding surface soil variation. In many project areas, thick pile of surface soil is inevitable. Further, the occurrence of 2015 Gorkha earthquake has significantly changed the seismicity scenario of Nepal. In this regard, the calculated seismic design coefficient based 2002 PGA map may not represent exact ground reality. So it is to be re-evaluated, the seismic design coefficient based on real geological condition in project sites for different scenario earthquakes.

6. Conclusion

Geologically, the Kokaha Khola Reservoir Project lies in the Siwalik & Lesser Himalaya sequence and occupies Northern part of the Sunsari District of Koshi zone of the Eastern region of Nepal. The rock of the project area comprises the sandstone of Siwalik and slate of the Lesser Himalaya. The general strike of rocks in the area is NW-SE with dip towards NE at an angle ranging from 45° to 86°. Three set of discontinuities are prominent in the area with occasional presence of four sets discontinuities in some area. Superficially, thick colluvial deposits are found on the hillslope on either side of the reservoir area. The rock exposures are well exposed on the weir axis area. Kinematic analyses of discontinuities were made to analyze and confirm slope stability in the area. The Reservoir area does not have significant impact on the mass wasting phenomenon, while the weir axis area shows unstable plain and wedges on the hillslope of left bank whereas wedge failure and possible toppling on the hillslope of right bank. Indicates protection measures should be carried out on the hillslope of weir area.