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Preliminary Geological Investigations in Hydropower Development: a report of Midim Khola Hydroelectric Project, Lamjung, Nepal

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ABSTRACT

In the challenging Himalayan terrain of Nepal, the Midim Khola Hydroelectric Project (MKHEP) serves as a case study for the crucial role of geological investigation in hydropower development. Situated in the Lamjung District, the project, with an installed capacity of 16 MW, had to contend with steep slopes, complex geology, and varying hydrological conditions. The project's design, which includes a 3,680 m long penstock and an underground powerhouse, was informed by extensive engineering geological and geotechnical surveys. These investigations involved detailed mapping of rock types and soil profiles, revealing key features like steeply dipping formations, sheared zones, and areas prone to weathering and landslides. The study identified critical issues such as weak alluvial terraces, colluvial deposits, and landslide-prone slopes, which necessitated specific design measures. For instance, the settling basin is on loose alluvium, while sections of the penstock alignment traverse unstable colluvial deposits and old landslide zones. The presence of flash floods and high sediment loads further complicated the site, requiring integrated geological and hydrological data to optimize the penstock alignment and select suitable locations for key structures. Ultimately, the project highlights the need for detailed site investigation, risk assessment, and adaptive design strategies to ensure safety and sustainability in such demanding environments.

Keywords: *Hydropower; Geological investigation; Midim Khola; Himalaya region*

INTRODUCTION

Hydropower development in the Himalayan region presents unique engineering challenges due to the combination of steep terrain, geologically complex formations, and variable hydrological conditions. Slope instability, landslides, and differential settlement are common concerns, requiring careful geological, geotechnical investigation and design mitigation measures. Developing hydropower projects involves significant risks that must be carefully managed to ensure their sustainability. These large, complex projects affect many parties and can have major economic, environmental, and social impacts on local communities ((Liu et al., 2013). The case study of Midim Khola Hydroelectric Project (hereafter MKHEP), situated in Lamjung District, Nepal, is a run-of-river project designed to harness the hydropower potential of the Midim Khola. The project has an installed capacity of 16 MW and utilizes a gross head of 700 meters, reflecting the steep topography of the region. The project's design incorporates a 3680 m long penstock, an underground powerhouse, and associated intake and tailrace structures, all tailored to minimize environmental impact while optimizing energy generation.

Comprehensive engineering geological and geotechnical investigations were undertaken to inform the project design. These included detailed mapping of rock types, structural discontinuities, and soil profiles along the project alignment. Key geological features encountered included steeply dipping formations, sheared zones, and areas prone to weathering and slope failure. The geotechnical assessment highlighted the necessity for slope stabilization, tunnel lining design adjustments, and foundation treatment for underground structures. The project also considered the hydro-meteorological conditions of the Midim Khola watershed, as flash floods and high sediment load could pose risks to project infrastructure. Integration of the geological and hydrological data facilitated the optimization of the penstock alignment to reduce excavation in unstable zones, as well as the selection of the most suitable locations for diversion weirs and powerhouse caverns. The MKHEP exemplifies the careful balance between engineering feasibility, safety, and environmental sustainability in high-altitude hydropower development. The findings from this case study provide critical insights for future projects in the Himalayan region, emphasizing the importance of detailed site investigation, risk assessment, and adaptive design strategies in challenging terrains.

Main purpose of this study is to assess the geological and geotechnical conditions of major hydropower structures (headworks, penstock, surge tank, powerhouse, and tailrace). This study presents the engineering geological investigations carried out for the MKHEP in Lamjung District, western Nepal. The study focuses on key project components, including the headworks, settling basin, penstock alignment, surge tank, powerhouse, and tailrace canal. Field-based geological mapping and site assessments were conducted to evaluate lithology and engineering suitability. Findings highlight critical issues such as weak alluvial terraces, colluvial deposits, potential block falls, and landslide-prone slopes. Recommendations for protective and stabilization measures are presented, providing practical insights into hydropower development in Himalayan conditions.

STUDY AREA

The study area is located in Bhujung, Lamjung District, Nepal. Geologically, it lies within the Higher Himalayan rock formations of western Nepal. This region is characterized by high-grade metamorphic rocks, primarily consisting of gneiss, schist, and intercalated carbonate bands. The Midim Khola watershed features a diverse and rugged landscape. It's defined by steep, rocky terrain and narrow river valleys. Key geographical features in the area include river terraces, small floodplains, and slopes that range from steep to moderate

METHODOLOGY

The study began with a review of existing geological maps (Amatya and Jnawali 1994; DMG 2020) and field surveys. Fieldwork was a key part of the methodology, involving on-site geological mapping and structural measurements. Researchers used a Brunton compass and GPS to take measurements and a topographic map for navigation and location tracking. The field data was used to create an engineering geological map to document terrain conditions and areas of instability. This map highlighted the distribution of rock and soil types and potential zones of instability.

RESULTS

Site Geology of the study area

The study area is consisting of light grey-colored gneiss, interlayered with minor bands of schist. These metamorphic units exhibit well-developed foliation, generally dipping northeastward at angles ranging from 25° to 30° (Fig.2 and Fig.3). Locally, outcrops of Augen gneiss are observed, characterized by large, lenticular feldspar porphyroclasts set within a foliated matrix, indicative of significant ductile deformation. These metamorphic units exhibit well-developed foliation, generally dipping northeastward at angles ranging from 25° to 30°.

Engineering Geological study throughout the proposed penstock alignment

The proposed penstock alignment (Fig.4) traverses a range of geological formations, including alluvial, residual, and colluvial deposits, as well as zones of exposed gneiss bedrock. To characterize the subsurface conditions and assess geohazards, an engineering geological map (Fig. 5) was prepared for the project area. This map outlines the distribution of rock and soil types and highlights zones of potential instability. The alignment intersects multiple seasonal gullies and three perennial rivers, requiring careful consideration of erosion, slope stability, and foundation conditions during design and construction.

The following sections present detailed engineering geological characterizations along the proposed penstock alignment.

Headworks

A geological traverse along Midim Khola shows light grey gneiss with minor schist bands, and occasional Augen gneiss outcrops. Foliation dips NE at 25°–30°, and rocks are fresh to slightly weathered. The proposed weir site lies ~200 m upstream of the Midim–Ankhara Khola confluence (Fig. 6), where alluvial deposits are present. Both abutments are founded on rock with steep to vertical slopes, though bedrock is not exposed in the riverbed. Riverbed materials include silt, sand, cobbles, and boulders of gneiss and quartzite, with bedrock expected 2 to 3 m below the surface.

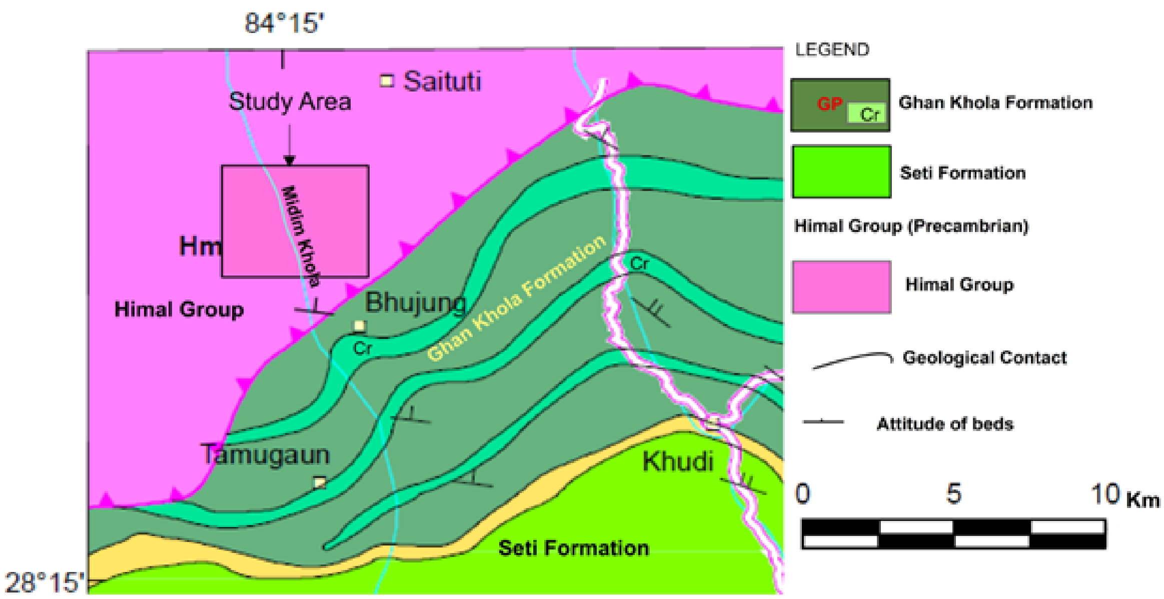

Fig. 1: Regional Geological Map Showing the study area (DMG 2020).

Fig. 2: Augen gneiss (Left side) and Quartzite (right side) observed around the study area.

Fig. 3: Augen gneiss (left side, observed near the surge tank) and big boulders of gneiss and schist (right side, observed near the proposed powerhouse area).

Settling Basin

The settling basin is situated on a loose alluvial terrace approximately 8 to 10 m above the river level. The terrace comprises unconsolidated deposits of boulders, cobbles, pebbles, and sand, with an estimated thickness exceeding 10 m. Frequent colluvial boulders originating from upslope are also present, indicating active slope processes and potential sediment influx

Penstock Alignment

The 3,680 m penstock alignment traverses' diverse geological conditions, requiring careful engineering consideration throughout its route. From the head pond to Ankhara Khola, it passes through loose alluvial deposits, necessitating protective structures to mitigate erosion and settlement risks. Between Ankhara Khola and the river crossing, the alignment cuts across colluvial slopes prone to block falls and landslides, demanding slope stabilization measures. At the Midim Khola crossing, the right bank offers stable gneiss bedrock suitable for anchoring, while the left bank comprises loose alluvium and boulders, posing instability and requiring reinforcement. From the river crossing to the surge tank, the penstock traverses colluvial deposits up to 8 meters thick and rocky slopes with seepage zones, where drainage systems and gabion walls are essential for stability. Finally, the segment from the surge tank to the powerhouse encounters an old landslide zone with large boulders, prompting realignment and slope stabilization to ensure structural integrity and operational safety.

Powerhouse and Tailrace

The powerhouse is proposed on a paleo-river terrace with boulder-rich deposits (80% boulders, 20% fines). The tailrace canal lies on an alluvial terrace composed mainly of gneiss and quartzite boulders with minor matrix.

DISCUSSION

The geological investigation of the Midim Khola Hydropower Project highlights how diverse lithological and geomorphological conditions shape both opportunities and challenges for project development. The dominance of gneiss, schist, and Augen gneiss along the alignment provides a strong and stable foundation in many locations, particularly at the headworks and powerhouse abutments. These hard rock formations are favorable for anchoring major structures such as the weir, surge tank, and underground powerhouse, reducing risks of differen ial settlement and ensuring long-term stability. In contrast, sections underlain by loose alluvial terraces and

Fig. 4: General layout of the project Site.

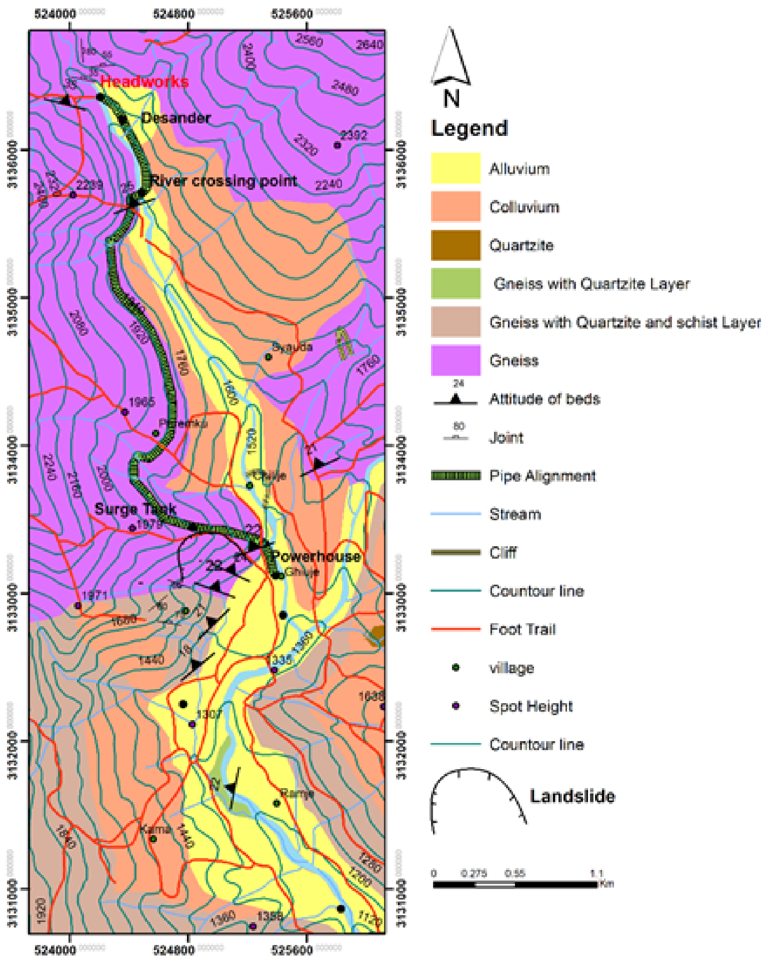

Fig.5: Engineering geological map of the study area.

thick colluvial deposits present much greater challenges. For instance, the settling basin is positioned on unconsolidated alluvium, which is inherently unstable and susceptible to settlement and slope failure if not properly stabilized. The varying conditions along the penstock alignment further illustrate the geological complexity of the site. While parts of the alignment traverse stable gneiss bedrock, other stretches cut across weak colluvial slopes, seasonal gullies, and seepage-prone zones. These weaker zones increase the likelihood of erosion, block falls, and landslides, particularly during the intense monsoonal rains characteristic of the region. The presence of paleo-landslide deposits near the powerhouse adds another layer of concern, as the potential reactivation of these old failures could threaten both structural integrity and project operation. Such findings highlight the inherent uncertainty of Himalayan terrain, where geological processes remain highly

Fig. 6: Weir axis of the Project.

active, and where engineering solutions must be flexible, adaptive, and supported by continuous monitoring.

Hydrometeorological conditions further compound these geological risks. The Midim Khola watershed is prone to flash floods and high sediment loads, which, when combined with unconsolidated terrace deposits and active gullies, can lead to excessive sediment inflow at the intake and settling basin. Without adequate sediment management strategies, this not only threatens the operational efficienc of the project but also drives up long-term maintenance demands. The integration of geological findings with hydrological and sediment dynamics therefore emerges as essential, ensuring that the design of headworks, penstock alignment, and powerhouse facilities is both technically sound and resilient to the natural processes of a dynamic mountain environment.

CONCLUSIONS

The geological investigation of the Midim Khola Hydropower Project revealed a mix of both favorable and challenging site conditions. The presence of stable bedrock, specifically gneiss, at the headworks and along certain parts of the penstock alignment, provides a reliable foundation for the project's structural integrity. However, the project also faces significant risks from thick alluvial and colluvial deposits. These deposits, particularly in terrace and gully-prone zones, introduce the potential for settlement and slope instability. Additionally, seepage zones and seasonal gullies were identified along the alignment, which could worsen erosion and slope failure if not properly addressed. The study concludes that these challenges are typical of Himalayan hydropower sites, where the complex terrain and active geomorphology necessitate robust engineering solutions.

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