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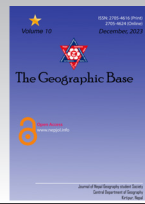

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Geological Causes of Shrawan Danda and Siddhababa Landslides in the Northern Vicinity of Butwal City, Western Nepal

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Abstract

Nepal, characterized by diverse and rugged topography, is prone to landslides due to various natural factors such as heavy rainfall during monsoons, frequent seismic activity, steep slopes, and adverse geological conditions. The situation worsens during the monsoon period, posing long-term threats to individuals and residential properties. The study aims to determine the landslide controlling factors in Siddhababa and Shrawan Danda, located north of Butwal City. Geologically, the region lies in the Sub-Himalaya or Siwalik region of Nepal. Field conditions were evaluated at and around the landslide regions in this research from the perspective of engineering geology, tectonics, and other man-made interventions. The study's main objective was to determine the geological cause of landslides in this region. Inherently weak geological settings of rocks and active tectonics of the region are the major causes of landslides in these areas. The most remarkable is that the Himalayan Frontal Thrust (HFT), an active fault of the Himalayas, passes from this area. Additionally, the alternating layers of sandstone and mudstone, the hard *and soft rock orientation, contrasting rates of weathering and densely developed adverse discontinuities are the other factors contributing to landslides in these areas. Along the Siddhartha Highway in the Siddhababa area, rockfall incidents have resulted in significant loss of life and property. Similarly, the Shrawan Danda landslide has caused extensive damage to infrastructures and livestock in the densely populated settlement at its base due to debris flow in the past.*

Introduction

Nepal Himalaya is a part of the broader Himalayan Mountain range formed by the collision and convergence of two tectonic plates- the Indian plate and the Eurasian plate, over millions of years and the process is still ongoing. The geology of Nepal's landform is rugged and fragile with several shear zones, active faults, and thrusts. The major causes of landslides in Nepal Himalaya are the region's adverse geological setting and active tectonics along with monsoon precipitation and earthquake activities as triggering factors (Budha, et. al, 2016; K.C. et. al., 2018; Budha et al., 2020; Shahi, et. at, 2021; Paudyal and Maharjan, 2022; Paudyal and Maharjan,2023; Acharya, et. al., 2023; Paudyal et al., 2024). Based on recorded data from 2011 to 2020, a total of 2,116 landslides have been confirmed across Nepal. Among these, 488 incidents resulted in fatalities, with 297 deaths occurring during the monsoon season (June to October 2020) alone (bipadportal.gov.np, 2021). This indicates that Nepal is highly susceptible to landslides. A landslide is a process where a mass of rock, soil, and debris slides down a slope often with a destructive result. It can occur due to natural as well as human-induced activities and range from small to huge and disastrous. Landslides in mountainous areas like Nepal have resulted in serious issues like loss of life and property as well as harm to the environment and other infrastructures. The main triggering factor in such areas is the combination of natural and human activities. Rockfalls, rockslides, and debris flow are commonly observed all around the country. Especially, those landslides that occur during the monsoon season are the biggest challenges.

The Siwalik range is the mountain range that lies in the southern foothill of the Himalayas and runs parallel to the main axis of the Himalayas. The Siwalik region of Nepal is composed of sedimentary rocks, including shale, mudstone, sandstone, and conglomerate in varying proportions (Dhital, 2015; Sah, 1999; Thakur, 2001; Upreti, 2001).

The Siwalik hills are more prone to landslides compared to other parts of the Himalayas due to their fragile geology, weak lithological composition, and active tectonic activity (Tamrakar et al., 2002; Dahal & Paudyal, 2022; Neupane et al., 2023). The main causes of soil erosion in this geographic location are Himalayan energy and their population activities (Gurung, 2021). Loose sedimentary rocks like sandstone, siltstone, and mudstone are the dominant lithology of this tectonic region. Such inherently weak rocks in the steep slope make the land unstable during monsoon. Additionally, the slope cut during the infrastructural development through such regions has triggered the landslide in our Himalayan region (Shrestha et al., 2023).

To effectively mitigate and control these types of landslides, it is crucial to thoroughly understand the primary causative factors, particularly the geological aspects. This study focuses on the Siwalik region of western Nepal, specifically near Butwal city, encompassing areas within the Palpa and Rupandehi districts of Lumbini Province (Figure 1). Shrawan Danda landslide lies on the southern slope of the Siwalik hills just north of the Butwal city and the Siddhababa landslide is located at the Siddhartha Highway section near Siddhababa temple. Along the Siddhartha Highway in the Siddhababa area, rockfall incidents have resulted in significant loss of life and property. Similarly, the Shrawan Danda landslide has caused extensive damage to infrastructures and livestock in the densely populated settlements- Settlements of Laxmi Nagar and Jyoti Nagar are located at its base. Two prominent landslides, the Shrawan Danda landslide, and the Siddhababa landslide are studied in this research to find out the geological cause behind their occurrences.

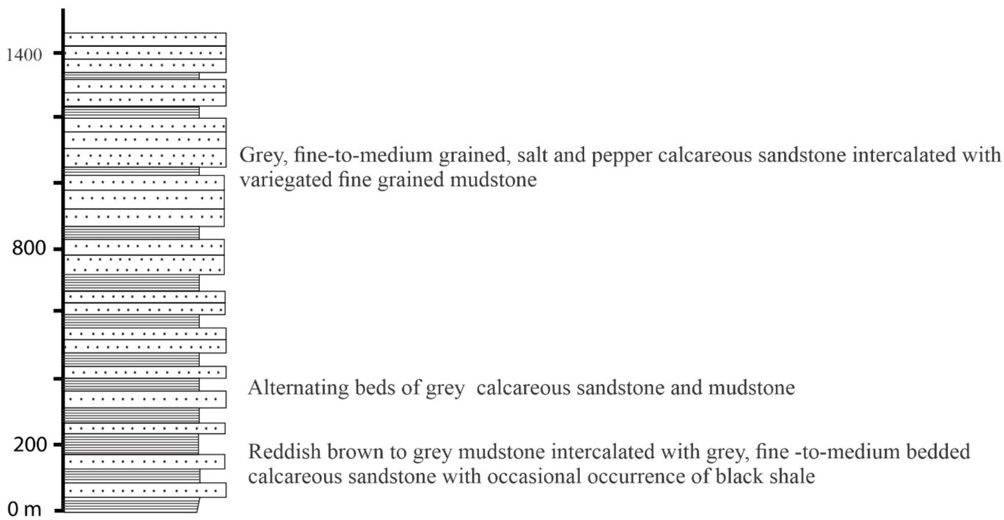

Figure 1: Map of Nepal indicating the study area around Butwal city in Lumbini Province

Methods and Materials

At first, all the literature related to the Shrawan Danda and Siddhababa landslides as well as the geology and stratigraphy of the region were studied. Extensive fieldwork was conducted at the landslide region to study the landslides regarding tectonics, stratigraphy, topography, geomorphology, and hydrogeology. Additionally, anthropogenic factors that induce the landslides were studied. The local people also inquired about the history of the initiation and development of landslides. A geological hammer, Brunton compass, dilute hydrochloric acid of normality 1:10 and hand magnification lens were used to study rocks during the field visits. Photographs of important features and locations were taken.

Results and Discussion

Geology of the Area

Geologically, the rocks of this region can be correlated with the rocks of the Arung Khola Formation (Tokuoka et. al, 1990). It is composed of rapid alteration of variegated and mottled beds of mudstone and fine-to-medium-grained sandstone (Figure 2 and Figure 3). In general, mudstone dominates the succession. The thickness of beds varies from a fraction of a meter to several (5-6) meters.

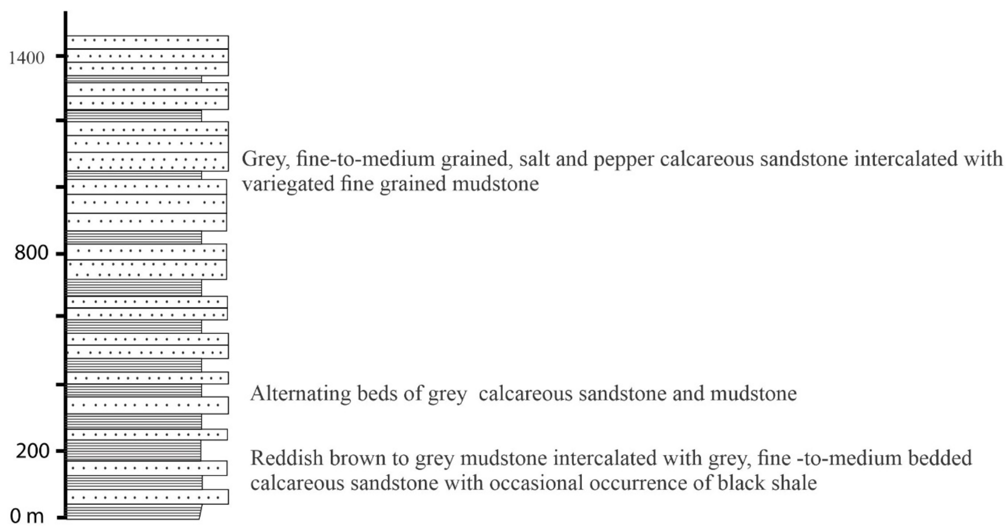

Figure 2: Columnar Section of the Rocks Developed in the Area

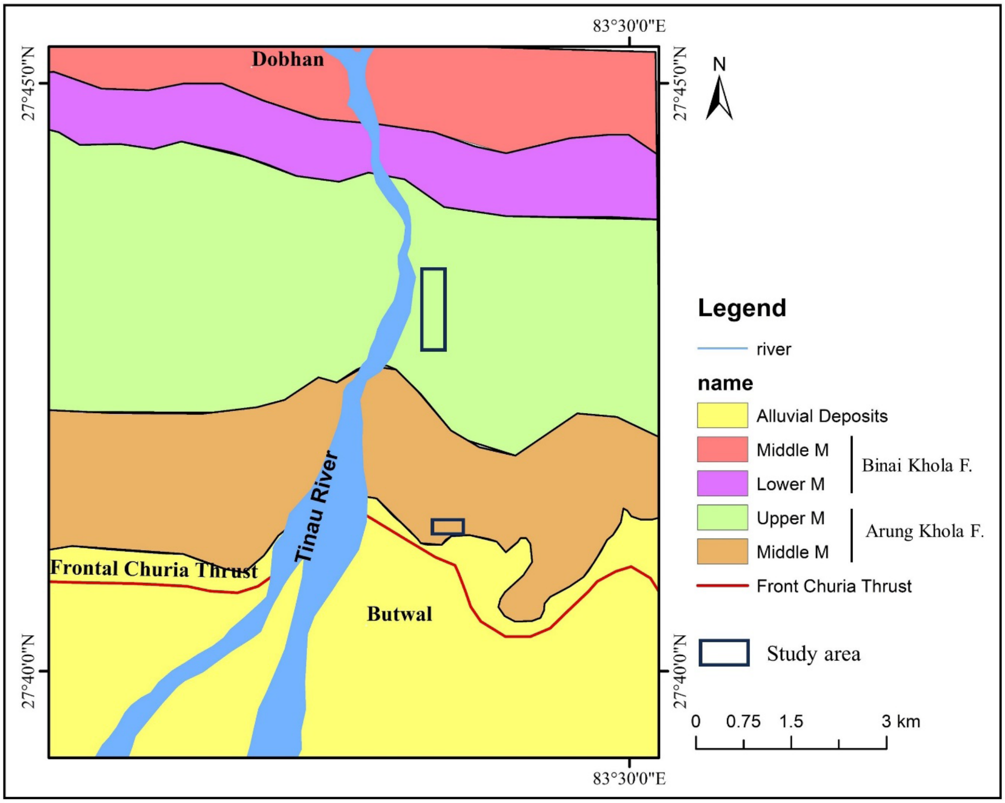

Figure 3: Geological map of the Tinau Khola area in west-central Nepal (adapted from Tokuoka et al., 1990)

Status of Landslides

Shrawan Danda Landslide: The Shrawan Danda landslide is located within the middle member of the Arung Khola Formation, characterized predominantly by variegated mudstone layers up to 5 meters thick and fine to medium-grained sandstone layers up to 3 meters thick. The landslide covers an area of approximately 0.70 km² and consists of mudstone and sandstone boulders mixed with mud and sand-sized particles. The primary causative factors contributing to this landslide include:

Precipitation: A deep layer of colluvium consisting of mud and sand-sized particles is observed all along the slope. The slope is stable throughout the year but mostly during heavy rainfall especially during monsoons, water enters easily into the soil and thus increases the pore water pressure resulting in debris flow in the settlement residing downwards (Figure 4).

Weak lithology: Through the fractured rock mass found at the crown of the landslide as well as the top of the hill, water enters easily and drains out through different areas containing the loose colluvial soil downwards resulting in the debris flow (Figure 4).

Figure 4: Crown of Shrawan Danda Landslide (GPS: 27°42'55.77" and 83°28'31.30")

Human activities: Human activities such as deforestation, poor drainage, haphazard use of land, toe-cutting for unplanned settlement and construction of roads, and unscientific landslide control methods have also triggered this landslide (Figure5).

The Shrawan Danda landslide, triggered by intense rainfall, first occurred on August 12, 1998, resulting in one death, five injuries, and property damage estimated at NRS. 58 million in Jyotinagar and Laxminagar (DPTC, 2000). The landslide remains active, affecting over 10,000 residents who have migrated from the mountains and hills and are unfamiliar with the landslide risks and triggers. In August 2021, intense rainfall once again triggered the same landslide in the Shrawan Danda area. This event caused significant damage, with 11 houses being destroyed and the road linked to the town being blocked by debris (MyRepublica, 2023).

Figure 5: Debris flow in the existing water channel at the base of Shrrawan Danda (GPS: 27°42'44.71" and 83°28'15.44")

Siddhababa Landslide: Siddhababa landslide lies in the upper member of the Arung Khola Formation and is represented by fine to coarse-grained, calcareous sandstone up to 5 m thick alternations with mudstone.

Rockfall: Rockfall refers to the movement of fragmented rock blocks along a vertical or nearly vertical cliff face, primarily triggered by intersecting discontinuities within the rock mass. In the Siddhababa section, the rock mass is characterized by three distinct joint sets and a prominent bedding plane. The alignment of these joint sets with the road on a steep slope is the main factor contributing to rockfall events (Figure 6). The various causes of rockfall include:

Orientation of road and joints: SW dipping joints and alignment of highway towards NS direction is observed in the maximum place. This orientation in the steep slope (>70) has caused the rock failure.

Presence of contrasting lithology: The rainwater easily erodes the mudstone/siltstone lying in between massive sandstone beds, causing loss of support for the fractured sandstone (Figure 6). Hence, those fractured pieces of sandstone start to fall in the steep slope as rockfall.

Figure 6: Alternating bands of sandstone and mudstone along with rockfall observed at the section of Siddhartha highway near Siddhababa Temple (GPS: 27°43'58.82" and 83°28'5.22")

Precipitation: Since the rock is highly fractured with the presence of infilling material, the rainwater enters easily into those cracks and increases the pore water pressure as well as the rate of weathering. As a result, the rock becomes weak and gradually falls as a rockfall. Also, the surface runoff water during rainfall with high velocity transfers those weathered rock blocks and falls downwards through the steep slope causing rockfall.

The Siddhababa section of the Siddhartha Highway is one of many highway sections in Nepal with a long history of fatal rockfall events resulting in numerous casualties. This has created a hazardous environment for travellers on these highway sections. Over the past 10 years, around 70 people have lost their lives in accidents caused by landslides along the three-kilometre section at Siddhababa (Onlinekhabar,2023).

A geological investigation of the Main Frontal Thrust (MFT) reveals a slip rate of 21 ± 1.5 mm/yr in the Nepal Himalaya, indicating that the thrust is active (Burgess et al., 2012). This movement of thrust is a contributing factor to landslides near this geographical location (Bhandari and Dhakal, 2021). These landslides are situated in seismically active zones close to major thrusts i.e., the Main Frontal Thrust or the Frontal Churia Thrust (Figure 1 and Figure 3). Hence, earthquake also triggers the fragile rock mass movement situated there. Additionally, the region experiences intense and prolonged rainfall, which can initiate rockfalls and debris flows. Water-induced soil erosion is the most significant, affecting 45.5% of the country's land (Ministry of Population and Environment, 2016). The combination of the fragile nature of sedimentary rocks, the tectonic setting, and climatic conditions contribute to the area's high susceptibility to landslides and soil erosion. The fragile nature of the sedimentary rocks in this geographical and tectonic context contributes to the areas' susceptibility to landslides and soil erosion (Neupane and Paudyal, 2021).

The landslide area is composed of young sedimentary rocks, including mudstone, siltstone, sandstone, and shale, occurring in regular intercalation. This rock succession can be correlated with the upper part of the Lower Siwalik group and is comparable to the Lower Member of the Arung Khola Formation (Tokuoka et al., 1986). Additionally, it shows similarities with the upper part of the Bankash Formation in the Surai Naka section and the Katari Formation in the Hetauda section (Sah et al., 2000).

Landslide occurrences in Nepal result from a combination of inherently weak geology and rugged, steep slopes, along with triggers such as heavy monsoon rainfall, cloudbursts, and earthquakes. These factors differ across various physiographic, geological, and climatic zones (Paudyal et al., 2021). A better understanding of landslides can be achieved through a thorough analysis of preconditions, including the physiographic features, climatic zones, and geological contexts that influence the terrain of a specific area (Upreti, 2001). The current trend of huge rainfall in a limited time is also an additional factor for such debris flow and landslides in this geographical location (Ghimire,2020). The rocks of this area are inherently weak in terms of their geological setting, i.e., there is perfect intercalation of soft and hard rocks. The situation is that after weathering and erosion of the soft rocks, the overlying hard rocks topple or fall. Additionally, the rocks have developed numerous discontinuities. The rocks of the Siwalik are thrust over the Terai through the Main Frontal Thrust in this region. The southern part of this region consists of alluvial deposits of the Indo-Gangetic plain while the northern part consists of sedimentary rocks of the Siwalik region. The field evidence of the presence of the MFT can be justified based on rock types where the loose sediments of Terai abruptly give rise to the steep slopes consisting of bedrock. The rocks of this region consist of breccias, slickensides, and striations which are good indicators of the presence of faults. Additionally, the area consists of highly sheared rocks which are good sites for rainwater percolation and fill up the pores of the rocks. The pore-water pressure during the rainy season is one of the most notable issues for causing the landslides in this zone. Rocks are weathered as indicated by their bleaching effects and fragility in nature. The dipping of beds is moderate towards the north, and the overall strike is east-west, forming a steep escarpment towards the Terai. Geomorphologically, The Siwalik hills in this region show a very immature topography with highly rugged terrain dissected by numerous gullies. Human activities have significantly contributed to this landslide through deforestation, which destabilizes the soil by removing trees that anchor it. Poor drainage systems lead to waterlogged soil, increasing its weight and instability. Unplanned land use and toe-cutting for settlements and roads disrupt natural slopes, making them more prone to collapse. Additionally, ineffective landslide control methods fail to address or even worsen these underlying issues. This aligns with Ghimire (2017), who states that various human activities, including road construction, deforestation, overgrazing, and mining, are responsible for soil erosion in the Siwalik region.

Conclusion

This recurring landslide highlights the ongoing vulnerability of the region to such natural disasters, emphasizing the need for improved hazard assessment, risk evaluation, and mitigation strategies to protect the lives and properties of those living in these susceptible zones. Both the landslides in question are complex types in nature induced due to multiple causes and triggering factors. The fragile nature of the sedimentary rocks and the presence of the Himalayan Frontal Thrust (MFT) are considered the major causes of both the Shrawan Danda and Siddhababa landslides in this area. The alternating layers of sandstone and mudstone, the hard and soft rock orientation, with contrasting rates of weathering and densely developed discontinuities in the rock mass, and the pore water pressures developed in the rocks during the monsoon period are the main primary factors contributing to landslides in both cases. The role of discontinuities is high for the rock fall while the role of pore water pressure is high for the debris flow and debris slides in these landslides. Further human activities such as deforestation, inadequate drainage, unplanned land use, toe-cutting for settlements and road construction, and unscientific landslide control methods have significantly triggered the landslide.

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References

Acharya, M., Dhakal, R. P., and Paudyal, K. R. (2023). Application of frequency ratio method for landslide susceptibility mapping at the Thulo Lumpek area, Gulmi, Nepal; *Journal of Development Innovations,* ©2022 KarmaQuest International, Canada. www.karmaquest.org journal 7 (2), 56-76.

Bhandari, B. P., & Dhakal, S. (2021). A multidisciplinary approach of landslide characterization: A case of the Siwalik zone of Nepal Himalaya. *Journal of Asian Earth Sciences: X*, *5*, 100061.

Bipadportal (2021). Government of Nepal, accessed on 2nd March 2021, source: bipadportal.gov.np.

Budha, P. B., Paudyal, K., & Ghimire, M. (2016). Landslide susceptibility mapping in eastern hills of Rara Lake, western Nepal. *Journal of Nepal Geological Society*, *50*(1), 125–131. https://doi.org/10.3126/jngs.v50i1.22872

Budha P. B, Paudyal K, Ghimire M. (2020). Indicator-based vulnerability assessment of Chhayanath-Rara Municipality, Western Nepal. *Environment and Natural Resources Journal*;18(3):224-233. DOI: 10.32526/ennrj.18.3.2020.21

Burgess, W. P., Yin, A., Dubey, C. S., Shen, Z. K., & Kelty, T. K. (2012). Holocene shortening across the Main Frontal Thrust zone in the eastern Himalayas. *Earth and Planetary Science Letters*, *357*, 152-167.

Dahal, A., and Paudyal, K. R. (2022). Mapping of geological sensitive areas along the Budhi Khola Watershed, Sunsari/Morang districts, Eastern Nepal Himalaya, *Journal of Development Innovations*, Canada. (Available: www.karmaquest.org/journal, vol. 6, No. 1, 44-68.

Dhital, M. R. (2015). *Geology of the Nepal Himalaya: Regional perspective of the classic collided orogen*. Springer.

Ghimire, M. (2020). Landscape characteristics and cultural process in the Siwalik Hills: A geographical perspective. *Studies in Nepali History and Society*, *25*(1), 59-109.

Ghimire, M. (2017). Historical land covers change in the chure-tarai landscape in the last six decades: Drivers and environmental consequences. *Land cover change* *and its eco-environmental responses in Nepal*, 109-147.

Gurung, S. B. (2021). Soil erosion status of Nepal. *NUTA Journal*, *8*(1-2), 112-123.

K. C., Jharendra, Gautam Deepak, Neupane Purushottam, and Paudyal, Kabi Raj (2018). Landslide inventory mapping and assessment along the Ramche-Jharlang area in Dhading, Rasuwa, and Nuwakot districts, Lesser Himalaya, Central Nepal. *Journal of Nepal Geological Society*, 55, (Sp. Issue: pp 103-108). DOI: 10.3126/jngs.v 55i1.22798.

Ministry of Population and Environment, (2015). *National action programme (NAP) on land degradation and desertification, under the United Nation Conservation to combat Desertification (UNCCD)*. Ministry of Population and Environment - Kathmandu, Nepal.

MyRepublica (2023). Landslide destroys houses in Butwal. *MyRepublica*. https://myrepublica.nagariknetwork.com/news/landslide-destroys-houses-in-butwal/

Neupane, A., & Paudyal, K. R. (2021). Lithological control on landslide in the Siwalik section of the Lakhandehi Khola Watershed of Sarlahi district, south-eastern Nepal. *Journal of Development Innovations*, *5*(2), 44-65.

Neupane, A., Paudyal, K. R., Devkota, K. C., & Dhungana, P. (2023). Landslide susceptibility analysis using frequency ratio and weight of evidence approaches along the Lakhandehi Khola watershed in the Sarlahi district, southern Nepal. *Geographical Journal of Nepal*, *16*(01), 73–96. https://doi.org/10.3126/gjn.v16i01.53486

Onlinekhabar (2023). Alternative road under construction to skip Siddhababa landslides. *OnlineKhabar English News*. https://english.onlinekhabar.com/alternative-road-under-construction-to-skip-siddhababa-landslides.html

Paudyal, K. R., Devkota, K. C., Parajuli, B. P., Shakya, P., & Baskota, P. (2021). Landslide susceptibility assessment using open-source data in the far western Nepal Himalaya: Case studies from selected local level units. *Journal of Institute of Science and Technology*, *26*(2), 31–42. https://doi.org/10.3126/jist.v26i2.41327

Paudyal K. R., and Maharjan R. (2022). Landslide susceptibility mapping of the Main Boundary Thrust (MBT) region in Tinau-Mathagadhi Section of Palpa District, Lumbini Province, Journal of Nepal Geological Society, vol. 63, pp. 99–108. *https://doi.org/10.3126/jngs.v63i01.50845.*

Paudyal, K. R., and Maharjan, R. (2023). Landslide susceptibility mapping of the Main Boundary Thrust region in Mandre-Khursanibari section of Arghakhanchi and Palpa districts, Lumbini province of Nepal. Nepalese

Journal of Environmental Science, 11 (2), 35-53; https://doi.org/10.3126/njes.v11i2.58152.

Paudyal, K. R., Maharjan, R., and Shrestha, B. (2024). Landslide susceptibility mapping of the main boundary thrust region in Thungsingdanda-Bandipur section of Nawalparasi and Palpa Districts, Gandaki and Lumbini Provinces, Nepal. *The Geographical Journal of Nepal*. 17:23-52, DOI: https://doi.org/10.3126/gjn.v17i01.63934

Sah, R. B. (1999). Current understandings and existing problems on the stratigraphy of Nepal Himalaya. *Journal of SAN*, *1*, 1-29.

Sah, R.B., Thakuri, N., and Yadav, B., (2000). Lithostratigraphy of Siwalik succession of Katari area, Sub-Himalaya, eastern Nepal. Journal of SAN, 2:18-28.

Shahi, Y. B., Kadel, S., Dangi, H., Adhikari, G., KC, D., Paudyal, K. R., (2022). Geological exploration, landslide characterization and susceptibility mapping at the boundary between two crystalline bodies in Jajarkot, Nepal. *Geotechnics*, 2(4), 1059-1083.

Shrestha, K. K., Paudyal, K. R., & Thapa, P. B. (2023). Numerical modelling of cut-slope stability in the Lesser Himalayan terrain of West-Central Nepal. *Journal of Nepal Geological Society*, *66*(01), 75–90. https://doi.org/10.3126/jngs.v66i01.57933

Tamrakar, N. K., Yokota, S., & Osaka, O. (2002). A toppled structure sliding in the Siwalik Hills, midwestern Nepal. *Engineering Geology*, *64*(4), 339-350.

Thakur, V. C. (2001). *Regional geology and geological evolution of the Himalayas. Landslide problem mitigation to the Hindukush-Himalayas*, International Centre for Integrated Mountain Development publication.

Tokuoka, T. (1990). Stratigraphy and geologic structures of the Churia (Siwalik) Group in the Tinau Khola-Binai Khola area, West-Central Nepal. *Mem. Fac. Sci., Shimane Univ.*, *24*, 71-88.

Upreti, B. (2001). *The physiography and geology of Nepal and landslide hazards*. Landslide problem mitigation to the Hindukush-Himalayas, ICIMOD, 312.

Varnes, D. J. (1978). Slope movement types and processes. *Special report*, *176*, 11-33.