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Research Article

DECADAL EVOLUTION OF LANDSLIDES IN THE SIWALIK ZONE: A CASE STUDY OF BABAI WATERSHED, NEPAL

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ABSTRACT

The Siwalik zone of the Nepal Himalaya is highly sensitive to landslides. The study of landslides in the catchment scale gives the basic concept of the overall landslides of the typical zone. In this study, the decadal evolution trend of the four largest landslides of the Babai River watershed was evaluated. The Landsat, Sentinel-2, and Google Earth imageries were used to obtain the physical data of the landslide from 2010 to 2019. The area, total length, and width of scar toe, and the body of landslides were obtained from the images. The rainfall data of two stations was used to evaluate the role of rainfall in the landslide development and evolution process. The trend of rainfall and area of landslides was not the same but the development process of all four landslides was more or less similar. The area of landslides fluctuated till 2014 but suddenly increased after 2015. The landslide area was highest in 2017 and moderately changed in 2018 and 2019. The landslides showed dynamic behavior in a decade with their typical expanding, widening, and reducing characters.

Keywords: Babai watershed, Image analysis, Landslide evolution, Siwalik, Temporal dynamics.

INTRODUCTION

Landslide is a very common geological hazard in the Himalayas of Nepal that causes a long-term threat to the people, properties and vegetation (Devkota *et al*., 2013; Regmi *et al*., 2014; Acharya & Khadka, 2016; Gadtaula & Dhakal, 2019). Steep topography, dynamic geomorphology, inherently weak geological setting, and complex geological structures are the major contributing factors for the landslide evolution in the Himalayas of Nepal (Devkota *et al*. 2013; Regmi *et al*., 2014; Dhakal, 2015; Bhandari & Dhakal, 2021). After 2000, the torrential rainfall caused soil erosion and land degradation in the southern face of the Siwalik Hills (Bhattarai, 2015); and it has exacerbated the flood and sedimentation in the Terai (Dhakal, 2013; Pathak, 2017).

To reduce the future threat and risk, the evolution mechanism of the landslide should be identified. The Babai River catchment of the Siwalik group of Nepal has been selected for the present study. The study area lies in the western part of Nepal and a geologically small part of the Siwalik group. Politically, the area extends into three districts of Western Nepal as Bardia, Dang, and Salyan.

Previous researchers divided the Siwalik zone into the three geological divisions based on mapable lithological similarity as the Lower Siwalik, Middle Siwalik, and Upper Siwalik from bottom to top respectively (Auden, 1935). The rock found in the present study area was also divided into three geological units namely the Lower Siwalik, Middle Siwalik, and Upper Siwalik (Bhandari & Dhakal, 2018). The geological map is shown in Fig. 1.

Interbedding of fine to very fine-grained sandstone and red-purple, brown mudstone are a composition of the Lower Siwalik. The sandstone beds are weak and erodible. The mudstone along with shale is highly fractured and easily breakable. During the Monsoon period, the mudstone erodes out after the continuous effect of rainwater. The characteristics feature of the Middle Siwalik is medium to coarse-grained, thickly-bedded as pebbly-sandstone and variegated mudstone. The thin layers of mudstones are present alternatively with thickly-bedded sandstone. After the continuous interaction with water, the thin layer of mudstone undergoes physical weathering.

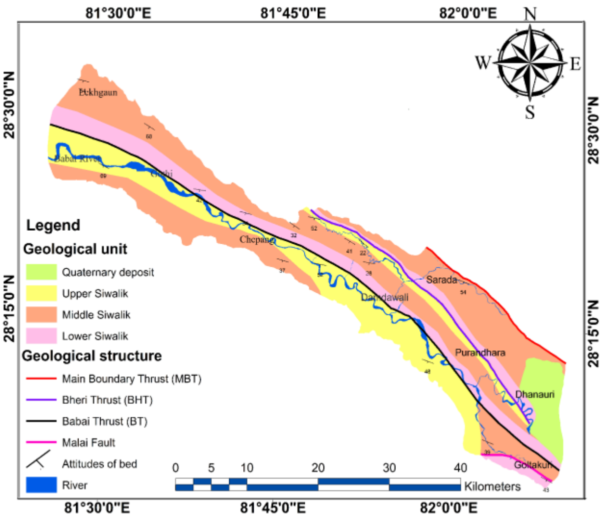

Fig. 1. Geological map of the Babai River watershed

After eroding the mudstone, the thickly bedded sandstone loses its support. Ultimately, the landslide (rockfall) occurs in the Middle Siwalik (Bhandari & Dhakal, 2020a). The Upper Siwalik consists of the cobble and pebble-bearing conglomerate. The conglomerates' beds are cemented with clay and mostly calcite. The cementing clay loses cohesion in the saturated state. Similarly, the calcite undergoes chemical weathering. The detached boulder, cobble, and pebble along with clay particles move down on the slope in the saturated state.

Numerous researchers (Ghimire, 2011; Devkota *et al*., 2013; Regmi *et al*., 2014; Gyawali & Tamrakar, 2018; CDES, 2016; Tamrakar *et al*., 2002; Thapa & Bhandari 2019) studied the landslide susceptibility and dynamics however, the studies lacked the evolution process of landslides. The landslides of the Babai River catchment are not inherent by road construction and human disturbance where most of the landslides naturally occurred (Bhandari & Dhakal, 2021). Studying the natural process of landslide development in the Siwalik Hills is paramount important. This research was conducted to identify the decadal evolution process and temporal mechanism of landslides on the catchment scale at the Babai watershed of Nepal. The study will be useful for the policymakers, different stakeholders of the Siwalik region, and researchers to understand the landslide and to manage for a safe settlement.

MATERIALS AND METHODS

Methods

As this study focused on the formation of the landslide, a series of landslide events were selected. The four largest landslides of the study area were selected for the study of evolution trends. The four largest among all landslides were selected randomly by managing the spatial variation (Fig. 2). Satellite images of those landslides were studied in the temporal series from 2010 to 2019 using Sentinel-2, Landsat-8, and Google Earth imageries. The area of each year was obtained by drawing a polygon on each image of different years. The slide surfaces, too length, scar length, the width of landslide body, and geology of four selected landslides were studied in the field. Physical characteristics of landslides, including landslide description and the other parameters contributing to the initiation of landslides were studied.

RESULTS

Major 4 largest landslides were selected for the case study in the Siwalik group of Babai watershed. Typical features and evolution trends of each landslide are described separately.

Case 1

This landslide (Landslide 1 in Fig. 2) lies about 2.15 km downstream from Mathillo Bharyang ridge of Bardia district. This particular area is the contact between the Lower Siwalik and the Middle Siwalik. This landslide was initiated in 2000 AD but the area of the landslide varied till the end of 2019. The slope varies from 20^0 to 30^0 in the total landslide area. The area has SE to SW aspect, elevation ranges from 350-372 m. The mean annual rainfall in 2014, 2015, and 2016 was similar (2446-2678 mm). The decadal physical measurement is shown in Table 1. The landslide images are shown in Fig. 3.

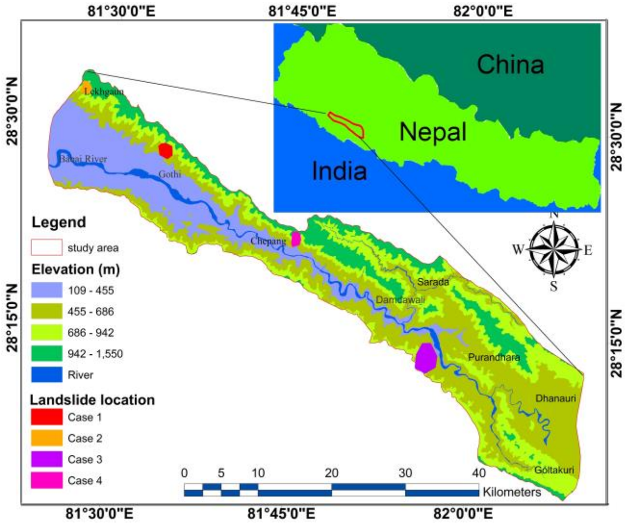

Fig. 2. Location map of the Babai River watershed with the selected four landslides for case study

Fig. 3. The temporal series of Google earth images show the dynamic nature of landslide (Source: Google Earth)

Case 2

This landslide (Landslide 2 in Fig. 2) is located 2.1 km downstream from Jumlibas hill of Bardiya district. Geologically, the area lies in the Lower Siwalik. The temporal images from 2010 to 2019 were used for landslide analysis. The annual rainfall pattern of this particular region is the same. Topographically, the slope angle varies from 25° to 40°, the aspect is the southwest, and the elevation difference is 400 m. The landslide masses were dumped in the valley and flows down with a high discharge of water during heavy rainfall. The same landslides became active every year and no new landslides were formed before 2015 (Fig. 4). The area distribution of landslides from 2010 to 2019 is shown in Table 2.

Table 1. The physical measurement of a landslide along with maximum rainfall within 24 hrs in the six different years

Year	Landslide area (m^2)	Length (m)	Scar length (m)	Body width (m)	Maximum rainfall within 24 hrs (mm)	Change in the area (%)
2010	16052	343	117	72.5	112.5	0
2011	21017	339	89.3	82.7	124.5	30.9
2013	15353	363	63	61.2	187.5	-26.9
2015	13846	368	132	114	263.3	- 9.8
2017	31746	338	135	133	220.4	129.2
2019	18558	315	126	98	224.4	-41.5

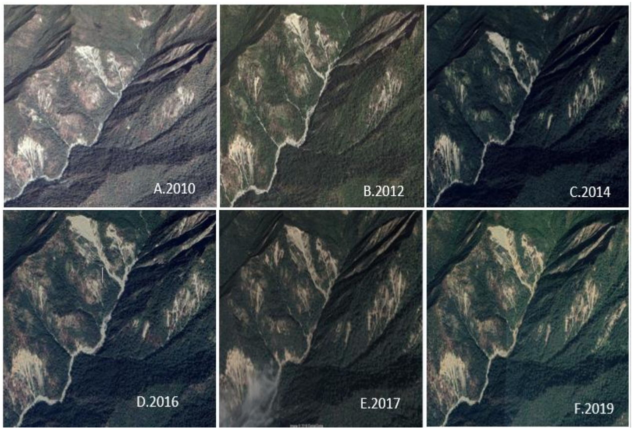

Fig. 4. Temporal dynamics of Jumlibas landslide of Bardia from 2010 to 2019 (Source: Google Earth)

Table 2. Area distribution of Jumlibas landslide from 2010 to 2019

Year	Landslide area (m^2)	Change in area (%)
2010	152790	0
2012	243517	59.38
2013	136021	44.41
2014	139241	2.36
2015	305725	119.5
2016	363195	18.79
2017	371512	2.28
2018	388199	4.49
2019	394051	1.5

Case 3

This landslide (Landslide 3 in Fig. 2) is located in the forest of the Bangaun area of Babai valley. Geologically, the landslide lies in the Middle Siwalik. The temporal evolution of the Bangaun landslide is given in Fig. 5. The landslide was active in 2010. The area of landslide subsequently decreased in 2012. Then, the landslide advanced and widened in 2014. The area increased in 2018 but decreased in 2019. Here, the landslide showed dynamic nature during the development process. The area distribution and physical measurement of landslides are shown in Table 3.

Fig. 5. The images of the landslide from 2010 to 2019 (Source: Google Earth)

Case 4

This particular landslide (Landslide 4 in Fig. 2) is called the Gidde landslide and is located at the boundary of the Salyan and Bardia district. This huge catastrophic landslide occurred on 7-28-1992 at midnight. The Babai thrust passes through it (black line in Fig. 6). The Gidde landslide is located at the hanging wall of the Thrust. The sliding surface has a slope greater than 45°, elevation 1340 m, aspect S, SW, and geologically at Middle Siwalik (Fig. 6). The landslide started with a huge rockfall, then slided to the downslope, and finally converted into a debris flow. The huge amount of debris deposited at the toe of landslides was carried out by flowing water through the narrow valley and finally deposited at the bottom of the slope in terms of talus cone and alluvial fan.

Table 3. Year-wise area distribution of Bangaun landslide

Year	Area (m^2)	Area changed (%)	Length (m)	Toe width (m)	Scar width (m)	Body width (m)
2010	37896	0	256	262	229	201
2012	26988	28.78	151	196	196	104
2014	35517	31.6	143	170	170	119
2015	37384	5.2	189	164	164	114
2017	34457	8.5	224	191	191	153
2019	31751	7.8	215	153	153	142

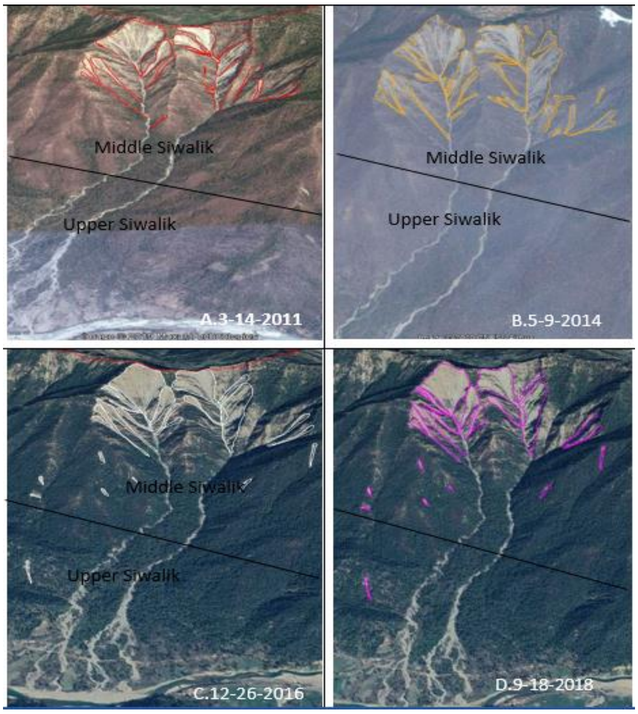

Fig. 6. The evolution of landslide of Gidde Khola from 2011 to 2018, black lines in the figure represent the Babai thrust

The landslide showed both active and inactive nature but the area of the total landslide was the highest in 2015. The slope surface consists only of bedrock predominantly sandstone. But there exists a thin layer of mudstones between thick layers of sandstone. The area of the landslide from the year 2011 to 2019 is presented in Table 4.

DISCUSSION

In the year 2010, the area of landslide 1 was 16052 m^2 but in 2011 the landslide widened towards the west though the total distance between toe and scar was similar. The area of landslide in March 2015 was only 13846 m^2 but in September 2016 the area was 31746 m^2. The landslides widened towards the east but there was no change in scar and toe length. The area increased by 2.29 times in 2016 compared to in 2015, whereas the area was 31746 m^2 in 2017. The landslide reactivated and some new landslides were generated nearby the major landslide. But the total area of landslides in August 2019 was 18588 m^2. The area decreased by 0.58 times in 2019. The mean annual rainfall in 2014, 2015, and 2016 was similar (2446-2678 mm) but the area of the landslide changed simultaneously. This landslide is located at the boundary between the Lower Siwalik and Middle Siwalik. In the Siwalik Hills, the contact between two geological units is weak and fragile due to which the landslide may occur even in the situation of less amount of rainfall if it is continuous.

Table 4. The area and rainfall dynamics of the Babai River catchment

Year	Area (km^2)	Change in the area (%)	Maximum rainfall within 24 hrs (mm)
2010	0.34	0	46
2012	0.42	23.52	65
2014	0.38	-9.5	112
2015	0.48	26.31	136
2017	0.43	-10.41	118
2019	0.35	-18.6	106

In the case of landslide 2, the landslides became active every year and no new landslides were formed before 2015. From 2010 to 2014, the area of the landslides slightly fluctuated but there was a sudden increase in the total area in 2015. The new landslides originated in 2015, 2016, 2017 & 2018. On 14^{th} February 2015, the total area of landslides was 192321 m^2 but on 19 December 2015, the total area of landslides was 305725 m^2. Similarly, in 2016 the area became 363198 and further increased in 2019 and reached 388199 m^2. The landslides became more active after 2015. Landslide 3 was active in 2010. The area of landslide subsequently decreased in 2012. Then, the landslide advanced and widened in 2014. The area increased in 2018 but decreased in 2019. Here the landslide showed dynamic nature during the development process. Landslide 1 and landslide 4 lies in the boundary between Lower and Middle Siwalik. Similarly, landslide 2 and landslide 4 are located on the thrust zone. According to Bhandari and Dhakal (2021), the thrust zone mainly hanging wall is more sensitive for the landslide in the Siwalik Hills.

Bhandari and Dhakal (2018) signified the geological control on the landslides in the same study area. The long-term rainfall in the monsoon period makes the soil saturated. After the higher saturation, the soil loses cohesion, and ultimately, it begins to slide down (Bhandari & Dhakal, 2020b). The soil composition also plays a major role on landslides in the rainy season. The proportions of sand, silt, and clay compositions are highly responsible for landslides during the saturation stage (Yalcin, 2011; Bicocchi, 2019; Bhandari & Dhakal, 2020b). The result shows that the mechanism of landslide does not depend upon the amount of rainfall but depends on the long-term rainfall. Bhandari & Dhakal, (2020a) concluded that long-term rainfall is more sensitive for landslides in the Siwalik Hills. The overall trend of landslide development in the four landslides shows that the landslide development process is dynamic in the study area.

CONCLUSION

The evolution trend of four landslides selected for this case study of the Babai River watershed was analyzed in detail. The data from 2010 to 2019 was obtained from satellite imageries of Google Earth, Sentinel-2, and Landsat. The evolution trends of four landslides were similar. The result showed that the landslides of the Siwalik zone are quite dynamic in nature that changes the geometry and area for a time. A favorable relationship exists between the slope and geology along with the sliding surface. Among the four case studies, landslides did not evolve directly due to the effect of intense rainfall. The initiation and development of the landslide process were similar for all four landslides. The area of landslides increased after 2015 and fluctuated till 2019. A sudden increment of the area of a landslide after 2015 could be due to the impact of the 7.8 ML Gorkha earthquake. The study concluded that the large-sized landslide occurred in the Siwalik hill without significant instance rainfall. A small but continuous rainfall in the rainy season also caused a large size landslide.

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