Distribution and Dynamic Behaviors of Landslide in Rangun Khola Watershed of the Western Nepal

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Abstract

Being a major devastating hazard, the study of landslides in Nepal Himalaya is very essential. For controlling and mitigate measures, understanding the behaviors and distribution of landslides over the temporal and spatial range is indispensable. The current study is carried out in the Rangun Khola watershed of western Nepal which spreads from Mahabharat Range (2,500m) to Dun valley covering an area of 489.39 km^2.Polygon-based landslide inventory within the temporal range of 18 years (2003 to 2020 AD)was prepared by using temporal series of Google Earth Pro,Sentinel-2 images, and Landsat images, which were verified during the field visit. The number of landslides and area covered in different spatial units and temporal intervals were analyzed using the Q-GIS. In total, 494 landslides were identified and the area covered by the landslide was 0.47% of the total study area. Landslides in this area are highly dynamic with different activity states and temporal fluctuation. The number of landslides were highest,i.e., 143, in 2005 and the Upper Siwalik region consist of a large number of landslides making them highly prone to landslide events. The presence of thrust and faults was also found to be influencing the landslides and size distribution. The study will be useful for further researches to map susceptibility and hazard and also for policymakers to understand landslide status to reduce the risk.

Keywords: *Landslides*, *Landslide Activity*, *Temporal and Spatial Distribution*, *Rangun Khola*

Introduction

Landslides can occur almost anywhere in the world; it is among the most lethal geological hazards in mountainous regions (Dhakal, 2014). Thousands of lives and the destruction of billions of properties are caused by the landslide each year globally (Petley et al., 2007).Adverse and weak geological structures along with the influence of hydro-meteorological conditions have triggered hazards like landslides (Dhakal, 2015). Landslide is the most command major natural hazard in Nepal, as the country is highly vulnerable because of its young and active geology, seismic activity, high rate of weathering, high relief, fragile geology along with steep topography, undercutting of the banks, high intensity rainfalls during monsoon, and so on (Dhital et al., 1991).

The clustering and categorizing of landslides and their activity state is considered as first step towards landslide hazard mitigation. The study of landslides and related phenomena is an emerging interdisciplinary field in Nepal, a quite small number of research work has been undertaken so far (Regmi et al., 2012; Devkota et al., 2012). These studies focused mainly to prepare susceptibility and risk maps based on landslide inventory and various intrinsic and extrinsic factors. The study of past and present landslides are guides to future events, i.e., it is likely that landslide will occur where it has occurred in the past, and have similar geological geomorphological and hydrological conditions as they have in the past (Ercanoglu et al., 2004).Broothaerts et al. (2012) studied the spatial patterns of landslide and their relationship with causes and consequences and found the different spatial clusters of landslides with similar characteristics. So the study of landslide characters on the spatial and temporal basis is very useful to judge the landslide dynamics. In this context, efforts should be increased for landslide mapping and landslide susceptibility assessment to understand the relationship between landslide and contributing factors which can be helpful for prediction and prevention of the landslide hazard in the area. As it is well known that, there are spatial differences in landslides based on geology and structures in Nepalese terrain (Bhandari & Dhakal, 2020).

The spatial distribution indicates the number of landslides in different geological formations whereas temporal pattern or dynamic behavior indicates the state of activity of the landslides. The activity can be described and classified based on state as - Active, Reactivated, Suspended, Inactive, Dormant, and Stabilized (Varnes & Cruden, 1996). Landslides that are currently moving which include first-time movements and reactivations are known as active. Inactive landslides are those that last moved more than one annual cycle of seasons ago which can be subdivided as dormant if the causes of movement remain apparent (Hutchinson & Gostelow, 1976). A landslide that is again active after being inactive may be called reactivated. And the landslides that have stopped movement either by natural or artificial measures can be described as stabilized. The study of the state and behavior of landslides can be possible with the temporal inventory of the landslides, which is used in this study.

Rangun Khola watershed in Sudurpaschim Province constituted of Mahabharat range and Siwalik region that has faced several damages due to landslides. Different sized landslide is observed in this area every year and landslide is the second-ranked disaster in terms of affected family and estimated loss (MoHA, 2019). Apart from large, many small-scale landslides go unreported; losing productive lands unless and until they involve the loss of life and properties or causes the blockage of the road in rural areas of Nepal (Dahal, 2012). Such unreported landslides are very frequent over this study area and damages are severe. This can be minimized through the implementation of prevention and mitigation strategies, which can be achieved through the application of proper landslide mapping. To reduce the present and future risk and to cope with the impact of landslides, the distribution and dynamics along with mapping of landslides should be carried out. Thus, the main objective of this research is to study the distribution and dynamic behaviors of landslides in Rangun Khola watershed of Sudurpaschim Province, Nepal.

Materials and Methods

Study area

Rangun Khola situated in the Sudurpaschim Province of Nepal; is one of seven watersheds within the Mahakali River Basin. The watershed ranges in elevation from 2,500 m in the north, (Mahabharat range), to 258 m along its southern reaches where the watershed drifts into the Mahakali River at Parshuramdham. This watershed covers an area of

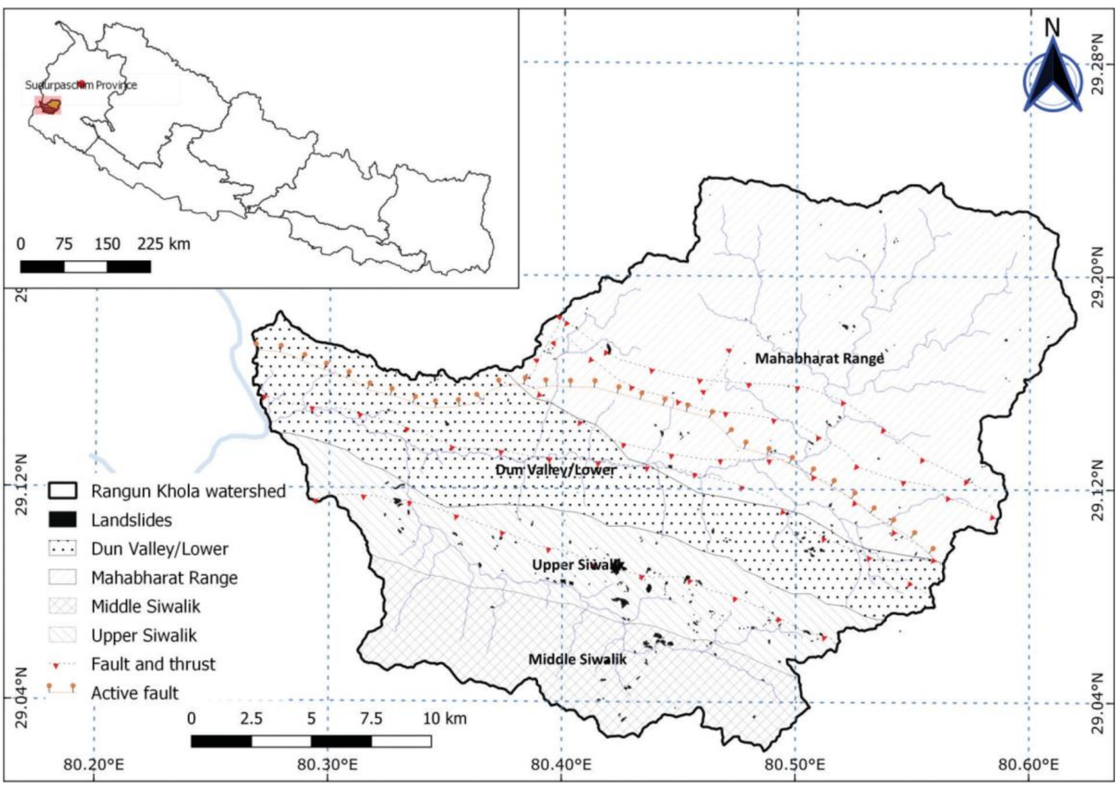


Figure 1: Location of the study area showing landslides distribution geological features (fault and thrust lines adopted from DMG (2020) and active fault adopted from Dhital (2015).

489.39km^2 and is fed by many tributaries within the Siwalik zones that accumulate into the Rangun Khola, which is the main drainage channel for the watershed. The level of the water varies significantly and water-induced disasters like floods, landslides, river cutting, and sand deposition are frequent over the area during the monsoon. According to census 2011, about 53,109 people inhibit within this watershed. The annual average rainfall in the watershed is 1,346.6 mm and the annual temperature ranges between 10°C to 25°C, and (DHM, 2017).The geology of the watershed is comprised of Precambrian augend and banded gneiss and various mixtures of mica-schist and phyllite. An active fault passes close to the main boundary thrust and runs through Budar, Alital, and Kalena (Dhital, 2015). This existing geology and topography make this area prone to landslide hazards. Several historical and present landslides are prevalent in this area. Thus the study of landslide and their distribution and dynamics is necessary for this area.

Data and Methods

For this study, polygon-based spatio temporal Landslide Inventory Map (LIM) was developed from 2003 to 2020 AD based on both the desk study. Primarily Google Earth Pro historical imagery was utilized and in case of data deficient and blurred images, Sentinel-2, and Landsat images were used. Similarly, different published and unpublished reports were utilized for verification of the identified landslides in the area. Based on this inventory and repeated field visit the distribution and dynamic behavior of landslides were studied. Preliminary field visit of one week was carried in February, 2020 for identification of landslide prone areas, and after the preparation of inventory a next field visit was conducted in June 2020 for 20 days in order to characterize the landslides.

Distribution and Dynamics of Landslide

The distribution and dynamics of the landslide in this study stand for the spatial distribution of landslides in different lithological zones, the temporal distribution of landslides from 2003 to 2020 the size of the landslides, and state of activity. The classification of landslides was carried out within five years intervals, for example landslides before 2005 were counted and classified in 2005. The classification of activity classes is adopted from Varnes & Cruden(1996) and Bhandari & Dhakal (2020) as classified into the following five classes (Table 1).

Table 1: Landslide classification based on its activities

Name	Activity Class
New (N)	Landslides that have occurred in the last 36 months
Active(A)	The landslide that has been moving every year/Movement has occurred in the last 12 months

Inactive(I)	No movements have occurred for three years and haveno prior probability to reactivate shortly
Reactivated (R)	Landslide reoccurred in the inactive or stabilized landslide
Stabilized(S)	The landslide mitigated naturally or structurally and seems stable at present

In terms of size, landslides were classified into five class namely very small, small, medium large and very large, which were proposed on the basis of logarithmic scale. In the present study size classes were adopted from Bhandari and Dhakal (2020) as described in Table 2.

Table 2: Classes of landslide based on area

SN	Area (m^2)	Size Class
1	<100	Very small
2	100-1000	Small
3	1000-10,000	Medium
4	10,000-100,000	Large
5	100,000-1,000,000	Very large

The study area is composed of four distinct geological units Mahabharat range, Upper Siwalik, Middle Siwalik, and Dun Valley (Hagen, 1969; Dhital, 2015). Above activity class and size of the landslide as behavior is classified and their spatial distribution was studied based on geological formation.

Results and Discussion

Landslide inventory

In the study area total of 494 landslides were identified from 2003 to 2020 based on satellite images and field verification. The size of the individual landslide was found in the range of 68.21 m^2-149,120.10 m^2, with an average size of 4,677.35 m^2, which eventually covers the area of 2,301,058.62 m^2. The total area covered bya landslide is about 0.47% of the total study area. The highest number of landslide events found to occur in 2005 whereas the area covered by the landslide is higher in 2020.The identified landslide was also classified in different five classes based upon size namely very small, small, medium, large, and very large based on area. The frequency of the small and medium-sized landslide having an area between 10^2-10^3 m^2 found to be dominant in the study area as shown in Figure 2. The medium and small-sized landslide covered 38% and 50% of the total landslide by number and though the percentage of landslides having a large size is 12% but occupies significant in terms of the area.

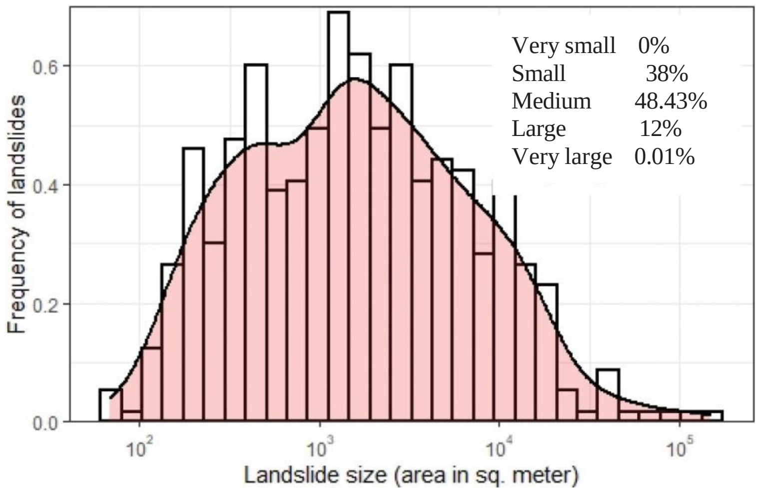


Figure 2: Frequency of different sized landslide.

The elevation ranges from 258 to2,500 m within a very small area and has a higher slope gradient up to 77 degree. Along with the sedimentary rock this caused slope instability and due to which various slope movements like rockfall rock flow, rock slides, and complex types (Varnes & Cruden, 1996) were observed in the study area.The distribution of the small landslides in the study area is due to the fragile nature of the Siwalik region, whereas the occurrence of medium and large sized landslides is due to the presence of active fault that passes close to the main boundary thrust and runs through Budar, Alital, and Kalena. In the south of this active fault, Budar thrust delimits the Siwaliks from the Mahabharat Range. The higher frequency of the small and medium-sized landslides in this study area is a similar result to that of (Bhandari & Dhakal 2020). The densities of the landslide were found higher in the vicinity of these faults and thrust. This shows that the landslide mobility in the study area is greatly affected by lithology along with terrain height and slope. Currently, there are two very large-sized landslides found to be active and the morphology shows the evolution of the landscape found to be greatly influenced by landslide events. As concluded by Fort et al. (2009), landslide events may influence landscape morphology and evolution for thousands of years.

Distribution of Landslides

The spatial distribution of the landslide was studied based on geological formation. The area is composed of four distinct geological units Mahabharat range, Upper Siwalik, Middle Siwalik, and Dun Valley (Hagen, 1969; Dhital, 2015). The spatial distribution of the different size classes of the landslide is presented in Figure 3.

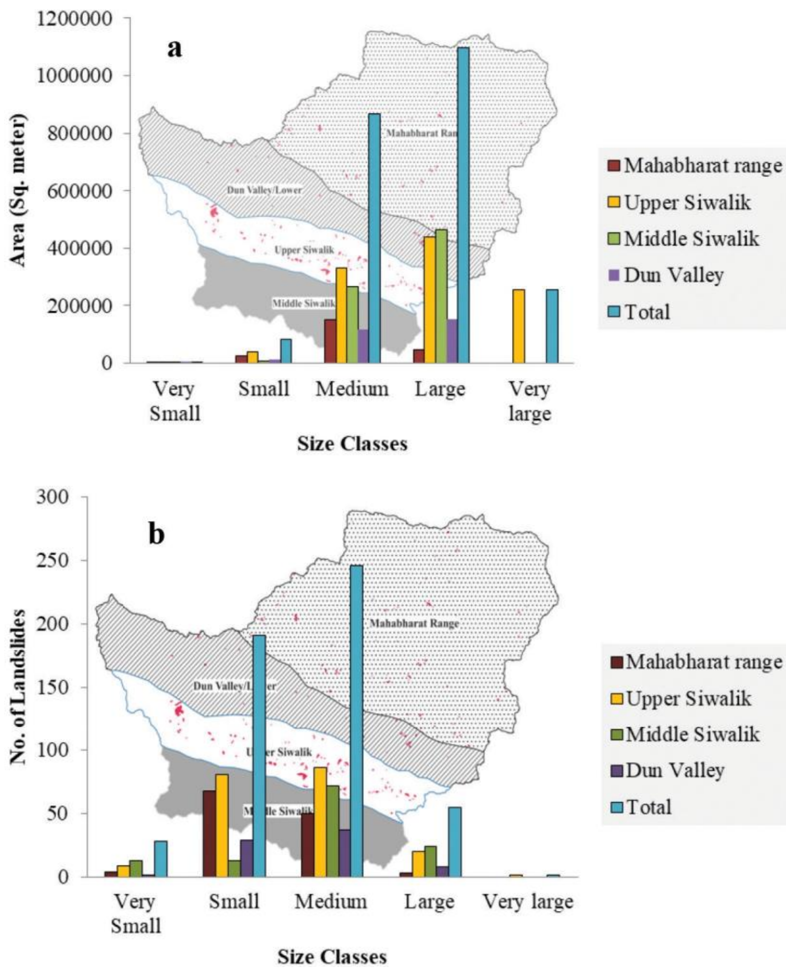


Figure 3: Distribution of landslide in different geological units a) area of landslides and b) number of landslides

The spatial configuration is based upon the number of landslides present inthe study area Upper Siwalik > Mahabharat Range > Middle Siwalik >Dun Valley with 190, 121, 109, and 74 landslide events, respectively. Spatially, there is no significant difference in the size-frequency of the landslides. In the Upper Siwalik, Middle Siwalik, and Dun Valley medium-sized landslides are dominant whereas in the Mahabharat Range,small-sized landslides are more frequent (Figure 4b). There are only two landslides identified having a very large size in the Upper Siwalik region. Upper Siwalik region is in the highest rank (1,062,230.16 m2) in terms of area covered by the landslides and followed by Middle Siwalik (738,325.56m2). Though the number of landslides in the Mahabharat falls in the second-highest rank, the area covered by them is lowest among all four regions due to a higher number of small landslides. From this analysis,Upper Siwalik can be identified as a highly potential region for landslide occurrence in the Rangun Khola watershed.

The temporal distribution of the size-based class and number of landslides was analyzed from 2005 to 20120 AD (Figure 5a). The annual frequency of the landslide was found to be varying significantly. As it is very difficult to differentiate each year event for active landslides, and to examine the exact number of events,five-year interval was considered. The numbers of landslides in 2005 were 143 covering the area of 557,877.19 m^2, but, there was a significant decline in the numbers between 2005 and 2010 and reached 103, covering 521,832.08 m^2 area (Figure 5b). Then the number of landslides was in increasing trend and extended up to 112 and 136 in between 2015 and 2020, respectively.

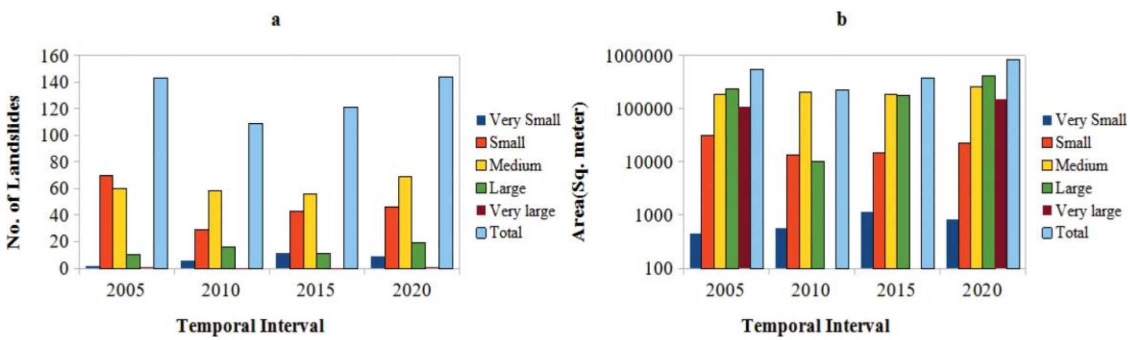


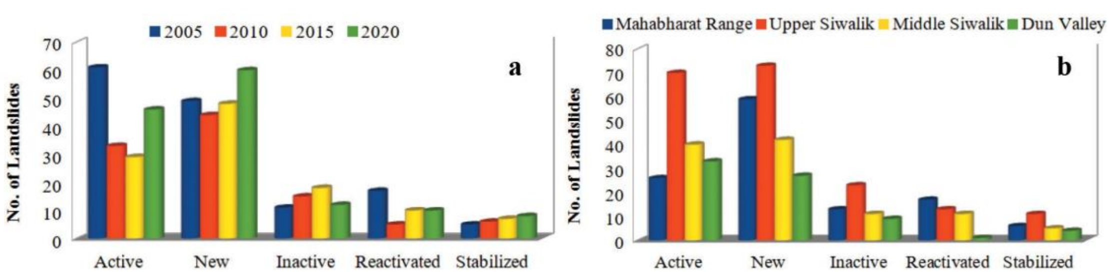
Figure 4: Temporal distribution of landslide, a) number of landslides and b) area of landslides

The number of small-sized landslides was found to be in similar trend as that of the total number of landslides. But the number of medium and large-sized landslides which were dominant of all was in a linear trend. Overall, there were two very large-sized landslides observed, one before 2005 and another during the 2015 to 2020 interval. The distribution of the landslides size shows was not found to be uniform between these geological units. Medium to large scale landslides is commonly found in higher densities temporally and spatially. The trend of the result is similar for temporal intervals. The Mahabharat Range alone covers 51 % of the study area but the number of landslides area is lower than that of Upper and Middle Siwalik and Dun valley (consist of 49% of the area). In the Mahabharat Range, new landslides were dominant, but overall landslides are dominant in the Upper Siwalik region, could be due to Budar thrust and an active fault through Alital, living behind several sag ponds and lakes in its depressions (Dhital, 2015). In the past studies Middle Siwalik was observed as highly prone to landslides in the similar terrain (TU-CDES, 2016; Bhandari & Dhakal, 2019; Bhandari & Dhakal, 2020).

State of activity

The inventories of the identified landslides were classified according to their activity classes in temporal and spatial units. Overall, the area covered by new landslides is about (41%), followed by an active landslide (36%), reactivated landslide (10%), inactive (7%), and stabilized (6%). The number of the landslides classified according to activity class isplotted in a different time interval and geological areas are presented in Figures 8a and

b. The number of the landslides is in the order of New> Active > Inactive> Reactivated > Stabilized with 201, 169, 56, 42, 26 number, respectively. The highest numbers of active landslides were observed in 2005 whereas new landslides were highest in 2020. The numbers of the stabilized landslides werein the increasing trend whereas the numbers of other classes found to be fluctuating over time. All classes of landslides were found to be dominant in the Upper Siwalik followed by the Mahabharat Range and Middle Siwalik region. In the Mahabharat Range, new landslides were found to be more dominant, but overall, the numbers of reactivated landslides were highest in the Mahabharat Range than other geological units. The stabilized landslides were observed in the lowest count in all geological units.



The distribution and activity of the landslides were found to be significantly varying spatially and temporally. This is mainly caused by the existing geological setting, types, and weathering status of rocks and morphology. The Mahabharat Range consists of Lesser and Higher Himalayan rocks having higher grade metamorphism steadily increases upwards. At first, gray biotite schists, quartzites, and feldspathic schists are seen, and then there are zones of schist with some tiny garnets (Dhital, 2015). Upper Siwalik, which most prone area for landslide in this region is characterized by coarse, dissected, and subdued topography. Ephemeral streams can be observed running through

They produce a huge amount of coarse sediment. Upper Siwaliks are interstratified with sands and a subordinate amount of clay. The sediments consist of poorly graded materials, including pebbles, cobbles, and boulders, derived from the Lesser Himalaya and the Higher Himalaya (Dhital, 2015).

Conclusion

The study concludes that there are clear spatial differences in the distribution of landslides based on the geological units and temporal intervals. The total area covered by a landslide is 0.47% of the total area.The new and active landslides are commonly observed. The landslides having a size distribution between 10,000 m^2 and 100,000 m^2 are characteristic ofthe study area.Along with the lithology, the presence of thrust and faults was also found to be influencing the landslides.The Upper Siwalik region consists of a large number of landslides making them highly prone to landslide events. The total numbers of landslides fluctuated yearly and the highest, i.e., 143, landslides were in 2005. Some of the areas found to be dominant with frequent landslides and characterized as active landslide zone. Frequent landslide zones should be avoided or require further engineering geological and geotechnical considerations. Thus, to protect life and propertyfrom these landslides, mapping can be used as the basic tool to understand landslides. Also,further study of landslides along with land management andplanning future construction is immediate need in this area.

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