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Spatial and Temporal Analysis of Landslides during Last Decade in Nepal

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Abstract
Landslides are very dangerous in mountainous places such as Nepal, posing a threat to human life, economic damage, and environmental destruction. Despite this scenario, Nepal continues to lack a credible attempt to identify landslide-prone regions, which is a necessary first step toward landslide prevention and mitigation. The purpose of this study is to offer a spatial and temporal analysis of landslides in the Nepal Himalayas and to identify regions at risk of landslides. Ten years of landslide data were collected from 2011 to 2020 to assess annual variations, investigate the relationship between rainfall and landslides, describe the landslide distribution pattern, conduct statistical spatio-temporal analysis, and finally, predict the causes and influential factors of landslides. The findings indicate that landslide occurrences are spatially and temporally concentrated, with 93.26% of all landslides occurring during the wet season. For the cumulative frequency distribution of daily landslides, clear power-law correlations are found. Additionally, the mean centres of landslides are shifting each year, with the majority centred in the country's central area.

Keywords
Landslides, Spatial Distribution, Temporal Distribution, Power Law, Nepal Himalayas

1. Introduction

Landslide is one of the most severe natural hazards in Nepal in terms of causalities and economic loss. In the single year 2020 itself, 303 people lost their lives, 64 were missing, and 226 people were injured due to 493 landslides. Rainfall is a major triggering factor for landslides, accounting for many significant landslide events. In addition to intense rainfall during monsoon, urban growth, construction in landslide-prone regions and complex interaction of socio-economic factors have also exacerbated terrain conditions over the last few decades, resulting in more landslides [1].

Landslide disaster casualties are often underestimated, resulting in unexpected landslide risk [2]. The primary explanations for underestimating landslide-related losses are challenges in observing landslides due to their local effects and a shortage of hazard tracking networks such as earthquakes and floods. Consequently, it is crucial to comprehend the Spatio-temporal characteristics of landslides, including their frequency, severity, and human impact [3]. Since landslides often occur in regions where they have already happened, comprehending the Spatio-temporal distributions of landslides enables identifying vulnerable locations [4]. It enhances our understanding of landslide mechanisms, landslide occurrences, and predisposing factors.

Numerous studies have examined the Spatio-temporal distribution of landslides globally [4, 5, 6] and continental scale [7, 8]. Although severely affected by landslide events, very few studies have been conducted on Nepal's distribution of landslides.

This research analyses the current trend of landslides between 2011-2020 in Nepal and their Spatio-temporal distributions. A total of 2121 landslides from 2011 to 2020 were collected to assess annual variations, distribution patterns, examine the relationship between landslides and rainfall, conduct statistical Spatio-temporal analysis, and identify the causes and influential factors of landslides. The findings of this study will be valuable for the government, decision-makers and planners concerning landslide risk management and infrastructures development.

2. Study Area

Nepal has the world's highest relative relief, with a minimum elevation of 70 m and the highest 8848 m at Mount Everest's summit (Figure 1) within 200–300 km distance from south to north. The geomorphic and tectonic history of the Nepal Himalayas usually affirms the existence of deep and steep river valleys in central Nepal. These valleys are the result of frequent large-scale landslides. Moreover, those landslides are being triggered by haphazard construction of roads neglecting geological investigation and engineering design. Annual rainfall varies from less than 250 mm north of the Himalayan range to about 6000 mm at Lumle in central Nepal, with 80% falling over the four months from mid-May to mid-September [9]. The highly irregular rainfall trend is also regarded as a significant cause of landslide-related disasters in Nepal.

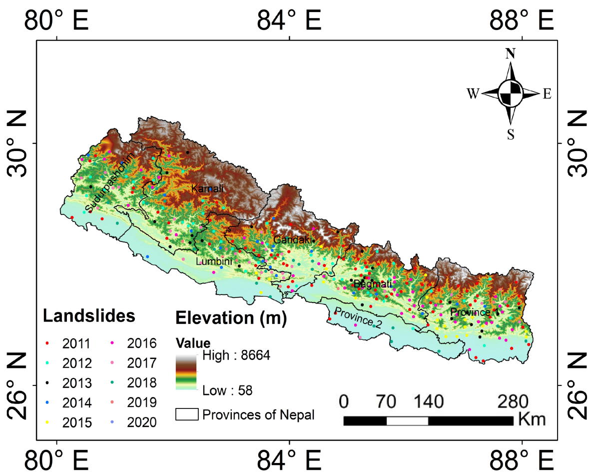

Figure 1: Location map of the study area with distribution of landslide events from 2011-2020 A.D.

3. Material and Method

A dataset of historical landslides from 2011 to 2020 (Figure 1) were assembled based on Nepal Disaster Risk Reduction (DRR) catalogues. The dataset contains information about 2121 landslides that occurred between 2011 and 2020. The landslides between 2011 to 2020 killed 1206 people, injured 996 and left 297 people missing. The regional rainfall data considered in this study were collected from the Department of Hydrology and Meteorology (DHM). Using the annual rainfall database of 261 rain gauges located throughout the region, yearly rainfall distribution was interpolated and produced.

4. Results and Discussion

4.1 Spatial and Temporal Distributions

The distribution of fatal landslides across Nepal is exceptionally unevenly distributed in the complete dataset for 2011–2020 (Figure 1). It can be seen a significant increase in both landslide accidents and causalities over the last few years.

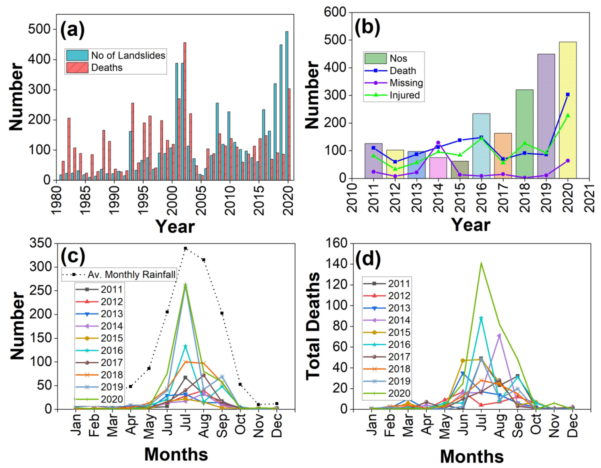

Figure 2: Graphical representation of (a) number of landslide events and death caused scenario for the period 1980–2020 (b) number of landslides and casualties (2011–2020) (c) number of landslide events (2011-2020) with average monthly rainfall (1901-2016) shown for context, and (d) monthwise deaths

The annual death toll from landslides ranges from 62 in 2015 to 493 in 2020. To analyze the trend of landsides in 40 years period (1981-2020), 30 years (1981-2010) data of Nepal, DesInventer Database by NSET (2015) has been combined with the ten years study data (Figure 2 (a)). Two general increasing trends can be observed in the data, one from 1981 to 2002 and another from 2005 to 2020. The number of landslides and the number of fatalities during 2011–2020 is represented in Figure 2 (b). Furthermore, as shown in Figure 2 (c), the landslide and rainfall distributions are highly consistent. They cluster in large numbers during the rainy season, which lasts from June to September. A total of 1978 landslides (93.26%) were there during this time frame. Additionally, Figure 2 (d) illustrates the month-by-month death toll from landslides. The fatality rate was worst in July when the number of landslide events was greatest.

Province 1, Bagmati, and Gandaki were the landslide hotspot provinces, accounting for 68.32% of widespread landslides between 2011 and 2020 (Figure 3 (a)). Based on the landforms of Nepal, there are three regions, namely Terai, Hilly and Mountain regions. The study showed that the landslide intensity is exceptionally high in the Hilly region, especially in the central and eastern parts of the country, with 1413 landslide events (66.62% of total landslides) (Figure 3 (b)).

Moreover, the study area has five types of geological regions among which landslides were most commonly seen in the lesser Himalayan series on a geological scale (Figure 3 (c)) with 1134 events and 11 deaths, followed by the greater Himalayan sequence. The elevation based distribution is shown in Figure 3 (d).

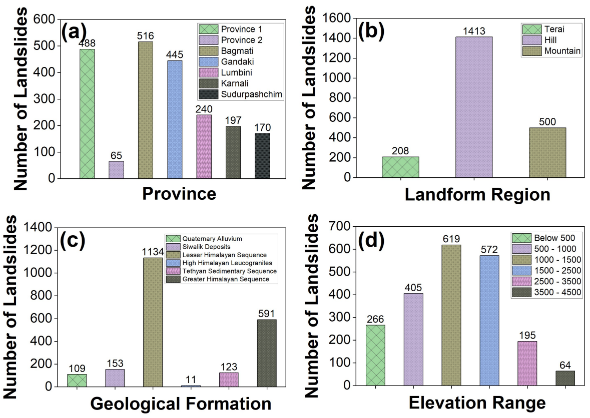

Figure 3: Feature-wise landslide events distribution (a) province (b) landform region (c) geological formation, and (d) elevation range

4.2 Spatial Analysis

4.2.1 Average Nearest Neighbour

The average nearest neighbour (ANN) algorithm can determine the spatial distribution of spatial data. It calculates the distance between the centroid of each feature and its nearest neighbour and then takes the sum of all of these distances between closest neighbours. It is calculated by using the following relation:

$$ANN = \frac{D'_O}{D'_E} \quad (1)$$

Where D'_O denotes the observed average distance between each element and its nearest neighbour and D'_E is the predicted mean distance between the features in a randomly generated pattern.

If ANN is less than 1, the pattern exhibits clustering, and if it exceeds 1, the trend is toward dispersion. The findings indicated that the overall ANN ratio is 0.046, which is less than one, from 2011 to 2020 which proved that the landslide points are clustered.

4.2.2 Mean Centre

The average of all the landslides in a given year's x- and y-coordinates is called the mean centre. This parameter is used to measure landslide spatial distribution changes and analyze spatial distributions of landslides over time. The mean centre is calculated as follows:

$$(X', Y') = \frac{1}{n}\left(\sum_{i=1}^{n} x_i, \sum_{i=1}^{n} y_i\right) \quad (2)$$

Here, X' and Y' are the mean centre coordinates, x_i and y_i represents the x-and y-coordinates of the landslide 'i' and 'n' as the annual average landslide number. The mean centre is used to locate the geographical centre of a set of features. It can be used to determine the spatial distribution and concentration point of a landslides group. For each year, the mean centres were measured using Equation (2). The findings indicated that the mean centre shifted annually (Figure 4). For the majority of years, the mean centres were located in the country's central area.

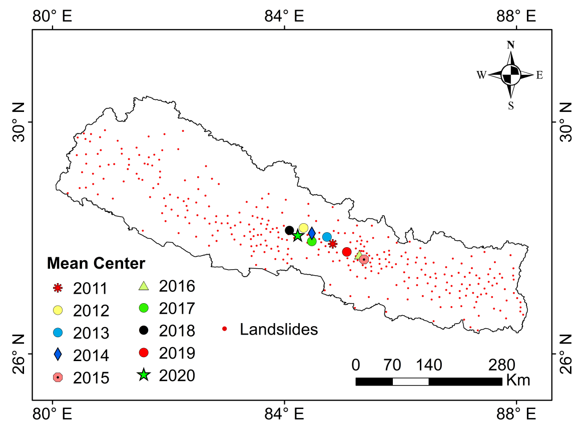

Figure 4: Mapping of mean centres of landslide distribution for years 2011 to 2020

4.2.3 Kernel Density Estimation

The kernel density tool calculates the density of features in a neighbourhood around those features. It can be calculated for both point and line features. The landslide intensity or spatial density of landslides was defined in this work as the kernel density of landslides.

We utilized kernel density estimation to generate landslide intensity. The following equation approximates the kernel density in two-dimensional space:

$$\lambda(s) = \sum_{i=1}^{n} \frac{1}{\pi * r^2} k\left(\frac{d_{is}}{r}\right) \quad (3)$$

where $\lambda(s)$ denotes the density of position 's'; 'n' denotes sampling points number; 'k' represents the point 'i' weight at d_is distance from 's' and finally, 'r' denotes the radius of the search for estimating kernel density. Landslide intensity, or spatial density, refers to the number of landslides in a given area. Using kernel density estimation, a map of landslide intensity is developed (Figure 5). The findings indicated that the distribution of landslides was highly clustered and heterogeneous. Numerous landslides occurred in evident concentrated areas.

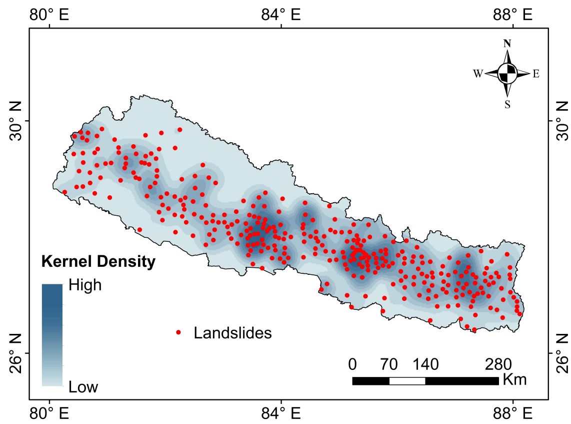

Figure 5: Mapping of landslide intensity using Kernel density analysis

4.3 Power Law Relation

The total sum of frequencies greater than the daily landslide occurring at the moment can be called cumulative frequency (F_C) of daily landslides (N_L). In this scenario, the cumulative incidence can illustrate the daily occurrence of more than a certain number of landslides. We employed a power law relation to estimating the cumulative occurrence of landslides daily. Between 2011 and 2020, Nepal experienced 758 days with an average of $1 \leq N_L \leq 47$ landslides per day. Numerous days in this time series contain 0 values, indicating that there were no landslides. Single landslide occurring days made up about 52.63% of all landslide event days. As shown in Figure 6, as the number of landslides every day rose, the cumulative distribution shrank dramatically. The cumulative frequency distribution of regular landslides in Nepal is best represented by the following inverse power law function, as seen in Equation (4).

$$F_C = 95.49 N_L^{-1.81} (R^2 = 0.974) \quad (4)$$

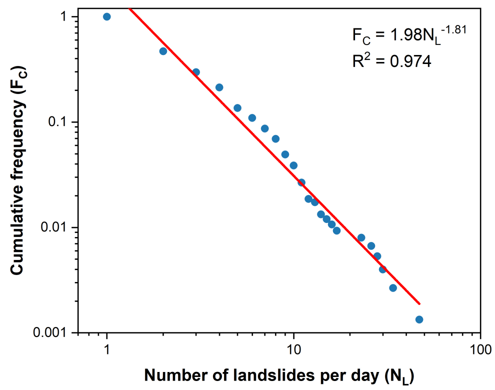

Figure 6: Power law relationship between F_C and N_L

5. Conclusion

The following findings were reached as a conclusion of this study:

- The temporal distribution of landslides demonstrates two general increasing trends in distinct periods 2012-2016 and 2017-2020. Additionally, it has a significant correlation with monthly rainfall having an intensive cluster of 93.26% of total landslides during the rainy season.
- Landslides are unevenly distributed in various geographical regions, defined by their distinct geologic and climatic environments. Bagmati province has the densest clusters, led by Province 1 and Gandaki province, while Province 2 had the fewest landslide cases.
- The lesser Himalayan area is especially vulnerable to landslides due to its geographical formations.
- Spatial analysis using ANN, mean centre, and Kernel density demonstrated that landslides are heterogeneous and clustered in Nepal.

- Between 2011 and 2020, Nepal experienced 758 days with an average of $1 \leq N_L \leq 47$ landslides per day. Days with a single landslide event accounted for about 52.63% of all days of landslide events.

References

[1] B.P. Bhandari and S. Dhakal. Spatio-temporal dynamics of landslides in the sedimentary terrain: a case of siwalik zone of babai watershed, nepal. 2020.

[2] Q. Lin and Y. Wang. Spatial and temporal analysis of a fatal landslide inventory in china from 1950 to 2016. 2018.

[3] F. Zhang and X. Huang. Trend and spatiotemporal distribution of fatal landslides triggered by non-seismic effects in china. 2018.

[4] D. Kirschbaum, T. Stanley, and Y. Zhou. Spatial and temporal analysis of a global landslide catalog. 2015.

[5] F. Nadim, O. Kjekstad, P. Peduzzi, C. Herold, and C. Jaedicke. Global landslide and avalanche hotspots. 2006.

[6] D. Petley. Global patterns of loss of life from landslides. 2012.

[7] S.A. Sepúlveda and D. Petley. Regional trends and controlling factors of fatal landslides in latin america and the caribbean. 2015.

[8] U. et al. Haque. Fatal landslides in europe. 2016.

[9] N.P. Bhandary, R. Yatabe, R.K. Dahal, S. Hasegawa, and H. Inagaki. Areal distribution of large-scale landslides along highway corridors in central nepal. 2013.