Numerical Modeling of Debris Flow Originating from Topographic Hollows at Koyalghari and Simaltal Area along Narayangadh-Mugling Highway

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Abstract: Assessing debris flow runout is essential for evaluating landslide hazards and developing effective land use plans. This study used the LISEM (Limburg Soil Erosion Model) to analyze debris flow runout based on geotechnical soil parameters. By integrating rainfall-induced failure and runout through physically-based modeling, the study aimed to predict landslide impact areas using forecasted precipitation. Focusing on the Koyalghari and Simaltal areas along the Narayangadh-Muglin road, the model's validation in Simaltal showed substantial agreement with historical runout patterns. For extreme rainfall events, debris flow heights between 0.92 m and 1.1 m were estimated at the highway, indicating potential damage to traffic. The findings highlight the model's reliability in predicting debris flow runout and providing valuable insights for hazard management.

Keywords: ***Physical based modelling, Cohens Kappa, Debris flow runout, LISEM model***

Introduction

The mountainous areas of Nepal are naturally unstable and particularly vulnerable to landslides for number reasons like their rugged topography, presence of soft soil cover, high intensity monsoon rainfall and frequent earthquake. Rainfall plays a crucial role in triggering debris flow from topographic hollow. In addition to the intensity and duration of rainfall, the hydrological phenomenon, soil particles, and properties influence the slope stability (Dahal and Hasegawa, 2008). The main objectives of the research are to apply a physically based model for debris flow runout estimation and validate the model using laboratory data and field observation of historical landslides.

LISEM (LImberg Soil Erosion Model) developed by Faculty of Geo-Information Science and Earth Observation (ITC) of Twente University is a physically based dynamic model that offers a more comprehensive analysis by taking into account the physical processes involved in debris flow runout. It uses a physically based approach to model the movement of water and solid material down a slope taking into account the physical processes involved in debris flow and the interaction with the topography (Bout et al., 2018).

Methodology

The study area of the research is located at Simaltal and Koyalghari in Ichhakamana Gaupalika, Chitwan district (Figure 1)

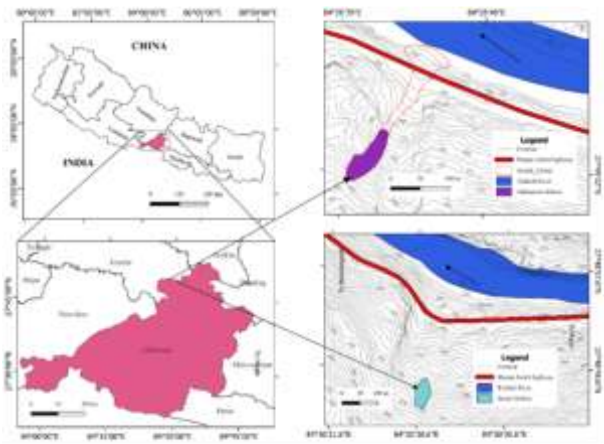

Figure 1: Location map of study area.

The flow chart of the methodology used for modeling debris flow in the LISEM model is shown in Figure 2. Using different soil parameter determined from laboratory and field test, various input maps were prepared in GIS. Finally, prepared map was imported in LISEM model and suitable rainfall data was taken for simulation.

Results

Geologically, the study area lies in the Nourpul Formation of the Lesser Himalaya Zone. The area is mostly covered up to 3m thick colluvial soil, primarily low plastic silt (ML) and low plastic clay (CL). The input map of the soil parameter was determined from the average value of geotechnical parameter obtained from field and lab test given in Table 1.

Runout modeling was performed in LISEM model for two areas i.e. first in the Simaltal area to represent debris flow occurred in 2010 using actual precipitation that triggered debris flow and then in the Koyalghari area using extreme rainfall intensity. The maximum debris height of 9.243 m was obtained in Simaltal area as shown in Figure 3. The debris flow runout covers total area of 15492.24 m^2. At highway the average maximum debris height was 1.107 m and affected about 60 m length of highway from chainage 23+630 m to 23+690 m.

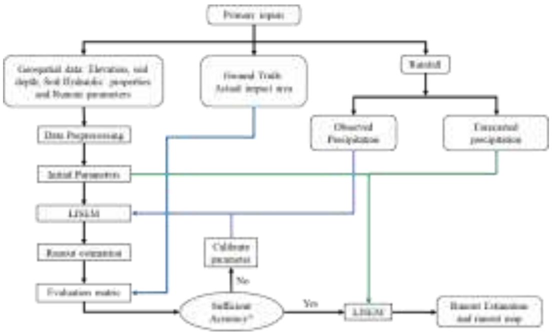

Figure 2: Flowchart of LISEM model employed for debris runout estimation.

Table 1: Summary of values of various parameter used in the study hollow and validation hollow.

Parameters	Values in validation area	Values in Study area
Cohesion (KN/m^2)	13.83	16.51
IFA (radian)	0.46	0.46
Soil density (Kg/m^3)	1757.76	1640.12
Porosity	0.323	0.385
Specific gravity	2.58	2.51
Initial rock size (m)	2.62E-04	1.19E-04

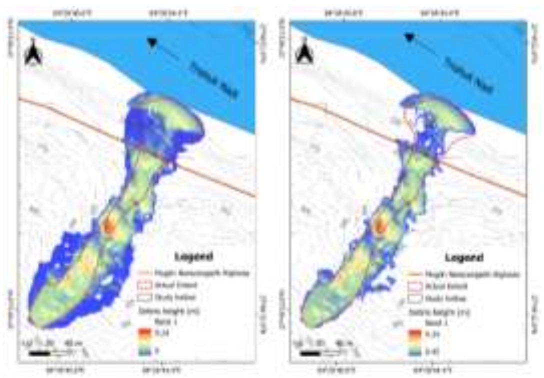

Figure 3: Debris flow runout in Simaltal area considering total debris height (left) and Threshold height that results maximum value of Cohens Kappa (right)

The accuracy of the runout modeled in Simaltal area was calculated using Cohen's Kappa. The sensitivity analysis was carried out changing debris flow height during accuracy estimation to understand how different thresholds height impact the performance of a model. The maximum value of Cohen's Kappa was 0.7453 using the threshold height of 0.45 m. Map obtained using observed precipitation in the Simaltal area that resulted in maximum Cohen's kappa value is shown in Figure 3.

Simulation was also performed in Koyalghari area along Narayangadh-Mugling road section. The study hollow was modelled for various extreme events based on 23-year rainfall data. Based on the result, the average debris height for various rainfall event at highway is shown in Table 3. The highest debris height was obtained for 3-day maximum rainfall as shown in Figure 5.

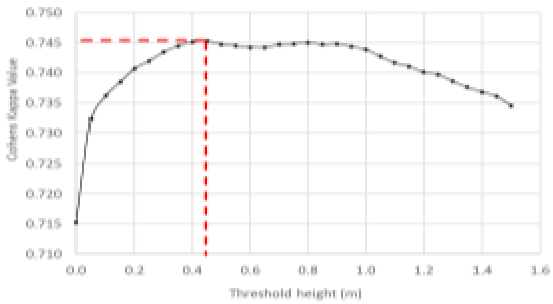

Figure 4: Cohens Kappa value for various threshold height.

Table 3: Average debris height at Highway for various rainfall period.

Maximum rainfall	Average debris height (m) at highway for various return period rainfall			
	Actual	5 yrs	10 yrs	25 yrs
1-day	0.9626	0.9266	0.9482	0.9689
3-day	1.1153	0.9563	0.9341	0.9333

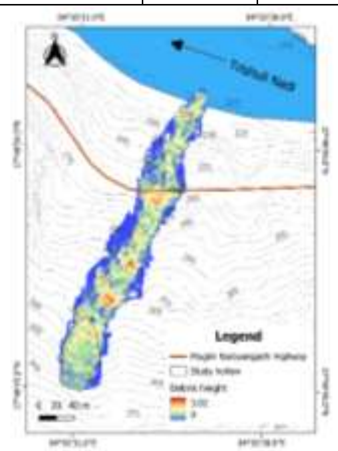

Figure 5: Debris height simulated in Koyalghari for 3-day max rainfall of 2006.

The study successfully applies the LISEM model to simulate and estimate debris flow runout in topographic hollow based on debris height at Koyalghari area. The model validation in the Simaltal area demonstrated substantial accuracy and supported the conclusion that physically-based models can reliably predict debris flow runout in similar geotechnical and topographical settings.

References

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