Predictive Numerical Modeling of Landslide Susceptibility: A case study for Uma Oya catchment, Sri Lanka

Tohoku University・Regular member・So Kazama*
University of Moratuwa・Regular member・Chaminda Samarasuriya
Tohoku University・Student member ○ Hashani Anuttara Abeygunasekara

1 Introduction

Landslides are catastrophic events induced by various causes. The factors that induce landslides include both natural and anthropogenic processes. Rainfall and the geomorphology of a specific location act together to determine the slope stability of the ground leading to the generation of a slope failure. Ground water table acts a significant role in shaping the slope stability of the ground. The weight induced by the increased water table tend to induce much weight on the sliding plane which causes the land to slide along the sliding plane. Accordingly, the rainfall acts a significant role in determining the slope stability of the ground.

Comprehensive understanding of the processes related to hydrology cycle enables understanding the related mechanisms and causative factors behind the disaster events. In the events of landslides, the extreme rainfall causes the precipitation to exceed the infiltration capacity of the ground, which in turn generate surface runoff contributing to the surface water channels shaped by the topography of the terrain. The water that infiltrates is subjected to either interflow or deep percolation. The interflow then contributes to the stream network while the deep percolations cause the ground water recharge that shaped by the deep aquifers, and the state of equilibrium, which in turn causes the dynamics of water table.

1.1 Research gap

Past research exists proposing predictive frameworks for landslide susceptibility; however, many demonstrate limited applicability to local site conditions while the rest relies on data intensive machine learning algorithms. On the other hand, the current study focuses on integrating the numerical modeling principles with adaptive internal learning algorithm to include the strengths of machine learning techniques while improving the applicability of the model derivations to a different extent.

1.2 Objective

The research is intended to investigate the predictability of landslide susceptibility within the region, by numerically modeling the regional hydrological processes. Accordingly, the proposed methodology is a stepwise approach i.e., to model the dynamics of the water table within the region and then use the same to evaluate the dynamics of the slope stability to predict the likelihood of a landslide event.

2 Methodology

ArcGIS model builder platform was used to develop a numerical model that simulates the hydrogeological processes that shape the dynamics of slope stability within the study region.

2.1 Numerical Model

The observed daily rainfall and temperature values were used to infer the spatial distribution of rainfall across the study region at daily time intervals. Sequential evaluation of evapotranspiration, infiltration and groundwater recharge rates enabled developing an iterative mathematical representation [1] of the hydrogeological processes applicable to the region.

The study period was set to 2015-2016 based on the availability of input data for the study region. Daily values for the precipitation measured at 15 rainfall gauges and minimum and maximum temperature measured at one temperature gauge were used to calculate the rate of evapotranspiration [2] and net effective precipitation. Then the landuse distribution of the region was analyzed to recategorize the existing landuse classes, which were used as the basis to determine the infiltration capacity of each unit of ground within the grid. Provided the effective rainfall intensity exceeds the infiltration capacity of the

Keywords: slope stability, factor of safety, landslide susceptibility, disaster risk management, rainfall induced landslides

*Corresponding author: *Email address*: hashani.anuttara.abeygunasekara@dc.tohoku.ac.jp

ground, the surface runoff is generated, in terms of infiltration-excess overland flow. Accordingly, the water balance on a cell was used to derive the formulae to model the daily water table within the study region.

Finite difference approximations for the time derivative of head [1] were used to represent the amount of change in water table over a unit timestep (i.e., with daily temporal resolution), where net amount of water either accumulated into a cell or dissipated out of a cell was used to evaluate the distribution of transient water table. Finally, the calculated head values were used in evaluating the factor of safety within each cell to represent the distribution of slope stability.

2.2 Model optimization and validation

The model incorporates gradient descent updates to the model parameters by setting the objective to find the local minima of the error or disagreement between consecutive iterations.

3 Results

The series of maps generated suggested that the regions with elevated risk of slope instability were mostly accumulated across the south-eastern part of the study region. **Figure 3** demonstrates the generated map for July 1, 2015. Besides, the relative changes in stability distribution were evaluated to identify the temporal trends as demonstrated in **Figure 1** and **Figure 2**.

4 Conclusion

Assessment of landslide susceptibility is of utmost importance in disaster risk reduction efforts aimed at

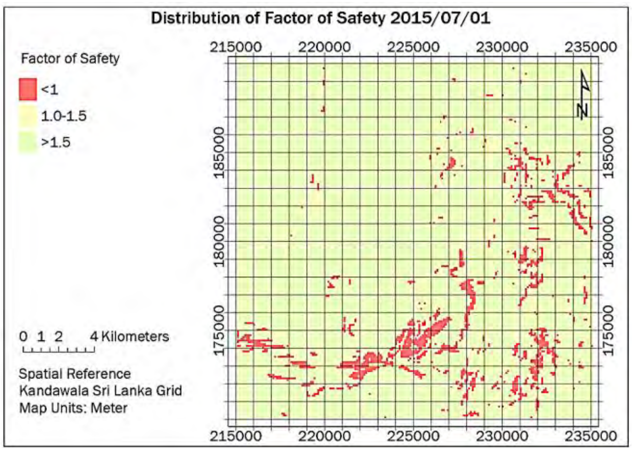

Figure 3: Spatial variation of slope stability on July 1, 2015

The regions where factor of safety is less than one indicates the regions with high risk of slope failure on this date.

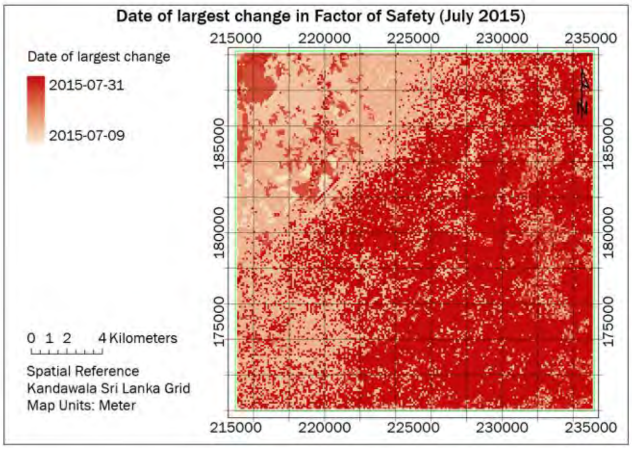

Figure 1: Dates with the most significant drawdown of stability

Each segment of the region is attributed with the date on which it experienced the largest change in factor of safety.

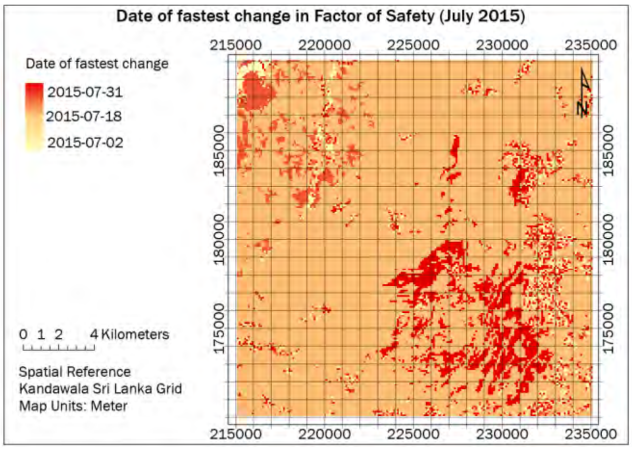

Figure 2: Dates with rapid drawdown of stability

Each segment of the region is assigned with the date on which it experienced the fastest drop in factor of safety.

minimizing the associated losses. Improved predictability of the various scenarios of risks favors the community in terms of improved risk awareness, and preparedness; thus contributing the community-wide resilience against the downturns caused by the disastrous events.

References

[1] U.S. Department of the Interior and U.S. Geological Survey, "Documentation for the MODFLOW 6 Groundwater Flow Model," 2017. Accessed: Jan. 16, 2023. [Online]. Available: https://pubs.usgs.gov/tm/06/a55/tm6a55.pdf

[2] G. H. Hargreaves and Z. A. Samani, "Reference Crop Evapotranspiration from Temperature," *Appl Eng Agric*, vol. 1, no. 2, pp. 96–99, 1985, doi: 10.13031/2013.26773.