## INDIA

### Landslide Risk Assessment and Real Time Monitoring for minimizing the Impact of Rainfall Induced Landslides in Indian Himalayas

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Landslides affect about 15% of Indian landmass aggregating to about 0.49 million square kilometers area. Landslides cause destruction and losses to life and property every year in 22 States of the country and Union Territory of Pudducherry. During recent years, the impact of landslide disasters has compounded due to extreme natural events, urbanization in hill areas and non-adherence of land use policies. Thus the severity and impact of disasters are increasing both in terms of magnitude and frequency of occurrences affecting the GDP and development of region. Therefore, landslide risk assessment and real time monitoring is the need of the hour for minimizing the impacts of extreme natural event such as rainfall in Indian Himalayas. This framework encompasses identification of potential landslide slopes and associated precursor phenomena, reliable landslide hazard and risk assessment, development of reliable and durable slope monitoring system and slope conservation and disaster mitigation measures. In light of this, the present paper discusses the following contributions in this direction in Indian context:

- Combined neural and fuzzy technique for landslide hazard/susceptibility zonation
- Rainfall thresholds for prediction of shallow landslides
- Ground based wireless instrumentation and real time monitoring of a landslide
- Quantitative estimation of physical vulnerability of buildings exposed to landslides

Landslide susceptibility zonation (LSZ) is necessary for planning future developmental activities in hilly areas. In this paper, combined neural and fuzzy set theory concepts have been assessed for preparation of LSZ maps in a part of the Darjeeling Himalayas, India. Relevant thematic layers pertaining

to the causative factors have been generated using remote sensing data, field surveys and Geographic Information System (GIS) tools. In the context of objective weight assignments, a novel weight assignment procedure based on artificial neural network (ANN) is implemented to assign the weights to each thematic layer and the cosine amplitude method of fuzzy similarity concept is implemented to determine the membership values/ratings for each category of the thematic layer. Finally, weights of each thematic layer are combined with ratings to produce the LSZ map. The novelty of this combined neural and fuzzy technique lies in its objective way of delineating the landslide potential zones in the area.

Majority of landslides in the Indian sub-continent are triggered by rainfall. Several attempts in the global scenario have been made to establish rainfall thresholds in terms of intensity-duration and antecedent rainfall models on global, regional and local scales for the occurrence of landslides. However, in the context of the Indian Himalayas, the rainfall thresholds for landslide occurrences are not yet understood fully. In this paper, an attempt towards deriving local rainfall thresholds for landslides based on daily rainfall data in and around Chamoli-Joshimath region of the Garhwal Himalayas, India is presented. Rainfall events pertaining to 81 landslides were analyzed to yield an empirical intensity–duration threshold for landslide occurrences. The rainfall threshold relationship fitted to the lower boundary of the landslide triggering rainfall events is $I=1.82\ D^{-0.23}$ (I=rainfall intensity in millimeters per hour and D=duration in hours). It is revealed that for rainfall events of shorter duration (≤24h) with a rainfall intensity of 0.87mm/h, the risk of landslide occurrence in this part of the terrain is expected to be high. Also, the role of antecedent rainfall in causing landslides was analyzed by considering daily rainfall at failure and different period cumulative rainfall prior to failure considering 128 landslides. It is observed that a minimum 10-day antecedent rainfall of 55mm and a 20-day antecedent rainfall of 185mm are required for the initiation of landslides in this area. These rainfall thresholds presented in this paper may be improved with the hourly rainfall data vis-à-vis landslide occurrences and also data of later years. However, these thresholds can be used in landslide warning systems for this particular region to guide the traffic and provide safety to the tourists travelling along this pilgrim route during monsoon seasons. Such rainfall thresholds can be derived and used for fore-

warning the landslide events for different catchment areas having cluster of villages in hilly region.

The installation of a real-time monitoring system is often a cost-effective risk mitigation measure. A Landslide Observatory with wireless instrumentation for real time monitoring of ground deformation and hydrologic parameters is established at Pakhi Landslide in Garhwal Himalayas, India. The measurement sensors include in-place inclinometers (IPI), piezometers, wire-line extensometers and an automatic weather station (AWS). The real time data is being monitored to establish warning thresholds. At the crown of landslide beyond main scarp, there is negligible displacement being the stable part. Within the main body of the landslide, it could be inferred that the colluviums, greatly weathered bedrock and their interface experience somehow greater extent of movement at different depths in comparison to the interface between greatly weathered bedrock and unweathered bedrock. A correlation between higher intensity rainfall events and displacement pattern across the inclinometer sensors is also witnessed. Such type of real time monitoring of landslides through intensive instrumentation is a very costly affair and may not be advisable to replicate in each landslide to issue early warning. Hence, this type of extensive conventional instrumentation for establishing early warning can be planned and designed for perennial active landslides only. Further, establishing a warning threshold based on rainfall in relation to landslide occurrences in hilly terrain and then using this threshold for early warning to save lives and property and to control the traffic on hill roads is the only suitable, feasible and cost effective option. On establishing a rainfall threshold for a particular terrain having a specific lithotectonic and geomorphological setup, a number of AWS units in the region can be wirelessly networked at a central station and an early warning can be issued.

With such contributions towards landslide disaster mitigation in Indian Himalayas, an executable framework for landslide risk assessment is drawn involving hazard zonation for identification of landslide source areas, influence zone demarcation through run-out-effect mapping, mapping of risk elements and their vulnerability. Further, rainfall threshold based models and MEMS based ground sensor network for real time monitoring of landslides are being worked upon to develop a reliable and cost effective landslide early warning system for Indian Himalayas.