**NASA DEVELOP National Program**



Goddard Space Flight Center

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Himalayan Disasters II

*Utilizing a Landslide Identification Product and a Hazard Assessment Model for Enhanced Landslide Detection*

 **Technical Report**

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# I. Abstract

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Landslides, Precipitation, Remote Sensing, Mass Movement, GPM, Landsat, Risk Assessment

# II. Introduction

A landslide is a type of mass wasting event that occurs when down-slope forces exceed the strength of the slope materials (Cruden, 1991). Changes in slope stability can occur due to natural forcings like intense rainfall, rapid snowmelt, fluctuating water levels, and seismicity (Caine, 1980; Wieczoreck, 1996), as well as anthropogenic factors like deforestation and land use change (Swanson and Dyrness, 1975). Nepal and the Himalayan region is highly susceptible to landslides due to mountainous topography, active seismicity, complex terrain, and monsoon rains. Additionally, Nepal’s underdeveloped infrastructure coupled with its vulnerable location results in hundreds of fatalities and millions of dollars in losses caused by landslides in the region annually (Dahal and Hasegawa, 2008).

On April 25, 2015, the M7.8 Gorkha earthquake struck Nepal, causing more than 9,000 fatalities, 21,000 injuries, and $1-2 billion in damages. Given the approaching monsoon season, rainfall-triggered landslides are likely to emerge as a significant induced hazard in the region. While the Gorkha earthquake is thought to have caused over 900 landslides (British Geological Survey and ICIMOD), historic data shows that more than 80% of landslides in the region occur between June and August due to increased levels of precipitation associated with the summer monsoon season (Dahal and Hasegawa, 2008). As such, more attention must be given to mitigating loss of life and economic damages during the monsoon period.

The devastating Gorkha earthquake has garnered (awkward, maybe attracted?) the attention of international organizations who have increased landslide mapping efforts and high-resolution imagery acquisition. These collaborative developments present an exciting research opportunity to prevent loss of life and economic damages caused by rainfall-induced landslides in the region by developing near real-time automatic detection products, hazard assessments, and decision support tools for end-users. With current underestimation of landslide impacts and the increasing trend in frequency and intensity of landslide events due to anthropogenic factors (Petley et al., 2007), this work is critical even outside the scope of the earthquake.

Previous work in this study aimed to collate and mine available landslide inventories including NASA’s Global Landslide Catalog (GLC) and The International Centre for Integrated Mountain Development’s (ICIMOD) landslide datasets to create a 23-year landslide database detailing landslide event information from 1992 to 2015 for the Nepal and Himalaya region. Along with event data collection, a Sudden Landslide Identification Product (SLIP) was generated to identify landslides that were not recorded in the GLC and the ICIMOD landslide datasets. A landslide susceptibility map was created using an empirical frequency ratio model to analyze the impact of anthropogenic and natural variables on slope stability, and event information from the 2010 ICIMOD dataset was used as a validation tool.

The current phase of this study seeks to leverage SLIP, the Susceptibility Map and Earth Observation data like the Global Precipitation Measurement Mission (GPM) and Tropical Rainfall Measuring Mission (TRMM) to develop a near real-time landslide hazard assessment model for Nepal and the Himalaya region. This product will serve end-users, including The International Centre for Integrated Mountain Development, with the intention to prevent landslide-induced casualties and damages.

Our partner and boundary organization, ICIMOD, is an intergovernmental organization that serves eight regional entities located within the Hindu Kush Himalayan region, including Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan. Through partnerships with regional institutions, ICIMOD is able to serve as a regional knowledge hub that provides its end-users with insight on how climate change and globalization impact the fragile mountainous ecosystems as well as local communities. ICIMOD oversees a variety of programs that were constructed to generate innovative forecasting products. ICIMOD’s Koshi Basin Program was assembled to enhance the management of the Koshi River Basin within Nepal and to improve the wellbeing of local communities through evaluation of water-related pathways. As of now, few efforts have been made to use remotely sensed information to document landslide locations and estimate potential landslide conditions in near-real time within the region. The hazard model and nowcasting product provided as an outcome of this study will be used by ICIMOD to protect and manage the river basin ecosystem and to reduce casualties, injuries, damage to infrastructure, and poverty through integrated natural resources management and basin-wide cooperation.

# III. Methodology

This should be the focus of the paper - concise, yet explanatory, and highlight the NASA Earth observations utilized and its/their capabilities. Include a paragraph or more for each of the following items. No word cap, but be thoughtful and keep it in the two to six page range.

Content to include:

* Data Acquisition: What data did you get, what level products are they, for what dates did you get images, where did you get the images from, etc.
* Data Processing: What did you do to the data? Were there conversions needed to be able to analyze it? Did you have to mosaic images? Did you have to normalize anything to fit other datasets? Did you run an NDVI, change detection, etc?
* Data Analysis: How did you analyze the data? What methods did you use?

**Sudden Landslide Identification Product (SLIP)**

*Algorithm (\*\*Methodology in this section still being developed \*\*)*

The initial development of the Sudden Landslide Identification Product (SLIP) detection algorithm involved downloading a single Landsat 8 scene from January 2015 to quantify the spectral characteristics of a specific landslide event, the Jure Landslide, which occurred in November 2014. The original algorithm focused on the combination of the visible red, green, and blue wavelengths to find areas that matched the color of a landslide. Testing and validation indicated that increases in red wavelengths better captured the spectral characteristics of landslides. Therefore, percent red wavelength was calculated for each pixel, and a comparison was made between consecutive Landsat scenes to flag areas of interest. Large percentage increases in the red wavelengths (Band 4) are indicative of bare soil areas that are more likely to be landslides. Red wavelengths are calculated using a simple percent change technique: ((Red Date 2-Red Date 1)/Red Date 1)\*100. In addition, the near infrared and short-wave infrared bands are used to calculate a moisture index (Modified from Qu), and (IR-SWIR)/(IR+SWIR). This product is calculated over each scene individually and then between dates to identify change. Values falling within the range of expected values for a landslide event are translated into binary matrices, and then summed.

Cloud cover is a well-documented issue in remote sensing and image analysis (e.g. Asner, 1999). Clouds alter the overall spectral signature of Landsat images and obscure relevant information on the landscape. This study sought to expand on previous work by applying corrective measures (TBD either masking or backfilling) to Landsat imagery in order to account for their influence, or pixels classified as clouds by the Landsat 8 Quality Assurance band were masked and not considered in the SLIP analysis.

*Automation*

In order to apply SLIP to near-real time satellite imagery, a Python program was written to automatically download Landsat 8 scenes in the Nepal and Himalaya region (Paths 139-145; Rows 37-41) when they become available every 16 days. The SLIP algorithm is applied to each new scene, and new scenes are compared against old scenes in order to identify areas where spectral changes have occurred at the pixel level. Changed pixels are flagged as potential landslides that merit further inspection.

*Integration with Ancillary Datasets*

Other datasets and analytical techniques were considered in order to assess the likelihood that pixels characterized as “changed” from one Landsat scene to the next did in fact reflect landslides. Considered datasets include 30-meter Digital Elevation Model (DEM) mosaicked from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery, a Normalized Difference Vegetation Index (NDVI) calculated from Landsat imagery, and near-realtime precipitation data from GPM. TBD: Pixels flagged as landslides with <15° slope were eliminated from consideration. Pixels falling outside the NDVI range X < Y were eliminated from consideration. Areas experiencing <X mm/hr precipitation were excluded from consideration.

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**TBD: Precipitation Analysis using GPM, TRMM, and Historic Gauge Data**

*Intensity Duration Frequency (IDF) Thresholds*

Following the methods of Elsebaie (2012), IDF curves were developed by applying the Gumbel Distribution technique to GPM data. IDF curves characterize the frequency at which a given rainfall intensity (mm/hr) will occur, and the corresponding durations for a given intensity.

*Historic Daily Maximum Precipitation from Gauge Data*

Historic accumulated rainfall data was acquired through ICIMOD, spanning the eastern region of Nepal with 65 gauge stations with daily accumulation data from 1970-2010, offering a rare perspective into long-term precipitation trends in Nepal. The gauge data was processed and analyzed in MATLAB by examining the provided daily accumulated rainfall, as well as 3-day, 5-day, and 7-day summations. These summations were then graphed by average and by sum to determine climatology trends in this region of Nepal.

*Slope Failure Threshold Determination Analysis*

\*\*Being developed\*\*

*Forecasting Landslides using Near Real Time GPM Data*

\*\*Being developed\*\*

# IV. Results & Discussion

Insert images, graphs, maps, charts, etc. here. Choose the most important results to highlight here. No word cap, but two to six pages is a good range.

Things to discuss:

* Analysis of Results: What can you tell from your graphs, images, etc? What does this mean for your project?
* Errors & Uncertainty: What factors could you not account for, what things didn’t work out like you expected they would, etc.
* Future Work: If this project was to be selected for another term, what would be the focus? What other areas would be of interest?

# V. Conclusions

Final conclusions. Word count: 200-600 (~a page).

# VI. Acknowledgments

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# VIII. Content Innovation

Planning to collaborate with ICIMOD.

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# IV. Appendices

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