# Landslide mapping along the Karnali highway, Nepal using high-resolution imagery

Pukar Amatya[1,2,*], Dalia Kirschbaum[2] & Thomas Stanley[1,2]

1. Universities Space Research Association ,Columbia, MD,USA, 2. NASA Goddard Space Flight Center, Greenbelt, MD, USA

*Correspondence: pukar.m.amatya@nasa.gov

## Introduction

The Karnali highway (Figure 1) is the only major transportation link that connects the remote Karnali region to the provincial capital in Province 6 of Nepal. This area becomes inaccessible by roads during every rainy season due to landslides. Despite the known landslide frequency, there have been no systematic landslide inventories conducted along this highway to date.

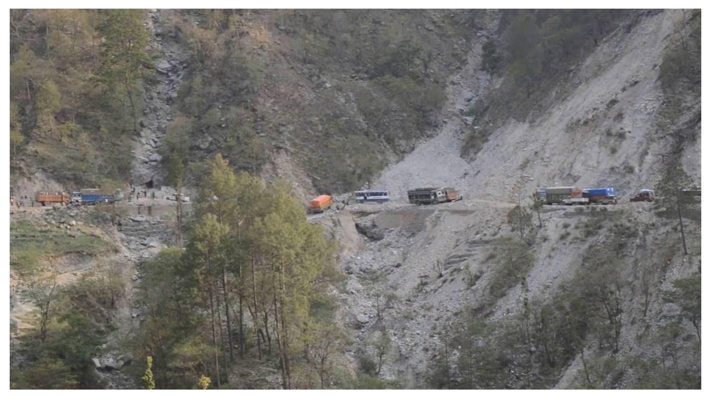


Photo: Prakash Neupane/Youtube

Recent advancements in remote-sensing technologies have significantly increased our ability to map landslides of various sizes rapidly with less in situ surveys or human interaction. Landslide susceptibility, hazard and risk studies require a complete landslide inventory, which might only be possible from very high-resolution (VHR) and high-resolution (HR) imagery. Recent launch of Sentinel-2 in 2015 has provided free access to HR imagery enabling landslide detection at finer scales then what was possible with previous open source satellite imagery obtained from Landsat and ASTER. Satellites providing VHR imagery are commercially owned, expensive and not freely available expect for when disasters charter is activated. NextView licensing agreement, a partnership between the US government and US commercial vendors provides access to VHR imagery to federal agencies in support of scientific research [1]. This partnership provides access to VHR imagery obtained from the DigitalGlobe (DG) constellation which enables mapping of small landslides (< 100 m$^2$). In this study, VHR imagery from DG and HR imagery from Sentinel-2 will be used to map landslides along the Karnali highway using a semi automatic method based on object-oriented analysis (OOA) to create most recent and up-to-date landslide inventory. The effectiveness of this remote sensing based landslide inventory to produce a susceptibility map and its predictive capacity will be tested.

## Study Area & Data

The Karnali Highway in Province 6 of Nepal runs south to north starting at Bangesimal in Surkhet District and ending in Khalanga, of Jumla District. This highway runs parallel to the Karnali River and its tributaries. Since we are interested in landslide activity that might affect the highway, we defined a buffer of 3 km along the highway as our study area. The route is 233 km long and paved. Construction of the highway started in 1991/92. However, the road was finally opened along the entire route to Khalanga only on 1 April 2007.

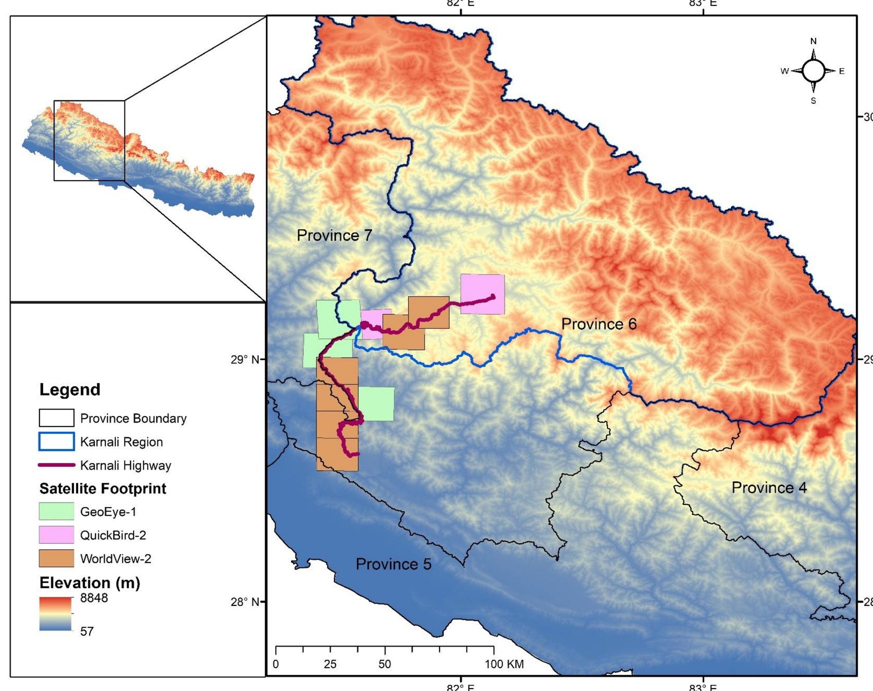


**Figure 1.** Study area and location of Karnali Highway

Multispectral data from three satellites of the DG constellation: GeoEye-1 (GE01), QuickBird-2 (QB02) and WorldView-2 (WV02) (Table 1) and Sentinel-2 were used for creating the landslide inventories. We queried the DG archives for images with off nadir angle < 20° and cloud cover < 20%. The coverage over this area was intermittent, with nearly complete coverage available only for the year 2012. In order to complete the coverage, we incorporated one frame from 2010, two frames from 2011 and two frames from 2013.This inventory will be referred as the 2012 inventory. Beyond 2012, we could not generate complete coverage based on DG. In our attempt to map recent landslides, two tiles of Sentinel-2A imagery from November 10, 2017 was also used.

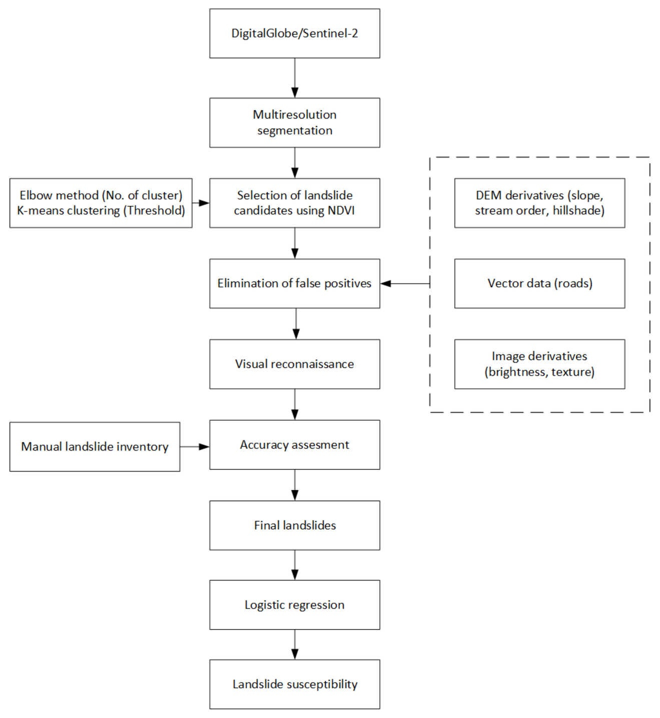
| Sensor | Acquisition time | Resolution (m) |
|---|---|---|
| GE01 | 12/30/2010 | 1.65 |
| GE01 | 12/11/2011 | 1.65 |
| GE01 | 12/11/2011 | 1.65 |
| WV02 | 1/12/2012 | 1.85 |
| WV02 | 10/8/2012 | 1.85 |
| WV02 | 10/8/2012 | 1.85 |
| WV02 | 10/8/2012 | 1.85 |
| WV02 | 10/8/2012 | 1.85 |
| QB02 | 10/12/2012 | 2.4 |
| WV02 | 2/26/2013 | 1.85 |
| QB02 | 5/30/2013 | 2.4 |

**Table 1.** VHR imagery used in this study

## Methodology

OOA was used to map landslides using VHR and HR imagery. Image segmentation was used to convert image pixels into objects based on spectral homogeneity. Spectral, spatial, textural and contextual properties of these objects were used to delineate landslides. In this study, landslides along with false positives were detected first using a NDVI threshold, with sequential elimination of false positives in second step.

Logistic regression, which allows for a multivariate regression between a dependent variable and several independent variables was used to create the susceptibility map. The dependent variable is binary, representing the presence or absence of landslides, and the independent variables are landslide explanatory variables. Eight landslide explanatory variables: slope, aspect, elevation, geology, land cover, distance to highway, distance to faults and distance to drainage were considered. The 2012 landslides were used to train the model and the 2017 landslides were used for validation.




## Results

Figure 2 shows the location and size of OOA-based landslides within the 980 km$^2$ Karnali highway study area. The size of 1103 landslides varied from 3.39 to 30,496 m$^2$. Landslides were located at lower elevations, on steep south facing slopes (Figure 3). Landslides were common near highway and drainages but not near faults. Phyllite, schist, metasandstone and quartzite rock types of the Kuncha geologic formation contained the majority of landslides, as did the forest and agricultural land cover types.

Figure 4 shows the susceptibility map of the study area. 47.28% of area lie in a low susceptibility zone whereas 36.60% of study area lie in high/very high susceptibility class. The map shows that the lower elevation area in the Kuncha geologic formation are the most hazardous. The banks of the Karnali River, its tributaries and areas near to the highway are also highly susceptible to landslides. The produced susceptibility map predicted the 2017 landslides well with area under the curve (AUC) value of 0.78 (Figure 5).

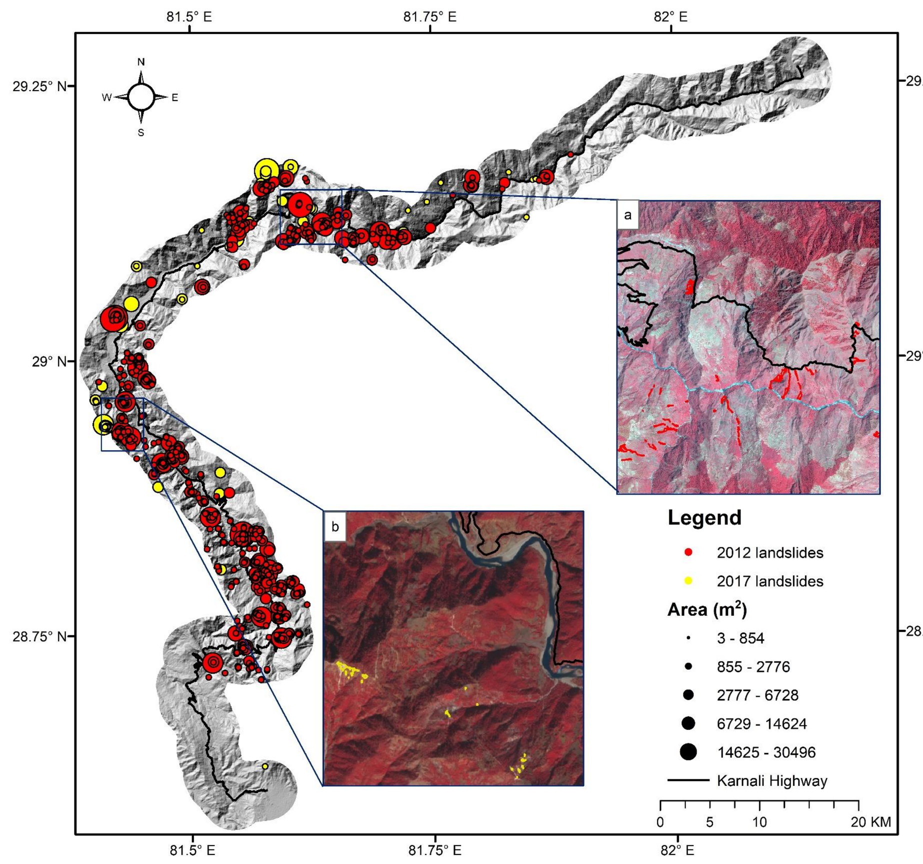


**Figure 2.** Location and area of landslides mapped along the Karnali highway for year 2012 and 2017. The insets show: (a) landslides mapped using QuickBird-2 imagery of 05/20/2013 and (b) landslides mapped using Sentinel-2A imagery of 11/10/2017. Imagery © 2013 DigitalGlobe, Inc.

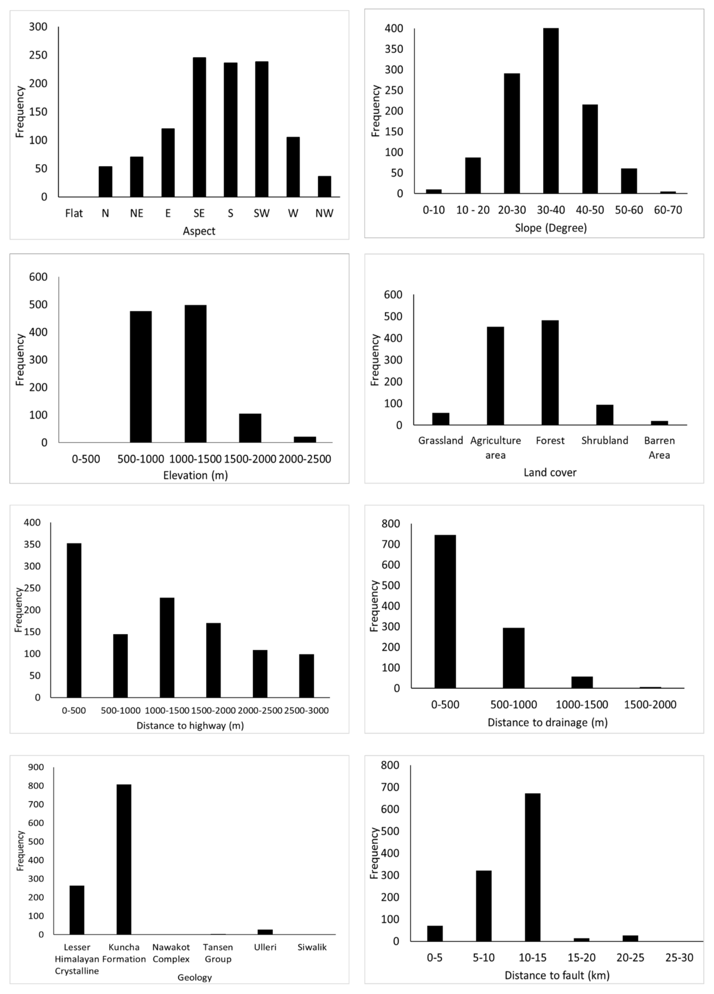


**Figure 3.** Frequency analysis of the landslide inventory for each explanatory variable

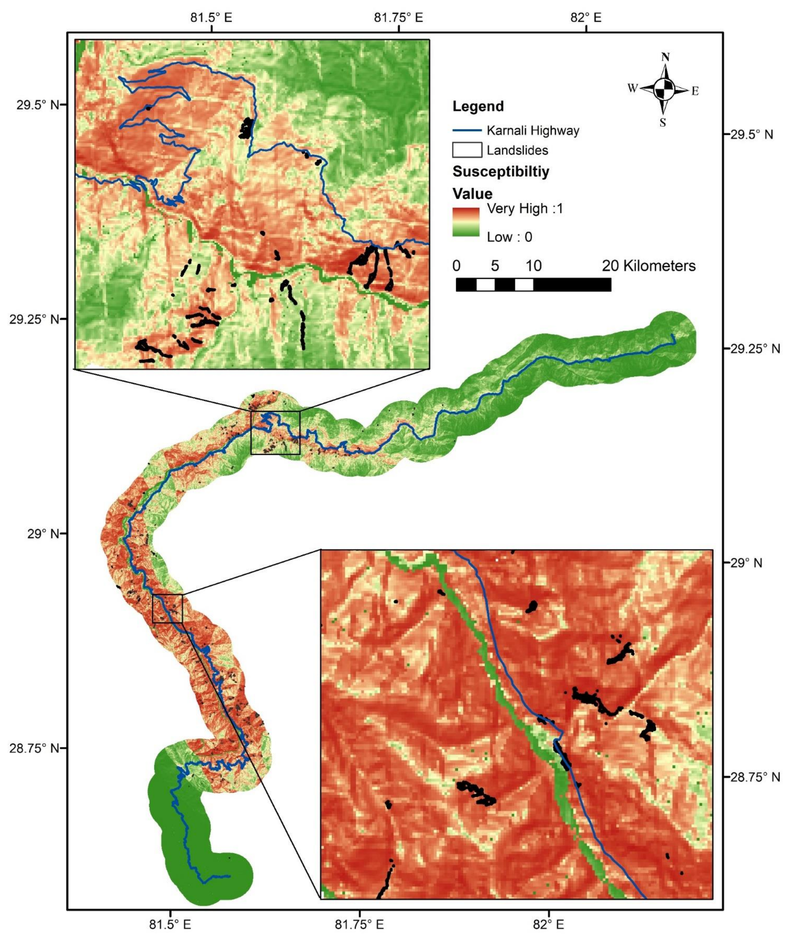


**Figure 4.** Landslide susceptibility map derived from logistic regression with inset plots highlighting two hazardous portions of the Karnali highway

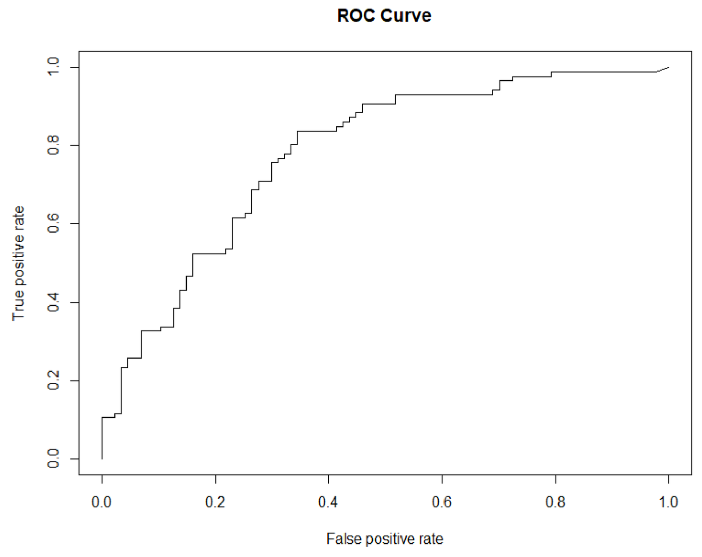


**Figure 5.** ROC curve computed from validation sample

## Conclusions

A landslide inventory was created from VHR and HR imagery of 2012 and 2017 respectively using OOA within a 3 km buffer of the Karnali highway. To our knowledge, this is the first landslide inventory in this area. The susceptibility map produced using the 2012 landslides highlighted good agreement with the location of the 2017 landslides. This susceptibility map provides the first estimates of highly susceptible areas to landslides along the Karnali highway, which can inform decisions about where to apply mitigation approaches such as bioengineering. This method demonstrates the potential for conducting similar analyses in other remote areas as well as provides the first step towards hazard and risk estimation.

**References**

1. Neigh, C. S. R.; Masek, J. G.; Nickeson, J. E. High-resolution satellite data open for government research. *Eos, Trans. Am. Geophys. Union* **2013**, *94*, 121–123.

**Acknowledgement**

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