Root system estimation based on satellite remote sensing: An applied study in Eastern Uganda

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Abstract

The density of roots is an important factor influencing the rate and magnitude of landslides. Due to the increased variability in climate, mainly rainfall, Eastern Uganda is severely struck by an increasing number of these mass movements, often with human casualties as one of the negative impacts. The aim of this study is to explore the possibility to estimate the depth and density of the root system influencing the resistance to landslides, from satellite remote sensing data. 104 samples were collected in field, where the root system was classified into 5 different classes, from non-existing to dense and deep (forest). The study was carried out in the Mount Elgon area located at the Ugandan-Kenyan border. The field data were then compared with 30 m Landsat TM data, in order to investigate possible links between reflectance (single bands as well as indices) and ground truth data. The results indicate that, following this methodology, it is not possible to estimate the root system density based on the remotely sensed data, since the maximum Cohen's kappa value of 0.081 is judged deficient.
Keywords: landslides, remote sensing, Uganda, root system density, NDVI, EVI

1 Introduction

Destabilization of the soil is triggered by various factors such as high precipitation, steepness, and shape of the slopes, as well as high clay content (Knapen et al., 2006). In developing countries like Uganda, erosion of the soil is considered as an important issue that has a direct negative effect on people's livelihoods and development. In addition, mountain ecosystems are sensitive to the climate variability and resulting changes in runoff pattern. Landslides generate the occurrence of debris flows and floods imposing a threat to the quality of both water and soil as well as physical threats. Consequently, the terrain becomes unstable and agricultural productivity weakens (Jiang, Bamutaze and Pilesjö, 2014). Hence, landslides can lead to a destructive outcome and be a hazard for the people in the affected area. They live of that land and depend on it to survive, so when a landslide takes place and wipes out the agricultural fields, there is no food to live on.

Earlier studies have shown that factors affecting risk of landslides include aspect, slope, profile curvature, geology, and vegetation cover, of which root system density is the major component influencing soil stability (Meng et al., 2015; Mugagga, Kakembo and Buyinza, 2012; Ngecu, Nyamai and Erima, 2004). However, when it comes to the root system there is a lack of knowledge about the possible link between remotely sensed data and the root system density. Instead, NDVI has often been used as a proxy of vegetation density, which has been supposed to reflect the roots (Yang, Wang and Shi, 2013; Oh et al., 2012).

Due to the climatic conditions, steep topography, and poor traffic connection, insufficient field data collection on Mt. Elgon is evident (Jiang, Bamutaze and Pilesjö, 2014). The possibility to assess landslide risk areas by using remote sensing for estimating root system density would be a more time and cost efficient method than field collection of root system data. According to Mugagga, Kakembo and Buyinza (2012), the expansion of grazing land and cropland in East Africa will continue to expand and replace natural forests by 38% of their 1995 areal extent until 2032. Thus, recommendations regarding plantations of certain trees, as well as implementing other preventative measures could be lifesaving.

2 Aim and objectives

The general aim of this study is to investigate the potential of using satellite remote sensing data to estimate root systems influencing landslides in Eastern Uganda. This will be done by fulfilling the following specific objectives:

1. To classify root systems in field.
2. To calculate a number of commonly used satellite remote sensing indices, from Landsat TM data.
3. To compare the indices as well as single wavelength bands with the field data.

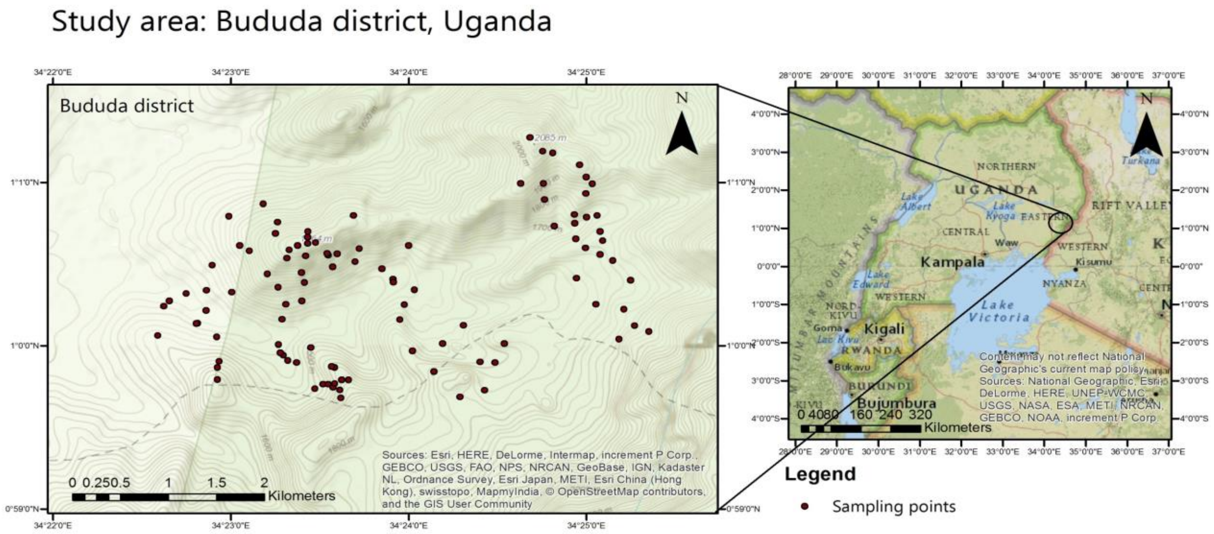
3 Study area

The study area is located in the Bududa and a small portion of the Manafwa district, in Eastern Uganda, on the slopes of the Mt. Elgon complex. The area is bounded by the latitude 0° 50' - 1° 05' N and longitude 34° 20' - 34° 30' E (Figure 1), located at the Ugandan-Kenyan border. The mountain range is an extinct Pliocene shield volcano with steep mountain slopes (Knapen et al., 2006). The slopes consist of clay loams to sandy loams such as: nitisols, cambisols, lixisols, ferralsols, leptosols, gleysols, and acrisols (Kitutu et al., 2009).

The region has a bimodal wet season climate stretching from March to June and August to October, separated by a distinct dry season from December to February. The land use in the area is mainly agriculture such as farming and grazing, but the region is also partly covered by forest. The crops grown in the area are mainly banana, coffee, cassava, onion, cabbage, and tomatoes.

The study area is one of the most densely populated regions in Uganda, and the Uganda Bureau of Statistics (UBOS) estimated 353,825 inhabitants in Manafwa and 210,173 inhabitants in Bududa (Nakileza et al., 2017; UBOS, 2016). Furthermore, the population density in the region ranges between 250 and 700 persons per square kilometer (Jiang, Bamutaze and Pilesjö, 2014). The area has experienced a large increase in population, which has caused major changes in land cover, from forest to agriculture. Due to the enhanced demand for land, agricultural fields are pushed up on the unstable mountain slopes. The disturbance of changing drainage pattern, destabilizing slopes and removing vegetation are according to Highland and Bobrowsky (2008) the primary reasons to how humans contribute to the increased occurrence of landslides.

Figure 1: Location of the study area. Dashed line represents the border between Bududa district in the North and Manafwa district in the South.



4 Data and methodology

The root density was estimated qualitatively in field on the 7th and 8th of February, 2018, by classifying the vegetation types divided according to root/shoot ratios (Foxx, Tierney and Williams, 1984). The measure of vegetation density was carried out in field by noting the field cover of grasses, shrubs, small trees (0-3 m), tall trees (>3 m) and agricultural crops. Average distance between trees, if present, was also noted. The information gathered in field for both vegetation type and density was combined into five classes aiming to describe both density and depth of the root systems: non-existing, little, medium, dense and very dense (see Table 1).

Table 1: Classification scheme for estimation of root system density based on vegetation type and density.

Root system density	Vegetation class	Criteria	Example of vegetation type
1. Non existing	No vegetation	>50 % cover	Harvested field
2. Little	No vegetation	>50 % cover	Elephant grass, cabbage, sweet potato, tomato, onion, beans
3. Medium	No vegetation	>50 % cover	Banana, coffee, cassava
4. Dense	No vegetation	>50 % cover and >5 m distance between trees	Banana with eucalyptus, guava or pine
5. Very dense	No vegetation	>50 % cover and <5 m distance between trees	Eucalyptus, pine

Sampling was performed following (walking) transect lines in a random direction with a stop every 15 minutes. The location of the stop was considered the middle of the sampling plot, which covered an area of 30 x 30 m, corresponding to the cell size of the satellite data.

The satellite indices Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) are commonly used for remote estimation of vegetation density (Xue and Su, 2017; Matsushita et al., 2007). To investigate the possible relationship between these indices and the ground truth data, NDVI and EVI were derived from band 1 (blue), band 4 (red) and band 5 (NIR), (see equation (1) and (2) below) of Landsat 8 Operational Land Imager (OLI) sensor data (Broadband Vegetation Indices, 2015).

$$NDVI = (NIR - Red) \div (NIR + Red) \quad (1)$$

$$EVI = 2.5 \times (NIR - Red) \div (NIR + 6 \times Red - 7.5 \times Blue + 1) \quad (2)$$

Satellite data were recorded on the 12th of February 2018 with a 30 m resolution (surface reflectance). Apart from the two indices mentioned above, analysis based on the visible spectrum (3 bands) and NIR were also evaluated. The continuous satellite data for the field sample locations were divided into five equal intervals based on the spectral reflectance or index value, with the classes for extreme values being open ended.

Cohen's kappa values were computed for the whole dataset as well as for the individual classes within each index and wavelength band (Foody, 2010).

5 Results

Three single bands as well as the two indices have been tested for possible links to root system density, and the results are presented in the following two sections.

The maximum kappa coefficient was found for blue wavelength band, with a kappa value of 0.081 (see Table 2 below).

Table 2: The kappa statistics for each single wavelength band and root system density class, respectively.

	NDVI	**EVI**
1. Non-existing	-0.002	0.002
2. Little	0.012	-0.003
3. Medium	0.023	-0.021
4. Dense	-0.264	0.000
5. Very dense	0.016	-0.002
Overall kappa	0.061	-0.025

The possibility of each index to estimate root system density is presented in Table 3 below, and shows that NDVI has a higher overall kappa than the EVI.

Table 3: The kappa statistics for each index and root system density class, respectively.

	Blue	Green	Red	NIR
1. Non-existing	-0.002	0.012	-0.001	-0.003
2. Little	0.015	-0.005	-0.001	-0.002
3. Medium	0.018	0.092	-0.001	-0.018
4. Dense	0.022	-0.024	0.000	-0.031
5. Very dense	0.011	-0.005	0.005	0.000
Overall kappa	0.081	0.078	0.002	-0.064

6 Discussion and conclusion

This study was aimed to test the accuracy of using satellite data as a proxy for root systems. However, the results are showing weak relationships between remotely sensed and ground truth data. Surprisingly, NDVI, EVI, and NIR, that are common for vegetation mapping (Yang, Wang and Shi, 2013; Oh et al. 2012) have lower kappa values than the results gained from the single wavelength bands of blue and green. Possible reasons for this are discussed in the following section.

First, the ground truth data is based on a qualitative field estimation based on the vegetation type and density, whereas a larger study could include quantitative measures of the root system density (Gaidashova et al. 2012). Second, another limiting factor is the available data over the Mt. Elgon region. This study demonstrates that a resolution higher than 30 m might be necessary for identifying a possible link between different wavelength reflectance and vegetation cover, which indicate that current accessible data may not be sufficient. Third, transect sampling following existing paths was considered the only possible sampling methodology in the densely populated and cultivated study area. This leads, however, to a large number of sampling points being cultivated areas rather than the less accessible forest areas. This uneven distribution of field points within each root density class might have contributed to the unsuccessful results and for future studies a stratified random sampling method, where a larger variance in vegetation could be studied, should be taken into consideration.

Another method, which could improve the accuracy of estimated points is image classification (maximum likelihood classification) where training field data is used to help the program automatically classify each cell of the image/satellite data.

To conclude, with a maximum kappa value of 0.081**,** this study finds no proven link for using satellite data as a proxy for root systems.

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