

Landslide management on the Ugandan national road network

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ABSTRACT

Landslides are recurring natural phenomena that occur frequently in the Ugandan mountain areas of Rwenzori, Mufumbiro and Elgon. In these areas, significant environmental, social and economic losses, such as road infrastructure damage and displaced settlements, have resulted. Despite these impacts, there have been no significant efforts to extensively map landslide-prone areas in relation to the road infrastructure. Maintaining the stability of the road reserve and its associated engineering assets is a priority for the Uganda National Road Authority, and this requires a focus not only on earthworks slopes but also the wider terrain in which the road is constructed. A web-based landslide data inventory has been set up within the Uganda National Road Authority to record landslide events and impacts and this will be combined with other GIS and remote sensing sources to develop a map of hazard-prone areas. The establishment of guidelines to maximise environmental and social benefits through optimum management of the road reserve, integrating engineering with community participation and agricultural extension would also be of benefit to future practice. Community liaison and cross-agency co-ordination on aspects of slope management outside of the road reserve are also critical to road asset management within the road reserve.

INTRODUCTION

With assistance from the Research for Community Access Partnership (ReCAP) programme, funded by DFID (Department for International Development, United Kingdom), the Uganda National Roads Authority (UNRA) is implementing a project that examines the distribution, cause, mechanism and impact of landslides and related slope geohazards on the road network, and examine ways in which the management of the road reserve and adjacent terrain can be optimised in order to avoid, reduce and mitigate these hazards. The project also aims to develop and apply a holistic approach to slope management benefiting road reserve maintenance and the livelihoods of adjacent communities.

BACKGROUND

Geography

Uganda straddles the Equator in East Africa between the western and eastern branches of the East African Rift System (Figure 1). It has a surface area of approx. 240,000 km², the majority of which is comprised of flat to low relief terrain at an elevation of 1,000-1,500m a.s.l. However, there are mountains to the west, east and south of the country, reaching approximately 5,100 m a.s.l on the DR Congo border. Average temperatures range between 16-25°C in Kampala and rainfall is generally between 900mm and 1500mm per annum, with December to February being the drier months.

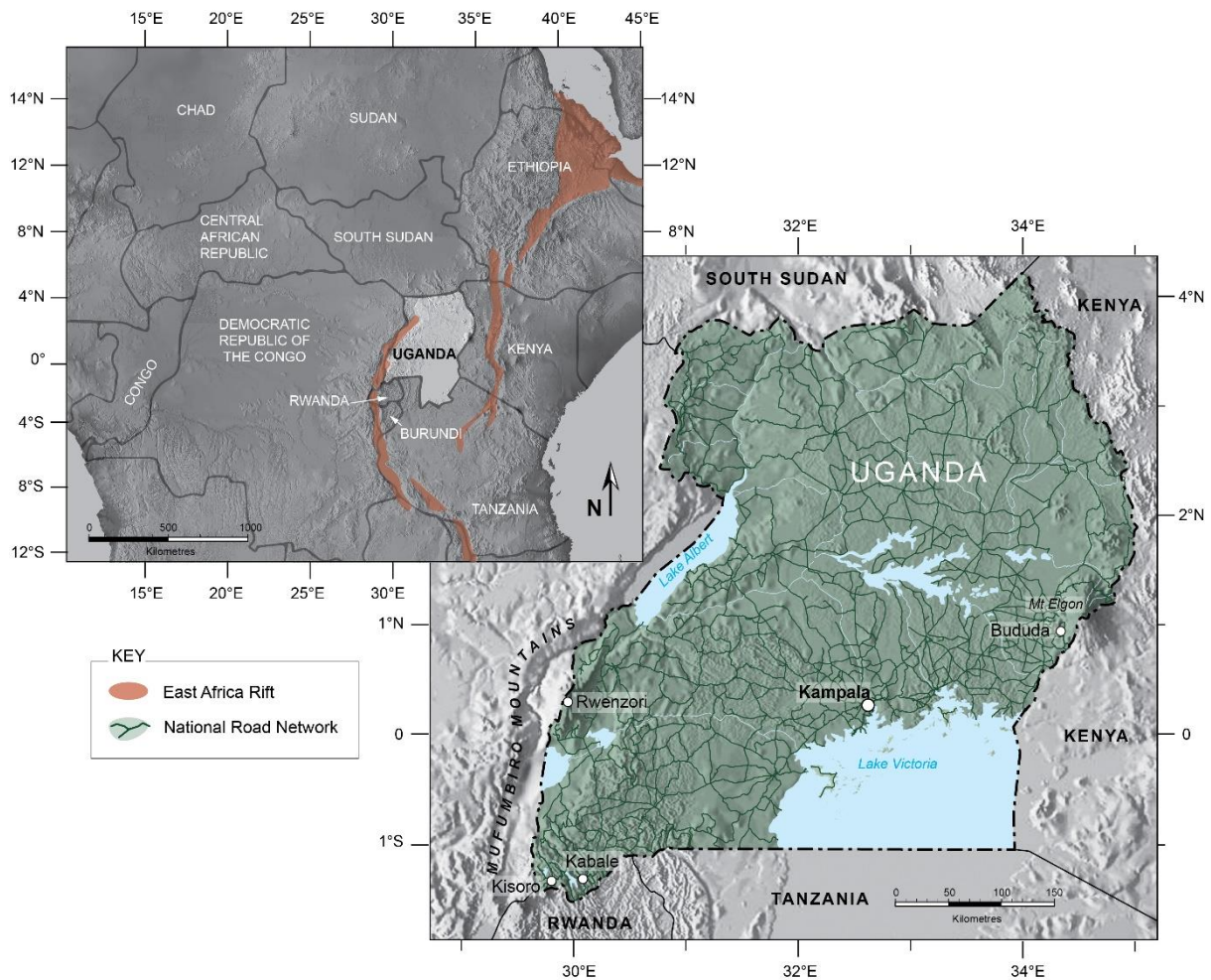


Figure 1 - The topography and road network of Uganda

Geology and geomorphology

The underlying geology comprises Precambrian granitic and low to high grade metamorphic rocks (mostly meta-sediments, shale, phyllite, schists and gneisses). Both intrusive and especially extrusive volcanic rocks are also present, including lavas, tuffs and other pyroclastic materials. There are several volcanic provinces in the country, including the now extinct Mount Elgon region (Figure 2) in the east (Palaeogene - extinct) and the Mufumbiro region (Figure 3) west of Kabale in the south of the country (Quaternary - active). Given the equatorial climate of the country, weathering has been intense and ferrallitic soils are extensively developed, and is locally susceptible to landslides. This contrasts with areas where the soils have been eroded away to expose an extensive rock surface that is rarely susceptible to slope failure. Elsewhere, silt and clay soils have been deposited within alluvial basins and on valley floors, many of which underlie swampy, low-lying, areas. Further information on the geology of the country can be found, for example, in [1].



Figure 2 - Cliffs and debris slopes formed in lava and pyroclastic materials, Mount Elgon, where rock falls and toe-slope landslides are common.



Figure 3 - Volcanic terrain around Kisoro (collapsed cones and lava flows are common)

Road network

Uganda's total road network is estimated to be 129,469 Km long, 50 % of which are community access roads, 26% are district roads, 7% are urban roads and 17% are national roads (www.works.go.ug). UNRA is a semi-autonomous government agency that was created in 2006 and became operational in 2008. It is responsible for the management of the national roads network. At the time of UNRA's operationalisation, about 10,000km of district roads were reclassified as national roads bringing the national road network to approximately 20,544km. 21% of the national road network is bituminous while the rest are gravel or earth roads.

LANDSLIDE HAZARDS

Landslide impacts on rural communities

There have been major landslides affecting parts of Uganda in recent years, inflicting considerable loss of life and resulting in the displacement of rural communities. For example, landslides have struck the district of Bududa, to the south of Mt Elgon (Figure 1), with records from as early as 1818 and 1933 [2], and key events noted in 1964, 1970 and 1997-1999 [3]. Large events in 2010, 2012, 2013 and, as recently as October 2018, have caused a significant number of fatalities on each occasion. In 2010, for example, a reported 365 people lost their lives [4]. Up to 3,000 people have been displaced and reports indicate [2] that up to perhaps 10,000 people may need to be relocated away from high hazard areas. The landslides have destroyed homes, villages, community centres and large areas of farmland. Figure 4 shows a rock failure from a cliff face that occurred in October 2018, causing several fatalities and demolishing part of Lusabe village below.

A large number of research publications and reports have been prepared that examine the causes and consequences of landslides, especially in the Bududa-Mt Elgon and Rwenzori regions (e.g. [4], [5], [6], [7], [8], [9], [10], [11] & [12]). Most of these studies focus on the human losses that accrue from landslide activity and the interaction between land cover change, population increase and landslide hazard. There are no published studies that address the interface between these landslides and the stability of the road reserves and how public sector agencies and affected communities can work together to avoid or mitigate these hazards.



Figure 4 - Rock fall debris in foreground from slide scar in centre of background (Oct 2018)

Landslide impacts on the road network

Sections of the road network are affected periodically by landslides and slope failure, of which the following are usually the most common:

- Cut slope failures, often involving movement along adversely orientated rock jointing (Figure 5A)
- Fill slope failures, often involving movement along low-strength clay horizons beneath (Figure 5B)
- Earth flows from the slopes above the road reserve, often triggered by spring seepage and irrigation practices (Figure 5C)
- Rock falls from natural cliffs above the road (Figure 5D)

In addition to the above, there are cases where sections of road have been excavated across large, deep-seated, landslides that have subsequently become reactivated. In the example shown in Figure 6 more than one kilometre of alignment was constructed across such a landslide. What was originally a designed vertical and horizontal alignment has now become an erratic track that requires regular reinstatement to allow traffic to pass.



5A Rock failure along adverse joints



5B Fill slope failure with underlying soft clay



5C Slide scar of earth flow that blocked road



5D Rock falls from natural cliffs above road

Figure 5 - Illustrations of earthworks failures and natural slope instability affecting parts of the Uganda road network



Figure 6 - Horizontal displacement to this originally straight section of road with rotation and structural damage to adjacent buildings

THE UNRA/ReCAP LANDSLIDE AND ROAD RESERVE RESEARCH PROJECT

The overall objective of the research is to improve the resilience of road infrastructure through landslide management and optimisation of road reserve use. Specifically, the research will:

1. Analyse landslide and road reserve use problems in Uganda;
2. Develop a spatially referenced, web-based system for landslide data collection and geographical analysis; and
3. Develop guidelines for the optimum use of the road reserve and adjacent hillsides in terms of land use and slope management.

Road reserve use

The Road Reserve in Uganda is currently nominally 40m either side of the centre-line. In hilly and mountainous parts of the country this road reserve comprises cut slopes and fill slopes, with the occasional use of retaining walls (Figure 7). Incursion into the road reserve for commercial use is commonplace in built-up areas and along the more highly-trafficked roads, potentially leading to conflicting priorities in the need to preserve rural livelihood while at the same time maintain the stability and engineering functionality of the road reserve.



Figure 7 - Use of gabion retaining walls to support vulnerable sections of cut slope

In terms of slope stability and landslide risk, encroachment into the road reserve has the following main elements:

1. The construction of roadside structures for commercial use and living accommodation. This often involves excavation of slopes to provide space, thus reducing the stability of slopes and placing buildings and their occupants at risk;
2. Excavation of materials from within the road reserve for commercial exploitation, often removing support to hillsides above and potentially precipitating slope failure;
3. Construction of accesses (paths and farms tracks), usually through excavation; and
4. Farming on slopes adjacent to the road, thus potentially encouraging soil saturation through irrigation or reduced stability through excavation for agricultural benches.

While all four elements are important, it is the agricultural use of the slopes adjacent to and within the road reserve that will be one of the prime focuses of this research. Significant progress has been made by DFID-funded investigations, particularly in Nepal (e.g. [13] & [14]) and Laos [15], into the use of bio-engineering as an important tool in erosion control and in assisting with the improved stability of cut slopes and fill slopes. In particular, a participatory approach, whereby local communities are engaged in slope management through controlled water use and harvested planting schemes that add engineering value will also be explored. Low cost techniques of slope stabilisation will also be examined using engineering approaches in parallel with these initiatives.

Outside the road reserve, there is need to engage with rural communities, government agencies and other stakeholders in order to develop guidelines for sustainable slope management.

Development of a GIS-based landslide susceptibility dataset

Although there are research publications that show landslide locations in specific areas of the country, notably around Bududa and in Rwenzori, no systematic mapping has been undertaken. The UNRA/ReCAP study is currently examining stereo aerial photography and satellite imagery to determine whether they offer any practical basis for landslide mapping. An alternative, or complementary, approach will be to use a geomorphological terrain classification to help identify landslide-prone areas, probably along the lines of that developed by [16] (see Figures 8 and 9). This will enable UNRA to prioritise its investment in the use of proactive avoidance and mitigation measures.

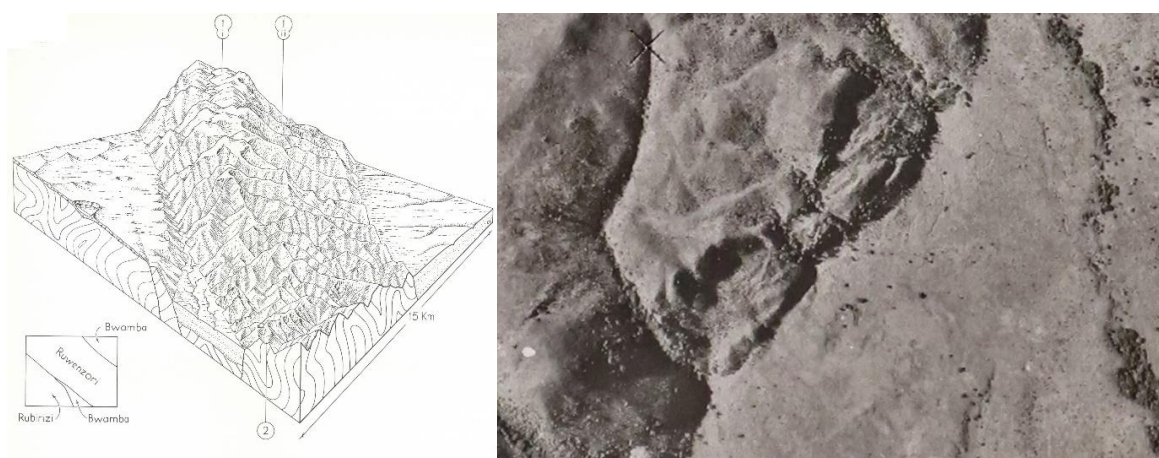


Figure 8 - Example of Northern Rwenzori Land Unit (from Ollier, 1969) and aerial photograph of large landslides at the slope-floodplain boundary

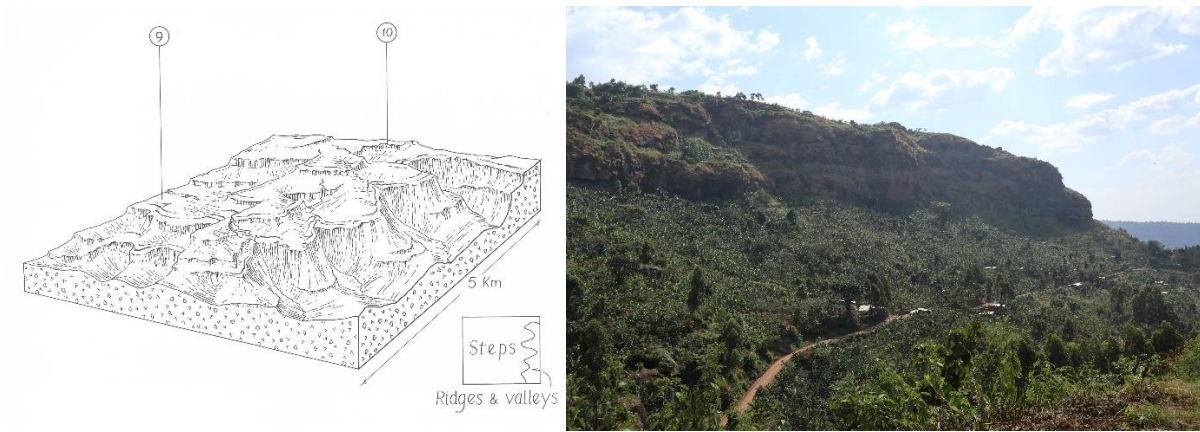


Figure 9 - Example of Elgon Steps Land Unit [16] and field photograph of terrain with rockfall and earth flow hazard to the adjacent District Road.

Web-based tool for data collection and road reserve management

A key requirement in the management of landslide hazards on the road network is a knowledge of where the main landslides are and which parts of the network are most susceptible to future landslide activity. To this end a web-based landslide inventory system has been established that will enable UNRA's station managers to enter landslide data for road sections for which they are responsible. This system has only recently been launched and it is too early to commence data analysis. Table 1 summarises the data fields that are required to be completed. The data fields are subdivided into six categories, as indicated in the column headings of Table 1. The rows below these headings illustrate the main data fields that have to be completed.

Table 1 - Summary of data fields in the web-based landslide inventory

General	Landslide Origin	Impact	Land use	Reinstatement	Other damage
Date of inventory	Inside or outside Road Reserve; On natural slopes above/below	Blockage (side drain; inside carriageway; entire road)	Land use in the source area	Reinstatement measures employed/ planned	Buildings, retaining walls, culverts, bridges, cables, pylons
Location of road	Cut slope failure; Fill slope failure; Wall failure	Cracking (side drain; inside carriageway; entire road)	Evidence of change	Reinstatement cost	Traffic accidents: injuries fatalities
Location on road (Km and GPS)		Displacement (inside carriageway; side drain; entire road)	Drainage condition	Funding for reinstatement	
Cause		Road closure period			
Road length affected		Volume of debris			
Road surfacing					
Type of slide (new; reactivation; extension)					

DISCUSSION AND CONCLUSIONS

The research project outlined in this paper commenced in early 2019 and is therefore in the process of early development. Its aim is to establish a dataset that can enable UNRA to record, monitor and perhaps anticipate landslide hazards on the road network. It will also investigate and provide guidance on the management and stability of the road reserve and the wider terrain. This will require discussion and co-operation with rural communities and other government agencies who have an interest in maintaining the stability of the natural terrain. Measures to enhance community livelihood through the use of the road reserve as a potential extension for controlled agriculture will also be examined so that both engineering and social benefits can ensue.

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