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Landslides Mapping and Susceptibility Analysis Using RS and QGIS Techniques in Chiweta Area, Northern Malawi

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Abstract

Landslides are disastrous and fatal geohazard capable of retarding developmental process of the nation as it grapples with recovering from the damage incurred. In this study, Remote sensing (RS) and QGIS techniques were used to map out landslides and assess susceptibility to landslides occurrence around Chiweta area in Rumphi, Malawi. RS input data was acquired from a USGS website. Deskwork involved identification of sites of landslides occurrence on the downloaded satellite images. Fieldwork was then done to validate the information from satellite images. During the landslides mapping survey, 46 landslides were recorded. DEM data and landslides data were processed in QGIS to obtain the results. The outcome show that the distribution of mapped landslides and the exposure to landslides hazard risk is high on NE-SE and S-SW facing and occurred within 15 m distance to the road and 0-100 m from the major streams. Landslides also tend to concentrate in altitudes of 500-1000 and a few others in the 1000-1500 at slope angles ≥ 60^0 and in a rare phenomenon at ≤ 30^0. With respect to geology, mapped landslides are concentrated in sedimentary rocks which are inherently weak rocks as compared to crystalline rocks but some landslides were found in highly weathered cut metamorphic rocks.

Keywords: QGIS; Chiweta; RS; Landslides; Predisposing factors

Introduction

Landslides are disastrous and fatal geohazards that can retard the developmental process of the nation. Global examples of such phenomena include: the 1958 Kanogawa slides and mud/debris flow in Japan that recorded 1,094 fatalities, the 1963 Vaiont rockslide that claimed 2000 lives, the 1987 Reventador landslides in Ecuador that killed 1000 people, the 1994 Paez landslides in Colombia in which 271 people died, that 2008 Cairo landslides that gave rise to 119 fatalities, the 2010 Gansu mudslides in China that claimed 1,471 souls, the 2010 Uganda landslides that killed up to 300 people, the 2014 Malina landslides in India in which 150 people died, the 2015 49 feet high Guatemala landslides that claimed 220 lives, the recent 2017 Bangladeshi landslides that killed 152 people, the 2017 Siera Leone mudslides that led to 1,141 fatalities and the recent 2018 South California landslides that claimed 20 live [1,2]. All these events were associated with lossess in billions of dollars and displacement of people due to distruction of infrustructures. The mountainous terrain of the region is generally a recipe for occurrence of landslides. Landslides susceptibility mapping of an area can be assessed and predicted through scientific investigation of landslides and many methods and techniques have been proposed to evaluate landslide prone area using Geographic Information System (GIS) and/or remote sensing (RS) [3-6]. With prohibitive cost of GIS software, Quantum Geographic Information System (QGIS) which has resemblance to GIS is applied in this study. However, the operations of the two applications are quite distinct. QGIS is a well-known and equally efficient open-source GIS software package capable of creating multiple maps with multi-layered projections and short start-up time [7]. Additionally, QGIS falls under the General Public License (GNU) so that it can be modified to carry out various special tasks. Assessment of landslides susceptibility assists in identifying and delineating hazard-prone areas so that planners can select favourable locations for sitting development projects like dams, roads etc. Chiweta area experiences a number of landslides which are merely considered events of no terror. For instance, [8] documented 98 landslides that occurred in 2003 at Ntchenachena and Chiweta areas in the Rumphi District. This is because of no fatalities as most people are settled close to the lake in search for a better source of income from fishing industry. Since the area is uninhabited landslides that occur are never qualified as disasters. However, the current settlement pattern and anthropogenic activities have the potential to influence major annihilating event. This contribution is aimed at mapping out landslides and provides an insight on landslides susceptibility of the study area.

Location and geology

The study area is situated in Rumphi district North of Malawi (Figure 1a). Chiweta, just as Karonga is potentially vulnerable to strong seismicity as it fall within the Malawi Rift System (MRS) which is part of the East Africa Rift System (EARS). Temperatures in the area are generally high with a maximum of over 30°C due to the proximity to lakeshore and low altitude. But, the upper areas of the Chiweta beds register relatively low temperature [8]. Additionally, the area receives high precipitation with annual rainfall ranging from 949 to 2631 mm with an average of over 1400 mm.

The geology of the area comprises of the basement complex of Precambrian to lower Paleozoic rocks principally biotite gneiss and schist (Figure 1b) [9]. The Precambrian rocks are overlain by the sedimentary Karoo system which extends from South Africa. The sedimentary rocks in the area consist of chocolate brown and grey mudstone referred to as the Chiweta beds which dip Northwards at about 10° [10,11]. In the upper part, Chiweta grits which are composed

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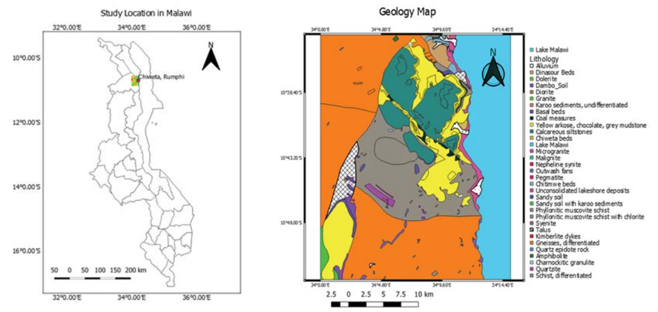

Figure 1: Location and geology of the study area.

of thick-bedded purplish grits with rare partings of mauve sandstone, are separated from the mudstone by an unconformity and the lower part of the mudstone consist of modular limestone and marly conglomerates [11]. Conglomerates in the central part of the mustone sequence contain pebbles with limestone, mudstones and rolled bone fragments [9].

Methodology

A heuristic approach in interpreting the QGIS processed results layers is applied in the assessment of landslides distribution and susceptibility (Figure 2).

RS data

RS images have the ability to provide data even from difficult to access areas. Apart from free access, they provide a good historical data on a regional scale with a high degree of accuracy. The study has made use of Land Remote-Sensing Satellite Operational Land Imager (Landsat8OLI), Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) as inputs in QGIS to assess susceptibility to landslides occurrence. The data was downloaded from a UGS website. Deskwork involved identifying sites of landslides occurrence which were then validated through field survey.

Field survey

Ground-truth was conducted to establish and authenticate identified spots of landslides using satellite images. The points were recorded using a Geographic Positioning System (GPS) since the size of the features is not very huge. The dip angle and dip direction of the rock outcrops were recorded using a Brunton compass and the distance of the landslides from the road and/or streams was measured using a tape measure. Geological and structural mapping was also carried out during the landslides mapping to ascertain the literature information on the geology and structures. The data collected include: lithological units, discontinuities and their attributes and weathering conditions of the outcrops. Potential sites of debris and/or rock fall were also observed but not recorded alongside landslides. Geomorphological observations were done to appreciate and compare terrain view with the remotely acquired data from satellite images (Figure 3).

Data analysis in QGIS

To establish landslides distribution and susceptibility leading to production of landslides map, RS input data and field survey data were processed and analyzed in QGIS. The key predisposing factors to landslides were tested in QGIS using the DEM data to investigate the slope angle, elevation, slope aspect and lithology. Landsat-8 and ASTER data assisted in imagery desk work identification of landslides and the

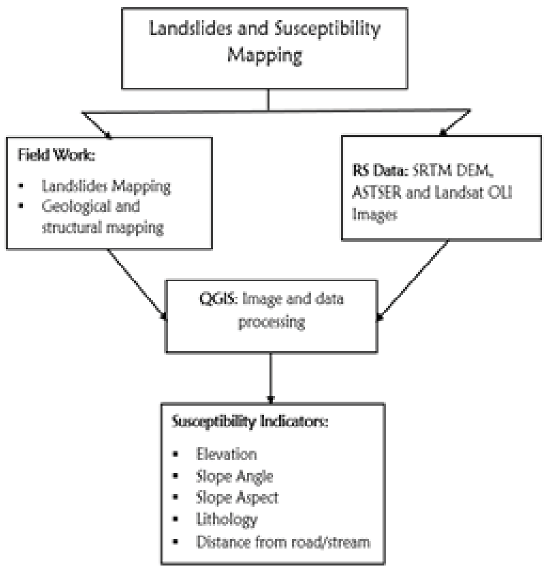

Figure 2: Approach to landslides and mapping.

Figure 3: Landslides recording and measurement during field survey.

field collected data was exported onto the images for validation. Other input data include: seismic data and measurements of distance from the road and/or water bodies.

Results and Discussion

This section presents results of landslides predisposing factors and an ultimate landslides and susceptibility map. Knowledge of the key contributing factors to landslides is vital in the evaluation of spatial distribution and feasibility of landslides occurrence.

Slope aspect

Aspect, which is the compass direction that a slope faces, plays a pivotal role in influencing landslides occurrence. In QGIS, the DEM was processed through the spatial analysis tool to evaluate the extent of its effect in landslides distribution around Chiweta area. The aspect was separated into nine classes: flat, N, S, E, W, NE, SE, NW, and SW. The classes were separated at an equal interval of 45°. Figure 4a shows that greater density values from the recorded landslides are concentrated in NE and SE and S and SW facing slopes. This is contrary to the trends observed in LS studies performed in the northern hemisphere where greater density values are concentrated on the E-SW and NW facing slopes [6,12-17]. The pattern in Chiweta can be attributed to penetrative and quite persistent discontinuities which are either orthogonal or

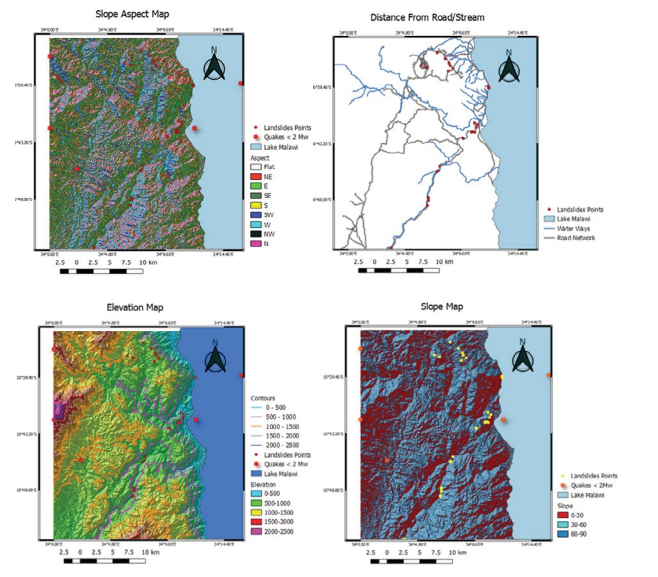

Figure 4: Landslides predisposing factors.

parallel to the dipping direction of rock beds. The NE and SE facing slopes are also favorable for landslides due to longer exposure time to sun rays as the slopes daylight expediting physical weathering by repeated heating and cooling of the rocks. The S and SW facing slopes are characterized by mixed water and gravity trigger landslides which would imply precipitation direction during rainy season leading to intense wetting effect.

Proximity to road/stream

The field survey affirmed that landslide hazard is strongly correlated to mountain road ways in Mwale Chiweta area. Mapped landslides occurred within 15 m distance to the road and 0-100 m from the major streams (Figure 4b). While it is apparent that the water action in the streams deduce the shear strength of geological material on the slopes dipping into the streams, the landslides incidences on the road way is ascribable to a number of factors. Road constructed on the side of the slopes causes a decrease in the load on both the topography and on the heel of slope. Consequent to an increase in stress at the back of the slope due to changes in topography and decrease of load some tension cracks may develop rendering the cut faces susceptible to failure. The road cutting faces are also exposed to excessive water ingress and they have become extremely weathered due to adverse climatic conditions such that they can no longer withstand the overloading on the hill slopes and there is no regular inspection to make required remediation. The interventions, in the area, are only reactive to incidences when it occurs like in 2016 when a huge landslide blocked the road rendering it impassable. Additionally, the roads are characterized by poor engineering designs. For instance, there is lack of proper drainage system and slope toes are left unsupported making the slopes vulnerable to landslides. The observation echo a generalized comment that in developing countries highways are vulnerable to landslides due to poor road engineering designs [18].

Elevation

Topographic influence was evaluated from DEM to establish its role in the distribution of landslides. The processed image was classified at an equal interval of 500 m with the highest altitude at 2413 m. The results reveal that landslides are concentrated in altitudes of 500-1000 and a few others in the 1000-1500 (Figure 4c). Highest categories of elevation did not show manifestations of landslides on the ASTER and Landsat image and the field investigation could not identify any occurrences. These elevations locate on the base of hillslopes of mountainous terrains. The results are in agreement with other studies that studied altitude effect on landslides occurrence [19-21]. For instance, [21] study revealed that 980 m and 755 m elevation fell in the high susceptibility zone and 1,020 m, 1,150 m, and 1,110 m elevation fell into the very low susceptibility zone. The outcome of elevation in this study must be a cause for worry for probable fatal landslide event in the area as people are constructing closer to the toe of the hillslopes and also cultivating on the hillslopes.

Slope angle

Slope angle is a principal predisposing factor in landslides susceptibility mapping owing on the fact that it is directly associated with landslides occurrence. Many authors [19,22-24] point out that local slope is likely to be the strongest control on landsliding with distinct outcome. Thus we created slope map from the DEM and divided the categories into three equal intervals in order to appreciate the distribution of the risk (Figure 4d). The results of the slope map correspond well with the mapped landslides during the field survey in which dip angles $\geq 60^{\circ}$ recorded 51% of the landslides. Mapped landslides locate at the base of steep hillslopes which are not supported by some engineering reinforcement. Since the faces are highly weathered, landslides constantly occur on these cut faces. It was also fascinating that dip angles $\leq 30^{\circ}$ registered landslides principally due to penetrative and persistent discontinuities parallel to the slope face and orthogonal to the dipping direction of the rock beds. This structural complexity renders the slopes vulnerable to gravity controlled landslides.

Lithology

Geology was evaluated to establish the distribution of landslides in the study area with respect to lithology and draw inference on the susceptibility of the area. Figure 5 reveals that mapped landslides are concentrated in sedimentary rocks which are inherently weak rocks as compared to crystalline rocks. The uniqueness of the study results to similar results on lithological influence on occurrence of landslides [25-32], is the controlling strength of the structures. Discontinues were found to be penetrative and quite persistent plunging transverse to the bedding planes of the rock beds on the slope faces. This structural

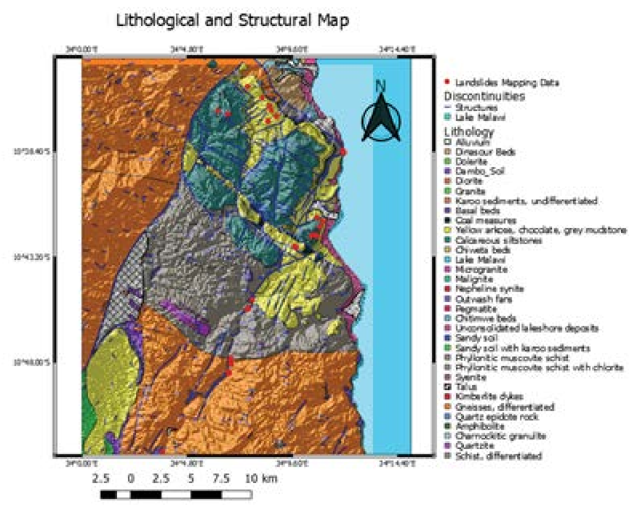

Figure 5: Landslides distribution with respect to lithologies and discontinuities.

Figure 6: Structures built on the mountain base with unsupported landscaping and cassava field on the slopes of one of the many mountain ranges in the area.

complexity renders the lithological units vulnerable to landslides. It should be noted from Figure 5 that the sedimentary rocks predominate in the area which raises the landslides susceptibility. A few landslides also occurred on degraded slopes of highly weathered metamorphic rocks whose outcrops are cut on the hillslopes. The cut faces have a poor drainage mechanisms and are not reinforced with no regular maintenance (Figures 4-6).

Conclusion and Recommendation

The results of the landslides mapping indicate that landslides, which are characterized by rock falls and debris and rock fall, are concentrated along the M1 main road and on slopes dipping into the streams. The field survey conducted revealed evidence of rainfall trigger on some landslides but most of the recorded landslides are the function of gravity. Thus we recommend shortcreeting highly weathered crystalline rocks and creating retaining walls on weak sedimentary rocks coupled with good drainage system. Despite, being located within the active rift zone, seismic effect in the study area is negligible because most of the quakes occurring around the area are less <2 Mw which is far less than the minimum ≥ 4 Mw magnitude acceptable to trigger small landslides [25-34]. They study also establish a great change in land use. It was observed that people's settlement and agricultural practices are trending towards the foothills and hillslopes creating predisposing interference that may lead to fatal landslides. People are constructing their structures within 0-100 m away from steeping mountains, wantonly cutting down trees on the mountain ranges for biomass and cultivating on the slopes rendering it vulnerable. It is recommendable that this trend be halted and people should be encouraged to plant trees and refrain from cultivating the mountain slopes. Most, importantly the district council and government arms should provide civic education for a better understanding.

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