DISASTER SCIENCE AND ENGINEERING p. 1-7, 1(1), 2015

Landslide Occurrences in The Hilly Areas of Rwanda, Their Causes and Protection Measures

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Received: 10.02.2015 Accepted: 15.04.2015
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Abstract Rwanda being a small country in central Africa, it is not well known for landslides, but recently especially in the years with above normal rainfall and with high increase in population per kilometer square the loss of life and property from landslides and mud flows is increasing. This research assesses the factors that influence landslide occurrences in Rwanda, their impacts on the livelihood of the people, their causes and protection measures. For almost 10 years from 2000, heavy rains and landslides left 108 people dead and ten thousand displaced and landless mostly in North and Western provinces. The volume of debris from landslides was 110 million m3 in and this was deposited into rivers and streams or in transportation roads. Twenty nine of these landslides dammed rivers resulting in high losses of fertile soils and infection of fresh waters with used chemicals in cultivating those lands. The main landslide types are debris flows which occur on concave slopes where water concentrates and with the layer of clay downward water pushes the land to slides laterally. These landslides occur on steep slopes that are concave and between slope angles of 140 to 550. Slopes facing north-west and West are most prone to landslides which coincide with the dominant rainfall in the areas. The soil types in this area are those conditioned by topography and tropical climate namely Nitisols, Ferralsols, Leptosols, Gleysols, and Acrisols. The soils contain medium to high plasticity clays and according to the Atterberg limits they approximately fall in the categories of kaolinite. The top soils also have a high infiltration rate which allows fast flow of water into the deeper clay rich horizons promoting water stagnation causing slope failure. The main triggering factor is rainfall and rainfall events of low intensity but prolonged for days are thought to be more disastrous however, this is an area that needs further investigation. İn order to reduce the occurrences of landslides terraces have started being constructed by the government and local people and afforestation is being promoted everywhere with the theme ‘’cut one tree plant three’’ in order to fight against landslides disasters with the construction of slope retaining walls, but still not yet a zoning map hasn't being done, it is of high need to implement a map of zones vulnerable to landslides in the whole country so that people will be able to avoid those places in their daily works.

Index Terms— Landslides, Slope, Convex, Concave, Cohesion, Atterberg limits, Rainfall

I. INTRODUCTION

MASS movements are recognized and well-documented global geomorphic hazards due to their major role in the development of slopes in mountainous areas, and their considerable economic, social and geomorphological impacts to the environment. However, many researchers have attributed landslide in Central and East Africa with the marginally stable and actively unstable slopes of mountainous areas to a combination of preparatory and triggering, causal factors such as rainfall, land use, earthquake zones etc. Those triggering factors, including human activities (such as cultivation, excavation for housing, foot paths and deforestation) tend to place slopes in a marginally stable state, making them susceptible to mass movement without actually initiating it. Triggering factors shift slopes from being marginally stable to becoming actively unstable by initiating movement. Such factors include seismic activity, extreme rainfall events related to the equatorial zone and the concentration of runoff in restricted infiltration zones with high silt-clay soils and hollows [1].

Rwanda is currently vulnerable to climate change as it is strongly relying on agriculture which makes the high use of available land both for rural and cities livelihoods and for this we experience emergency situation from flooding and landslides disasters caused by the change in weather resulting from high deforestation and cultivation of high slopes [1]. Rwanda is located in equatorial zone of Africa, with high intensity of rainfall per year. This is particularly important for agriculture, where crop yields are positively affected by temperature and rainfall but also negatively affects the soils by providing high saturation of soil profiles resulting into high occurrences of landslides and mud flows [2]. According to the report from the ministry of natural disasters in Rwanda, from April to June 2012, at least 17 people have been killed and hundreds of houses were destroyed in the North-western Rwanda by landslides [2]. In December 2006, 14 people died and 2,000 were displaced after heavy rains caused flooding in northern Rwanda. The flood-waters submerged at least 5,000 homes and 3,000 hectares of farmland, forcing farmers to seek refuge on higher ground [2].

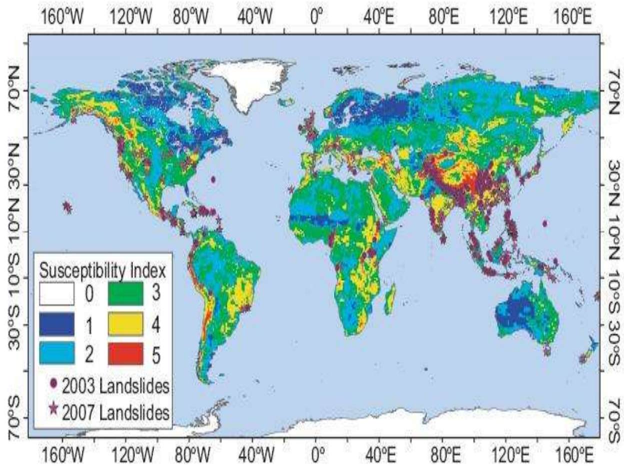

Fig.1 Landslides occurrences in the worlds.

Landslides in Rwanda like in most of East Africa, are among the very deadly natural disasters that are killing people without warning and at the same time carrying the county's most fertile soil to foreign water catchments among them Nile river catchment and Congo River catchment where the country is losing every year averagely 15,000,000 tons of very fertile soils [3].

Fig.2 A house destroyed by a LANDSLİDE in North of Rwanda, a family of 6 people killed MIDIMAR, 2011

Fig.3 A house destroyed by lateral landslides

Fig.4 Landslide block sliding into a stream

II. Types and Causes of Landslides in Rwanda and East Africa

A. *Influence of soil properties*

Two soil series occur in Bududa District as described by Ollier and Harrop in 1959 and these are the Bududa Series which consists of red clay loams originating from the Elgon volcanics and Basement Complex colluvium with a high to medium productivity [1]. The other is the Bubutu Series which consists of non-lateritised brown sandy clay loams originating from the Basement Complex granites with a medium productivity. A third series, the Bubulo Series is located in Manafwa District and consists of non-lateritised red loams and clay loams originating from the Basement Complex granites and amphibolites with a medium productivity [4]. According to recent researches , two basic types of residual soil occur at Cyanika carbonatite in Burera. These are light grey sandy soils which are rarely more than 5m thick and the fenite complex gave rise to much finer grained, red-brown soils, with a very thin A-horizon, which grades imperceptibly into an extremely thick and uniform B-horizon [5].

The influence of soil in mass movements cannot be underestimated. Soils play a dual role because it is a by-product of the landslide process and at the same time it is an important causal factor. The most important properties in soil stability are those that influence the rate of water movement in the soils and the capacity of the soil to hold water [5]. These include particle size and pore distribution of the soil matrix.

Finer soils tend to hold higher volumes of water under unsaturated conditions than do coarse textured soil. Clay particles are 0.002 mm or less in diameter and clay soils normally have more than 20% of these particles and this plays a great role in clay impermeability.

Soils in Rwanda have high clay content [5]. High clay content in deeper soils may increase the water holding capacity and give rise to long term progressive movement in certain cases and to move rapid failure in extreme cases [6]. Rwanda natural hazards ministry in 2013 reported a landslide in Burera village in North Rwanda, caused by over saturation of clay wich result in death of a family of 8 people. Soil layers rich in clay in deep horizons are significant in the cause of the slumps in the western side of Rwanda. Clay minerals result from the chemical weathering and breakdown of minerals in rocks and the production of secondary minerals. Chemical weathering disrupts the bonds between particles thus causing a reduction in cohesion.

Fig.5 High silt clay soils projected to landslides, MİDİMAR 2011

Three parameters play part in the triggering of landslides and these include, the clay content of the soil at a particular depth, the rate at which water infiltrates into the clay at that depth and the volume change of the soil over the period of water infiltration [6].

B. Influence of Slope Steepness

Relief is a principal factor in the determination of the intensity and character of landslides [1]. It has direct as well as indirect influences. Direct influences encompass slope, steepness, river valley morphology and talweg gradients. The most important relief characteristic is the steepness, which affects the mechanism as well as the intensity of the landslides [1]. The greater the height, steepness and convexity of slopes, the greater the volumes of the landslides [3]. The stability of the slope against sliding is defined by the relationship between the shear forces and the resistance to shear. The main force responsible for mass wasting is gravity [7]. Gravity is the force that acts everywhere on the earth's surface, pulling everything in a direction toward the center of the earth. On a flat surface the force of gravity acts downward and so long as the material remains on the flat surface it will not move under the force of gravity [7].

The perpendicular component of gravity helps to hold the object in place on the slope. The tangential component of gravity causes a shear stress parallel to the slope that pulls the object in the down-slope direction parallel to the slope. On a steeper slope, the shear stress or tangential component of gravity increases and the perpendicular component of gravity decreases. The forces resisting movement down the slope are grouped under the term shear strength which includes frictional resistance and cohesion among the particles that make up the object. When the shear stress (t) becomes greater than the shear strength (W) then the slope fails [8].

An important factor in the distribution of landslides is the slope gradient and mass movements only occur when a critical angle is exceeded. Mostly in Rwanda, landslides occur on slopes as high as 14° which is the lowest in all the studies. Most of North province in Rwanda are above 45° of slope gradient, West more than 35° and and South more than 25°.

Fig.6 Landslides in Rulindo, North province, REMA, 2010

C. *Influence of Undercutting of Slopes*

Rockslides resulting from human activities such as undercutting by roads or railroad excavations are more widespread than rockslides resulting from natural causes [2]. Human activities such as construction of roads, building developments, mines and quarries, dams and reservoirs, canals, increase of groundwater levels, changes in vegetative cover, tunnels and communication systems have a great impact on the stability of the area and are seen as the major factors causing slope failures in the twentieth century [2]. These human modifications fundamentally alter hill slope stability [2]. Slope undercutting due to house construction and also foot paths cause concentrated flows which trigger landslides mostly in the western part of Rwanda [2].

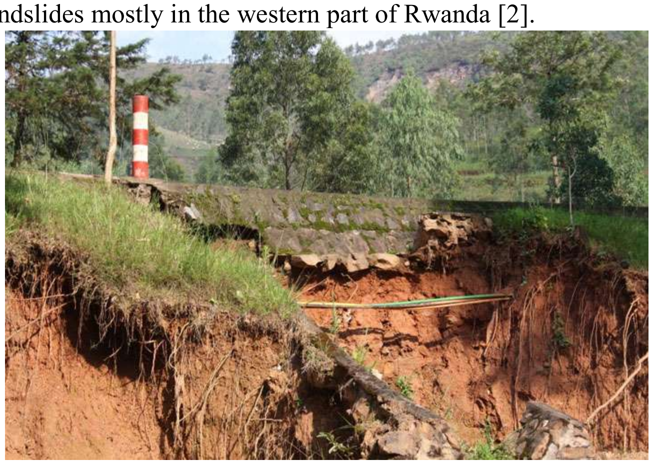

Fig.7 Landslides caused by manmade works (Roads), Ngororero and Rubavu, REMA 2013

D. *Landslides triggering factors in Rwanda*

A triggering factor is an external stimulus that triggers the movement and one of the renowned triggering factors is rainfall. Rainfall is an important factor in triggering landslides in Rwanda. Precipitation conditions determine infiltration and run-off. Prolonged rains with a lower intensity result in a higher and deeper infiltration and lower run-off in sloping areas. On the other hand, in these regions, torrential rains increase run-off and result in a lower amount of infiltration in many areas of the country. Nevertheless they promote the wetting of soil along fissures which serve as natural rainwater collectors [8]. The amount of rainfall has a considerable influence on the moisture content and the pore pressure in the soils [8]. Higher moisture content can increase the specific mass of rocks by 20 to 30% and at the same time lower their shear resistance by 50% and even more, due to increased pore-water pressure [9]. This greatly reduces shear strength and hence slope failure. İn Rwanda most areas receive more than 800 mm of rain fall per year and in some areas it goes up to 3000 mm [2].

E. *Influence of Rainfall on LandsLides in Rwanda*

The climate in Rwanda varies a lot from its surroundings in view of geomorphologic settings. The climate is determined by the alternating moist south-westerly and dry north-easterly airstreams. The mountain areas experience a bimodal rainfall pattern. The wettest period of the year is from March till May, while the dry season occurs from July till August with a short dry period around January to February and short wet season from September to December. Rainfall is higher at the Northern and western slopes (1500-3000 mm/yr) than at the eastern and Southern slopes (600-1500 mm/yr). Information from old rainfall data reveals that most areas in Rwanda receive an average rainfall of 800 mm . No temperature extremes exist in this region due to its location near the equator and altitudinal variations. Average maximum temperature ranges from 27 to 32°C, the minimum temperature from 15 to 17°C. High cloud cover, relatively low temperatures, high rainfall and high relative humidity (76% in the morning and 57% during afternoon) contribute to low evapotranspiration [2].

Climate can have a dramatic influence on mass wasting events. Heavy precipitation can initiate certain types of mass wasting by creating hydrostatic pressure and serve to lubricate slides once they are in motion and hence mostly results the mud flows.

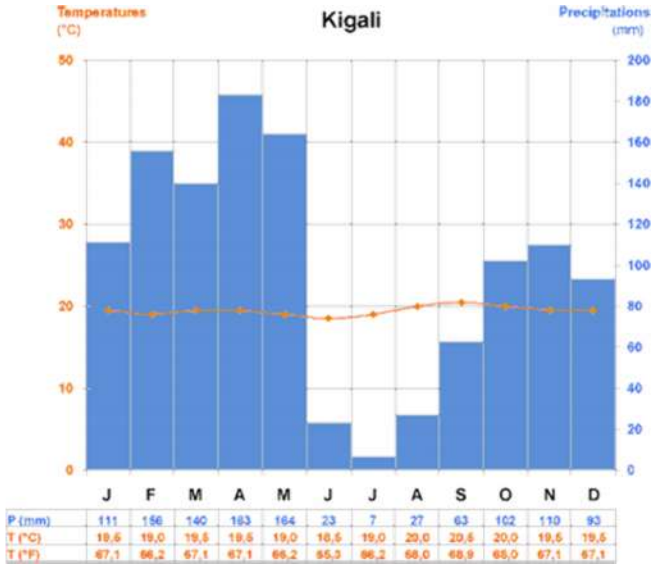

Fig.8 Rainfall and temperatures in Kigali city, REMA, 2012

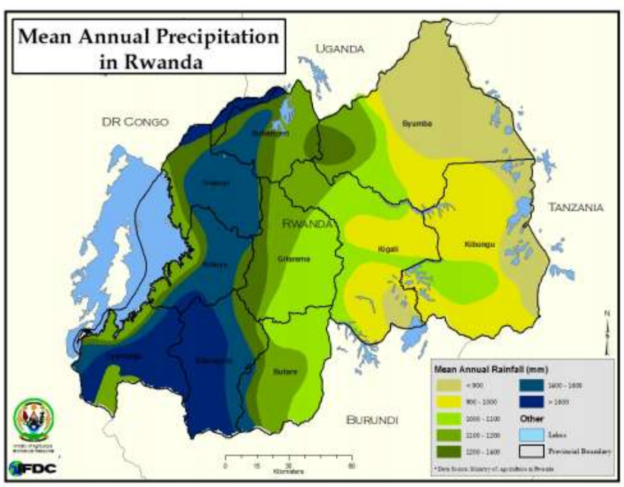

Fig.9 Rainfall distribution in Rwanda, REMA, 2012

The landslides that affected Musanze in the period of 1997 to 1998 were as a result of continuous heavy rainfall leading to over saturation of soils. Rainfall is one of those factors that have been found to trigger landslides because high rainfall events result in high water saturation in soils reducing the strength of the soil. Increase in water content increases pore water pressure. The influence of precipitation is even more complicated because landslides are more common when rainfall is continuous and exceeds the field capacity of the soil [3]. Landslides are more likely to happen if high amounts of intense rainfall are preceded by a period of light but incessant precipitation. Drizzle infiltrates easily downwards in the soil, increasing the soil moisture. In the Birunga ranges in North Rwanda, many landslides happen at the beginning of the rainy season. After a period of dry and hot weather, the soil will be desiccated with lots of deep cracks. The first torrential rains cause very much run-off, but also a lot of water infiltrates in the soil to deep levels through the cracks. Water absorption will be very high and rapid where the silt clay soil content is high, leading to a rapid and huge volume change triggering landslides. As the rainy season progresses, the moisture absorption rate does not cause rapid changes in volume anymore, lowering the risk for 16 landslides [7]. Saturation of the soils needs a much longer period, explaining the higher number of landslides in the Rwandan highlands during August than in July. The higher precipitation amount during July is absorbed by the dry soil. Towards August these soils become saturated resulting in a higher possibility of slope failures.

A distinct rainfall threshold for the initiation of landslides is difficult to assess in Rwanda because of the range of landslide types and dimensions, the heterogeneity of the study area and the lack of known landslide dates and rainfall data . Landslide events most frequently take place in years with exceptionally high rainfall, such as 1998, 2007 especially at the end of the rainy season when the soil saturation is maximized.

Between 2000 and 2014, heavy rains and landslides left 108 people dead and ten thousand displaced and landless. The volume of debris from landslides was 110 million m^3 in and this was deposited into rivers and streams or in transportation roads. Twenty nine of these landslides dammed rivers resulting in high losses of fertile soils and infection of fresh waters with used chemicals in cultivating those lands destroying all things on their path. The main landslide types are debris flows which occur on concave slopes where water concentrates in soil profiles.

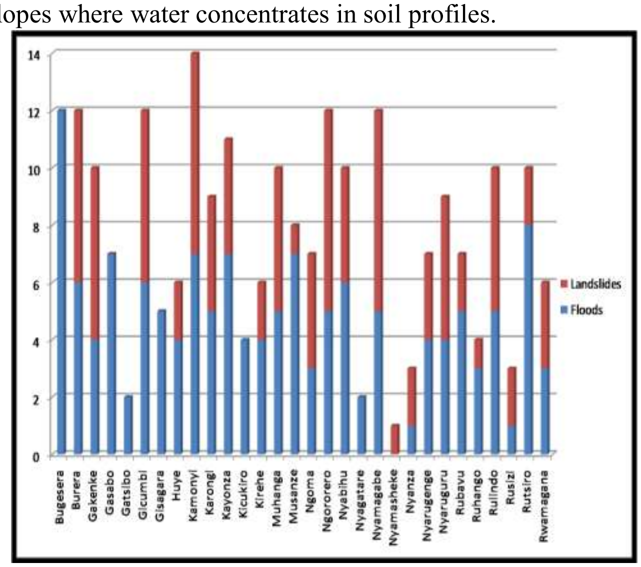

Fig.10 Floods and landslides per District (in terms of affected sectors)

According to the figure above, some Districts in Rwanda are highly prone to floods and landslides than others. This is due to many different reasons such geo-aspects, soil type and other triggering factors etc. Most affected Districts are Burera, Rubavu, Gicumbi, Nyabihu, Ngororero, Musanze, Rutsiro, Nyamagabe, Muhanga, Kamonyi and Bugesera and this is exacerbated by high level of vulnerability and exposure. For other Districts, the level of vulnerability is not very high. It is obvious that floods and landslides are increasing due to different triggering factors. Except natural triggering factors such as heavy rains, deforestation, land use change, climate change, etc, researchers also give anthropogenic triggering factors. The main anthropogenic factor is land use change. So, the combination of natural and anthropogenic factors increases the trends in floods and landslides hazards all over the world.

Table 1: Destructive Landslide cases and their prone areas

Districts	**Number of Landslide cases**	**Triggering factor**	**Damages**
Kamonyi, Ngororero, Nyamagabe	7 cases to each District	Heavy rain, Illegal mining, steep slopes	Environmental degradation, loss of lives and farmlands
Rulindo, Muhanga	5 cases	Heavy rain water, steep slopes,	Environmental degradation, loss of lives and farmlands collapse.
Gicumbi	6cases	Heavy rain water, steep slopes	Environmental degradation, loss of lives and farmlands collapse

III. General Conclusions, Solutions and Recommendations

The conclusive examination of many factors controlling landslide processes in Rwanda shows that these landslides are likely to continue occurring given that the population and demand for land is growing which leads to settlements in areas prone to landslide hazard and with high rainfall occurring in the whole country. Hence different points must be well studied such as:

A. Geomorphic factors such as geology, topography and relief have a high influence on landslide types and occurrences in many regions of the country

Verification of this hypothesis involved the mapping and classification of landslides, assessment of slope, aspect and distance to the water divide. Areas most sensitive to landslides are between slope angles above 14^0 on convex slope and above 41^0 on concave slopes. The depth of the landslide scar controls the volume of material displaced from the erosional area of the landslide. The width and length have no relationship with the volume of material displaced. Variation in type of movement as rotational or translational is topographically controlled. The brecciation and shattering of the basement granite caused accelerated weathering resulting into thick soil profiles rich in clay. The areas with dykes and fenitised basement are most vulnerable to landslides. The hypothesis that "Geomorphic factors such as geology and relief factors have a major control on the landslide processes in in Rwanda" is accepted on the basis that slope, slope shape, aspect and lithology contribute to landslide processes in all areas in Rwanda. Hence the government together with local people must keep on constructing radical terraces and planting new trees on high slopes. The government must keep constructing gabion retaining walls on road side in order to reduce land sliding into high ways and roads.

Fig.12 Terracing in Nyabihu District, Rwanda

Fig.13 New trees plantation, REMA, 2011

Fig.14 Gabion-retaining wall

B. Rainfall is the main triggering factor for landslide occurrences in Rwanda

Although researchers mention rainfall as one of the triggering factors for landslides in Rwanda, there are limitations in its measurement in the field because in some areas rainfall is not well recorded. Despite this limitation it is very evident from the little information collected that extreme rainfall events have led to landslides occurrences. Therefore, the hypothesis rainfall is the main triggering factor is could be accepted but further research on relationship between rainfall, flooding and landslides is recommended especially to understand the rainfall intensity and distribution in the area in relation to flooding and landslides because sometimes rain data used are far from the local area. Hence a map of vulnerable zones to landslides and flooding must be made quickly

C. Recommendations

1. High population in Rwanda is the main driver to land pressure which consequently results in the environmental disasters and encroachment on the fragile ecosystems. Therefore, population control should be taken as a critical intervention if the proposed restoration activities are to succeed.
2. To strengthen programmes that target education of the youth and enhance their vocational skills so that they can get alternative solutions when such disasters happen. This will reduce the money spent on goverment's and foreign experts and spend it in protecting vurnerable regions
3. Vegetation and trees cover on landslide occurrences, several researches have shown that landslides are likely to reduce when trees are planted. Roots from trees reinforce the soil through growing across failure planes, root columns acting as piles, and through limiting surface erosion [3]. When roots grow across the plane of potential failure there is an increase in shear strength by binding particles. The roots anchor the unstable surficial soil into the deeper stable layers or bedrock [4]. This most readily occurs when there is rapid deep growth (1.5 m deep) of roots which last for more than two years. However it is important to note that the strength exerted by roots generally only extends down to 1 m while most failures occur between 1.2 – 1.5 m soil depth [3&4].
4. Farmers should avoid settling in areas of high hazard. The landslide hazard map if developed should guide the resettlement plan.
5. Local governments should promote integrated watershed management.

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