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APPLICATION OF GEOSPATIAL TOOLS FOR LANDSLIDE HAZARD ASSESSMENT FOR UGANDA

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ABSTRACT

The need to predict possible occurrence of landslides is increasingly becoming a concern of governments and humanitarian bodies in developing countries. The occurrence of landslides and other related disasters in Uganda requires a shift from the current disaster management approach where interventions come into play following the disaster, towards a better approach where mitigation measures are planned before the disaster. In Uganda, studies that utilize spatial technologies to develop tools to support landslide disaster prediction have been limited by the problem of spatial data suitability and availability. This paper explores the suitability of the available spatial datasets as inputs into GIS-based landslide risk assessment in Uganda. The datasets used in this study included digital elevation model, soils, precipitation, vegetation cover and population. The relative importance of datasets was established by a combination of literature review, expert opinion and pair wise comparison technique. Through GIS tools, a prediction map was generated that showed risk levels of various areas in Uganda. The results from GIS analysis showed that the areas of highest risk included mountain slopes associated with high rainfall and clayey soils. The predicted high risk areas coincided with areas where landslides have recently occurred. On the basis of this, it was concluded that the current spatial datasets in Uganda, combined with data in the public domain could still be useful in providing reasonable predictions about landslides at a national level. The results of this research demonstrate the need to incorporate the use of geospatial tools in Uganda's disaster management strategies.

1 Introduction

The term Landslide hazard refers to the probability of occurrence within a specified period and within a given area, of a landslide, of a given magnitude (Varnes and IAEG 1984, Guzzetti et al. 1999). Like most other definitions of hazards, landslide hazard definition incorporates three basic elements (i) magnitude, (ii) geographical location, and (iii) time. Landslides primarily result from geological, hydrological and geomorphologic factors. Globally, it is estimated that between the years 2004 - 2010, fatal landslides, numbering around 2,620 killed a total of 32,322 people and this figure excludes landslides triggered by earthquakes (Petley, 2012). Furthermore, Martha and Kerle (2008), point out that the effects of landslides on people and property have been mounting in recent decades due to increasing slope instability as a result of deforestation, road cutting and urbanization.

Likewise, Muhammad et al (2010) have identified that landslides have posed serious threats to settlements and structures that support transportation, natural resource management and tourism. According to the official figures of the United Nations International Strategy for Disaster Reduction (UNISDR) and the Centre for Research on the Epidemiology of Disasters (CRED) for 2006, landslides ranked third in terms of number of deaths among the top 10 natural disasters (Ramakrishnan et al, 2002).

In Uganda, the most destructive landslide occurred on March 1, 2010 in the eastern district of Bududa. The landslide is believed to have been triggered by heavy rains that the area experienced on that day which had been preceded by a long period of unusually heavy rains. The disaster left about 300 people dead, many more people missing, more than 6000 homes displaced and a number of schools closed. Landslides have also been reported in the steep mountains of Rwenzori (Western Uganda), Kabale and Kisoro (South Western Uganda) and the districts of Sironko and Kapchorwa (Eastern Uganda) (International Federation of Red Cross & Red Crescent Societies (IFRC, 2007)

Landslide hazard prediction and management in Uganda is essentially a responsibility of Minister of Relief and Disaster Preparedness under the Directorate of Disaster Preparedness, Management & Refugees. The major responsibilities of the directorate include coordinating risk reduction, prevention of risks, and disaster preparedness and mitigation and response actions on a national scale. The Ministry works hand in hand with other line ministries, humanitarian and development partners, local governments and the private sector. The Ministry has already developed preparedness and contingency plans for at least 15 districts neighbouring steep slopes. Risk hazard and vulnerability assessments have been carried out in more than 58 districts predominantly using field based approaches. The limitation with field-based approaches is that they are costly and require a lot of time for the assessment to be completed. Secondly, the results of the assessments are not easy to explain to the beneficiaries, who include local leaders and the general population. It is also clear from operations of the ministry that most of the effort in landslide hazard management as well as other disasters are mainly focusing on post disaster management rather than early warning.

This paper explores the possibility of adopting geospatial techniques to improve landslide hazard assessment in Uganda based on available and accessible spatial data. GIS and related geo-spatial technologies have proved to be useful landslide assessment tools primarily because they combine mapping, field inventory spatial analysis and other tools.

2 Literature Review

2.1 Back ground

A landslide is a geographical phenomenon that involves the down slope movement of earth material due to gravity. Landslides manifest in several forms such as topples, slides, falls, slumps and creeps. Landslide-susceptible areas can be assessed and predicted through scientific analysis of landslide causal factors such as slope, precipitation, soil texture, vegetation cover and population. A Landslide hazard refers to the potential for the occurrence of a damaging slope failure within a given area and in a given period. After the recent natural catastrophes around the world, landslide monitoring and especially early warning, have gained enormous interest (Nadim et al., 2006). Landslide hazard analysis and mapping can provide useful information for catastrophic loss reduction, and assist in the development of guidelines for sustainable land use planning.

The current definition of landslide hazard, that incorporates probability, magnitude and time, presents a lot of demands in the nature and scope of the assessment that should be done for landslide hazards. The assessment should determine when a landslide will most likely take place at a given location and the magnitude of such a landslide. Unlike other types of hazards such as folds, (Guzzetti, 2002) observes that landslides are localized "point" events controlled by the intensity, duration and extent of the triggering mechanism, and by the local morphological, lithological, hydrological, structural and land-use settings. These settings vary with time. This situation therefore necessitates that before a complete landslide hazard assessment, accurate and reliable data should be collected on each of the input parameters. Furthermore, data should be collected as frequently as it necessitates so that any changes in the parameter values are captured. Methods of landslide hazard assessment either utilize the statistical analysis of geo-environmental factors related to the occurrence of landslides or deterministic modeling based on simple mechanical laws that control slope instability (Guzzetti, 2002). Landslide hazard assessment generally entails (i) identification and study of slopes, (ii) evaluation of the nature of hazards, and (iii) evaluation of associated risks. For any of the three types of assessment, various methods have been proposed (Guzzetti, 2002).

2.1.1 Landslide Location Identification

In general, landslide identification begins with the collection of information on the spatial location of landslides and presenting them on a map, hence providing a landslide inventory. Information collected during landslide inventory may include the date of occurrence, the type of land slide and so on. Traditionally, landslide inventory mapping has been the work of geo-morphologists who use field-based techniques to provide landslide inventory maps. (Guzzetti et al., 2000), reviewed available landslide inventory techniques which include use of topographical maps, aerial photographs, geo-morphological field mapping , innovative remote sensing technologies such as RADAR, historical analysis of archives, chronicles and newspapers. Of recent, Airborne Lidar generated DEMS and topographical derivatives have proved more reliable in identifying recent rainfall induced landslides (Ardizzone et al 2007). Field-based techniques have proved inadequate for assessments at national or regional level where data is required for larger areas. Furthermore, field-based techniques have also suffered the problem of loss of evidence for the existence of landslides as this is normally rapidly removed by erosion, growth of vegetation and human activity. There is therefore, a growing recognition that techniques that provide efficient tools for rapid data inventory, storage and retrieval of historical records are more relevant for landslide inventory and mapping. This recognition increasingly justifies the need to use geospatial technologies for rapid capture and analysis of temporal and multi-theme spatial data relating to landslides.

2.1.2 Evaluation of the Nature of Hazards and Associated Risks

There is acknowledged difficulty in quantifying the nature of hazards caused by a landslide (Wong, et al., 2006; Hervas (Editor), 2003; Jaiswal, 2011 and Middelmann, 2007). In contrast to other hazards such as earthquakes and hurricanes where units of measure exist, no units of measurement have been agreed upon for quantifying the magnitude of landslide hazards. Attempts to develop measures for landslide hazards have been made and as a result, various approaches have been proposed. These include factors such as number of occurrences, level of destruction, area or volume of landslide as well as the velocity of the landslide (Jaiswal, 2011). Landslide risk evaluation aims to determine the expected degree of loss due to a landslide (specific risk) and the expected number of lives lost, people injured, damage to property and disruption of economic activity (total risk) (Varnes et al., 1984).

2.2 Factors influencing Occurrence of Landslides

Many factors contribute to the instability of slopes, but the main controlling factors are; the nature of the underlying bedrock and soil, the configuration and geometry of the slope and ground-water conditions. Studies that utilize Spatial data and GIS techniques for landslide susceptibility mapping (Intarawichian and Dasananda, 2010) have adopted a number of factors and parameters such as elevation, slope aspect, slope angle, distance from drainage, lithology, distance from lineament, soil texture, precipitation and land use/land cover. Since these factors are considered to influence land slide susceptibility at differing levels, the datasets representing the factors should be weighted, ranked and combined during the assessment. This approach as reported in Ayalew et al. (2004) has an advantage that it subscribes to the multi-criteria decision analysis concept where each individual factor is given an opportunity to influence the final result. However, Intarawichian and Dasananda **(**2010) note that results from this kind of assessment could be subjective depending on the knowledge of experts. Data availability may also affect the results, more especially, if the required datasets are missing or if the desired attributes are not available in the accessible spatial datasets. In this study for example, only 5 datasets were available for the assessment and these are: slope, precipitation, land cover/vegetation, soil texture and population.

Slope - It is well established that as the degree of inclination of the earth’s surface or slope increases, the likelihood of a landslide increases (Schuster and Van Westen, 2003). To highlight the importance of slope in landslide occurrence probability, Chen and Lee (2003) have identified that the most important terrain-related risk factor influencing slope stability is the steepness of the slope.

Precipitation **-** Several researchers (*see for example,* Esmali and Ahmadi, 2003) consider precipitation to be a very critical factor in causing slope instability and landslides. In terms of ranking it is considered to be second coming after the force of gravity. Precipitation affects slope stability in many ways. First, precipitation affects rock formations hence the likelihood of slope failure. Secondly, precipitation increases the amount of water in surface soils which can increase the likelihood of landslide events (Zine, 2011). Precipitation increases the saturation level of surface soils, which increases pore water pressure in the voids between soil particles. This increase in pore water pressure decreases the friction and cohesion between soil particles and may lead to shallow seated landslides and debris flows. In Uganda, for example, most of the previous fatal landslides occurred after a heavy downpour. Research carried out for the Staffora River basin in Italy revealed that of 248 landslide events that happened over 45 years (between 1955 – 1999), (84.7%) were the result of intense rainfall (Intarawichian and Dasananda 2010).

Landcover/ Vegetation – Land cover and vegetation play a critical role in slope stabilization through several processes. Root systems bind soil together and decrease soil water saturation; foliage intercepts precipitation and decreases its erosive effect on the soil surface. Areas with little or no vegetative land cover and areas degraded by inappropriate logging, pastoral, agricultural or construction practices are predisposed to landslides and mass-wasting events (Varnes, 1978).

Soil texture – Soil texture is important because the size of soil particles determine the tendency of soil particles to resist sliding across each other. Soils with large particles such as sandy soils are the most cohesive while clayey soils with fine particles are almost cohesionless. Friction forces are dependent upon the load placed on the soil surface—the greater the load, the greater the likelihood that the forces of friction will be overcome. This results in the movement of soil particles within the soil layer and potentially to slope failure (Ramakrishnan et al., 2002).

Human activity **–** Human activity influences the likelihood of landslides since human beings disrupt natural processes. Incorporation of data on human activity as a variable in a GIS-based assessment is impractical because human beings interact with the environment in very numerous ways. Instead, population has been used as candidate variable to represent the influence of human activity in predicting landslide occurrence. Knapen et.al, (2006) reports that the increasing population pressure in Uganda leads to deforestation and slope disturbance as a consequence. However in many landslide assessment studies, population is not included as a causal factor and hence does not influence the prediction. Rather, population information is included as a means to assess the extent of vulnerability of people to landslide hazards (Sunil, 2010; Guzzetti, 2004).

3 Materials and Methods

The causative factors of the landslides were chosen after a careful bibliographical review of those most frequently referenced by researchers and expert opinion from Uganda National Environment Management Authority (NEMA), Directorate of Disaster Preparedness and Management and Makerere University College of Agricultural and Environmental Sciences. Each factor was subdivided into different parameter classes by value, interval or feature. All causative factors were obtained in the form of maps, each representing large quantities of spatial data at national level. Each thematic map was classified, rasterised, reclassified and then weighted. The preparation of a landslide prediction map involved addition of the weighted parameter maps in ESRI's ArcGIS software.

3.1 Data acquisition and Preparation

The major aim of this study was to assess the extent to which available and accessible data could be used for predicting the occurrence of landslides in Uganda. Data acquisition therefore involved identification of sources of the relevant data among data producers in Uganda. Availability of up to date spatial datasets in Uganda is a constraint to GIS analysis, essentially because institutions lack finances to update their datasets. As a result, some of the datasets used in this study are relatively old. The soils data set was acquired from Kawanda Agricultural Research Institute, population was acquired from the Uganda Bureau of Statistics (UBOS), the land cover dataset was acquired from the National Forest Authority and precipitation dataset was acquired from the Uganda Meteorological Centre, while the Digital Elevation Model was acquired from the public domain internet source (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1).

Preparation of the Soils Dataset: The soils dataset was acquired from The National Agricultural Research Institute (NARI) of the National Agricultural Research Organisation (NARO). The national soil dataset was compiled at a scale of 1:250,000 in 1996 from 17 soil map sheets, based on the soil survey of 1960. The most relevant attribute for deriving soil texture information was *soil class* which captures the type of soil in terms of texture. As part of preparation of this datasets, the classes were reclassified into clayey, sandy and loamy to reflect the different levels of texture for affecting landslide susceptibility. The four classes were assigned scores 1 to 4 to reflect the importance of each solid class in determining the susceptibility to landslides.

Preparation of the Landcover dataset: The landcover dataset was compiled by the National Forest Authority (NFA) under the NORAD-funded National Biomass Study Project in the period 1989-95 and is the most recent accessible national landcover dataset in the country. The dataset contains an attribute 'class' that gives information on land cover type. The dataset contains 13 classes in which 11 classes are land cover while 2 classes are land use classes. The analysis was based on only four classes: bare ground, low dense vegetation, fairly dense vegetation and dense vegetation. While mapping the original 13 classes to 4 classes, technical experts in the dataset were consulted.

Preparation of Population dataset: As mentioned earlier in this paper, population was used as a candidate variable to human activity because no particular dataset on human activity exists. The Population dataset was compiled from the population projections based on the Uganda Census data of 2002. The updated population dataset is expected after the planned national census scheduled to start in August 2014. The population figures were added to the administrative boundaries dataset from the Uganda Bureau of Statistics (UBOS). The 2006 Administrative Boundary dataset includes parishes as the lowest administrative units and therefore, the population data was compiled at the parish level. The population density was computed in ESRI's ArcGIS by dividing the population to the software generated area of each parish. Population density is considered more realistic in estimating human activity than population itself. Population density was reclassified into 5 classes and assigned codes from 1 to 5 based on expert opinion.

Preparation of the precipitation dataset: Measurement of rainfall is done by the Department of Meteorology in the Ministry of Water and Environment. The precipitation dataset was derived from the point data representing mean annual readings at various rainfall measurement gauges in Uganda. The data was interpolated using the Krigging tool, in ESRI's ArcGIS to generate a spatial dataset covering the entire country. The dataset was further reclassified to derive 5 classes that reflect the relative importance of rainfall quantities in predicting landslides in Uganda. The 5 classes were generated at equal intervals.

Preparation of the DEM dataset: The available and accessible dataset on elevation in Uganda is from National Forest Authority. The dataset was compiled from 1:50,000 topographical maps by digitizing 50ft interval contours. The data was captures in the period 1962-1970 and thus very old. Alternatively the 90m resolution SRTM DEM from NASA was used since it is freely available from the public domain. The dataset was processed to derive a slope map which was further reclassified into four classes. Slopes more than 50% were given the top score whereby slopes less than 12% were given the least score. The scoring was also based on expert opinion.

3.2 Interviews

Interviews were conducted with officials in the Ministry of Water and Environment, the Uganda National Environmental Management Authority and Directorate of Disaster Preparedness, under the Prime Minister's Office, in May 2012. The purpose of the interviews was twofold: to identify the areas that had in the recent past experienced landslide hazards and to seek any existing knowledge on the parameters that are essential in predicting the occurrence of landslides.

3.3 Pair wise Comparison Techniques:

Pair wise comparison as a decision making tool has been employed in landslide multi-criteria decision analysis involving multiple variables and found to be effective (Huat *et al*., 2008; Golder, 2006). The technique was used to derive weights for each landslide dependent parameter ranked verbally by importance. This was accomplished by first weighing each factor on a scale going from 1 to 9 (Table 1)

Table1: Verbal judgments and corresponding ordinal values used for the pair-wise comparison

Verbal judgement	Value
Extremely more important	9
	8
Very strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1
	½
Moderately less important	1/3
	¼
Strongly less important	1/5
	1/6
Very strongly less important	1/7
	1/8
Extremely less important	1/9

Using this scale, each of the five parameters was successively evaluated with the next and a verbal weighting factor was assigned to reflect the importance of one factor relative to the other in influencing the occurrence of landslides (Table 2).

Table 2: Pair wise comparison of the landslide causal factors

Parameters	**Annual daily maximum precipitation**	**Soil texture**	**Vegetation/ land cover**	**Population**
Annual daily maximum precipitation	1	1/2	3	4
Soil texture	2	1	4	5
Vegetation/ Land cover	1/3	1/4	1	2
Population	1/4	1/3	2	1
Total	3.583	2.083	10	12

The parameters were then normalized by dividing each cell value by the column totals and then computing the row mean to obtain values going between 0 and 1 (Table 3), which correspond to the weights needed for the application of the approach.

Table 3: Generation of weights for the causal factors

Parameters	**Annual daily maximum precipitation**	**Soil Texture**	**Vegetation/ Land cover**	**Population**	**Mean (Factor Weights)**
Annual daily maximum precipitation	0.279	0.24	0.3	0.333	0.288
Soil texture	0.558	0.48	0.4	0.417	0.464
Vegetation/ Land cover	0.093	0.12	0.1	0.167	0.12
Population	0.07	0.16	0.2	0.083	0.128

3.6. Weighted Linear Combination Technique

The weighted linear combination (WLC) method (Drobne and Lisec 2009) was used to obtain a linear combination of weighted parameters for landslide susceptibility. The intra-parameter scores (Table 4) developed through literature review and expert opinion were multiplied by the corresponding parameter maps to derive an intermediate relative susceptibility distribution map as presented in Figure 1. The intermediate susceptibility map excluded the reclassified slope map deliberately as a precaution against including flat areas in the final results.

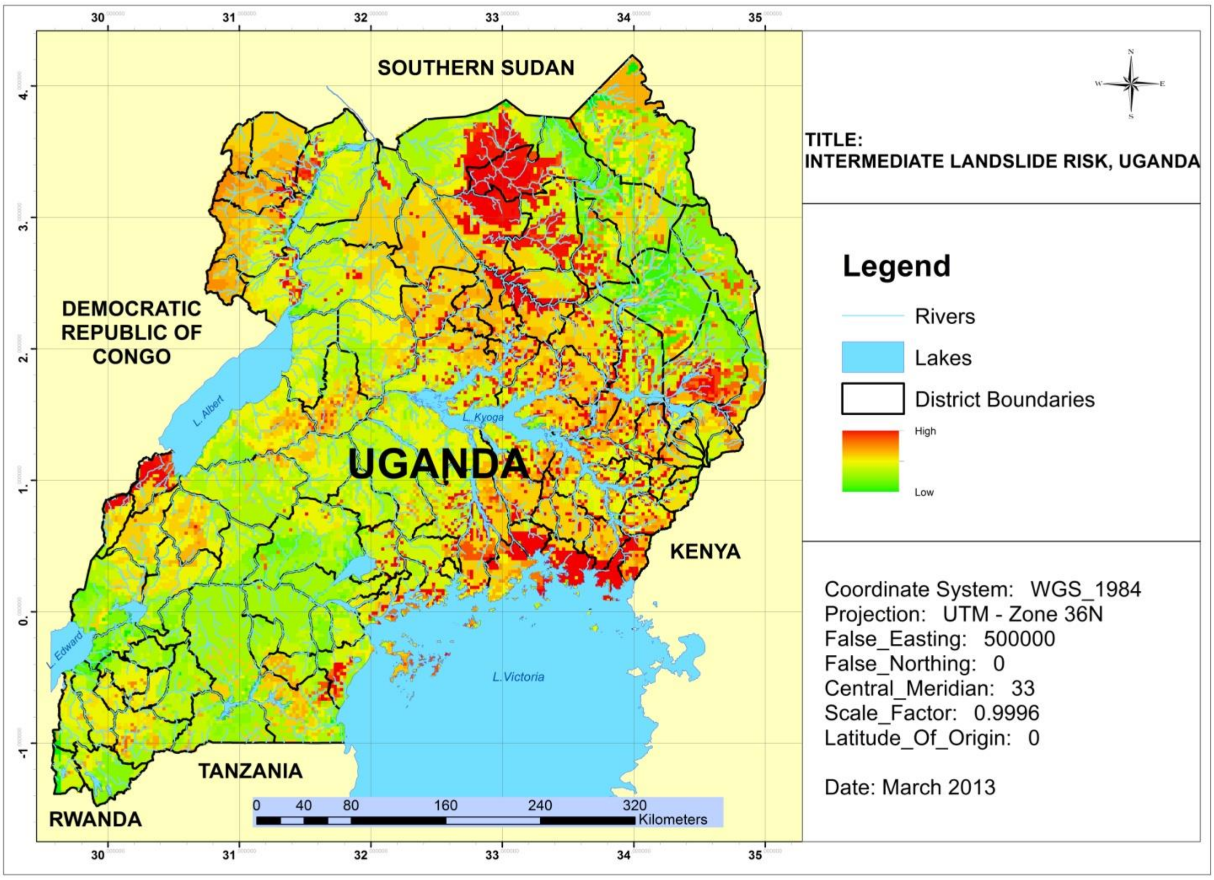

Figure 1: Intermediate Susceptibility map for Uganda

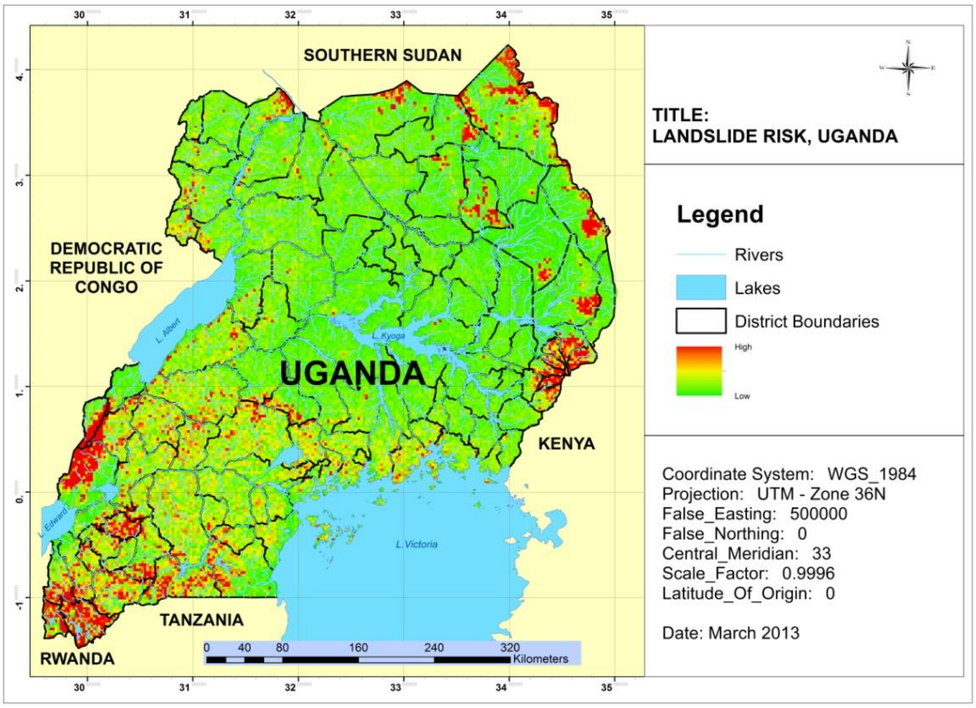

Figure 2: Final landslide risk map for Uganda

Table 4: Summary of the inter and intra-parameter Weighting and Ranking

Theme	Weight	Units	Rank
Slope	1	0-12%	1
		12-25%	2
		25-50%	3
		≥50%	4
Soil Texture	0.464	Unsuitable	1
		Coarse	2
		Medium	3
		Fine	4
Rainfall	0.288	595-931mm	0.8
		931-1267mm	1.0
		1267-1603mm	1.2
		1603-1939mm	1.4
		1939-2275mm	1.6
Vegetation/ Land cover	0.12	Bare ground	1
		Low dense	2
		Fairly Dense	3
		Dense	4
Population/ Land use	0.128	0-9	1
		10-99	2
		100-999	3
		1000-9999	4
		≥10000	5

Finally, the intermediate susceptibility map and the reclassified slope map were then combined by overlay, to eventually come up with the final landslide susceptibility map (figure 2)

4 Results and Discussions

4.1 Landslide Risk Zones

The final GIS generated land slide susceptibility map presented in Figure 2 indicates that the most susceptible areas are located in Eastern Uganda, south-western Uganda, western Uganda, and to a less extent, the north eastern part of the Country. The less or no risk areas are located in the central, north and north-western parts of the country. Indeed, the eastern and western parts of the country have in the recent past, experienced landslide hazards and the major catastrophie has been reported in Eastern Uganda. According to the available information, the most affected areas include Bududa on the slopes of Mt Elgon, Mt. Rwenzori, Mt. Moroto, Kisoro and Kabale. Experts interviewed from the Directorate of disaster preparedness and National Environment Management Authority attribute the landslides to high rainfall amounts and human activities such as deforestation and cultivation.

4.2 Availability and suitability of Data for land slide assessment in Uganda

One of the greatest impediments to GIS-supported landslide susceptibility assessment and GIS analysis is the availability of quality spatial datasets. In this study, most of the input datasets were very old, for example the soils dataset was more than 40 years old, the land cover data was more than 20 years old and the population data was more than 10 years old. Apart from the age of the data, most of the data lacked appropriate attributes to match the kind of parameters and parameter classes. In order to utilise the datasets, semantic translation was undertaken to match the most related attributes found in the data themes. It is expected that some errors were introduced as a result of this matching.

5 Conclusions and Recommendations

In this study, available spatial datasets were used as inputs into GIS to predict landslide susceptible areas in Uganda. The expectation was that the analysis would be affected by the quality of the data such as the age, semantics and geometrical properties. Furthermore, the subjective nature of the linear combination and pair-wise comparison matrix generation would impose additional errors. Despite these limitations, the results were still reasonable since the predicted landslide zones coincided with areas that had recently experienced landslides. On the basis of these results, we conclude that pair-wise comparison and linear combination GIS techniques and the available spatial datasets could still be used to predict landslide susceptibility at a national level in Uganda. We therefore recommend these techniques for use in Uganda and other countries facing landslide risks. To improve the prediction of landslides risk areas, we recommend use of more recent data. Since expert opinion introduces subjectivity in the results, we recommend replacement of such opinions with researched parameters as more scientific studies are undertaken to determine the actual parameters.

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