The use of Geographical Information System (GIS) and Remote Sensing (RS) technologies in generation of information used to mitigate risks from landslide disasters: a review

Abstract

Landslides, whether induced by nature, or human activities, are one of the most prominent disasters which are of great concern in the world. They cause a lot of havoc to the environment hence a necessity to avoid them whenever possible. This literature review is basically aimed at finding out how Geographical Information System (GIS) and Remote Sensing (RS) technologies are used in avoiding landslides and risks associated with them at different levels; Challenges encountered while using GIS and RS techniques for landslide disaster risk reduction are identified; and therefore, dealing with them requires the involvement of developed countries who have the capacity to provide the necessary equipment to the developing countries that are faced with disasters. This study discusses the use of GIS and RS in mitigation of risks from landslides, and mainly points out how these techniques are applied to avoid disaster risks. Secondary data was reviewed from journal articles, institutional reports, and online publications from similar studies. GIS and RS tools are important in predicting, monitoring and managing landslide disasters. It was concluded that GIS and RS tools provide cheaper, reliable, and faster techniques of accessing spatial data in a given area, therefore regarded as essential technologies that may be necessary for predicting landslide occurrences, these technologies need to be considered in communities which are prone to landslides.

Keywords

Geographical Information System, landslides, landslide disaster risk reduction, spatial data, Remote Sensing.

1. Introduction

Landslides are a major concern to most countries and are the most prominent natural hazards in the world (Fathani *et al.,* 2016; Ratemo & Bamutaze, 2017). Each region that is susceptible to disasters has features, such as high population, deforestation, frequency of high rainfall, which expose the land to risks of natural hazards (Van, 2000). The number of people settling on the slopes of the hills has increased, hence putting a lot of pressure on the environment, weakening it and making it prone to landslides (Nor *et al*., 2021; Mei *et al*., 2019). Human activities and natural factors have led to a number of geological disasters, which are a danger, not only to the lives of people, but also to their property (Fathani *et al*; 2014; Riegel *et al*., 2020; Van 2000; Cheung, 2021).

Globally, 3,876 landslides that occurred in the last 20 years led to the death of 163,658 people, and 11,689 injuries (Haque *et al*., 2019). Similar studies that were conducted by Sarwar, (2008) also found out that Landslides that occurred in Bangladesh, most especially, the Southern part of the country in Chittagong in the year 2000, left more than 300 people dead, while property, worth millions of dollars was destroyed. From the 476 Landslides that occurred in mountainous areas of Europe 1,370 deaths were recorded, while 784 people were left with injuries (Haque *et al*., 2016). Within a period 115 years, that is, 1861-2015, a total of 1,017 landslides erupted in 958 places allover Italy leaving 5,571 people dead, while others were injured, and a lot of property was damaged (Rossi *et al*., 2019).

Studies conducted in Africa, indicated that landslides that occurred in Democratic Republic of Congo in 2017 killed over 500 people, leaving more than 2000 people homeless (Igwe, 2018). Similarly, the Landslides that arose as a result of heavy rains from 2000-2010, left over 108 people dead, over a thousand people were left homeless, and a lot of infrastructure, like roads and bridges were destroyed (Bizimana *et al.,* 2015). On 14th August 2017, the landslide that hit Sierra Leone had killed 499 people by 20th August, and more than 600 people were declared missing (Leone, 2017).

Landslides have consistently occurred, not only in East Africa, but also in other parts of the world (Thiebes *et al.,* 2014). Mount Elgon Sub - Region in Eastern Uganda has been declared a landslide prone area in Uganda and in East Africa at large (Osuret *et al*., 2011; Broeckx *et al*., 2019; Osuret *et al*., 2016).

Further studies that were conducted by Atuyambe *et al.* (2011) revealed that a major landslide that occurred in 2010 in Bududa District, in Uganda, left 400 people dead, while over 5000 residents were displaced and relocated to the neighboring villages.

Focusing on the havoc landslides leave behind after their occurrences, some technological advancements have been developed mainly with an intention of reducing risks encountered and also for providing effective communication on when, how, where landslides are likely to occur, for better planning (UNDRR, 2012). In order to overcome risks from natural disasters like landslides, it is necessary to obtain multiple spatial data so as to understand factors that influence man and his environment. Geographical Information System (GIS) combined with Remote Sensing (RS) were put forth and they aimed at giving frameworks that can be used to avoid disasters in different phases of disaster risk reduction, i.e. preparedness, response, and recovery (Van, 2000). GIS and RS can be used to record data for a large area in a shortest time possible, and hence, they have been identified to be fit for disaster management (Van, 2000; Twumasi *et al*., 2019). GIS and RS, have been applied to help and obtain early warnings, predict, prepare, prevent,

and evacuate the vulnerable members of community in time and avoid risks (Van, 2000; Twumasi *et al*., 2019). The statements are in agreement with the results from a study conducted by Twumasi *et al.,* (2019), who postulated that GIS and RS, have for several years been used towards the risk reduction and management of several disasters, including, Landslides, earth quakes, floods, tsunamis, and droughts. This study therefore, aims at documenting how GIS and RS can be used to generate information which may be essential for mitigating risks from landslides.

2. How Geographical Information System and Remote Sensing technologies are used to generate information for risks reduction from landslides disasters.

2.1 Detect Warning Signs: GIS and RS are vital in giving Early Warnings (EWs) because they enable planners to detect warning signs for landslides from a distance, and be able to monitor changes that could arise on the planet earth, and hence give timely warning to the vulnerable communities (Tulsi & Aneri 2007; Vyas & Desai, 2007). Similar studies that were conducted by Tanavud *et al*. (2010) and Vyas & Desai (2007) found out that quick information can be obtained faster with GIS and RS than observations done on ground, and covers a very big area in the smallest time possible, and gives ideas of what is most likely to happen.

These results were in agreement with those of Vyas & Desai (2007) who stated that GIS and RS help to guide policy makers and planners to identify escape routes as soon as they receive EWs, hence prepare response actions, to avoid risks from disasters like landslides (Vyas & Desai, 2007). In Nepal, the state of landslides was managed because GIS and RS were used by the government to address the risks that could arise from landslides (Meena *et al*., 2021).

2.2 Reliable information: GIS and RS also consist of Aerial Remote Sensing which enables the recording of information, like photographs taken from aircrafts (Vyas & Desai, 2007). The information likely to be recorded is in form of photographs and images from sensor on aircrafts and satellite remote sensing, which can be used to integrate natural hazard assessments into development planning studies (Tulsi & Aneri, 2007; Dinesh, 2016). The remote sensing systems include, among others, Land sat, SPOT Satellite, Satellite Radar System (Tulsi & Aneri, 2007; Vyas & Desai, 2007) among others. Images extracted from remote sensing systems are very important because they are accurate, reliable, and have good resolution and hence more clear. Remote Sensing and GIS are so effective when it comes to generating and

processing spatial data, and are required for providing information for landslide risk reduction (Singhroy, 2009).

2.3 Disaster Identification: GIS and RS are very effective at managing and analyzing spatial data. They have been applied to reduce risks from landslides and it has in most instances been a success (Merrett & Chen, 2013). It is well understood that GIS and RS are good at hazard identification and land management which help in reducing the risks from landslide natural disasters (Merrett & Chen, 2013). Further research conducted by Al Rawashdeh *et al*. (2016) and Schetselar (2001) revealed that Remote sensing technology is a trusted tool which is used to analyze geological data in hard-to-reach areas.

The images from satellite images are easily accessed at a cheap price because they can be freely downloaded from google earth, and they provide images with high resolution, which are constantly updated. The images are coordinated with the data obtained from the ground and is able to detect land use change as a result of landslides. The interpretation of aerial photographs made it possible to identify landslide prone areas in Boun, Korea, by collecting and processing data derived from topography, soil, forests, and land use was possible with the help of GIS and remote sensing technologies (Lee *et al.,* 2004; Lee, 2005). The causes of landslides like slope aspect and curvature of the topography, were calculated from the available topographic database using GIS techniques (Lee *et al*., 2004).

Relatedly, GIS and remote sensing were used in identify landslide prone areas in Penang, Malaysia. This was done by interpreting aerial photographs and from field investigation. The data gathered was mainly on Topographical and geological information and the satellite images were gathered, processed and constructed into a spatial database using GIS and image processing (Lee, 2005).

2.4 Risk analysis: GIS together with RS technologies have the power to analyze risks from landslides that occurred for a long period of time, and on a large scale and information for prediction may easily be availed. They obtain data from existing maps, remote sensing, digital data, and also from field observation, and there after data is kept in GIS database for analysis. The information generated may help to identify landslide prone areas, and predict when another event is most likely to occur (Merrett & Chen, 2013). Similar studies done by Arnous (2011) in Wadi Watier area, South Sinai, in Egypt where he used GIS and RS technologies to assess landslide disasters prone areas, and they used thematic layers like rocks, land-use, topography, geography of the area, derived variables that predicted landslides, so as to avoid risks like human and property destruction. Views from Tulsi & Aneri (2007); Omieno & Khabamba (2012); Bhavika *et al.* (2009) showed that GIS and RS technologies are used to uplift the nature of analysis for landslide

assessment, enhance development activities, guide development planning, and help policy makers to find appropriate responses and preparedness to mitigate risks that could arise from landslide disasters.

2.5 Identification and mapping vulnerable areas: GIS and RS technologies can be used to identify the exact areas where landslide occurred and the extent at which it caused harm. A study conducted in the Balik Pulau area in Penang Island, in Malaysia indicated that landslide prone areas were easily identified by interpreting aerial photographs, reports from earlier landslides, satellite images, and subject area (Pradhan *et al*., 2011). This was accomplished by collecting and processing data on topographic, geologic, soil and satellite images using GIS and image processing tools, which gave a clear location for the landslide prone areas (Pradhan *et al*., 2011). Landslide threat maps produced as a result of GIS and RS technologies help the meteorological departments to better the nature of the landslide warning services and disseminate prompt and accurate information about the likely risk to the people in the vulnerable community (Tulsi & Aneri, 2007).

A study conducted by Ahmed (2015) in Chittagong Metropolitan Area (CMA) in Bangladesh, indicated that the maps from the hilly area were helpful in providing measures that helped to reduce risks from landslides, and it was also realized that the maps gave authentic findings with the available information which helped to reduce risks in selected landslide prone areas.

Other studies conducted by Mavroulis & Lekkas (2023) also found out that mapping vulnerable areas played a major role in managing landslides and reducing risks from landslides. GIS and remote sensing were applied and used to map Landslide prone areas in Boun, Korea, using the landslide-occurrence factors, by the probability–likelihood ratio method. It was then discovered that the results obtained were accurate and valid because there was a relationship between mapping and the data which existed in landslide prone areas (Lee, *et al*., 2004; Fabbri, *et al*., 2003). Landslide susceptibility mapping is also accomplished using GIS and remote sensing technologies. Mersha and Meten (2020) successfully mapped susceptible areas to landslides in Simada area, northwestern Ethiopia and generated very interesting results as shown in Fig. 1

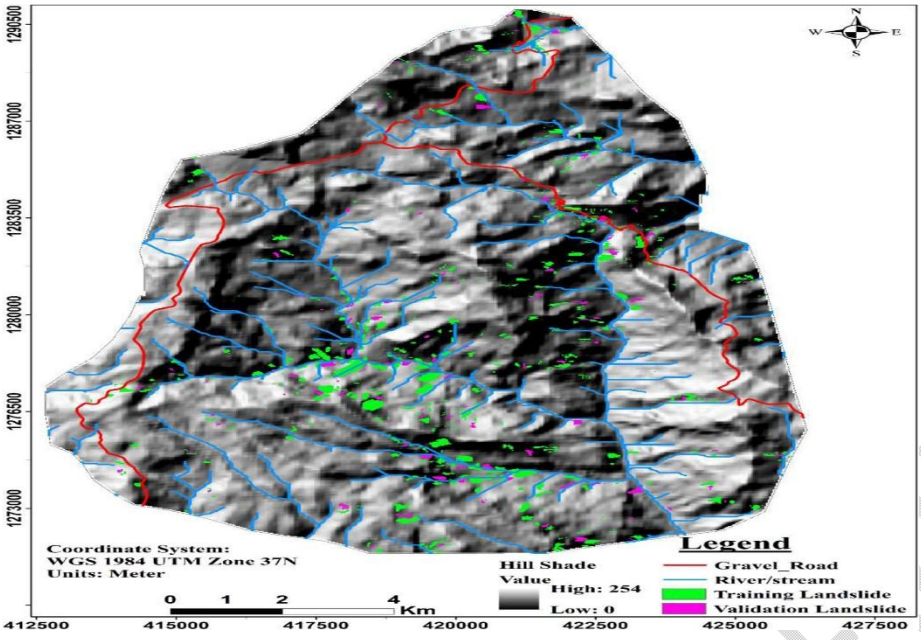

Fig. 1 showing an extract of a GIS-based landslide susceptibility mapping and assessment

Source: Mersha, & Meten, (2020)**.**

3. Challenges of using GIS and RS techniques for landside disaster risk reduction

GIS and RS technologies when used appropriately may provide data that may reduce or prevent the degree at which disasters cause havoc. However, using them consumes a lot of time since they require a lot of data inputs (Ram *et al*., 2020). GIS technology is a software that is too expensive for some developing countries to afford. Equipment such as GPS, and ways to access data are very expensive ventures (Bello & Aina 2014; Ram *et al*., 2020).

On the other hand, after a study that was conducted in Cameroon by Bello & Aina (2014), it was revealed that some governments don't have the human resource potential to use GIS and RS technologies. To be able to handle and manage the mentioned technologies, some scholars like Bang (2013) and Bello & Aina (2014) suggest that developing countries need support from developed countries if they are to succeed in this endeavour.

4. Conclusion

GIS and RS tools are applied because they can provide information on landslides that are likely to occur. Although GIS and RS technologies pose some challenges, they have made it easier to manage disasters. Disasters could be induced by man and natural factors. GIS and RS have the ability to detect warning signs, give reliable information, identify disasters, analyze risks, monitor land, and map vulnerable communities, which gives people early warning signs to be able to prepare, respond, and mitigate risks

from landslide disasters. GIS and RS tools provide cheaper, reliable, and faster techniques of accessing spatial data in a given area and therefore, they need to be embraced by communities which are prone to disasters like landslides.

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