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Enablers and Consequences of Landslide Outbreaks in Bududa District, Eastern Uganda

Caroline Namuenge [a], Jamilu E. Ssenku [a,b], Shaban A. Okurut [b], Ali Kudamba [a,b], Nulu Nansikombi [c], Hussein M. Kafeero [d] and Abdul Walusansa [a,b,d]*

[a] Department of Environmental Science, Faculty of Science, Islamic University in Uganda, P. O. Box- 2555, Mbale, Uganda.
[b] Department of Biological Sciences, Faculty of Science, Islamic University in Uganda, P. O. Box- 2555, Mbale, Uganda.
[c] Department of Food Science and Nutrition, Faculty of Agribusiness, Islamic University in Uganda, P. O. Box -2555, Mbale, Uganda.
[d] Department of Microbiology, Faculty of Health Sciences, Islamic University in Uganda, P. O. Box- 2555, Mbale, Uganda.

Authors' contributions

This work was carried out in collaboration among all authors. Authors CN, JES and AK Conceived the research idea. Authors SAO and NN contributed by conceptualizing, data collection and statistical analysis. Authors HMK and AW supervised this research. All authors contributed to the writing and final approval of the manuscript. All authors read and approved the final manuscript.

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**Corresponding author: E-mail: abdulwalusansa@gmail.com;*

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ABSTRACT

Landslides are rapid movements of rock and soil on the Earth's surface, currently ranked among the most catastrophic environmental disasters worldwide. Bududa district, located on the steep slopes of Mount Elgon in eastern Uganda, has experienced a rising incidence of severe landslides. However, the environmental and human-driven factors contributing to these disasters remain poorly understood, hindering effective intervention strategies. This study investigated the causes, intervention strategies, and impacts of the persistent landslides in Bududa, aiming to generate insights for optimal solutions.

A descriptive cross-sectional study was conducted, utilizing pre-validated semi-structured questionnaires and Key Informant Interviews to collect data from a random sample of 212 respondents, including household heads and district leaders. Additionally, 38 soil samples from landslide-affected sites in Bududa were analysed through experiments at Makerere University. This was complemented by observational surveys and digital photography. Qualitative data were analysed using thematic synthesis and photographic interpretation, while quantitative data were processed with descriptive and inferential statistics in STATA version 15.0. Graphs were generated using GraphPad Prism® version 9.0.0.

In the findings, factorial analysis of variance (FANOVA, $p<0.05$), showed that the high soil- organic content ($p<0.001$), bulky density ($p=0.002$) and water saturation levels ($p=0.011$), in addition to other environmental factors such as the steep terrain and heavy rains are the cardinal mediators of landslide outbreaks in Bududa, while soil porosity ($p=0.718$) and permeability ($p=0.267$) were not implicated. These environmental drivers were found to be noticeably moderated by the widespread incidence of unregulated anthropogenic activities, primarily human settlement, infrastructural development and monetary enterprises like agriculture and cutting of trees. While some positive outcomes of landslides were acknowledged such as survivors improving their livelihoods after relocation, there was strong consensus on the adverse impacts, including casualties and deaths, and significant damage to infrastructure, agriculture, the economy, and social services. The majority of respondents confirmed the widespread presence of awareness campaigns, multisectoral collaborations, and mechanical preventive measures like physical mapping. Most participants agreed that tree planting could reduce landslides and that external support would enhance coping strategies in Bududa more effectively than local resources. However, they were uncertain about the effectiveness of existing local defensive measures, such as slope geometry modification. Additionally, monitoring for future outbreaks, household micro-land use interventions, and promoting slope stability were perceived as inadequate.

Conclusively, reliable evidence was generated, indicating that the main factors enabling the recurrent landslides in Bududa are tri-faceted. That is, natural topography and soil characteristics, climate, and human influence. Consequently, strengthening the cooperative participation of stakeholders from sectors related to those three facets may improve the results of interventions.

Keywords: Natural disasters; landslides; bududa district; eastern Uganda; mount elgon.

1. INTRODUCTION

Disasters are a major disruptive phenomenon to the functionality of communities across the globe given that they often lead to considerable losses in human life and valuable assets. The burden manifests more in resource-limited countries especially in Africa where the coping capacity is limited mainly by finances and technology deficits [1]. Apparently, disasters are categorized with as; natural disasters, environmental emergency disasters, complex emergency disasters and pandemic emergency disasters [2]. According to the World Bank and Global Facility for Disaster Reduction and Recovery [3], natural disasters are the commonest category accounting for an estimated loss of 4.4 million humans over the past two decades and about $ 2 trillion colossal economic loss. Among the natural disasters common globally include earthquakes, volcanic eruptions, typhoons, drought, floods, landslides and normally impact widescale suffering, misery and damages [4]. This study however concentrated on the landslide disaster. Globally, landslides take place across developed and third world countries due to several factors; physical, human, geological and morphological in nature [5]. They are common in areas of hilly and mountainous terrain yet likely to negatively impact upon humanity, economic property and national and local economies [6]. Given the colossal losses often registered as a result of landslide occurrences due multiple factors [7], it has become fashionable to make strategic interventions through collaborative and coordinated modalities at local, regional, national and international levels [8]. The practice of making interventions to mitigate disasters of all kinds is magnified by the Hyogo Framework Action, HFA of 2005 and carried forward by the Sendai Framework for Disaster Risk Reduction (SFDRR) of 2015.

On the international scale, the disaster trend in terms of frequency and intensity continue to manifest, culminating into big losses and unprecedented damage of viable resources; human, vegetation and infrastructure [7]. It is argued that internationally, fatal landslides of numerous extents took root with effect from the second half of the 20th [9]. It is estimated that over the past years, over 250 million people have been displaced by conditions of climatic and weather-related disasters; the numbers are anticipated to surge in future given that disasters are turning out to be more intense and severe [10]. The disasters are both man-made and natural. In particular, the frequency, severity and extent of the landslide manifestation is rapidly increasing in various countries in Asia, United States of America, Europe and Africa [6]. Several areas are identifiable with landslides; with Asian parts like Himalaya, Taiwan, Sri Lanka, Central China, India, Indonesia, Vietnam [11], and USA, parts like the Appalachian Mountains, the pacific coastal ranges and Europe [12]. In the eastern part of the Caribbean, landslides take place in urban and rural areas losses of high magnitude are often registered [13]. However, landslide outbreaks and fatalities are more pronounced in Asian nations like the Philippines, India, Nepal, China and Indonesia [14,15]. This trend continued in the new millennium with numerous landslide manifestations totalling to 4399 outbreaks [9,16], indicating an increment in fatalities of damage. It has to be noted that Save for the exposure to direct risks to human life and health, it is argued that landslide disasters culminate into gradual losses of property and land which has a negative bearing upon community livelihood in terms of food security especially in mountain-like topographical areas [17].

Africa is no exception from the vulnerability of landslides, particularly areas of equatorial Africa, East Africa in Kenya and Tanzania as well. In the East African region particularly the highland areas, landslides are a common phenomenon given the wet climatic atmosphere, population pressure, mountainous and hilly topography [18,19]. Anecdotal evidence suggests that the highlands in East Africa have witnessed numerous landslide outbreaks, some of which with damage of great intensity [20]. In Uganda, landslides are common the Western and Eastern regions [21]. In Bugisu sub-region, including the entire mount Elgon belt, is prone to landslides, and the risk is more pronounced in districts like Bulambuli, Sironko, Manafwa and Bududa [22,23]. The landslides in these districts incur colossal losses in terms of infrastructure, biodiversity, the economy, and the environment [18,24]. Elsewhere, the surging outbreak of landslides in prone mountain areas is largely attributed to poor land management practices in addition to the natural as well as environmental drivers [20]. However, in Uganda, recent evidence that is required to guide effective redress, especially the information on enabling factors and consequences of these calamities is scarce [25].

In Bududa district where landslide disaster outbreaks have persistently caused devastating loses and damages to the population and to the environment, the situation could worsen in the future given the apparently increasing population pressure and the changing climate, whose effects have been associated with land-mass movements in such ecologically sensitive areas elsewhere [26,27]. That is to say, the high population leads to massive human settlements and intense, largely unregulated livelihood activities such as poor farming practices and quarrying, which accelerate landslides. Despite the steps taken by Government to respond to this challenge, such as relocation of the victims [23], the problem still persists partly due unclear factors, occasioned by profound scarcity of up-to-date guiding evidence on landslide drivers, intervention-gaps, and effects. Therefore, the aim of this research was threefold. To determine the factors enabling the persistent outbreaks of landslides, to examine the effects of landslides on the community and on the environment, and to examine the interventions used for mitigating landslides and minimizing their effects to the communities and the environment in Bududa district. The rationale was to generate actionable insights for improving the results of interventions.

2. METHODS

2.1 Research Design

The study applied a cross-sectional survey design, involving mixed methods for both quantitative and qualitative approaches. Additionally, the experimental design was adopted in studying the soil properties in relation to landslide occurrence, such as soil texture, organic content, porosity among others.

2.2 Study Area

The study was conducted in Bundesi (Nametsi), Bumayoka and Bukalasi sub counties in Bududa District (Fig. 1). It is located in Bugisu subregion, Eastern Uganda. Bududa was originally known as Manjiya county and was curved out of Mbale District. It lies in the direction of south west in the vicinity of the Mount Elgon Volcano. Geographically, Bududa lies between 34° 16' 12.536'' Longitude, 0° 57' 55.667'' Latitude and 34°32' 14.995'' Longitude, 1°7' 15.661'' Latitude.

In terms of population, Bududa has approximately 271,100 people and with a 317.4 km² Area. Nametsi, Bumayoka and Suume are particularly chosen given their uniqueness in terms of the steep topography and vulnerability to landslides compared to other areas in Bududa. It has to be noted that compared to other areas in Bududa, landslide scars are more visible in Nametsi.

2.3 Study Population

The targeted study population included: Chief Administrative officer/Deputy Chief Administrative Officer (CAO/DCAO), District Environmental Officer (DEO), District Health Officer (DHO), Community Development Officers (CDOs), Deputy Disaster Management Committee chairpersons (DDMC), Senior Disaster Management Committee members (SDMC), household heads and local policy makers. These were derived from Bududa district (Nametsi in Bundesi subcounty, Bumayoka and Kushu in Bumayoka subcounty and Suume in Bukalasi Subcounty) given their vulnerability to landslide outbreaks. The entire population is estimated to be 37, 028 households in Bududa district [28], majority of whom are vulnerable to landslides since they live in risky areas. However, the targeted study population was 265 as presented in Table 1.

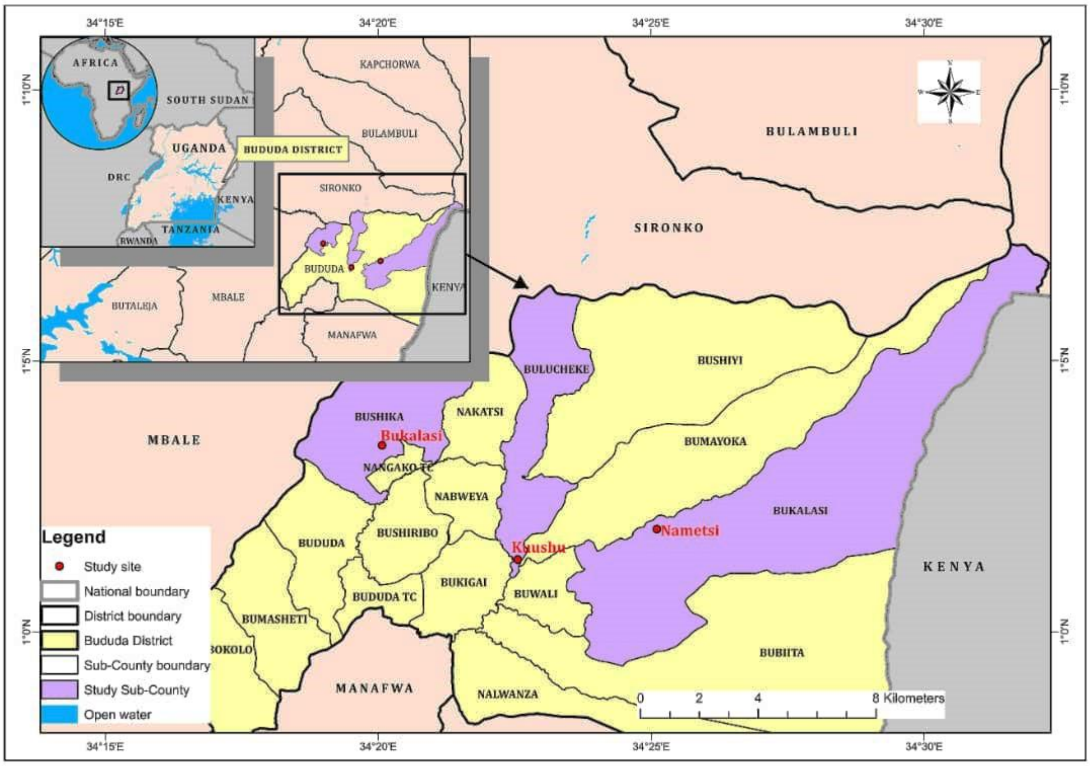

Fig. 1. Map Showing the location of (study area) Bududa District, It's Sub counties, Rivers, Elevation and neighbouring Districts

Table 1. Showing the Targeted Study Population and Sample Size

Category	Target population	Sample size	Sampling method
CAO/DCAO	2	2	Purposive
DEO	1	1	Purposive
DHO	1	1	Purposive
CDOS	21	18	Simple random
DDMC	25	20	Simple random
SDMC	25	20	Simple random
Household heads	150	120	Simple random
Local leaders	40	30	Simple random
Total	265	212	

Source: Bududa District Registry: 2022 (Not pubished)

2.4 Sample Size

2.4.1 Sample size determination

A sample size of 212 respondents has been determined using the table Krejice and Morgan [29], with reference to the target population of 265, as shown in Table 1.

The sample size included 212 drawn from Nametsi, Bumayoka and Suume (Bundesi Sub County) in Bududa District. This is because they were the most vulnerable to landslide risks and have been victims in the past [18]. However, of the total 212 sample, 180 provided responses that were utilized for data analysis and this gave a response rate of 84.9%.

2.4.2 Sampling techniques

Purposive sampling was used to select the study area, Bududa district since it is characterized by more experiences of landslide outbreaks in Uganda [30]. Stratified sampling was used to select the villages of Nametsi, Bumayoka and Suume given that they are highly vulnerable to landslide risks than other villages in Bududa district. However, systematic sampling was used to select sample households. It is opined that randomization promotes validity and reliability of data since it minimizes the effects of the extraneous variable [31].

2.5 Data Collection Methods

Primary data was collected using laboratory soil testing, questionnaire, interviews and observation methods. They were carried out between the months of 1st August, 2023 to 15th September, 2023. Data collected from household heads and local leaders involved the utilization of Likert-scale questionnaire. However, key informant interviews enhanced data collection from the technical staff (CAO, DEO, DHO, CDOs, DDMC, SDMC, VDMC). Soil testing was done at Makerere soil, plant and water analytical Laboratories. Secondary data was collected through documentary analysis. This involved the reviewing government policy documents regarding landslide disasters.

2.5.1 Soil specimen collection and sampling procedure

Soil samples were collected from three depths (0–50 cm, 50-100 cm, and 100-200 cm) in each pit using a soil core sampler, across five sampling sites within the study area. These sites included three sub-counties experiencing landslides, one control sub-county where landslides have never occurred, and a neighbouring sub-county with observed soft ground and sinking houses. A purposive sampling technique was employed, with three soil pits sampled per site. Composite soil samples for texture and organic carbon analysis were collected at each depth, carefully labelled, and stored. Core samples for bulk density and permeability tests were also collected. The 5 cm soil cores were inserted into the soil using a core sampler, ensuring an undisturbed sample was obtained. After extraction, the cores were trimmed, covered, and placed into labelled sampling bags. The samples were then sent to the soil, plant, and water analytical laboratory at Makerere University's College of Agricultural and Environmental Sciences for further analysis. The samples were saturated, drained of excess water, and weighed in their canisters.

2.5.2 Soil sample preparations in the laboratory

The air-dried samples were ground with a mortar and pestle, sieved through a 2mm mesh to remove debris, and repackaged in labelled bags. These samples were then analysed for texture using the hydrometer (Bouyoucos) method and for organic carbon using the Walkley-Black (wet oxidation) method. All analyses followed standard operational procedures [32].

2.5.3 Determination of grain size and type

The 50 g of air-dried, < 2 mm soil samples were placed in 400 ml bottles, saturated with distilled water, and mixed with 10 ml of 10% calgon solution to disperse the soil into sand, silt, and clay fractions. The suspension was shaken for two hours, then transferred to a graduated cylinder and mixed by inversion. A hydrometer reading was taken at 40 seconds, with the suspension's temperature recorded. After 2 hours, final hydrometer and temperature readings were taken. Soils were then classified into textural classes using a soil textural triangle based on the distribution of sand, silt, and clay.

2.5.4 Determination of organic carbon using wet oxidation method

A 0.30 g sample of ground soil was weighed into a labelled digestion tube. After recording the weight, 10 ml of 5% potassium dichromate solution was added to wet the soil completely. Then, 5 ml of concentrated H2SO4 was carefully added while swirling the mixture. The mixture was digested at 150°C for 30 minutes to complete oxidation and then allowed to cool. The digest was transferred to a 100 ml conical flask, 0.3 ml of indicator solution was added, and the mixture was titrated with ferrous ammonium sulphate solution [14];

$$\text{Organic carbon\%} = \frac{t*0.3*(eso4)}{wt}$$

2.5.5 Determination of soil bulk density

Soil cores (5 cm diameter, 5 cm height, wight = W1) were inserted into soil pits at various depths, then excavated and trimmed. The cores were dried in an oven at 105°C for 24 hours, cooled in a desiccator to room temperature, and then weighed (W2). The volumes (V) of the cores where calculated.

$$\text{Bulk density, } \rho b = \frac{\text{mass of oven dry soil}}{\text{total soil volume}}$$

$$\rho b\ (\text{g cm}^{-3}) = \frac{(\text{W2}-\text{W1})\text{g}}{V(cm3)}$$

An empty beaker 50 ml were weighed and recorded the weights. Air dry soils were added. The volumes were record and water added into the beaker. The volume of water left in the cylinder are recorded. Soil Porosity = (1 - (Bulk Density (ρb) / Particle Density (ρp) x 100. *Porosity* is the ratio of the volume of the pores in a soil sample to the total volume of the sample [10]:

$$\text{Porosity, } \varphi = 1 - \frac{\rho b}{\rho p}$$

2.5.6 Determination of permeability of Soil using constant head method

Soil cores were placed in a tray with water added halfway to saturate them for 24 hours. Porous cloth was attached to the bottom of each soil core, and a water reservoir was connected. Water was allowed to flow through the soil until a steady state was achieved. The difference in water energy (ΔH) and the height of the soil core (ΔL) were measured, and the water collected over a set time interval. Permeability of the soil was calculated according to Darcy's law.

$$\text{Permeability (KT)} = \frac{\text{QL}}{\text{Ath}}$$

Where: K_T = coefficient of permeability at temperature T, cm/sec. L = length of the soil in centimetres. t = time for discharge in seconds. Q = volume of discharge in cm^3. A = cross-sectional area of permeameter. h = hydraulic head difference across length L, in cm of water

2.5.7 Determination of saturation using gravimetric method

Gravimetric water content is the mass of water per mass of dry soil. Soil cores were saturated drained to remove excess water and measured moist soil (wet weight). The soils were then oven dried for 24 hours at a temperature of 105° C to remove all water. The soils were then reweighed to determine the dry weight. The difference between the wet and the dry weight is the amount of water in that soil [25].

2.8 Data Analysis

The analysis of the questionnaire data was done using Pearson rank correlation coefficient at bivariate level. A multivariate linear regression was then applied. The qualitative data was analysed using thematic synthesis., frequency tables and overall response means. For the Laboratory data, Cross tabulations with Chi-square statistics were conducted, followed by a factorial analysis of variance to investigate the significant differences between means of the quantitative parameters (i.e., organic content, permeability, bulky density, porosity and saturation). Fisher least significant difference (LSD), ANOVA, and post-hoc tests were conducted to understand which pairs of parameter means were significantly different.

3. RESULTS

3.1 Sociodemographic Profile of the Participants

The demographic variables are presented in Table 2. The social demographic data reveals that the majority of respondents were male (53.3%) and predominantly aged 50 years and above (41.7%). A significant majority were married (78.3%), with fewer respondents being divorced (10.0%) or widowed (6.7%). In terms of professional experience, over half of the respondents (53.3%) had 15 years or more of experience.

3.2 Correlation between the Different Forms of Landslides and Potential Enablers

Fisher's exact test for significance of association between each construct of natural and human factors, and the different forms of landslide outbreaks was performed and the results were reported in Table 3a. All the natural factors such as the hilly terrain and heavy rains were significantly associated with the occurrence of the four types of landslides, except some resources like rivers and vegetation which were not associated with one landslide type called topples. Also, Among the human factors, poor faming methods and unplanned settlements were not significantly associated with topples (Table 3a).

Further, natural factor response-mean score and human factor mean response scores were each correlated with landslide-mean response score using Pearson correlation test (Table 4). The bivariate analysis showed that both natural factor response-mean score and human factor response mean score had significant associations with the outcome variable, "the landslide response mean score". The natural factor mean response score was positively related to landslide mean response score and was very statistically significant at the 0.01 level ($r = 0.656$, p - value < 0.001), while the human factor means response score also had a positive association with the landslide outbreak mean score and statistically significant at the 0.01 level, the correlation coefficient was relatively low ($r = 0.429$, p – value = 0.001).

Table 2. Descriptive statistics on demographic characteristics

Demographic Characteristic	Frequency(n)	Percent (%)
Gender		
Male	32	53.3
Female	28	46.7
Age bracket		
20-29	5	8.3
30-39	12	20.0
40-49	18	30.0
50 years and above	25	41.7
Level of Education		
Masters	5	8.3
Degree	34	56.7
Diploma	19	31.7
Certificate	2	3.3
Marital Status		
Married	47	78.3
Divorced	6	10.0
Widow	4	6.7
Single	3	5.0
Level of Experience		
5-9 years	12	20.0
10-14 years	16	26.7
15 years and above	32	53.3

Table 3a. Statistical analysis of potential enablers of different types of landslides using fisher's exact

		Landslide			
S. N	**Factors**	**Falls**	**Flows**	**Topples**	**Slides**
		(p-value)	**(p-value)**	**(p-value)**	**(p-value)**
	Natural Factors				
1.	Hilly nature of the landscape	55 (<0.0001)	71 (<0.0001)	47 (<0.0001)	70 (<0.0001)
2.	Heavy Rainfall	64 (<0.0001)	93 (<0.0001)	55(.000)	69 (<0.0001)
3.	Natural features like rivers, vegetation	34 (<0.0001)	52 (<0.0001)	20 (0.072)	47 (<0.0001)
4.	Soil organic content	31 (<0.0001)	40 (<0.0001)	43 (<0.0001)	31 (<0.0001)
5.	Soil texture	73 (<0.0001)	82 (<0.0001)	54 (<0.0001)	54 (<0.0001)
6.	Soil Mineral content	53 (<0.0001)	41 (<0.0001)	35 (<0.0001)	30 (<0.0001)
	Human Factors				
7.	Poor land use planning	35(.000)	45(.000)	25 (0.006)	42 (<0.0001)
8.	Deforestation	66(.000)	82(.000)	55(<0.0001)	73 (<0.0001)
9.	Poor farming methods	25(.009)	40(.000)	16 (0.294)	29 (<0.0001)
10.	Unplanned human settlements	28(.002)	41(.000)	19 (0.137)	27 (0.018)

Significance level is 0.05, p-values highlighted yellow are insignificant

Table 4. Results of the pearson correlation between potential predictors and landslide occurrences in Bududa District

Potential Predictors	**Landslide Occurrence mean response score**	
	Pearson Coefficient (r)	**p - value**
Natural Factor mean response score	0.656	< 0.001
Human Factor mean response score	0.429	0.001

Correlation is Significant at the 0.01 level (2 - tailed)

When assessed simultaneously with natural factors, the human factors did not significantly contribute to landslide occurrences (multiple linear regression analysis, p = 0.464), hence, human factors act as moderators of natural factors in causing landslides. In the laboratory results, Organic content (p<0.001), Saturation (p=0.011), Bulk density (p=0.002), were found to be significantly associated with landslide occurrence, while Permeability (p=0.718), and Porosity (p=0.267) [Factorial Analysis of Variance (FANOVA, p<0.05)].

The Key Informants highlighted that landslides are influenced by natural causes like flow of water across hills, long spells of heavy rainfall, nature of the soils and its texture. As a consequence, therefore, sub counties like Bukalasi, Bumayoka and Bundesi are highly vulnerable to landslide occurrence. One of the participants testified that; *Naturally, the soils of Bududa district are characterized by certain content and texture that easily collapse and result into landslides. The clay and sandy content make it possible for landslides to occur especially during rainy seasons (local leader A).* Another testimony provided by a participant at household level further intimated that natural factors take a centre stage in the occurrence of landslides in this area. He added that, "*The natural make-up of the landscape of Bududa district is mountainous coupled with steep slopes. These are routinely exposed to landslide risks when they come into contact with lengthy rain intervals and often followed by devasting effects (participant B).*

Also, Key Informants were able to show human factors equally contribute to landslides in Bududa district. The constant use of land, year in and year out affects its stability especially that it is major source of livelihood to the local communities. This state of affairs results into changes in the land cover and eventually degradation, all of which culminates into landslides. In addition, cases of fragmenting land into small pieces without adequate preparation to safeguard from sliding across the hilly/mountainous terrain, poor farming methods/habits, deforestation and over cultivation of the same piece of land were reported.

Among the other factors causing landslides in Bududa district, attention was mainly given to the natural ones. Much as long rainy spells were noted, also persistent dry spells were reported to occur. The long dry spells affect the land stability by creating cracks along the cultivatable hilly areas and are worsened by the subsequent rainy seasons. The other is the practice of establishing homesteads or housing settlement in the hilly/steep slopes that are quite prone to landslide outbreak. In this regard, soils are weakened and rendered more vulnerable to slides along the steep slopes where farming is a major and regular economic activity. In support of this observation, one household participant held; *Dry seasons characterized by long spells of sunshine between November and march create conditions for major cracks along the hilly topographical areas. This is aggravated by coming of the rainy seasons, all of which creates slope instability and ultimate sliding of the land (participant C)*. Among the geological and tectonic factors observed, the geological structure of the area, including the presence of faults, fractures, and weak rock layers, were found to potentially promote landslide events. Wide and growing Cracks were reported in other sub counties in Bududa but they were not realized in the study area.

3.3 Effects of Landslides on the Community and Environment in Bududa District

The study found out that much as landslides largely have negative effects, there are also some positive outcomes, however, the most pronounced are the negative effects such as destruction of lives and property, destruction of valuable infrastructures (Fig. 2), loss of biodiversity. There was only minimal agreement on the fact that landslides occurrence positively impacted the community livelihoods (Table 5). The improved livelihood was majorly reported to be shelter/houses among the people that were relocated away from the landslide-stricken areas. The livelihoods of communities that persisted to continue living in the affected areas were reported to remain poor, surviving basically on agriculture for recovery.

From the observational survey and the Key Informant Interviews, landslides found to generally affect the communities in Bududa district in terms of livelihood in varying dimensions. Beginning from household level, the adversities were reported to spread to the general community level. Given that the survival of the local communities is entirely agricultural-based, landslide manifestations were found to present a serious setback in terms of the peoples' well-being. This is because big losses and damage of valuable resources like crops including coffee and bananas which are supposed to primarily provide income and food. One of the participants particularly a local leader remarked; "*Whenever landslides occur, they impact short- and long-term effects on the livelihoods on the local people given that they solely depend on land for their household incomes. Destruction of large acreage of coffee at Nametsi in 2011 devasted the livelihood of the people of Bundesi sub county" (participant D).* Another participant at household level stated that, "*Major sources of the livelihood of the people were devasted by the un-expected landslides that destroyed by Summe River in Bukalasi and more recently at Bumayoka. Livestock and zero-grazing activities were lost alongside the housing settlements. This led to loss of household income in turn" (participant E).*

In addition, the destruction of viable infrastructure due to landslide occurrence was also reported to have a negative bearing upon the livelihood of communities. In the event that landslides occur, essential infrastructure such as hospitals, schools, and houses are damaged and sometimes totally swept away. It is for instance noted that the landslides strike at the hilly areas near roads end up destroying road infrastructure and subsequently making mobility difficult. In another testimony, one participant remarked; *Over the years, vital infrastructure that is necessary in the process of the peoples' livelihood is destroyed. At Namesti for instance, a Health Centre III was buried while schools and roads were seriously damaged. This indirectly affected communities' livelihoods", Participant F.*

With regard to landsides effects on the environment, one of the participants remarked that, "*The environment in the most landslide prone areas of Nametsi, Bukalasi and Bumayoka has been degraded over the years. As a result, some areas cannot be easily identified given the drastic changes that have taken place in the land cover and vegetation," (participant G).*

Table 5. Showing responses on effects of landslides on the community and environment in Bududa district

S/N	Effects of landslides	N	1 n (%)	2 n (%)	3 n (%)	4 n (%)	5 n (%)	Overall mean	Std. Dev
1	Valuable infrastructures are often destroyed	60	5(8.3)	5(8.3)	1(1.7)	24(40.0)	25(41.7)	3.98	1.24
2	Damages are encountered at household level as a result of landslides	60	4(6.7)	4(6.7)	2(3.3)	28(46.7)	22(36.7)	4.00	1.14
3	Communities' livelihoods are devastated	60	8(13.3)	7(11.7)	3(5.0)	26(43.3)	16(26.7)	3.58	1.36
4	Causalities and deaths are realized due to landslides	60	16(26.7)	5(8.3)	3(5.0)	27(45.0)	9(15.0)	3.13	1.49
5	Farmland losses are colossal in terms of crops	60	6(10.0)	6(10.0)	3(5.0)	24(40.0)	21(35.0)	3.80	1.30
6	Livelihood sustainability is enhanced at community level	60	20(33.3)	17(28.3)	4(6.7)	**10(16.7)**	**9(15.0)**	2.52	1.48
7	National economic losses due reconstruction/rehabilitation	60	7(11.7)	10(16.7)	3(5.0)	20(33.3)	20(33.3)	3.60	1.41
8	Improved livelihood to those relocated and resettled	60	4(6.7)	7(11.7)	4(6.7)	27(45.0)	18(30.0)	3.80	1.19
9	Deformation of the landscape	60	6(10.0)	5(8.3)	6(10.0)	10(16.7)	33(55.0)	3.98	1.38
10	Interference with the social service delivery chain	60	6(10.0)	9(15.0)	4(6.7)	14(23.3)	27(45.0)	3.78	1.42

1 = Strongly Disagree (SD), 2 = Disagree (D), 3 = Not Sure (NS), 4 = Agree (A), 5 = Strongly Agree. The bolded values show the minimal level of agreement on the fact that landslides culminated in livelihood improvement

Table 6. Responses on interventions taken to mitigate landslides and minimize their effects on the community and environment by communities in Bududa district

S/N	Interventions to mitigate landslides	N	1 n (%)	2 n (%)	3 n (%)	4 n (%)	5 n (%)	Over mean	Std. Dev.
1	Local defensive barriers are used to mitigate landslides	60	11(18.3)	13(21.7)	4(6.7)	15(25.0)	17(28.3)	3.23	1.52
2	Community-based interventions of afforestation are utilized	60	**6(10.0)**	**8(13.3)**	6(10.0)	29(48.8)	11(18.3)	3.52	1.23
3	Monitoring takes place on a regular basis	60	20(33.3)	14(23.3)	2(3.3)	14(23.3)	10(16.7)	2.67	1.55
4	Micro-scale land-use management exists at household level	60	14(23.3)	18(30.0)	3(5.0)	14(23.3)	11(18.3)	2.83	1.49
5	Slope stability management is promoted at community level	60	14(23.3)	21(35.0)	2 (3.3)	17(28.3)	6(10.0)	2.67	1.37
6	Coping strategies are used through local resources	60	**13(21.7)**	**19(31.7)**	5(8.3)	12(20.0)	11(18.3)	2.82	1.46
7	Preventive modalities like physical mapping are utilized	60	8(13.3)	6(10.0)	3(5.0)	23(38.3)	20(33.3)	3.68	1.38
8	Sensitization of communities on landslides is common	60	6(10.0)	7(11.7)	3(5.0)	22(36.7)	22(36.7)	3.78	1.33
9	There are local-level structures of landslide management	60	7(11.7)	10(16.7)	13(21.7)	22(36.7)	8(13.3)	3.23	1.23
10	There is collaboration among various stakeholders in landslide management	60	5(8.3)	7(11.7)	3(5.0)	15(25.0)	30(50.0)	3.97	1.34

1 = Strongly Disagree (SD), 2 = Disagree (D), 3 = Not Sure (NS), 4 = Agree (A), 5 = Strongly Agree (SA). The bold values show the considerably low levels of disagreement

Fig. 2. Representative images of the remains of Nametsi Health Center II (Red Arrow), that was sunk by landslides in Bududa District, Eastern Uganda

Apart from the negative impact of landslides, some cases of positivity were registered upon the community and environment as well. As a consequence of landslide occurrence in parts of Bududa district, some interventions of strategic nature have been undertaken to enhance the way of life of the people. Most of these interventions have been initiated by the government over the past years. Land has been acquired for resettlement and relocation in order to avoid a repeat of the community damages inflicted by the past landslide outbreaks in the same scenes where they manifested. Bulambuli and Kiryandongo districts have ultimately become focal areas of relocating and resettling the Bududa landslide victims. The other has been re-planning the environment to avoid future losses of life and environmental destruction. On this note, one of the participants, a local leader said that, "*Following the routine outbreak of devastating landslides at Nametsi and Summe, the government came up with a relocation policy. Many of the victims were relocated for settlement in parts of Kiryandongo and Bulambuli (Bunambutye) for safety reasons environmental protection from further destruction"' ((participant H).*

3.4 Interventions Taken to Mitigate Landslides and Minimize Their Effects on the Community and the Environment in Bududa District

The levels of agreement on the interventions used to address landslides were generally high except for the question whether, "Community-based interventions like afforestation are effectively utilized", and that, "Coping strategies are effectively used through local natural resources such as rivers" (Table 6).

From the Key Informant Interviews, there are several community-based interventions reported. Among these interventions include modalities such as relocation the victims and those exposed to danger of looming landslides. Also, there was widespread digging and constructing of trenches and terrace barriers that involve using sucks filled with sand. As a matter of emphasis, one of the participants remarked; *There exist multiple mechanisms used to safeguard against landslides at community and household level namely; building defensive mechanisms and use of trenches. Those in prone areas have been sensitized about mitigative measures (participant J).* The other interventions included, the practice of afforestation, platting of trees, especially those that bear fruits like mangoes, avocado, oranges, and lemons. These fruit trees are grown not only to address landslides but also for income generation. The tree species were observed to be planted on hilly areas. As a way of emphasis, one of the participants at household level remarked; *Most species of trees are planted for food, fuel and generally income generation in the long-run. The trees at the same time aid in community development and protecting the environment from devastating effects of landslides ((participant K).*

A number of stakeholders was found to be involved in executing the interventions geared towards mitigating landslides and their effects. There was observable evidence that household heads, local leaders, sub county disaster management committees and development partners were important in enhancing mechanisms of intervention in most vulnerable parts to landslides in the study area. Relocation of the affected communities was reported to be executed by the government and development partners like Red Cross and Oxfam in close collaboration with sub county authorities. Afforestation cuts across household heads and local leaders. One of the participants remarked; *Stakeholders of multiple nature promote intervention measures in relation to community-based mechanisms. They are local and external although they are more of community driven. The Village and Subcounty Disaster Management Committees are Inactive. (participant L).* Another participant asserted that, *"Given the interventions like afforestation, trenches and relocation undertaken in Nametsi in the aftermath of the 2011 landslide, the reoccurrence of landslides has not had severe effects upon the community as the case was then (participant M).* Whereas awareness campaigns about landslide management were found to have been initiated, sensitization remained limited in scope with most of the high-risk areas not receiving the service due to various challenges. One participant particularly a local leader remarked; *Most community-based interventions are quite appealing but are hampered by delayed support from government agencies like the office of the prime minister. Funding necessary to support the planned interventions delays and therefore rendering some interventions ineffective despite the fact that they can make sense if executed on time (participant N).*

4. DISCUSSION

This study revealed that while both natural and human factors can act as catalysts for landslide outbreaks in Bududa district, natural factors alone are the predominant contributors when these variables are assessed simultaneously. This finding aligns with results of previous researchers, which underscore the significance of natural enablers like rainfall, slope gradient, and soil composition in precipitating landslides [33]. The impact of human activities, such as deforestation and poor agricultural practices, serves to exacerbate these natural facilitators, making them more severe [34]. Among the various soil properties, organic content, soil saturation, and bulk density were found to have a strong correlation with landslide events. Similarly, earlier studies have shown that high organic content can lead to increased water retention, making the soil more prone to becoming saturated, which in turn heightens the risk of landslides [35]. Bulk density, which signifies soil compaction, also plays a critical role, as more compact soils tend to have lower permeability, leading to increased surface runoff and erosion, further harnessing landslide conditions [36]. Although permeability and porosity are often considered important [36-38], in the current study, they did not demonstrate a significant relationship with landslide occurrences. This suggests that while these factors are relevant, they may be overshadowed by the more impactful soil parameters such as saturation and bulk density in Bududa.

This research also revealed that while soil types and properties are natural contributors to landslides, their impact is significantly accelerated by human activities. Deforestation, for example, reduces the root strength of soil, making it more susceptible to erosion and landslides. Unsustainable farming practices and settlement construction on vulnerable slopes further destabilize the land, increasing the frequency and severity of landslides [39]. Therefore, the interaction between human activities and natural soil properties is crucial in understanding the landslide dynamics in this study area. The topography, climate, and soil characteristics in Bududa district and the entire Mount Elgon subregion, create a natural predisposition to landslides, while human activities exacerbate these risks. Effective mitigation strategies should therefore address both natural and anthropogenic factors, emphasizing sustainable land use practices, reforestation, and the construction of defensive barriers to reduce landslide risks and protect vulnerable communities.

In the study, the effects of landslides were found to be generally more deleterious than beneficial as widely reported earlier. Landslides primarily have negative consequences, including the destruction of infrastructure [40], loss of valuable land [8,40], and most tragically, loss of lives [14,37,41]. The displacement of communities also leads to social and economic disruptions. However, this study a positive outcome was noted —the resettlement of survivors in better living conditions. These individuals, once relocated, often experience improved living conditions in their new environments, benefiting from better infrastructure and access to resources that were not available in their original locations. This finding aligns with other studies which have observed similar patterns of improved livelihoods post-resettlement in disaster contexts in different parts of the world [24,40].

We report several interventions adopted against landslide strikes at various levels in Bududa district, with community-based approaches being more predominant. Community involvement is critical, as local residents are the first responders during landslide events. This finding supports the ideal disaster management recommendations, which advocate for community engagement as a key component of effective disaster risk reduction strategies [42]. This study identified several challenges faced when addressing landslides, including limited resources for implementing mitigation measures. The major advances that may improve the outcomes of interventions include better land use planning, enforcing zoning laws to avert settlement in landslide prone areas, and investing in early warning systems. Engineering solutions such as retaining walls and slope stabilization are also suggested to reduce the impact of landslides [24]. However, the success of these measures is often hampered by inadequate funding and insufficient technical capacity at the local government and national levels in Uganda and other resource-poor countries [42,43].

5. CONCLUSION

The study identified that natural factors, such as rainfall, slope gradient, and soil composition, are the primary contributors to landslides in Bududa district, with human activities like deforestation and poor agricultural practices exacerbating these natural risks. Soil properties such as organic content, soil saturation, and bulk density were found to be strongly correlated with landslide occurrences. Human activities further destabilize the already vulnerable topography, increasing the frequency and severity of landslides. Despite the overall negative impact of landslides, the study noted that relocated survivors often experience improved living conditions. Community-based approaches were found to be crucial in landslide interventions, though limited resources and inadequate technical capacity hinder effective mitigation. Therefore, to address the landslide disasters in Bududa more effectively, there is a need to; Promote reforestation and sustainable farming practices to stabilize the soil and reduce the risk of landslides, strengthen and enforce regulations that prevent settlement in high-risk areas to mitigate landslide risks, develop and implement robust early warning systems to prepare communities for potential landslide events, construct retaining walls and employ slope stabilization techniques to reduce landslide impacts, and allocate more resources and build local technical capacity to effectively implement and maintain mitigation measures.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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