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Analysis of existing landslide early detection and warning systems "a case of Bududa District, Uganda"

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Abstract
Landslides are a major concern for hilly regions worldwide, claiming lives and livelihoods. Early detection and warning systems are crucial in mitigating the impact. This paper aims to identify and analyse the existing landslides early warning systems (LEWS) by analysing the community awareness and assessing the perception of the respondents toward the effectiveness of existing warning systems in Bududa District, Uganda. LEWS are integrated systems designed to monitor, assess, and provide timely alerts about potential landslides. Through mixed methods with sample size of 199 participants, the study revealed that majority of the respondents' (48.2%) lacked awareness about existing landslide early warning systems, while 28.2% were none committal, with only 23.7%, indicating awareness of some of these systems. Further identified that weather stations were the most popular (44.9%), and community radios (41%). Additionally, majority of the respondents (51.3%) ranked the systems effectiveness in terms of providing early detection and timely warning at 25%, and only 9.6% of the respondents ranked their effectiveness at 75%. The study recommends that Bududa district officials should increase community awareness of the installed landslide early detection and warning systems through sensitization programs, the Government should develop customized landslide detection and early warning system.

Keywords Warning systems · Community awareness · Perceptions · Effectiveness · District views

1 Introduction

Countries worldwide have experienced various disasters that resulted in the loss of lives and property. According to the international Emergency Events Database (EM-DAT) 2022 report, landslides account for at least 17% of all-natural hazard-related deaths worldwide and have been ranked as the third-largest disaster. In Uganda, Bududa district is among those that are prone to landslides. Bududa district is located on the western slopes of Mount Elgon in Eastern Uganda and deeply embedded in the cultural, social, and economic context of the local people who are agrarian and depend on the land for their livelihoods. With population growth and land scarcity, the traditional method of shifting cultivation is no longer sustainable. The economic marginalization of the population, combined with environmental degradation and increasingly unpredictable rainfall patterns, has made them more vulnerable to landslides [1–6].

Overtime, the community effort in mitigating the effects of landslides through contour farming and terracing, digging trenches, education programs, planting trees, and by-laws prohibiting farmers from using fertilizers in Bududa

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district has yielded low response [2, 7, 8]. This has continually impacted the social and economic well-being of the population. The prominence of landslides in Bududa forced the government to run a community resettlement program and together with humanitarian organizations to provide aid and support to affected communities [5, 9]. Furthermore, the government and humanitarian organizations' installed landslide early warning systems in the area [1, 4, 5, 10, 11]. However, even these have not been effective (51.3%) as per the findings in terms of detecting landslides and providing warnings to communities at risk. These ongoing challenges posed by landslides in the district continue to affect the lives and livelihoods of many people in the area. Recent studies have revealed challenges in utilization of the installed early warning systems, such as poor timing, poor coordination, and poor community sensitization [4]. This paper aims to identify and analyse the existing LEWS by analysing the community awareness and assessing the perception of the respondents toward the effectiveness of existing warning systems in Bududa District, Uganda.

2 Material and methods

The research adopted mixed methods and was a case study where qualitative data informed the quantitative data. According to the government agency responsible for the collection, analysis, and dissemination of statistical data in Uganda, Uganda Bureau of Statistics (UBOS) projections of 2019–2023, Bududa district has a population of 282,900, as operational in mid-2019. The participants were recruited from four randomly selected landslide prone sub counties with a study population of 70,300, two of which had landslide early warning systems installed. According to [12], close to 60% of Uganda's population are below 18 years of age and since the study does not include children, the study population was reduced by 60% of 70,300 leaving the target population of 28,120. One landslide prone parish from each sub-county was selected out of which two villages were identified through snowballing making a total of eight villages. Using 1960 Slovin's formular, written as: $n = N/(1 + Ne^2)$, where: n = the number of samples, e is the margin of error, N = the total population, the sample size of 199 participants was determined inclusive of twelve key informants, with eight being village local council authorities, two from the local governance structure established to coordinate disaster risk management efforts at the district level, the District Disaster Risk Management Committee (DDRMC) and two from is the centralized facility established by the Office of the Prime Minister's Department for Disaster Preparedness and Management in Uganda, the National Emergency Coordination and Operations Centre (NECOC). Accordingly, four research assistants knowledgeable in the local language "Lumasaba" were recruited and trained to facilitate the focus group discussions and management of the questionnaire.

In line with the Ethical Principles of the international and independent confederation of national medical associations representing physicians worldwide, the World Medical Association (WMA), Declaration of Helsinki (1964) guidelines, Ethical approvals were obtained from: School of Postgraduate Studies and Research, Nkumba University, Research Ethics Committee of Mildmay, Uganda, Uganda National Council of Science and Technology (UNCST), Written permissions from Bududa District Local Government, Office of Disaster Risk Management Committee, endorsement by Sub County Chiefs (Local Council Authorities III), Parish chiefs (Local Council Authorities II), Local Council Authorities I, and written consents from the research respondents.

The qualitative data collected through the focus group discussion, interviews and observations were translated in exactly the same words as used originally (transcribed verbatim). Content analysis was used to come up with themes. The quantitative data was descriptively analyzed using Statistical Package for the Social Sciences (SPSS) V20 software and exported to excel and Mind map for data presentation.

3 Results

This section shows results of qualitative and quantitative analysis regarding existing landslide early detection and warning systems.

3.1 Participants demographic findings

Sixteen Focus group discussions of 8–12 participants were held with a gender representation of 55.8% male and 44.2% female, of which 85.3% were married. 75% of them live in mud houses with an average household size of 6–10 persons. In terms of education, 51.3% attained tertiary/vocational education while 11.5% had no education, and the majority of the participants (76.9%) were peasants. The detailed demographic findings are presented in Table 1 below.

Respondents' demographic presentation provided a basis for analyzing existing landslide early detection and warning systems as it was quite informative of the respondents' characteristics.

3.1.1 Awareness of existing landslide early warning systems

Quantitative study findings indicated that majority of the respondents lacked awareness about existing landslide early warning systems, (48.2%), while 28.2% of were noncommittal and only 23.7%, indicated that they had seen some of these systems as shown in Fig. 1 below. Considering that the percentage of those who are not aware of the systems and those who were non-committal adds up to 76.4%, it implies that the majority of the respondents are not aware of the existence of the landslide early warning systems installed by Government and humanitarian organizations and so were not benefiting from them.

Table 1 Demographic data of the participants. Source: Primary data, 2023

Variables	Frequency	Sample size (%), n = 199
Age		
20–30	45	28.8
31–40	45	28.8
41–50	36	23.1
50 above	30	19.2
Gender		
Male	87	55.8
Female	69	44.2
Residential status		
Mud and iron roofed	117	75.0
Bricks and iron roofed	39	25.0
No. of household members		
1–5	38	24.4
6–10	118	75.6
Level of education:		
No education at all	18	11.5
Primary	42	26.9
Secondary	16	10.3
Tertiary/vocational	80	51.3
Occupation		
Peasant	120	76.9
Teacher	30	19.2
Other	6	3.8
Marital status		
Married	133	85.3
Single	17	10.9
Widow (er)	6	3.8

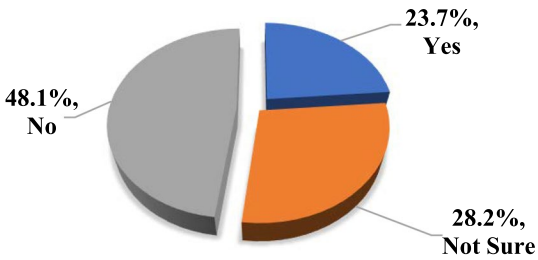

Fig. 1 Awareness of existing landslide early warning systems (Source: Primary data, 2023)

3.1.2 Existing landslide early detection and warning systems in Bududa district

Concerning existing landslide early detection and warning systems in the district, qualitative findings from a key informant stated that:

> *Several approaches have been employed to detect landslides and warn people by both government and humanitarian organizations including* ***Satellite imagery*** *that observe changes in land surface conditions,* ***weather stations*** *that measures both temperature and rainfall,* ***landslide hazard map*** *(2013) that help communities understand landslide prone areas,* ***drone*** *that collects graphical data for detailed mapping and monitoring of terrain features that could contribute to landslides,* ***community radios***, ***megaphones*** *which are community-based, that aid in alerting residents in case of potential landslide threats, it was based on the idea of using human observers to monitor potential landslide areas and trigger alarms when necessary,* ***river pegging*** *on riverbanks visually indicating rising water levels as to predict floods and landslides. Pole marks were made of durable materials that can withstand environmental conditions and placed at strategic locations based on historical flood levels, monitored manually and regularly to track water level changes and drum to alert the community. Data collected is analyzed manually to identify trends, patterns, and potential risks.* ***The manual ground-based survey*** *where a team of geologists, engineers, and other professionals collect data through direct observation, visual inspections, and field measurements. They analyze this data to develop predictive models that help in evaluating the potential for landslides. Additionally, a* ***toll-free telephone line*** *and* ***smartphones*** *are provided to locals for easy communication. However, these systems were not without weaknesses.* (Interview with the District Disaster Risk Management Committee member, Bududa Town Sub-County on 15th August 2023).

A key informant from NECOC when asked about existing landslide early detection and warning systems installed in the district by the government, stated that:

> *Under the Office of Prime Minister, we have been able to install five* ***automated weather stations*** *to collect rainwater using funnel-shaped collectors that direct rainfall into plastic containers with graduated markings for easy measurement. Once collected, built-in sensors detect the water level in the containers, converting it into an electronic signal for processing by a microcontroller. The data is typically transmitted to a server via satellite in real-time to meteorological departments for continuous monitoring of rainfall patterns. In addition, the district was given a D****rone****, which revolves around the concept of remote sensing. It is equipped with high-resolution cameras, it captures high-definition imagery and collects data from inaccessible areas. The collected data is then processed and analyzed by experts to identify signs of slope instability. Furthermore, a* ***new hazard map*** *which relies basically on human expertise and field observations to identify potential landslide-prone areas and assess the level of risk. The design thinking behind involves understanding the geological and environmental factors that contribute to landslides. The theory is based on the assumption that past landslide occurrences can help predict future events by identifying areas with similar characteristics. It involves a combination of field surveys, remote sensing techniques, and data analysis. Field surveys involve visiting potential landslide sites, observing terrain features, collecting soil samples, and documenting any signs of instability. Remote sensing techniques such as aerial photography, satellite imagery, and radar can provide valuable information about slope morphology, vegetation cover, surface displacement, and other indicators of potential landslides. Additionally, a t****oll-free telephone line*** *was given to the district for reporting weather-related incidents. However, he expressed disappointment over the community vandalization of some of the weather stations,* (Interview with the NECOC official, Kampala on 5th October 2023).

This implies that there has been a joint venture by government, humanitarian organizations and the local community to address the issue of landslide risk reduction in the district amidst some challenges. Figure 2 below is a presentation of the existing landslide early detection and warning systems mentioned above.

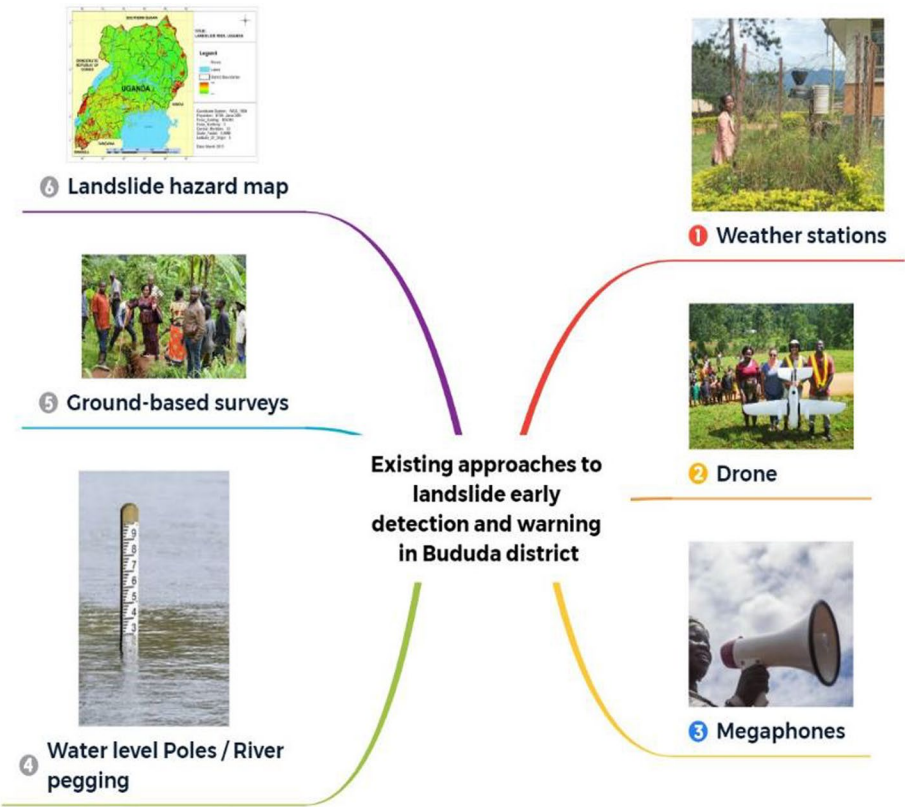

Fig. 2 Existing approaches to landslide early detection and warning in Bududa district (Source: Primary data, 2023)

However, key informants at the district identified weaknesses of the said landslide early detection and warning systems as expressed below:

Data collected by the drone and the weather stations is interpreted in Kampala and not in the district. The weather stations have been vandalized, the landslide warnings generated are general in nature to all people living on the mountains and not specific to individual sub-counties, the existing hazard map (2013) is no longer up to date given that new sub-counties have been created in the district. Other weaknesses were that committees formed along the river to alarm when landslides signs occur are not motivated and the community are not sensitized about several of these systems in place, (Interview with the District Disaster Risk Management Committee member, Bududa Town Sub-County on 15th August 2023).

Additionally, the key informant from NECOC expressed that:

As an office we are greatly disappointed by the failure of the district to effectively monitor and enforce protective measures over the equipment put in place for landslide risk reduction, (Interview with the NECOC official, Kampala on 5th October 2023).

These expressions indicated that the existing landslide detection and early warning systems had weaknesses which were likely to affect their effectiveness.

The above findings from key informant created a need to establish the quantitative views of the community about their knowledge of existing landslide detection and early warning systems which were expressed as follows in reference to Fig. 3 below. Study findings indicated that only 21.2% of the respondents were positive concerning Smartphones as one of the systems while 55.8% were negative and 23.1% were not sure. This implies that majority of the respondents were not aware of smartphones donated to communities for disaster awareness. Additionally, only 23.7% of the respondents were aware that Committees were formed along the rivers to monitor landslide signs and drum to warn people, though majority were not aware (56.4%) and 19.9% were not sure. This indicates that committees were not active possibly due to lack of motivation and the respondents were not sensitized about this type of landslide detection and early warning system. Furthermore, the issue of water level pegging on the riverbanks colored with red, green and yellow materials, had only 25.6% of the respondent's indicating knowledge about it while 19.9% were not sure and 54.5% expressed that

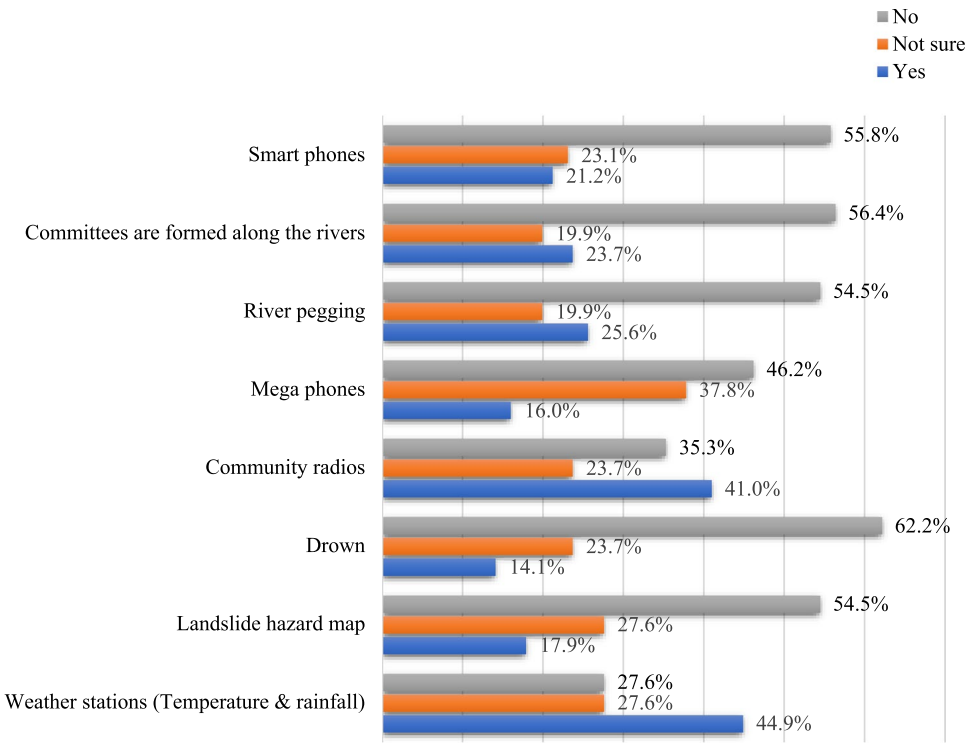

Fig. 3 Respondents' views on existing landslides early detection and warning systems (Source: Primary data, 2023)

rivers were not pegged at all. This meant that the majority of the respondents were not aware of this type of landslide detection and early warning system, possibly due to their distant residential location from the rivers. Meanwhile, existence of Megaphones as another landslide detection and early warning system, had findings indicating that only 16% of the respondents were knowledgeable about them, while 37.8% were not sure and 46.2% indicated ignorance about the same. This implies that majority of the respondents from the community were not aware of existence of this type of system (considering those not sure and those who objected straight away) even though this system was installed by Red Cross as far back as 2020. This ignorance could be interpreted as poor sensitization of the community by the district officials and humanitarian organizations about this system. Additionally, respondents' views indicated that the majority were aware of the existence of community radios (41%) even though 23.7% were not sure and 35% expressed ignorance about this system. However, given that a slightly lower than average percentage were aware of it, this could be considered to be representative enough in terms of community awareness. This was contrasted by a significant percentage of the respondents (62.2%) who expressed ignorance about the existence of the drone as one of the landslide detection and early warning system, even though 23.7% were not sure and 14.1% expressed knowledge about it. This meant that only a very small percentage of the respondents were aware of this system, which is again an indicator of low community sensitization. Concerning awareness of the landslide hazard map among respondents, 54.5% indicated they were not aware of this critical system, while 27.6% were non-committal and only 17.9% indicated awareness of this system. Since the majority of the respondents were ignorant of this system, then it was likely not to be useful to them unless they are sensitized about it and its functionality. And for weather stations in the community, 44.9% of respondents acknowledged their existence, though 27.6% remained neutral while a similar percentage (27.6%) objected to this. This implied that a significant percentage of respondents were aware of the existence of this system, which could be explained as by the fact that they are the oldest system installed in the area by the government (2018).

In summary, the findings in Fig. 3 above do indicate that weather stations are known by most of the respondents (44.9%) as a landslide early warning system, tailed by Community radios 41%, River pegging 25.6%, Committees formed along the river 23.7%, Smart phones 21.2%, landslide hazard map 17.9%, Megaphones 16.0%, Drone14.1%, satellite imagery 10.3%.

Quantitative findings can therefore be summarized as indicating a low awareness of the various landslide detection and early warning systems by respondents which are installed by the government and humanitarian organizations to mitigate the risk of landslides.

3.1.3 Primary sources of information to the community

Qualitative findings from key informants of both the District Disaster Risk Management Committee and NECOC were interviewed about the primary sources of information to the community about landslide detection and early warning systems. Their views were expressed as follows:

> *District officials and NECOC have put in place a number of sources that communities use to receive information on landslide detection and early warning systems. These include Radios, Televisions, Emails (from meteorological department), Heads of departments, Megaphones / toll free lines, Community radios, WhatsApp platforms, Local authorities' administrative structure, Word of mouth, Mobile Phone/SMS, and drumming. However, none of us was certain about the most commonly used sources of information by the community,* (Interview with the District Disaster Risk Management Committee member, Bududa Town Sub-County on 15th August 2023 and NECOC official, Kampala on 5th October 2023).

This implies that the locals were exposed to a number of sources of information concerning landslide detection and early warning. However, the effective use of each of these sources needed to be established.

Furthermore, the study quantitatively established the views of the community concerning the most commonly used source of information as expressed by the respondents. These views were tabulated below in Table 2.

In the quantitative data presentation of primary sources of information to the community, the analysis of findings involved combining the percentages of respondents who strongly agreed with those who agreed, as they both reflected positive inclinations. Similarly, the percentages of respondents who strongly disagreed and disagreed were combined since they both represented negative inclinations. On the other hand, responses categorized as neutral were presented separately because they did not lean towards either positive or negative sentiments. This is highlighted below in reference to Table 2 below.

The findings in Table 2 indicated that 96.1% of respondents viewed community radios positively as a primary source of information for communities, while 3.9% held a negative perception. This implies that radios can reach a wide audience, especially those in remote or underserved areas, making them a valuable communication tool. In contrast, findings revealed that 55.2% of the respondents agreed that televisions serve as a primary source of information for communities, 30.8% disagreed, while 14.1% were unsure. This indicates that an average number of community members use television as a primary source of information, though a notable percentage do not. Furthermore, regarding use of emails as another primary source of information for communities, 25.6% of respondents were in agreement, 50%, disagreed, while 24.4%, were unsure. This suggests that majority of the communities don't use emails as a primary source of information. Concerning heads of departments being a primary source of information for communities, findings indicated that only 28.8% of the respondents expressed a positive view, a sizable portion of 22.4% indicated uncertain stance, while another 28.7% showed ignorance on the matter. This signifies an opportunity for improvement and increased awareness surrounding their responsibilities and contributions towards better-informed communities. Additionally, the findings indicated that megaphones as a primary source of information for their communities was among the most rated with 60.2% of the respondents, however 7.7% were unsure, whereas 32.1% expressed ignorance. This highlights the need for alternative or additional sources of information to ensure that everyone in the community is adequately informed. The findings furthermore, indicated 46.2% of the respondents view WhatsApp as a primary source of information for communities, while 14.7% were unsure, and 39.1% disagreed. This highlights a high number of respondents who don't see WhatsApp platform as an information hopefully they don't have smartphones. The findings more still, showed that majority of the respondents, 66%, agreed that the local administrative structure serves as the primary source of information for communities, whereas 13.5% were unsure about this assertion, and 10.5% disagreed with the statement. This indicates that a large portion of the surveyed population relies on their local administrative bodies for information dissemination. Further on, findings revealed that a significant majority of respondents, specifically 91%, agreed that word of mouth is the primary source of information for communities. 3.2% of respondents were unsure, 5.8% of respondents disagreed. This high percentage implies a strong reliance on interpersonal communication and recommendations within communities. Findings more still, indicated 66% of the respondents agreed that phone calls and SMS messages serve as the primary source of information for communities, however 19.2% of the respondents were unsure and 14.8% were negative. This high percentage indicates the widespread reliance on these communication channels for disseminating information within communities. In contrast, other findings revealed that 42.3% of the respondents were positive that drumming is a primary source of information for communities, while 31.4% disagreed and 26.3% were unsure. This

Table 2 Respondents views on primary sources of information to the community. Source: Primary data, 2023

	Radios (%)	TV (%)	Emails (%)	Heads of departments (%)	Mega phones/ toll free lines (%)	WhatsApp platforms (%)	Local authorities' administrative structure (%)	Word of mouth (%)	Phone/SMS (%)	Drumming (%)
Strongly agree	89.7%	23.1	6.4	14.1	47.4	14.1	28.8	71.8	28.8	17.9
Agree	6.4%	32.1	19.2	14.7	12.8	32.1	37.2	19.2	37.2	24.4
Not sure		14.1	24.4	22.4	7.7	14.7	13.5	3.2	19.2	26.3
Disagree	2.6%	23.1	23.1	25.6	16.7	22.4	11.5	4.5	7.1	18.6
Strongly disagree	1.3%	7.7	26.9	23.1	15.4	16.7	9.0	1.3	7.7	12.8
	100.0%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

implies that there is a notable group of people who believe that drumming is no longer significant in transmitting information within communities.

The above findings do show that among the primary sources of information to the community, community radios were ranked by the majority having 96.1% views of the respondents, followed by word of mouth (91%), Local authorities' administrative structure (66%), Phone/SMS (66%), Megaphones (60.2%), Television (55.2%), WhatsApp (46.2%), Drumming (42.3%), Emails (25.6%), Heads of departments (18.8%).

3.1.4 Assessing the perception of the respondents towards the effectiveness of existing landslide detection and early warning systems

When respondents were asked about their perceptions regarding the effectiveness of the landslide detection and early warning systems in terms of providing early detection and timely warning, 51.3% ranked their effectiveness at 25%. Since most respondents were not aware of the early warning systems in place, it becomes hard to rank what they are not sure of. Ony 9.6% of the respondents ranked their effectiveness at 75%, this might have been the among the teams who participated in the installation process. This percentage aligns with that at the district level. See Table 3 below:

4 Discussion

Throughout history, it has been crucial to warn people about potential disasters, respond to emergency calls, and reduce economic losses to increase the chances of survival [13].

4.1 Awareness of existing landslide early detection and warning systems

Study findings on low awareness of existing landslide early detection and warning systems implied that the majority of the respondents were not aware of the systems developed by Government and humanitarian organizations. This contradicted with the findings of Sesanto et al. [14] who recommended that "citizens should have a basic knowledge, understanding and preparedness in the face of disaster". This practice was supported by scholars Osuret et al. [15] who underscored the role of awareness creation at individual, community and organizational level as a more effective tool in mitigating disaster risk in Mt. Elgon Region, Uganda. However, Alcántara-Ayala et al. [16] in their study "Landslide Warning Systems in Low-And Lower-Middle-Income Countries: future Challenges and Societal Impact" identified that engaging the community and other stakeholders is one of the main challenges of effective community and technology based LEWSs. This challenge was attributed to the need for efficient communication, trust-building, and collaboration among various stakeholders.

The current study findings further contradict with Onek [5] in Namono et al. [4] who claimed that the developed landslide early detection and warning system (weather stations) in Bududa district were done in collaboration with the communities. This overlooks the emphasis by Huggel et al. [17] who insists that the awareness of the communities exposed to landslide risk is important for their response to a warning. The lack of awareness among the respondents highlights the need for improved communication and public outreach efforts if existing landslide early detection and warning systems are to be effective in Bududa district.

Table 3 Respondents' views on effectiveness of the existing landslide detection and early warning systems. Source: Primary data, 2023

Effectiveness at	Percent
25%	51.3% (80)
50%	21.2% (33)
75%	9.6% (15)
Not sure	17.9% (28)
Total	100.0% (156)

4.2 Existing landslide early detection and warning systems in Bududa district

Additionally, study findings indicated weather stations and community radios as the most popular existing landslide early detection and warning systems as explained the high percentage of respondents who are peasants. WIMEA-ICT [18], reports that such a high percentage of farmers are primarily rain-fed, thus making weather information crucial for farming activities and the use of several other media channels including local and national radios, telephone calls and television among others vital for information sharing. Such observations were in line with Katamba [19] who established that community radios stations extend community services to the multitudes in the manner of benefiting the community as per their religions, local languages, cultural and tribes, community economic policies and behaviors. This advancement was supported by Solervicens and Plaugher [20] who acknowledged that community radio stations promote peoples' decision making on various issues, view sharing of the masses in the society, varying knowledge, solving community problems and empowering development despite government control.

Conflicting to the study findings, the report on the status of weather stations in Uganda by WIMEA-ICT [18], highlighted a number of challenges which render the currently installed weather stations unreliable including inadequate technical support, funding, human resources, and not forgetting extensive vandalization of the weather stations' equipment (especially the solar panels). This was also pointed out by DDRMC and NECOC key informants that weather stations' equipment was vandalized by the community. Considering the importance of analyzing the existing landslide early detection and warning systems in Bududa district in relation to its effectiveness to the community, there is a need to address the challenges so as to mitigate the impact of landslide effects.

4.3 Assessing the perception of the respondents towards the effectiveness of existing landslide detection and early warning systems

Furthermore, the study findings revealed valuable insights into how communities perceived landslide detection and early warning systems whereby the majority of the respondents experienced very little of their effectiveness. This is supported by Namono et al. [4] in their study investigating the barriers to sharing and managing landslides information and warning, expressing that the effectiveness of the weather stations in Bududa district was not well documented. This could be attributed to the views expressed by DDRMC key informants that data from the rain gauges and the drone chip were not being interpreted at the district level rather from Kampala, the Uganda National Meteorological Authority (UNMA) which provides weather and climate services, analyzes scientific research findings, and offer guidance on climate change. These has resulted in delayed or no feedback. Other findings in line with the above findings are by Badru et al. [21] who stated that the existing system for landslide monitoring in Bududa district is inaccurate, time wasting and unreliable because it is done manually by field experts.

However, the above findings contradicted those of Yongbo et al. [22] who established that the fast-deploying monitoring system (FDMS) in Tibet, China was effective in making predictions on precursory features concerning rainfall and soil moisture as causes of landslides. This meant that landslide detection and early warning systems can be effective if existing constraints are identified and addressed.

5 Conclusion

The study findings established that there was low awareness by the majority of respondents about existing landslide early detection and warning systems developed by Government and humanitarian organizations. Considering that engaging the community and stakeholders is identified as a key challenge in implementing effective landslide early warning systems, findings emphasized the need for improved communication, trust-building, and collaboration among all parties involved.

Study findings further established that weather stations and community radios were the most widely used early detection and warning systems for landslides amongst several others. This observation was credited to the high percentage of farmers who are primarily rain-fed, making weather information crucial in mitigating risk towards their

farming activities so as to make timely and informed decisions. Community radios were found to play a vital role in ensuring that critical information from weather stations reach the famers in time.

Furthermore, study findings established that participant expressed doubts regarding the effectiveness of existing structural mitigation strategies in terms of providing early detection and timely warning to the community in Bududa district. This was attributed to a number of causes including delayed or no feedback and inaccuracy since the processes are done manually by field experts.

6 Recommendations

The study sought to gain understanding and knowledge of the existing landslide early detection and warning systems and made the following recommendations to address the situation.

1. It is crucial for Bududa district officials to increase awareness and understanding of existing LEWSs among the stakeholders. This can be achieved through various awareness creation programs, such as community meetings, workshops, trainings and inclusive decision-making processes. This is essential in building trust, encouraging collaboration and mitigating disaster risk.
2. Bududa district administration should prioritize the maintenance and protection of weather station equipment in communities since their functionality significantly contribute to early warning for landslides. Additionally, the coverage of community radio stations should be extended since it is a vital channel for information dissemination to enhance preparedness and response efforts in landslide-prone areas.
3. The Government of Uganda should move away from manual monitoring methods and invest in automated systems that can provide real-time data analysis and alerts at the district and to specific local communities. This can help in reducing time wastage and improving the reliability of landslide monitoring in Bududa district. Thus, develop customized landslide detection and early warning system.

Author contributions S.N. wrote the main manuscript J.T.L, D.P.M and D.A all reviewed the manuscript.

Data availability The data supporting the findings of this study can be accessed from the authors upon a reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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