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Resilience and the dissemination of flood disaster early warning messages in a township in South Africa

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Disaster early warning systems are regarded as one of the key activities in the implementation of both disaster preparedness and response measures. The need to implement effective disaster early warning systems in Africa, in particular, dates back to the early nineties. Even before the UN Sendai conference, initiatives to improve existing early warning systems had already been identified. This study assessed flood resilience based on the dissemination of Early Warning Messages in Vosloorus Township. The study applied a quantitative approach by collecting data using a structured questionnaire and applying inferential statistics to analyse the data from 100 participants of two informal settlements of Vosloorus Extension 21 with a combined population size of 251. The study applied a series of one-way ANOVA tests separately, two separate General Linear models and one ordinal regression on R statistical software to address the objectives of this study. The study results showed the significant role that demographic characteristics play in shaping the understanding of disasters within the study community. These factors contribute to the community's resilience, particularly in the dissemination of early warning messages. There appears to be a disconnect in translating this awareness into effective understanding and action based on EWMs. This disconnect may be related to how information is communicated and the general preparedness of the community. For communities where cellphone ownership is limited, alternative methods of delivering EWMs should be considered to ensure broader and more equitable access to crucial information. Addressing infrastructural issues such as electricity and internet access is also essential to improve the timeliness and efficiency of early warning systems.

KEYWORDS

resilience, mitigation, dissemination, floods, early warning messages

1 Introduction

Disaster early warning systems are regarded as a complex component of disaster risk reduction and resilience (Brazzola and Helander, 2018). The International Decade for Disaster Reduction (IDDR) for example, highlighted early warning systems as critical for disaster risk reduction (Perera et al., 2019).

The IDDR was aimed at shifting the world focus to two aspects: disaster preparedness and response measures thereby building the resilience of communities (Lechat, 1990). Noyes and Yarwood (2013) reported that disaster early warning systems are placed at the centre of disaster risk management (DRM) initiatives that are meant to assist in saving the lives and properties of vulnerable communities during disaster events in various countries. In addition, Gough (2003) reported that for disaster management practitioners to manage the negative

impacts of disaster events, they have to focus on two aspects which are to provide early warning measures, which are the nature of the eminent risk; and the measures used to communicate the risk to the affected communities.

The need to implement effective disaster early warning systems in Africa, in particular, dates back to the early nineties (Alcántara-Ayala and Oliver-Smith, 2019). Even before the UN Sendai conference, initiatives to improve on existing early warning systems had already been identified (Alcántara-Ayala and Oliver-Smith, 2019). For example, disaster events such as the 2001 floods in Mozambique left the continent seeking better measures to alert the communities of imminent disasters (Lumbroso et al., 2008). In addition, Sufri et al. (2020) in their systematic review of community engagement in Disaster Early warning systems reported that community engagement in the disaster EWS plays an essential role in saving lives, reducing injuries, and limiting environmental damage associated with disaster events. Furthermore, Šakić Trogrlić et al. (2022) identified gaps in current early warning systems, including in the social components of warning systems and in dealing with multi-hazards early warning systems.

A study on the dissemination of disaster early warning messages is also critical as it will assist in aligning disaster risk reduction measures implemented with the Sendai framework for disaster risk reduction (Rokhideh et al., 2025). Studies reported that currently existing disaster dissemination systems are inaccessible to most local people (Al-Mueed et al., 2021; Hippola et al., 2020; Perera et al., 2019; Leon et al., 2021). For example, in Bangladesh, after reports of flood communications not reaching communities, the potential of incorporating community volunteers to the Union Council to disseminate FEW alongside a top-down approach was explored (Al-Mueed et al., 2021). In Sri Lanka, amongst others, automating possible components of the warning dissemination process by increasing the number of early warning towers and human resources was reported to be prominent by Hippola et al. (2020). While human resources are significant in disaster dissemination, Perera et al. (2019) reported that effective warning dissemination involving an operational telecommunication system that transmits warnings to at-risk communities is essential. Advanced systems, such as nationwide emergency alert systems, which push notifications en masse to at-risk people, are in place in developed countries. Still, all flood-prone developing countries have yet to create such harmonised systems. Flood-prone Nepal and South Africa have a mechanism that conveys bulk Short Messaging Service (SMS) directly to at-risk communities (Perera et al., 2019; Leon et al., 2021).

Across the world, communities suffer disasters mainly because of the lack of early warning systems, not to mention the lack of multi-hazards early warning systems. Following 2022, the United Nations Secretary-General announced the five-year goal of Early Warnings for All. Researchers have been making strides in addressing the issue of multi-hazards EWS (Rokhideh et al., 2025; ESCAP and Warning, 2023; Union, 2023). For example, Rokhideh et al. (2025) reported gaps in the need for a common understanding of warning processes and terminology, such as multi-hazard EWS, as one of the gaps in the SFDRR policy framework. In 2023, Escap and Warning reported the compendium launched at the G20 Disaster Risk Reduction Working Group Side Event: Early Warning Early Action on 30 March 2023. Whereby Section 1.0 provides a clear outline of what constitutes an effective multi-hazard early warning system (MHEWS) and the current challenges being faced for its implementation (ESCAP and Warning, 2023).

In Africa, Union (2023), in recognition of the urgent need to mitigate these risks and protect vulnerable populations, reported that "Early Warning for All" has emerged as a proactive approach to disaster management. The Early Warning for All (EW4All) initiative, which was launched at the 27th United Nations Framework Convention on Climate Change Conference of Parties (UNFCCC-COP27) in Sharm El Sheikh, Egypt, to protect every person worldwide through early warning systems by 2027, has seen Africa developing the action plan for EW4All (Perera et al., 2019).

In South Africa every year, various communities suffer due to the impacts of disaster events that could be mitigated through the implementation of effective early warning systems (Van Niekerk et al., 2018). Disaster early warning messages especially for floods have not always reached the vulnerable communities of South Africa (Kelman and Glantz, 2014). This has resulted in the loss of lives and economy for the vulnerable communities in South Africa (Kelman and Glantz, 2014). Flood early warning (FEW) is a vital component of disaster risk management and is particularly important for saving lives (Al-Mueed et al., 2021). Therefore, it is essential to develop effective flood early warning systems and disseminate the information to communities through various information sources to mitigate flood damages (Shi et al., 2020).

Indeed, South Africa has experienced several significant disasters in the past including shack and wildfires, tornadoes, droughts, pest outbreaks, and pandemics (Murray, 2009; Strydom and Savage, 2016; Lyon, 2009; Phophi et al., 2020; Arndt and Lewis, 2001). However, flood disasters are the most occurring since 1980, with notable impacts on communities, infrastructure, and the economy (Dube et al., 2022; Steinke and Ward, 1989; Chikoore et al., 2015; Ngcamu, 2022; Aliyu et al., 2023). Some of the storms accompanied by heavy floodings that were recorded in history were in January 1984 whereby tropical Storm Domoina, caused unprecedented rainfalls peaking at 950 mm in South Africa (Steinke and Ward, 1989). The storm resulted in 60 fatalities and affected approximately 500,000 people with damages estimated at R100 million South African Rands (Steinke and Ward, 1989). The following month, Tropical Storm Imboa accompanied by flooding affected the east coast of South Africa leading to four fatalities (Chikoore et al., 2015). Again in 2011, various Provinces of South Africa were affected by floods that resulted in fatalities, displacement of people and extensive damage to agriculture and infrastructure (Dube et al., 2022; Anekwe et al., 2024). The 2019 heavy rains led to flooding in parts of the KwaZulu Natal and Eastern Cape Provinces causing loss of lives, destruction of homes and significant damage to infrastructure (Ngcamu, 2022).

The devastating floods of April 2022 were the worst recorded floods in the history of South Africa, the floods accompanied by heavy rainfalls, caused extensive damage to infrastructure, including roads and bridges, and resulted in numerous fatalities and displacement of communities, in the KwaZulu Natal Province of South Africa (Aliyu et al., 2023). Recently in 2024, a severe storm system brought heavy rainfall, tornadoes and flooding, particularly affecting the Eastern Cape and KwaZulu-Natal provinces (Anekwe et al., 2024). These disasters highlight the recurring flooding issues the country has faced emphasising the need for robust disaster management strategies including effective early warning systems and infrastructure to mitigate future impacts.

Flood Early Warning Systems (FEWS) are currently operational in many countries (Perera et al., 2019; Leon et al., 2021). The UN Office for Disaster Risk Reduction recognises their importance. It strongly advocates for an increase in availability under the Sendai Framework for Disaster Risk Reduction and Sustainable Development Goals (SDGs) targets. However, despite widespread recognition of the importance of FEWS for disaster risk reduction (DRR), there's a lack of information on their availability and status worldwide, their benefits and costs, challenges, and trends associated with their development.

Disaster early warning systems are a critical aspect of disaster risk management measures (Macherera and Chimbari, 2016). Dissemination of disaster early warning messages on time is important to enable the affected communities to make informed decisions to save their lives and assets (Macherera and Chimbari, 2016).

Communities within the townships in South Africa have experienced disaster events that resulted in fatalities or loss of property due to various disaster events (Ngcamu, and Abrahams, 2024). As a measure for DRR, early warning systems should be developed and implemented by all municipalities as part of disaster risk management initiatives as prescribed by the act (Edoun and Bakam, 2022). Each municipality should have an early warning strategy that comprises warnings and dissemination thereof (Brown, 2008).

According to the UNDRR office resilience is "*the ability to absorb, adapt to, and recover from hazards. Resilience can apply to communities, systems, or societies*" Across the world, advocacy campaigns to build resilience to disasters are reported to be contributors in strengthening FEWS locally (Perera et al., 2020; Mohanty et al., 2020; Gill et al., 2020). Furthermore, there is growing recognition in disaster science to develop a framework to build the resilience of communities prone to natural hazards as highlighted by the Sendai Framework (Gill et al., 2020). Community resilience especially early warning solutions for Flash Floods has been a bone of contention worldwide (Mohanty et al., 2020). Joseph et al. (2022) analyse the socio-demographic and satisfaction variables within community resilience in the context of the Kerala floods of 2018 and elucidate its gaps from the perspective of a developing country. South Africa as part of a developing country could not be spared from these gaps and challenges when it comes to floods disasters as the country has and is still experiencing recurring floods Disaster for the past 10 years. This study therefore assessed the resilience to flood disasters of the Vosloorus township community in the Ekurhuleni Metropolitan Municipality in the Gauteng Province of South Africa in the context of early warning messages. This study addresses challenges in informal settlement, as most townships in South Africa consist of informal housing and limited infrastructure making traditional communication channels less effective.

This research study is of critical importance as it addresses a significant gap in the understanding and effectiveness of flood early warning systems (FEWS) within informal settlements, particularly in Vosloorus Extension 21, Ekurhuleni Municipality. Informal settlements are among the most vulnerable to flood disasters due to their precarious living conditions, inadequate infrastructure, and limited access to formal disaster management mechanisms. The novelty of this study lies in its focus on assessing the practicality, accessibility, and efficiency of existing early warning systems in highly vulnerable and underserved communities. Unlike previous studies that largely focus on formal settlements or broader urban areas, this research provides a granular, community-specific analysis of early warning systems' effectiveness in informal settlements. This unique focus enables the study to highlight systemic inequalities and barriers to effective disaster communication.

2 Background of the study

In Africa, floods represent a major natural hazard causing over 27,000 fatalities during the period 1950–2019 (Busayo et al., 2022). The overall decreasing flood trends prior to 1980 and increasing trends afterwards, especially in western and southern Africa have been reported to show that the annual maximum peak discharge that does not exhibit a monotonic pattern ascribed to changes in extreme precipitation around 1980 (Tramblay et al., 2020). In South Africa, several studies assessed the trends of flood events and their impacts, especially in the coastal areas of the country from 2020 to date (Dube et al., 2022; Mudefi, 2023). The coastal areas of KwaZulu Natal are still flooding even as this manuscript is being written. A scoping review after the April 2022 KZN floods showed that showed a lack of disaster preparedness which includes early warning and disaster response and recovery with no robust capacity and coordination among key stakeholders as some of the gaps in floods management in South Africa (Mudefi, 2023). In western Cape Province the entire east coast of South Africa flooding destroyed homes, electricity power lines, and road infrastructure, leaving 448 people confirmed dead in April 2022 (Mashao et al., 2023).

The EM-DAT 2023 reported that flood disasters affected over 93 million humans and caused a total economic loss of almost US $202.7 billion globally, with floods contributing significantly. The impacts of floods combined with inadequate levels of disaster preparedness in countries, especially developing countries, may contribute to higher socioeconomic, physical, and environmental vulnerability levels (Abunyewah et al., 2018). Floods have been terrorising South Africa as a developing country since the 1980s. However, for relatability, this background will focus briefly on the socio-economic impacts of floods in the past five years in South Africa starting with the most devastating recorded declared flood disaster of April 2022 in the KwaZulu Natal Province of South Africa. The April 2022 floods had catastrophic repercussions, 13,500 households were affected by the floods, 3,927 housing structures were destroyed, and another 8,097 were partly destroyed (Mwai, 2022). The floods resulted in 435 confirmed fatalities reflecting the grim human toll of the floods (Bouchard et al., 2023). Economic losses due to floods has been reported by studies in South Africa especially in urban Metropolitan Municipalities in Gauteng, KwaZulu Natal and the Western Cape (Grab and Nash, 2024; Nyam et al., 2024; Chikodzi, 2021). However, Raphela and Matsididi (2025), reported the costs for repairing flood damages ranging between R10,000 to over R15,000 in two communities in the Free State Province.

South Africa has implemented several initiatives to mitigate flood risks and enhance early warning systems, aiming to protect lives and property. The construction of the Berg River Dam exemplifies South Africa's commitment to water management and flood control. This dam increases water storage capacity, supplies Cape Town, and contributes to improved water quality in the region (Aller, 2021). As the first African nation to preside over the G20, South Africa has prioritised mobilising finance for countries affected by climate-induced disasters such as floods. This initiative underscores the country's dedication to strengthening disaster resilience and

supporting post-disaster reconstruction efforts. Effective early warning systems are crucial for safeguarding communities against flood-related hazards as they offer time alerts, risk assessment and resource allocation. The city of Ekurhuleni where this study took place, has SMS systems for real-time flood alerts and a Twitter account dedicated to life-threatening emergencies such as floods.

The United Nations Office for Disaster Risk Reduction (UNDRR) launched the Early Warning for All (EW4ALL) initiative to ensure that everyone globally is protected by early warning systems by 2027. South Africa, recognising the importance of such systems, has been strengthening its own early warning infrastructure, aligning with the goals of EW4ALL. While specific details of South Africa's formal stance on EW4ALL are limited, the country's proactive measures in disaster risk reduction reflect a commitment to the principles of the initiative.

Before the April 2022 flooding disaster, the South Africa Weather Services (SAWS) issued warnings predicting flooding, snowfall, hail, and strong winds that led to the devastating April 2020 flooding. In response, disaster management teams were activated, and evacuation plans were implemented in vulnerable areas. Despite these efforts, the storm caused significant damage, highlighting the challenges in disaster preparedness and response. However, South Africa's engagement in enhancing early warning systems and implementing anticipatory actions demonstrates a commitment to reducing disaster risks. Continuous improvement and alignment with global initiatives like EW4ALL are essential to protect communities from the adverse effects of disasters.

3 Research design

The study conformed to the quantitative research design approach to assess the flood resilience of a township community in South Africa, using flood early warning Message dissemination as a factor. This study purposively selected the two informal settlements (Vlakplaats 1 and 2) in Vosloorus Extension 21 that are experiencing recurring flooding disasters and randomly selected 100 households from a combined population size of 251 across the two settlements to administer the questionnaire from July to September 2021. Two research assistants from the community with Grade 12 qualifications were trained on ethical questionnaire administration by the researcher before data collection. Considering the disasters in South Africa, Vosloorus, issues such as extreme flooding and mudslide risks are predominant in Vosloorus (Mollo et al., 2022). Vosloorus has experienced dolomitic sinkholes and extreme floods in the past that have devastated communities (Storie, 2016).

We administered a structured questionnaire to 100 community members of the Vosloorus extension 21 township in the Ekurhuleni Metropolitan Municipality in South Africa. The sample size of 100 for this study on the flood early warning system is considered appropriate based on several factors. Firstly, the sample size provides a reasonable statistical power to detect significant relationships between variables, assuming a confidence level of 95% and a margin of error of ±5%, which are standard in social science and disaster management research. Additionally, similar studies investigating early warning systems and community resilience have successfully utilised sample sizes within this range, demonstrating the feasibility and reliability of such an approach. Considering the practical constraints of time, resources, and accessibility to participants, a sample size of 100 balances statistical rigor with logistical feasibility for a population size of 251. This approach provides a robust basis for drawing valid and generalisable conclusions from the study.

Vosloorus Extension 21 (Figure 1) was chosen as a study area because boreholes have the highest yield issues, which influence flash flood intensity in this area. These issues were determined during the Rhodesfield Station Gautrain tunnel construction for several shafts across Ekurhuleni (Mahlahla and Oparinde, 2019).

We sampled the community using simple random sampling techniques and collected data from participants who were 18 years and above. We used manual randomization to select the households whereby the researcher and the two research assistants would skip every second house from where we were stationed as the starting point.

To avoid Pseudo-replication of the results only one household member was allowed to fill in the questionnaire. Following the University of the Free State (UFS) General Human Ethics Committee requirement we first asked the potential participants if they consent to participate by reading out the UFS-POPIA approved consent form and study information sheet to them. Only potential who agreed to take part in the study were given the consent forms to sign and the questionnaire to fill out. Likewise, the identity of all respondents remained anonymous during this study as outlined in the conditions of our ethics clearance permit (UFS-HSD2020/1984/102). The study data was analysed using the R Statistical Programming Software R version 4.4.0 (2024-04-24 ucrt) from the R Foundation for Statistical Computing (see Figure 2).

3.1 Data analysis

This study analysed the data by applying a series of one-way-ANOVA; two General Linear mixed models (GLM) and an ordinal regression model. Firstly, to assess how some critical demographic information significantly impacts how individuals and communities comprehend and might respond to disaster early warnings in line with literature on Disaster Management (Perera et al., 2020; Shah et al., 2022; Šakić Trogrlić et al., 2022) the study applied four separate one-way ANOVA tests. The question of do you understand the term disaster? Was set as a response variable for all the ANOVA tests applied and the demographic variables that were correlated with these predictor variables were Age, gender, marital status and employment status.

Secondly, to assess the knowledge of the study community about early warning systems this study applied a Generalised Linear model (GLM) to specifically gauge the respondents' understanding of early warning messages by setting the question do you understand the term EWS as the response variable for the model? All respondents reported floods as a disaster that occurs frequently in their community. Therefore, this study changed the two questions (1) What is the impact of the frequently occurring disasters in your household and (2) which mitigation measures do you think will work for your community for the frequent disasters to be specific to flood disasters? The GLM model comprised three questions and one statement where the respondents were asked to select the source of their early warning messages and the questions of (1) What is the impact of those floods

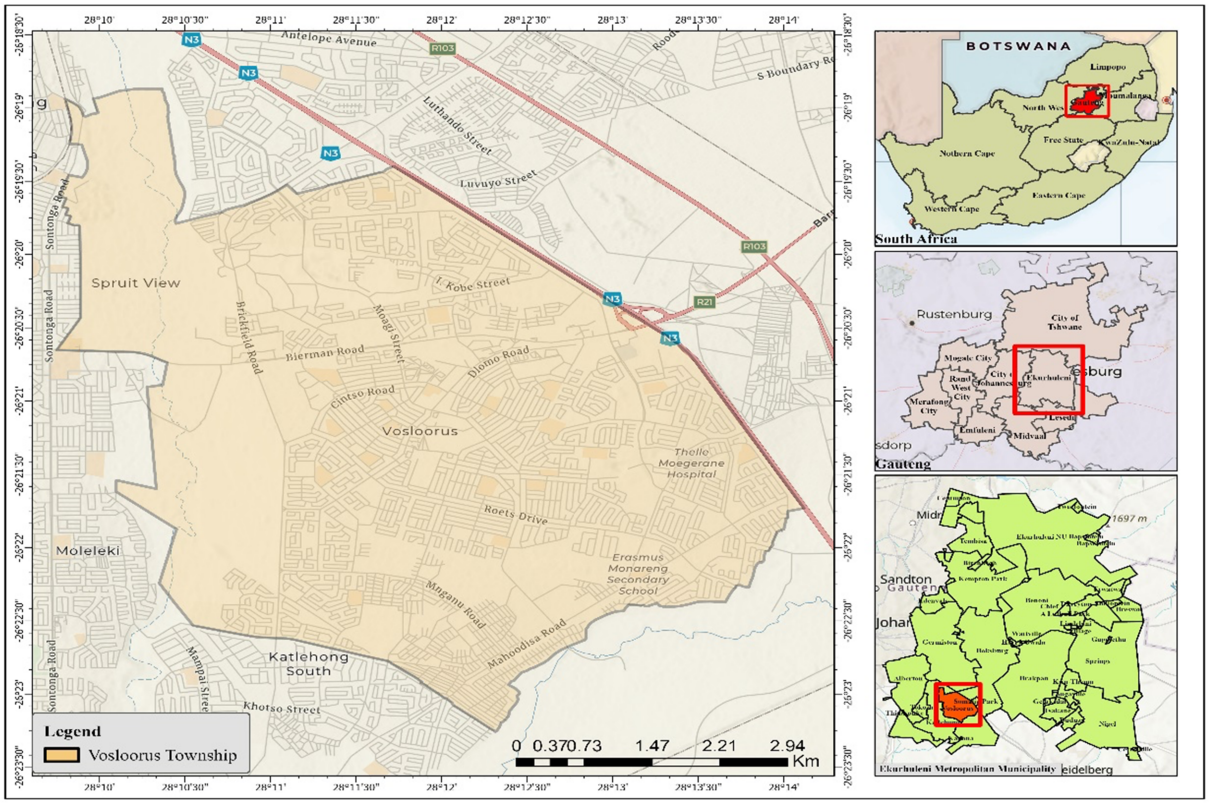

FIGURE 1
Map of the study township: the main map, top insert map showing the study province location in South Africa, middle insert showing the study municipality, and bottom insert showing the study location are all demarcated with red squares.

in your household; (2) which flood mitigation measures do you think will work for your community? (3) which method does your municipality use to disseminate early warning messages as independent variables?

Thirdly, to investigate the effectiveness and reliability of Early Warning Messages from respondents' perspectives, this study applied an ordinal logistics regression model. The study developed 11 questions that seek to answer how effective and reliable are the early warning Messages disseminated by the municipality in the study area. We set the question of have you ever received early warning messages for floods from your municipality as the outcome variable and the other 10 questions and statements were set as independent variables (see Table 1 in the results section for the 10 statements and questions). The questions were asked in a Lickert Scale format of 5 levels.

Lastly, the study applied another GLM to assess the dissemination of early warning messages by the municipality to the community. The study set the question of Do you own a cellphone? as the response variable. This is because we are now living in the 21st century and cell phones are now used as the main source of communication worldwide (Horst and Miller, 2020). Indeed, Studies have reported cell phones as the most important tool for receiving early warning messages (Sutton and Kuligowski, 2019; Cvetković, 2021; McBride et al., 2022). The questions of (1) have you ever received EWMs from your municipality; (2) Were the EWMs received on time; (3) Do you know the reason why the message was not received on time were set as predictor variables?

All GLMs applied for this study were with a Poisson distribution as the number of responses for the specific outcome variables was numeric. Furthermore, the p value across the study was set at $p \leq 0.05$.

4 Results

The research questionnaire used for this study was administered to 100 community members from two informal settlements in Vosloorus Township, with the help of three research assistants. The research assistants were selected from Vosloorus Township, and they were trained to administer the questionnaire and the associated research protocols. All 100 participants were attended to individually and each participant was given the option to accept or refuse participation in this study as per the study's consent form and the respondents who chose to participate in the study were requested to sign the consent form. Furthermore, engagements with each participant took 20–30 min for a questionnaire to be completed. The participants completed all 100 questionnaires with the assistance of the researcher and the research assistants. However, some questions in the questionnaires were not answered, as the respondents were told

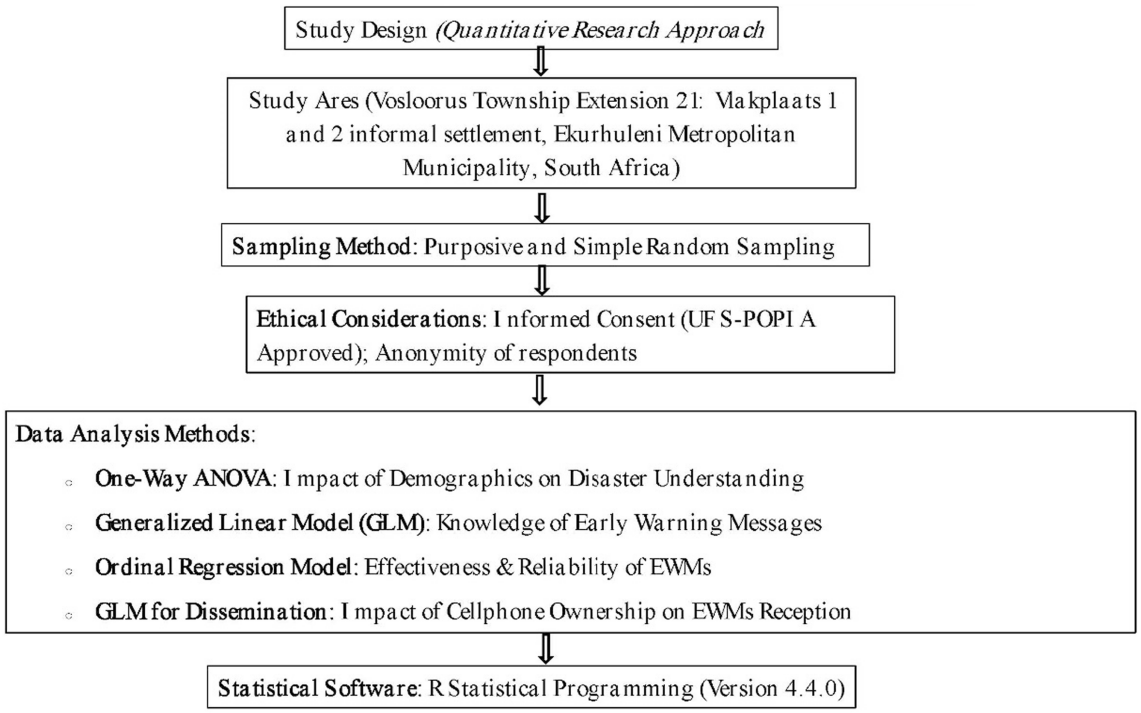

FIGURE 2
Flow diagram for the research design.

to feel free and had a choice not to answer questions, they were not comfortable with, such questions were coded as no responses during data analysis.

4.1 Demographic and understanding of the term disaster

Table 2 summarises the respondents' understanding of the term disaster based on the most critical demographic characteristics in Social Sciences in particular studies on Disaster Management that are related to the response of communities. Literature in Disaster Management has reported vulnerabilities of communities based on their age (Benevolenza and DeRigne, 2019.); gender (Hasan et al., 2019); marital status (Panday et al., 2021); and employment status (Drakes et al., 2021). Indeed, the Sphere Project for Humanitarian Assistance has reported gender and age as important determinants when it comes to disaster response (Lafrenière et al., 2019), based on the fact that women, children and the elderly are the most vulnerable in communities when it comes to disasters. This study has reported vulnerabilities of communities based on their knowledge of the term disaster using indicators for various demographic and socioeconomic factors. Based on the result, the majority of the respondents were youth between the ages of 18–35 ($n = 42$). This study's respondents were dominated by females ($n = 71$) whereas most respondents were single ($n = 70$) and most of the respondents reported being employed part-time ($n = 21$; Table 2). In addition, there were significant differences for one-way Anova for age group and understanding of the term disaster ($p = 0.008$) and Employment status and understanding of the term disaster ($p = 0.021$; Table 2).

4.2 Knowledge about early warning messages

When assessing the knowledge of the community about early warning messages, there was only a significant difference found for the question of which method the municipality uses to disseminate early warning messages (Wald $\chi^2 = 0.890$; $p = 0.001$). No significant difference was found for the questions of (1) What is the impact of those floods in your household (Wald $\chi^2 = 0.648$; $p = 0.985$); (2) which flood mitigation measures do you think will work for your community (Wald $\chi^2 = 0.414$; $p = 0.994$) and for a statement where the respondents were asked to select the source of their early warning messages (Wald $\chi^2 = 3.806$; $p = 0.577$) (Wald $\chi^2 = 0.247$; $p < 0.001$).

The GLM applied to this study assessed the knowledge and understanding of Early Warning Messages (EWMs) within a flood-prone community. The analysis revealed dropout from school (DOS), flood-related illnesses (FRI), homes being flooded (HF), and loss of important documents (LID) as the four major impacts of floods in their households (Figure 3A).

However, HF was the most reported impact (Figure 3A) even though there was no clear correlation between the impact experienced and understanding of EWMs.

In addition, the majority of the respondents reported the formation of flood management committees as their flood mitigation measure (Figure 3B). However, there was also no

TABLE 1 Respondents' demographic characteristics and understanding of the term disaster.

Categories		Frequencies	Yes	No	No response	One-way ANOVA (*P* values)
Age group	18–25	9	8	1	0	
	26–35	33	25	7	1	
	36–45	28	13	15	0	**0.008**
	46–55	17	14	3	0	
	56–65	10	8	2	0	
	No response	3	0	1	2	
Gender	Male	28	17	10	1	
	Female	71	51	19	1	0.398
	No response	1	0	0	1	
Marital status	Divorced	1	1	0	0	
	Married	20	12	7	7	
	No response	1	1	0	0	0.186
	Separated	1	0	1	1	
	Single	70	50	18	18	
	Widowed	7	4	3	3	
Employment status	Full time	3	1	1	1	
	No response	3	1	1	1	
	Part-time	21	15	6	0	**0.021**
	Self-employed	6	3	3	0	
	Student	1	1	0	0	
	Unemployed	66	47	18	1	

Significant values are highlighted in bold ($n = 100$).

statistically significant variation in the comprehension of flood Early Warning Messages. Furthermore, the Metro Police were the most reported sources of Floods Early Warning Messages in the community with no statistically significant difference in the understanding of EWMs based on the source of the messages (Figure 3C).

Moreover, community leaders, followed by social media and Short Messaging Services were the most reported method of disseminating EWMs by the municipality (Figure 3D), also a significant difference was observed in the understanding of EWMs based on the method of dissemination with respondents who received warnings through their councillors showing a better understanding of EWMs compared to those who received warnings through other channels (Figure 3D).

4.3 Reliability and effectiveness of early warning messages

The ordinal regression results showed a statistically significant relationship when the question of have you ever received early warning messages for floods? (dependent variable) for the question of whether you would act on early warning messages communicated to you through mainstream media only ($\chi^2 = 6.730$; df = 1; $p = 0.009$). No significant differences were found for all the other independent variables (Table 1).

4.4 Early warning dissemination

The results of the GLM when assessing dissemination of early warning messages showed a statistically significant difference for the question Do you know the reason why the EWMs were not received on time? (Wald $\chi^2 = 1.094$; $p = 0.001$). However, no significant differences were found for the questions Have you ever received EWMs from the municipality (Wald $\chi^2 = 0.898$; $p = 0.638$) and was the warning received on time (Wald $\chi^2 = 0.401$; $p = 0.818$). In addition, the majority of the respondents who did not have cell phones reported not receiving EWMs from the municipality (Figure 4A). Furthermore, the majority who reported not having cellphones reported not receiving EWMs on time or did not respond (Figure 4B). Moreover, the majority of respondents with no cellphone reported a lack of electricity, also a significant portion of the respondents did not provide any response (Figure 4C).

5 Discussion

This study set out to investigate how the community of Vosloorus Township in the Gauteng Province of South Africa were resilient to using flood Early Warning Message as a factor. We first found out how age, gender, marital status and employment status significantly impact how individuals comprehend disasters and how communities might respond to disaster early warnings, in alignment with existing Disaster

TABLE 2 Output of regression analysis for Likert scale questions on the effectiveness and reliability of early warning messages from respondents' perspectives.

Parameters	Chisq value	DF	*p*-values
Are the early warning messages communicated to you always easy to understand?	0.000	7	1.000
Are the early warning messages communicated to you accommodative of people who cannot read?	0.000	6	1.000
Is there a specific language used to communicate early warning commonly understood by your community members?	0.000	5	1.000
Are the disaster early warning messages disseminated specific to your area?	0.000	6	1.000
Early warning messages are communicated, early enough to allow you to take protective measures.	0.001	5	1.000
Are early warning messages communicated stating clear actions to be taken	0.000	5	0.734
Would you act on early warning communicated to you by social media	2.772	5	1.000
Would you act on early warning messages communicated to you through mainstream media?	**0.000**	**5**	**0.009**
Would you say the community members in your area trust warning messages communicated by your municipality?	0.000	5	1.000
would you say the way the municipality disseminates early warning messages is effective?	0.000	4	1.000

ANOVA of the model. Source: study data. Significant values are highlighted in bold ($N = 100$).

Management Literature (Phraknoi et al., 2023; Shah et al., 2022; Sufri et al., 2020). The majority of the youth with knowledge of the term disaster underscores the relevance and importance of youth engagement in disaster Preparedness. Indeed, youth across the world have been reported to be technologically adept (Combes, 2021; Meates, 2020; Svensson, 2023), making their participation in disaster communication strategies very important. What mirrors the gender-related vulnerabilities often reported in Disaster Management literature where women are in most cases disproportionately affected by disasters (Jeranko, 2023) is the majority of the female respondents in our study.

The Sphere project also ascertains gender as a critical determinant in disaster response, especially since women more often than not and as compared to their male counterparts carry the burden of caregiving during disaster (Cong et al., 2021). The higher number of single participants in our study might indicate the fewer responsibilities that come with single marital status, thereby influencing these single respondents to have more time for disaster preparedness and response behavior. The mobility and independence of single people could be advantageous in responding to early warnings; however, their lack of household support could also exacerbate their vulnerability in the aftermath of disasters. The correlation between the understanding of the term disaster and employment status. Indeed, studies have shown that unemployment could pose economic limitations that could hinder the ability to prepare for and respond to disasters (Balaei et al., 2021; Chang et al., 2022; Mathieu et al., 2022). However, employed individuals might also face inflexibility to participate in community disaster response activities.

The significant differences found for age group and Employment status indicate how crucial these two demographic factors are in understanding the term disaster. The youth and individuals who are part-time employed may have different levels of exposure to disaster education and resources, influencing their overall disaster preparedness. Worldwide, vulnerable communities often defined by age and employment status have been reported to be less equipped to handle disasters due to their limited access to information and resources (Benevolenza and DeRigne, 2019; Kuran et al., 2020; Panday et al., 2021).

In this study, the youth and individuals who were employed part-time represented a critical demographic for targeted disaster education and communication strategies. This study therefore recommends future interventions to consider these demographic insights to enhance effective early warning systems in the community.

The most significant finding of this study was the statistically significant results between the method of dissemination and the understanding of EWMs, with respondents who received their EWMs through Community Leaders demonstrating a higher level of comprehension compared to those who received information through other means. This finding implies that more direct and personal methods of communication may be more effective in enhancing understanding and engagement with EWMs. There is a need for effort to enhance the clarity and accessibility of EWMs in the study community. Flood management strategies should include the adoption of more effective communication methods, particularly those that ensure direct engagement with at-risk individuals. Additionally, further educational campaigns about flood mitigation and the importance of EWMs may be necessary to bridge the understanding gap.

The GLM applied to assess the dissemination of Early Warning Messages to the study community by the municipality focusing on the study community's ownership of cell phones revealed a statistically significant difference for the question "Do you know the reason why the EWMs were not received on time?" only across the three predictor variables. These results highlight the importance of cellphone ownership for effective, efficient and timeous reception and dissemination of EWMs. Indeed, cellphone ownership has been reported to improve communication links during emergencies (Diwanji et al., 2020; Kim et al., 2019; Olaleye et al., 2021). Our study also showed that other factors delay the receiving of EWMs, inadequate information from the municipality being prevalent as compared to lack of electricity and data. This implies that infrastructure and communication systems also play a crucial role in ensuring the effectiveness of EWM dissemination. The study implies that improving the overall infrastructure for EWM dissemination is necessary for more reliable communication during emergencies.

6 Study conclusion

The study assessed the community's knowledge about EWMs through various factors and concluded that the dissemination method impacts the community's awareness and understanding of EWMs. This

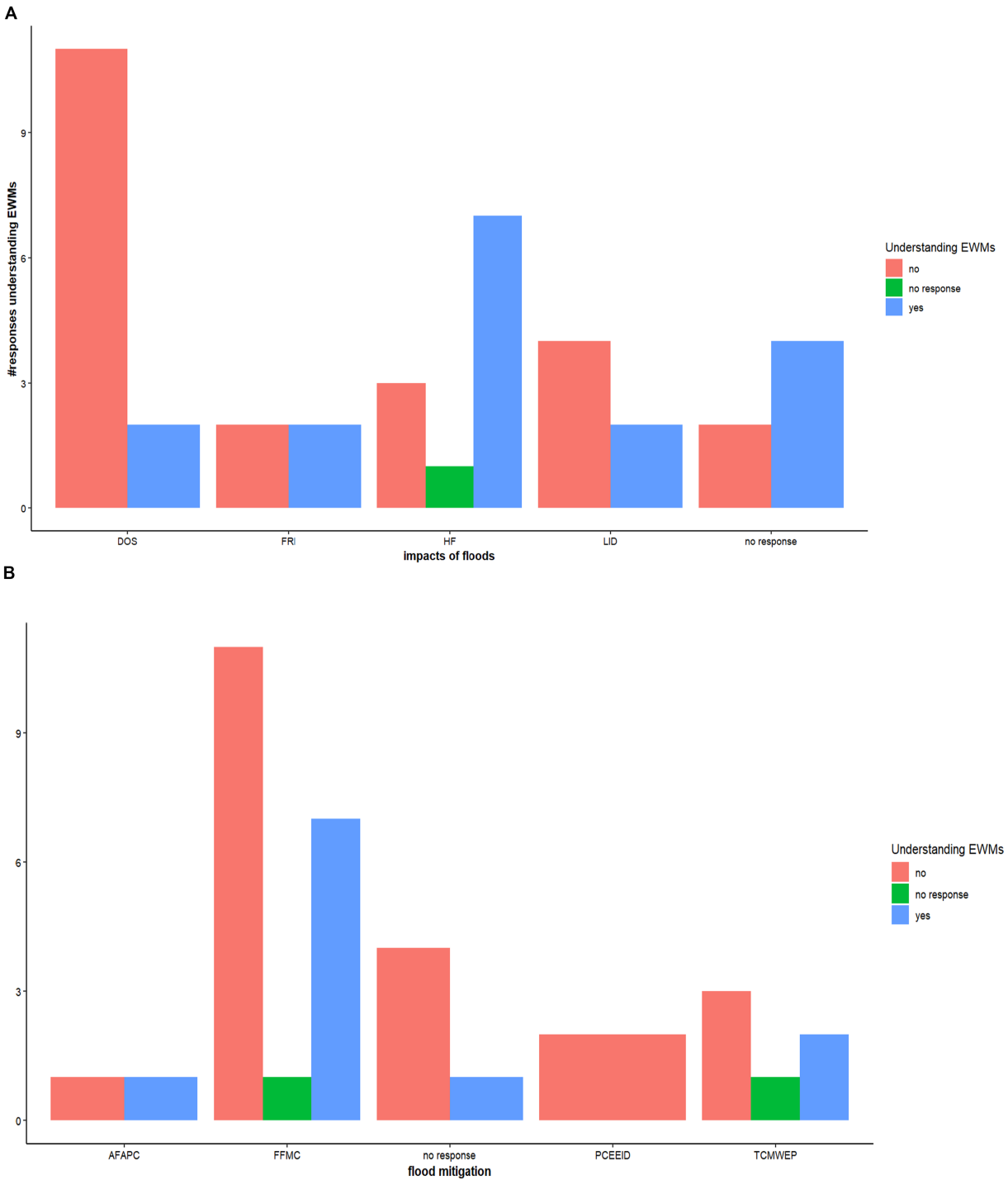

FIGURE 3 (Continued)

suggests that simply experiencing floods does not necessarily enhance the comprehension of warning messages, since the most reported flood mitigation measure was the formation of flood management committees. Despite this, there was no significant variation in understanding EWMs based on the proposed mitigation measures.

The Metro Police were the most reported source of EWMs. However, no statistically significant difference was found in the community's comprehension of EWMs based on the source. A significant difference in understanding EWMs was noted based on the method of dissemination, with respondents who received warnings via councillors showing better comprehension than those who received warnings through other channels. This suggests that councillors play a very important part in FEW disseminations. Many respondents who lacked cell phones reported not receiving EWMs from the municipality. Also, lack of electricity was associated with a lack of timely reception of EWMs. The study partially met its objectives by identifying factors affecting the community's resilience to flooding, particularly regarding the dissemination of EWMs.

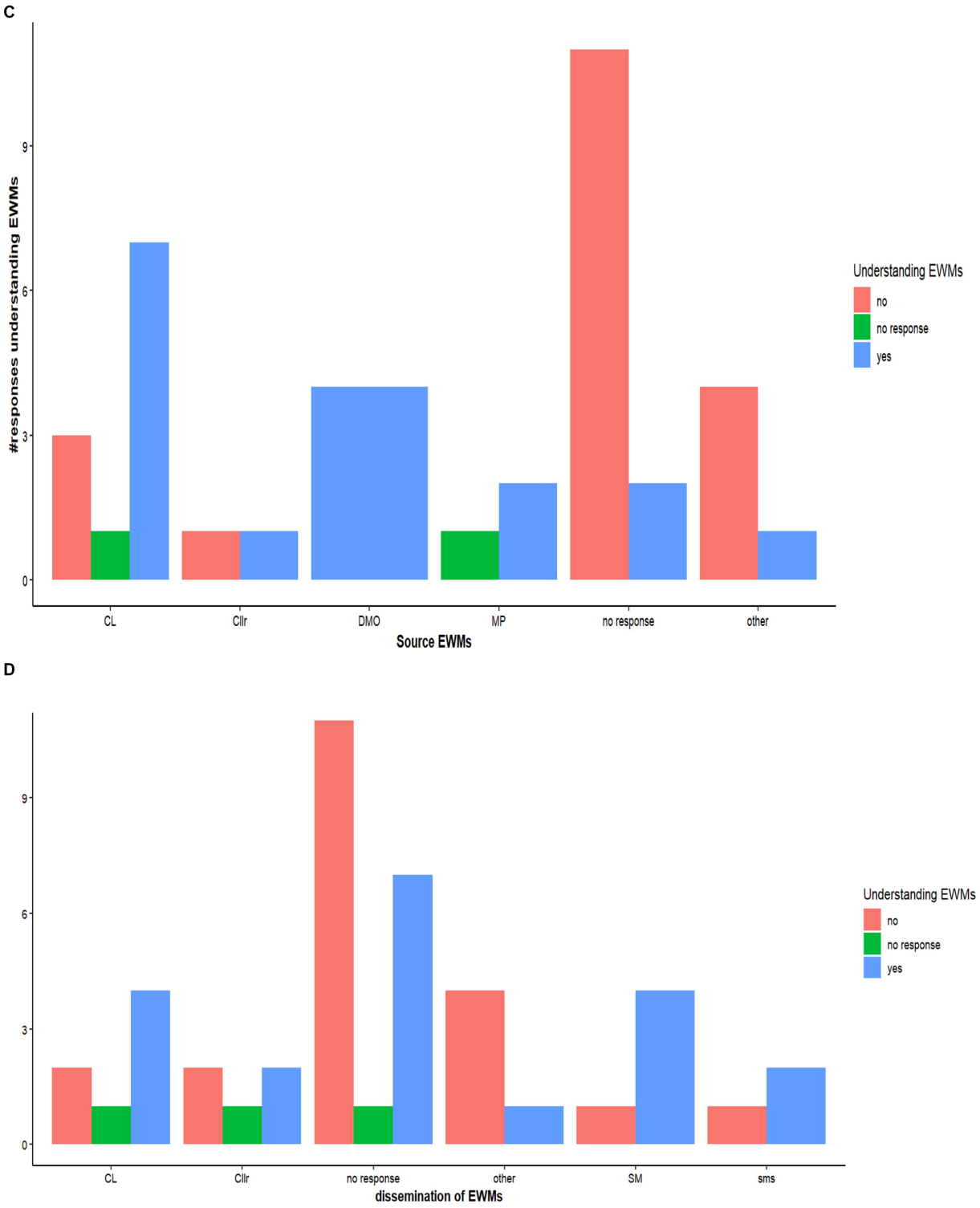

FIGURE 3
(A) Number of reports for knowledge of early warning messages by impacts of floods. Source: study data. DOS = drop out of school; FRI = flood-related illnesses; home flooded; LID = loss of important documents (*N* = 100). **(B)** Number of reports for knowledge of early warning messages by flood mitigation. Source: study data. AFAPC = availability of flood action plan for the community; FFMC = formation of flood management committees; PCEEID = provision of communication equipment for efficient information dissemination; TCMWEP = train community members in warning and evacuation plans (*N* = 100). **(C)** Number of reports for knowledge of early warning messages by sources of EWMs. Source: study data. CL = Community leaders; Cllr = Councillor; DMO=Disaster Management Officials; MP = metro police (*N* = 100). **(D)** Number of reports for knowledge of early warning messages by dissemination of EWMs. Source: Study Data. CL = community leaders; Cllr = Councillor; SM = social media; SMS = short message services (*N* = 100).

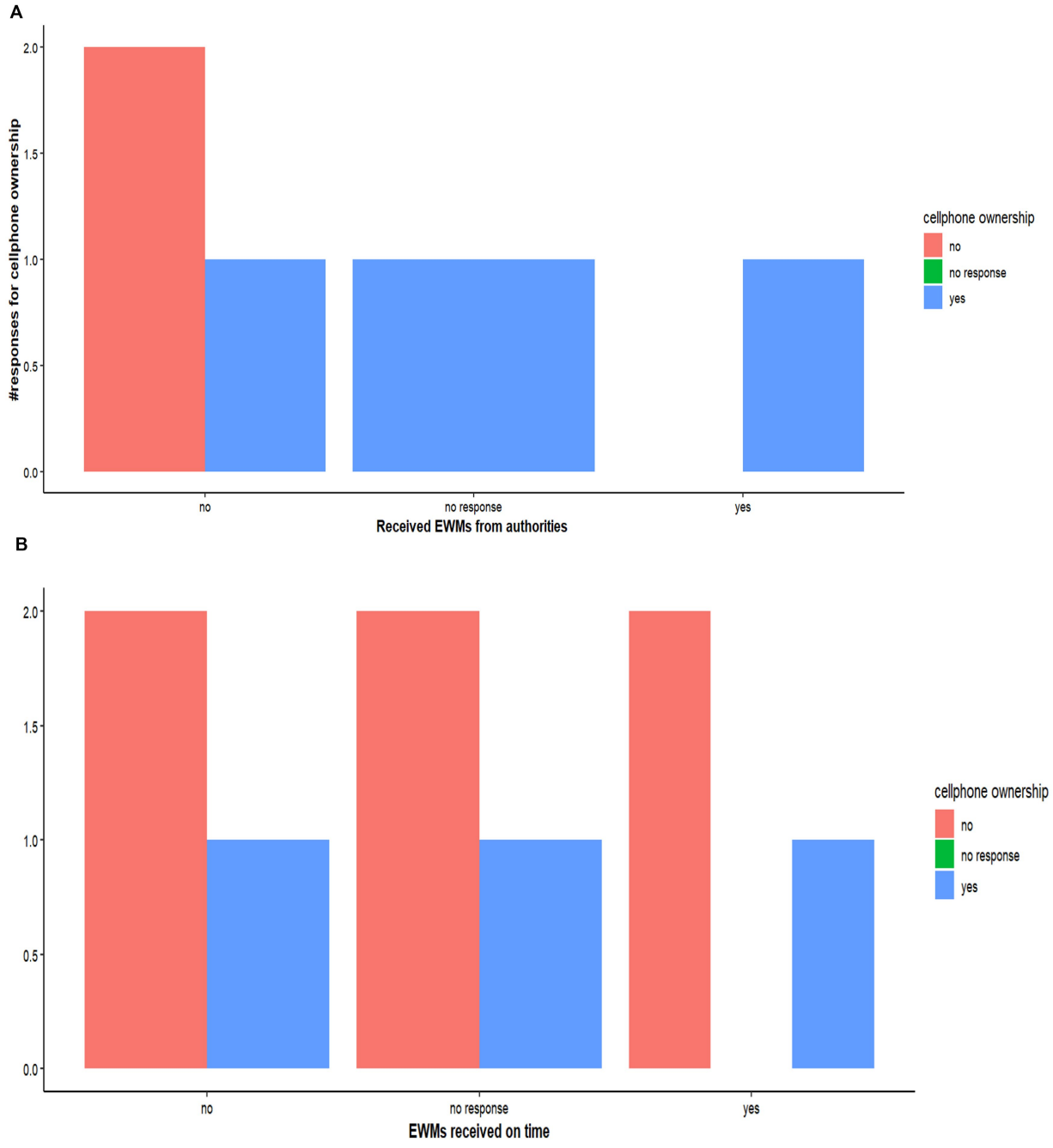

FIGURE 4 (Continued)

However, it fell short of establishing a clear relationship between understanding EWMs and the impact of floods experienced by the community. The study did highlight important gaps such as accessibility issues (lack of phones, electricity) and the effectiveness of dissemination methods. However, more comprehensive data is needed to evaluate the actual resilience of the community in responding to EWMs. The Vosloorus township community shows some resilience to floods based on their reliance on community leaders and Metro Police for information. However, limitations in dissemination methods, accessibility issues, and limited understanding of EWMs suggest that their overall resilience is inadequate. Therefore, the research objectives were only partially achieved.

7 Limitations and future research gaps

While this study offers valuable contributions, several limitations highlight areas for future research such as Geographical Scope. The Ekurhuleni Municipality currently has recorded a total of 163 informal settlements most of which experience floods continuously and the study is limited to two informal settlements which may constrain the generalizability of the findings. Future studies should expand the geographical scope to include a broader range of informal settlements across different municipalities and provinces to allow comparative analysis. Although the study evaluates existing early warning systems, it does not extensively address the integration of advanced technological

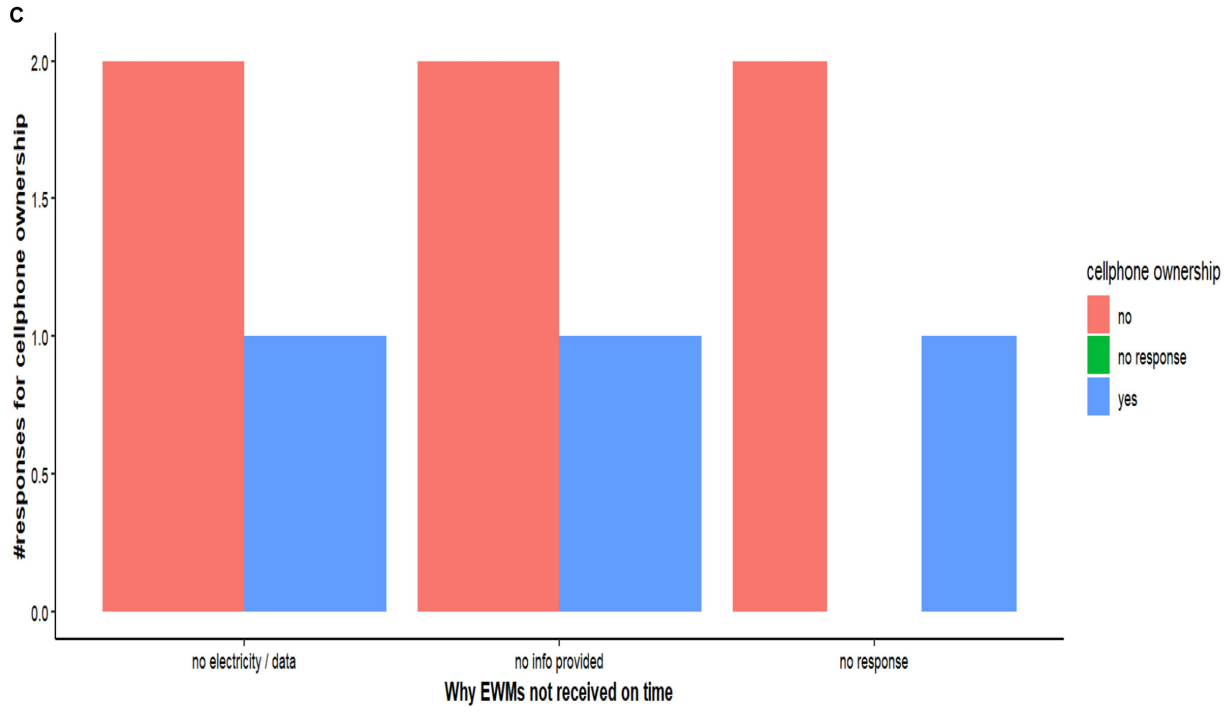

FIGURE 4
(A) Number of reports about cellphone ownership versus receiving Early warning messages from authorities. Source: study data (*N* = 100). **(B)** Number of reports about cellphone ownership versus timeous receipt of early warning messages. Source: study data (*N* = 100). **(C)** Number of reports about cellphone ownership versus reason why early warning messages were not received on time. Source: study data (*N* = 100).

tools such as mobile-based applications, Geographic Information Systems (GIS), and remote sensing technologies. Incorporating these technologies in future studies could enhance data accuracy, real-time monitoring, and the dissemination of early warnings. Limited resources and logistical challenges may have influenced the sample size and data collection processes. Future research should aim for larger sample sizes and diversified data sources to enhance representativeness and validity.

To address the identified limitations, future research should expand studies to other informal settlements across South Africa and beyond to allow for comparative analysis. Since we are living in the 21st century, integrating advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML) to enhance predictive accuracy and real-time dissemination of flood warnings should be looked into. The sample sizes should be increased diversified sampling techniques should be employed in future studies to ensure broader representation and generalisability of findings.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of the Free State General Human Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

TR: Conceptualization, Formal analysis, Methodology, Software, Supervision, Validation, Visualization, Writing – review & editing. NE: Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Writing – original draft.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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