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Enhancing Urban Resilience: Strategic Management and Action Plans for Cyclonic Events through Socially Constructed Risk Processes

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Abstract: Cities will face increasing challenges due to the impacts of global climate change, particularly in the form of cyclonic events, necessitating a deeper understanding and the establishment of effective response mechanisms at both institutional and citizen levels. In this research, we tested the efficiency of crowdsourcing in fostering participatory resilience and improving urban management. The main aim was to design novel and accurate proactive response strategies and mitigate the adverse effects of cyclonic wind events through volunteerism, citizen science, and urban science. To achieve this goal, as a case study, the municipality of Soledad, Colombia was used. This research employed a two-phase methodological approach: (i) initially evaluating the spatial distribution of emergency response resources, and (ii) developing a geo-referenced survey to map, systematize, and categorize data and outcomes. A total of three hundred and seventy-eight residents across five neighborhoods in Soledad, which have experienced a high frequency of atmospheric wind phenomena over the past two decades, were surveyed. The results indicate that the crowdsourcing mechanism effectively enhanced the empirical understanding of atmospheric wind events in Soledad, facilitating the establishment of a geo-referenced volunteer network for real-time responses. Additionally, this study shed light on previously undocumented challenges, in terms of reducing the number of people affected, and the actions that would lead to improved urban development to reduce the impacts of cyclonic events, emphasizing the significance of citizen science in the social construction of risk and disaster risk reduction (DDR) efforts.

Keywords: crowdsourcing; citizen participation; risk; natural hazards; urban management

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1. Introduction

In recent years, the world has experienced a significant increase in the frequency and severity of climate change-related events, ranging from extreme weather phenomena, like hurricanes, cyclones, and tornadoes, to prolonged droughts, heatwaves, and wildfires [1,2]. Despite the mounting evidence and scientific consensus on the urgency of addressing climate change, there remains a pervasive lack of recognition of its immediate threat, leading to complacency and delayed responses to these events [3].

Especially, Sustainable Development Goal 11, aiming for inclusive, safe, resilient, and sustainable cities and communities, faces a critical challenge in the face of climate change. Urban areas concentrate populations, infrastructure, and economic activity, making them vulnerable to climate-induced hazards [4,5]. A key challenge lies in understanding and quantifying the specific vulnerabilities of diverse urban systems to varying climate impacts. This requires robust data collection, modeling, and scenario analysis, considering factors like geographic location, socio-economic inequalities, and existing infrastructure [6]. Additionally, ensuring equitable access to resources and risk reduction strategies within cities requires addressing systemic inequalities that often exacerbate vulnerability for marginalized communities [7,8].

Urban researchers are actively addressing these challenges. One promising avenue is the development of climate-informed urban planning (CIUP) frameworks. These frameworks integrate climate projections into urban planning processes, enabling cities to design infrastructure and policies that are more resilient to future climate scenarios [9,10]. Additionally, research on nature-based solutions (NBSs) explores the potential of green spaces, urban forests, and wetlands to mitigate climate impacts and improve urban resilience [11,12]. Further research can also focus on social vulnerability assessment methodologies, aiming to identify and address the specific needs and challenges faced by vulnerable populations in urban settings [13,14]. By bridging the gap between science, policy, and community engagement, ongoing research efforts hold the potential to equip cities with the knowledge and tools needed to build resilience and thrive in a changing climate, aligning with the ambitious goal of SDG 11 [15,16].

However, there is a lack of adequate responses to the challenges posed by climate change in urban areas, especially in South America, underscoring the critical need for innovative approaches to enhance urban resilience and preparedness [17]. Digital citizen participation emerges as a powerful tool in this regard, offering avenues for real-time data collection, information sharing, and community engagement during crises [18,19]. By leveraging the collective knowledge and experiences of citizens, cities can improve their capacity to anticipate, mitigate, and respond to adverse events [7,14,20].

The concept of "smart cities" has gained prominence as cities increasingly leverage technology and data-driven approaches to enhance efficiency, sustainability, and resilience [21]. Digital citizen participation plays a crucial role in this transition, empowering residents to contribute to decision-making processes, co-create solutions, and actively engage in disaster preparedness and response efforts [22]. In addition to natural hazards, cities face a myriad of human-induced risks, including inadequate infrastructure, social inequalities, and economic vulnerabilities, which exacerbate the impacts of climate-related disasters [3,23,24]. Understanding and addressing these complex and interconnected risks requires a multi-dimensional approach that integrates social, economic, and environmental considerations.

While traditional emergency response mechanisms heavily rely on centralized systems and top-down approaches, there is growing recognition of the importance of decentralized, community-driven initiatives in building resilience [25]. Social networks, for example, serve as invaluable platforms for information dissemination and resource mobilization during disasters. However, the proliferation of misinformation and emotional reactions on social media platforms can hinder effective communication and decision making [1].

Conversely, geographic information systems (GISs) and geostatistics combined with qualitative analyses offer powerful tools for spatial analysis, risk mapping, and decision support in disaster management [26,27]. By visualizing data and simulating various scenarios, GISs enable planners and emergency responders to identify vulnerable areas, assess evacuation routes, and allocate resources more effectively.

Despite the absence of comprehensive scientific studies documenting the occurrence of strong wind events in Soledad, Rosales et al. (2011) [28] and Pérez et al. (2023) [17] caution about the frequency and intensity of such phenomena in the metropolitan area of Barranquilla. They suggest that the rise in air temperature during heavy rainfall days serves as a catalyst for these events.

Therán et al. (2023) [29] assert that the informal urban expansion in Soledad has led to unregulated urban planning and construction practices, resulting in a significant reduction in vegetation cover by up to 80–95% in the urban periphery. This reduction is attributed not only to the expansion of urban areas but also to anthropogenic activities in surrounding regions. According to Therán et al. (2023) [29], these urbanization practices exacerbate the municipality's vulnerability to atmospheric phenomena such as heavy rain and strong winds. They recommend the implementation of the national policy of the Integral Improvement of Neighborhoods (MIB) in a tailored manner for the Barranquilla metropolitan area. This entails undertaking initiatives aimed at enhancing housing conditions and environmental quality as measures to mitigate air temperature increases.

Therefore, this research aimed to evaluate the effectiveness of crowdsourcing as a participatory approach to enhance climate change resilience. By harnessing the collective intelligence of residents and leveraging citizen science initiatives, this study sought to create a more inclusive and responsive framework for disaster preparedness and responses, which could be applied to any urban area with similar characteristics. To achieve this goal, the methodology was designed in the municipality of Soledad, Colombia. Through a combination of volunteerism, digital technologies, and community engagement, our research also aimed to develop innovative strategies for reducing the negative impacts of cyclonic wind events and promoting sustainable development in the region.

1.1. Geo-Information

Geo-information technologies encompass a wide range of tools and methodologies for collecting, analyzing, and visualizing spatial data [30]. From satellite imagery and remote sensing to GPS tracking and geographic databases, these technologies offer unprecedented insights into the Earth's surface and its dynamics. By integrating data from multiple sources and applying advanced analytical techniques, geo-information professionals can generate detailed maps, models, and forecasts to support decision making in various domains.

One of the key advantages of geo-information technologies is their ability to facilitate spatial analysis, allowing researchers and planners to explore patterns, trends, and relationships within geographic datasets [31]. Whether mapping land-use changes, assessing natural hazards, or evaluating infrastructural networks, spatial analysis provides valuable insights into complex spatial phenomena and informs policy-making processes.

Moreover, geo-information technologies play a crucial role in disaster management and risk reduction efforts, enabling emergency responders to assess vulnerabilities, plan evacuation routes, and coordinate relief efforts more effectively [26]. By integrating real-time data feeds, such as weather forecasts, sensor networks, and social media feeds, GIS platforms can provide situational awareness and support decision making in rapidly evolving crises.

Recent advances in geo-information technologies have also led to the emergence of new applications and methodologies for addressing urban challenges. From smart city initiatives to climate change adaptation strategies, geo-information technologies are increasingly being integrated into urban planning and governance processes [32]. By providing decision-makers with timely, accurate, and actionable information, these technologies can help cities become more resilient, sustainable, and livable.

1.2. Crowdsourcing and Risk Management

Digital citizen participation involves citizens engaging in civic activities, decision making, and governance through digital platforms and technologies. It includes online interactions, such as social media engagement, virtual town halls, and crowdsourcing initiatives, enabling citizens to contribute ideas, voice concerns, and collaborate with stakeholders to address community issues. Digital citizen participation enhances transparency, accountability, and inclusivity in governance processes, fostering democratic values and empowering citizens in the digital era.

Crowdsourcing, defined as the practice of obtaining information or services by soliciting contributions from a large group of people, has emerged as a valuable tool for disaster management and risk reduction [1,33,34]. By harnessing the collective intelligence and expertise of volunteers, crowdsourcing initiatives can rapidly collect, analyze, and disseminate data related to disaster occurrence, impacts, and response efforts. One of the key benefits of crowdsourcing is its ability to engage a diverse range of participants, including citizens, scientists, and emergency responders, in collaborative data collection and analysis activities [35]. Through online platforms, mobile applications, and social media channels, crowdsourcing initiatives can mobilize volunteers to report observations, share information, and contribute to ongoing research efforts.

Moreover, crowdsourcing can also help bridge the gap between traditional top-down approaches to disaster management and bottom-up community-based initiatives [25]. By empowering local residents to actively participate in decision-making processes and response efforts, crowdsourcing initiatives can enhance community resilience and promote social cohesion in disaster-prone areas. However, despite its potential benefits, crowdsourcing also poses several challenges, including data quality issues, privacy concerns, and information overload [36,37]. Ensuring the accuracy and reliability of crowdsourced data requires robust validation mechanisms and quality control processes. Additionally, safeguarding the privacy and security of participants' personal information is essential to maintain trust and confidence in crowdsourcing initiatives.

2. Materials and Methods

2.1. Study Area

This study focused on the municipality of Soledad, situated in northern Colombia within the Caribbean region and the Atlántico department (Figure 1). Soledad is one of the five municipalities comprising the metropolitan area of Barranquilla. It is located at 10°55′ N and 74°46′ S, bordered by Barranquilla to the north, Malambo to the south, the Magdalena River to the east, and Galapa to the west.

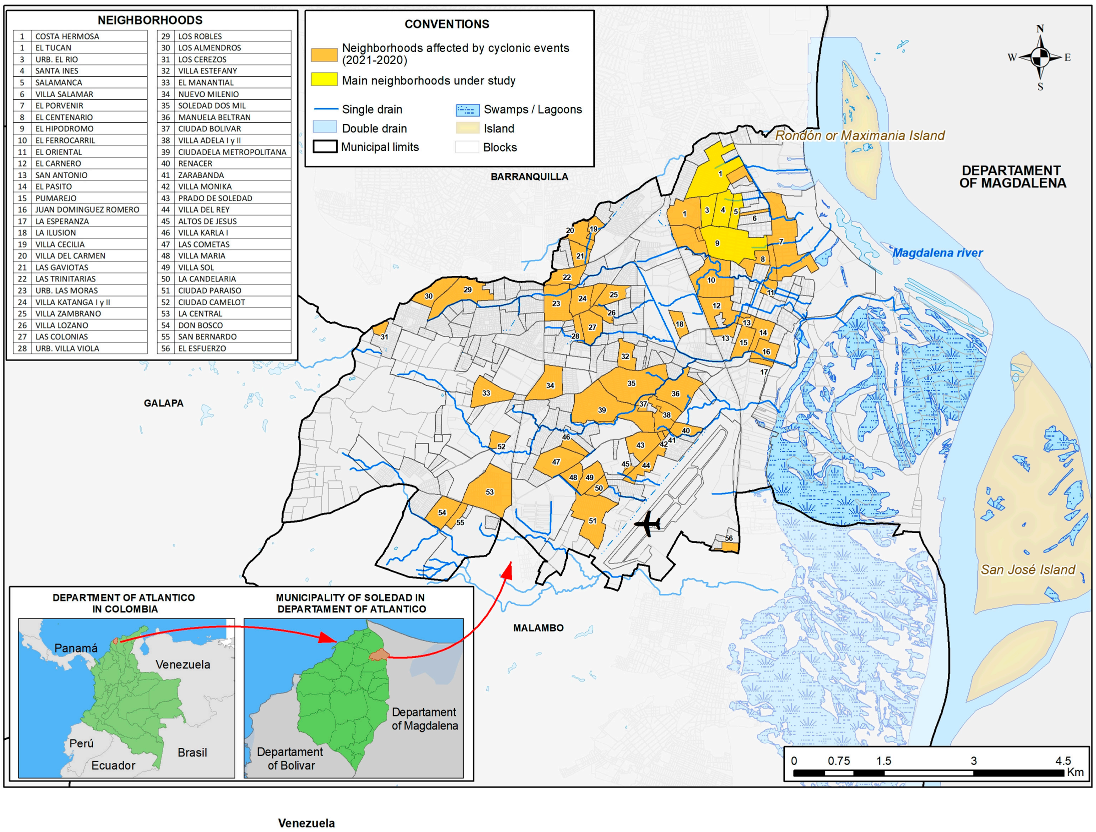

Figure 1. Study area.

The climate of the area is tropical [28], characterized by an average relative humidity ranging from 77 to 83%. Prevailing winds predominantly originate from the northeast

(42.7%) and north (25%) directions. During the windiest season, which spans from December to March, wind speeds peak at 24 km h^{-1}, whereas the least windy season sees average speeds of 11.6 km h^{-1} [29].

Soledad, with a population of 683,486 inhabitants as per the 2019 national census, stands as the most populous non-capital city in Colombia. Over recent years, it has witnessed rapid urban expansion, largely attributed to its conurbation with Barranquilla. Within the last two decades, Soledad has faced 33 cyclonic events affecting 30% of its neighborhoods. The impacts of these events include an average of 4.6 neighborhoods affected annually, 10 fatalities, and the displacement of 14,552 individuals, as well as affecting 5180 families or households [17]. These data highlight Soledad as an urban area with a special tendency and vulnerability to these events because of its density and urban morphology [17].

According to Pérez-Arévalo et al. (2023), a total of 59 neighborhoods have experienced the consequences of 33 cyclonic events between 2001 and 2020. Notably, 45.5% of these events have disproportionately impacted five neighborhoods: Costa Hermosa, El Hipódromo, Santa Inés, Salamanca, and El Río. These areas have seen 1183 houses affected, representing 16.7% of the total reported damages in the municipality (Table 1). This distribution underscores variations in construction quality and the formal origins of neighborhood development. For instance, in the Villa del Carmen neighborhood, characterized by informal settlements and self-construction, 1070 houses were affected by cyclonic events, constituting 15% of the municipality's total reported damages, despite being just one neighborhood (Figure 1).

Table 1. Neighborhoods with occurrence of cyclonic events in Soledad.

Neighborhoods	Gales—Tornadoes—Strong Winds 2001–2020					Events	Injuries	Deaths	Homes Affected
El Hipódromo	2005	2007	2008	2012	2014	5	215	0	815
Costa Hermosa	2007	2011	2012	2016		4	238	1	66
El Río	2005	2007				2	10	0	146
Salamanca	2005	2007				2	80	0	20
Santa Inés	2005	2007				2	60	0	136
Total						15	603	1	1183

2.2. Methodological Design

This research was based on a review of the scientific literature on topics related to crowdsourcing and the social construction of risk through geo-informatics tools. The methodological design was quantitative–qualitative, integrating digital media for the comprehensive collection of census data and statistics sourced from the National Administrative Department of Statistics (DANE). These data were then processed using geo-informatics techniques to attain a deterministic definition of the obtained results.

The methodological implementation (Figure 2) comprised two key stages:

i. The preliminary stage: The bibliographic review and selection of observation focal points and the demographic evaluation of the study area.
ii. The diagnostic phases of the problem:
    - Phase (i): The spatiotemporal evaluation of emergency response mechanisms;
    - Phase (ii): The spatiotemporal evaluation of healthcare centers/services;
    - Phase (iii): The implementation of crowdsourcing utilizing geo-informatics tools for data collection via geo-referenced web forms.

These phases aimed to comprehensively assess the emergency response infrastructure and gather pertinent data through a participatory approach.

Upon completion of the aforementioned stages, this study drew conclusions aimed at establishing an effective mechanism for emergency responses, grounded in a social perspective of disaster management. This approach emphasizes the importance of community engagement and collaboration in enhancing the efficacy of emergency response strategies.

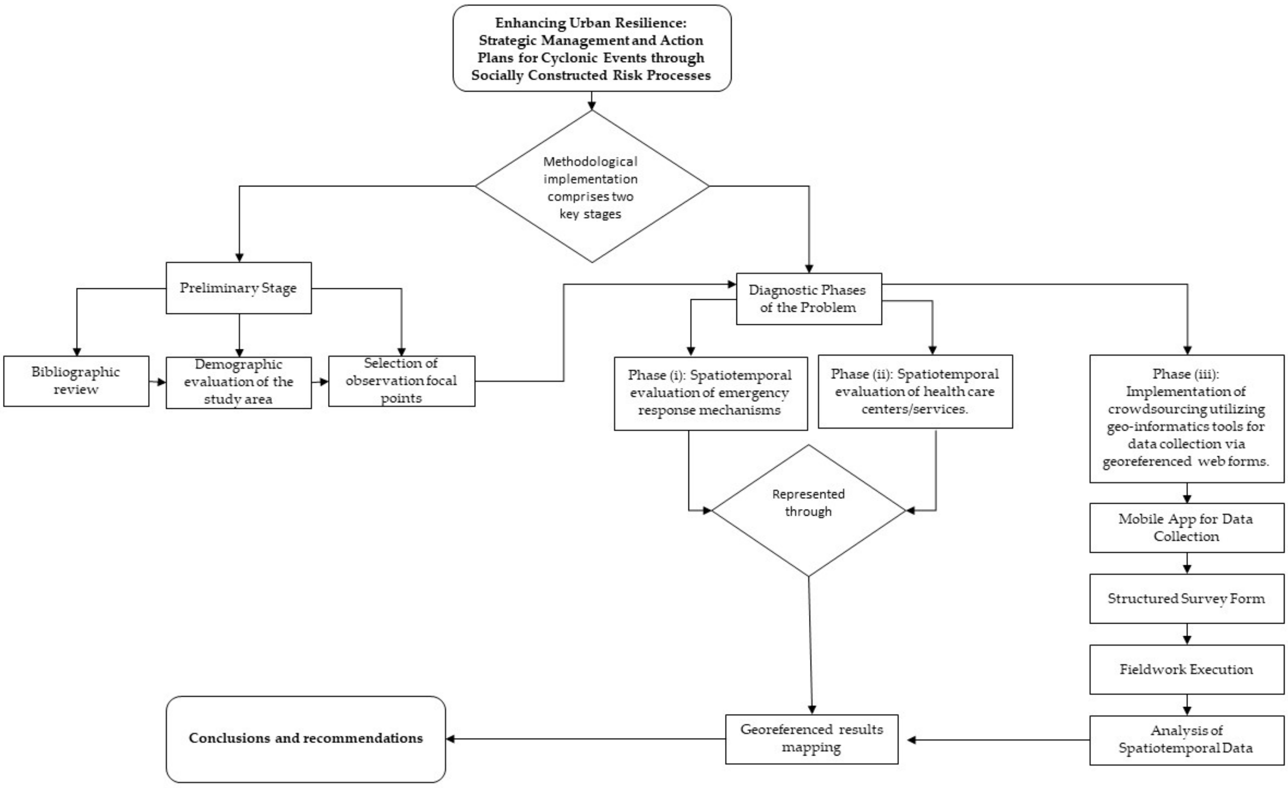

Figure 2. Flowchart: methodological design.

2.3. Urban Inhabitant Characteristics

The demographic assessment carried out herein focused on five neighborhoods within the municipality of Soledad, Colombia. The total population of the case study area was 37,946 inhabitants. This population was categorized into age groups spanning decennial intervals. These intervals were analyzed to ascertain the percentage contribution of each age group to the overall population distribution of the evaluated area. Specifically, this study focused on the economically active population, which corresponds to individuals aged between 20 and 60 years according to the DANE's classification.

The economically active population in Colombia are people of working age; this categorization is carried out by the DANE to know the size and structure of the labor force in the country's population. For this research, only this group was chosen to form a citizen support group that develops volunteer activities; however, these activities are susceptible to being formalized; therefore, children and older adults were excluded from the sample.

The population data for the study area are presented in Table 2 below, sourced from the DANE.

Table 2. Population data of the study area.

Neighborhood	Area (ha)	0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100	Population
Costa Hermosa	47.22	2031	2045	2336	2289	1623	1492	1234	514	171	34	2	13,771
El Hípodromo	47.64	1103	1443	1307	1141	1185	1127	653	671	257	47	2	8936
Salamanca	9.22	1014	1172	1164	1048	1084	819	644	459	138	18	1	7561
Santa Inés	11.49	487	603	575	571	577	410	413	249	67	15	0	3967
El Río	16.32	463	625	515	561	554	339	353	233	53	15	0	3711
Total	131.89	5098	5888	5897	5610	5023	4187	3297	2126	686	129	5	37,946

After isolating the economically active population aged between 20 and 60 years, the population sample for this study comprised 20,717 individuals, representing 54.59% of the total population of the selected neighborhoods. The combined area of the five neighborhoods under evaluation was 131.89 hectares, resulting in a population density of 28,773.13 inhabitants per square kilometer, one of the highest in Colombia.

To determine the sample size for survey administration, the following equation was utilized:

$$\text{sample size} = \frac{\frac{z^2 * p * (1-p)}{e^2}}{1 + \left(\frac{z^2 * p * (1-p)}{e^2 N}\right)}$$

where

N = the population size;
e = the margin of error (percentage expressed in decimals);
z = the z-score;
p = the proportion of individuals in the population evaluated who possess the characteristic under study. These data are generally unknown, and it is usually assumed that p = q = 0.5, which is the safest option. q, the proportion of individuals who do not have that characteristic, is $1 - p$.

For the cases analyzed, a margin of error of 5% and a confidence level of 95% (corresponding to a z-score) were assumed. Accordingly, the sample size for the research development was determined to be 378 surveys.

2.4. Crowdsourcing Instrument

In order to facilitate the analysis of citizen participation through information and communication technologies (ICTs) and effectively manage risks, as suggested by [38], and to promote the exchange of information and integration of solutions through collective intelligence and connective connections, as highlighted by Miranda Sara et al. (2016), the following methodological tools are proposed.

2.4.1. Mobile Apps for Data Collection

We propose the utilization of mobile apps such as ArcGIS Urban, MindMixer, OpenIDEO, and SafeClickFix, commonly employed in crowdsourcing and geo-information techniques [31].

2.4.2. Structured Survey Form

- We propose the development of a survey instrument with fifteen questions, designed to be completed within four minutes. The form should consist of four parts:
- Identification: The collection of demographic information about participants (gender, age group, and level of education);
- Linkage: The exploration of the connection between the respondent and the subject matter;
- Diagnosis: The evaluation of the perceived problem;
- Proposal: The assessment of the feasibility of creating a volunteer corps and providing citizens with training for emergency responses.

2.4.3. Fieldwork Execution

We propose the assignment of four surveyors to conduct fieldwork using cell phones over seven days, including both working days and weekends, and the utilization of the ArcGIS Survey123 mobile app for data collection, enabling geographic referencing to record the sample location alongside extracting information.

2.4.4. Analysis of Spatiotemporal Data

We propose the employment of data collected from various sources and scales to analyze catastrophes and disaster risks. A focus should be placed on gathering data regarding hazards, exposure, and post-disaster management to inform risk assessments [39].

2.4.5. Bottom-Up Information Gathering

A decentralized approach to information gathering should be emphasized, allowing for unexpected insights and specificity in understanding the studied events [40]. Geo-information should be utilized to determine the feasibility of establishing a volunteer corps to address emergencies in critical areas.

3. Results and Discussion

3.1. Evaluation of Municipal Life-Saving and Rescue Mechanisms

The spatial patterns of emergency response organizations were initially examined to determine the timeliness and effectiveness of their responses within the municipality of Soledad. The selected variables for analysis were the sole mechanisms currently implemented by the municipality for addressing such atmospheric events. In this context, the firefighting brigade and civil defense are the primary emergency response entities. The civil defense headquarters in Soledad, located in the Villa Katanga neighborhood, is accessible within a 10 to 20 min vehicle journey from the study area. Conversely, the municipal fire station is situated more than 20 min away at the southern extremity of the municipality, as depicted in Figure 3.

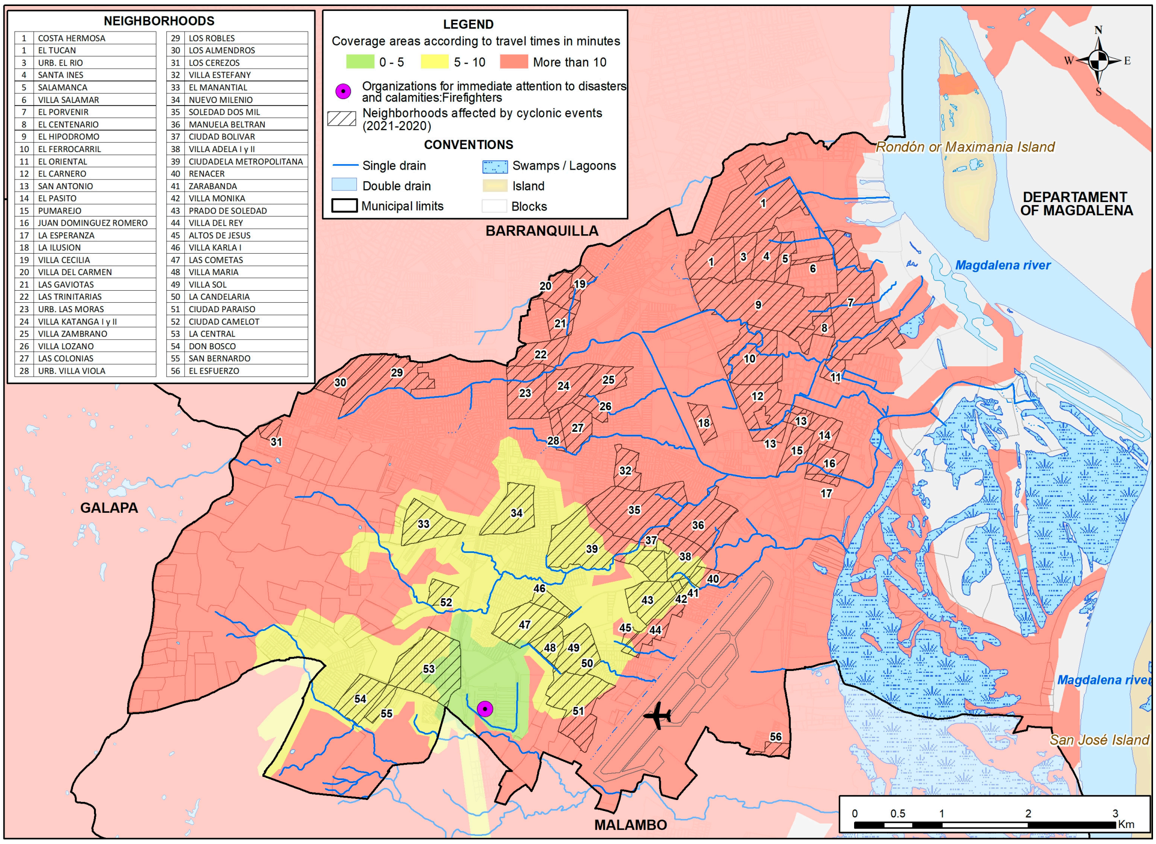

Figure 3. Location of rescue and life-saving devices (firefighters).

This spatial analysis highlights the potential disparities in response times between the two emergency response entities. While the civil defense headquarters appears to be relatively accessible to the study area, the distance to the municipal fire station may result in delayed response times, particularly in emergencies located on the southern side of the municipality. Such disparities could impact the overall effectiveness of emergency response efforts and may warrant further examination and potential adjustments in resource allocation and infrastructure planning to optimize emergency response capabilities throughout the municipality (Figure 4).

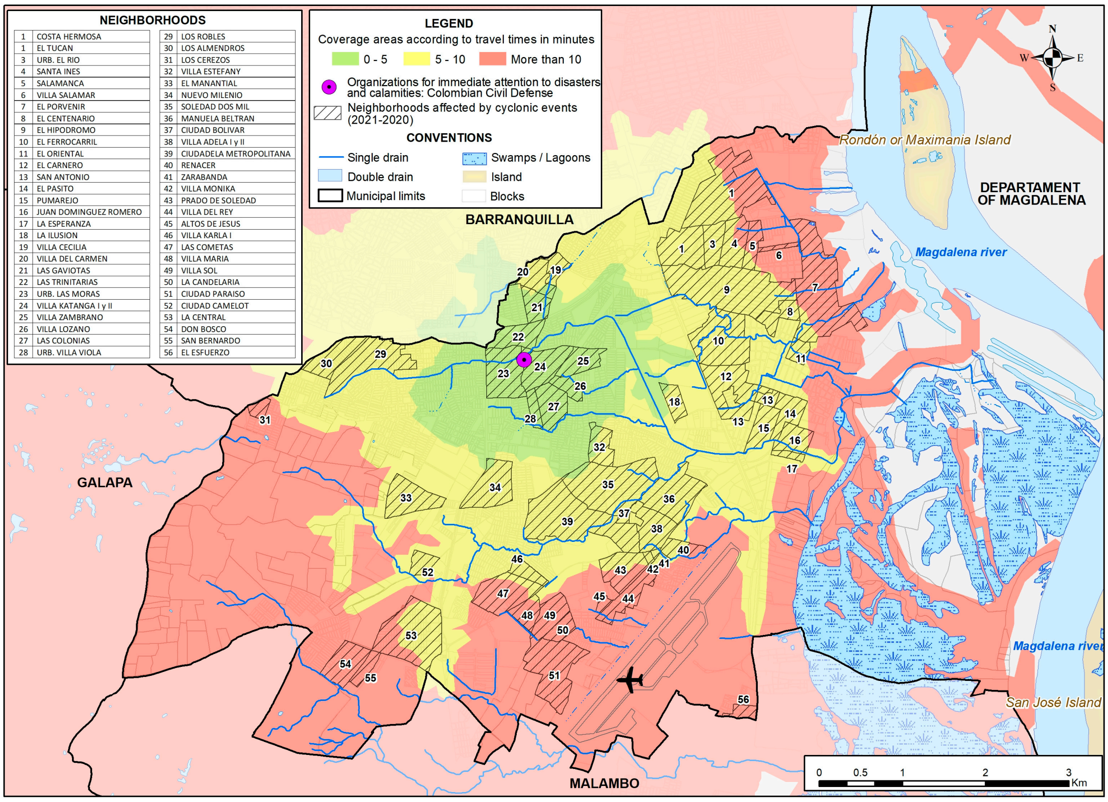

Figure 4. Location of rescue and life-saving devices (civil defense).

3.2. *Evaluation of Emergency Medical Response Mechanisms*

Emergency care facilities play a crucial role in ensuring public safety and mitigating the negative impacts of disasters. It is imperative to enhance resilience perceptions to effectively manage disasters, leveraging early detection mechanisms and assessing risk levels in relation to the proximity of care centers [41].

In Soledad, the public healthcare system consists of the Juan Dominguez Romero Hospital, classified as a second-level-complexity facility, and a network of lower-complexity health centers along with two mobile diagnostic units (Table 3). Additionally, the Universidad del Norte Hospital, a private facility catering to users of the contributory regime, operates nearby, providing medium-complexity care.

Table 3. Soledad's public healthcare centers.

Complexity	Second Level	Low Complexity	Low Complexity
Name of health care center	Juan Domínguez Romero Hospital	Low-complexity health centers 1. Centro de Salud Ciudadela Metropolitana 2. Centro de Salud 13 de Junio 3. Centro de Salud Villa Estadio 4. Centro de Salud Salamanca 5. Centro de Salud Manuela Beltrán 6. Centro de Salud Maclovia Niebles 7. Centro de Salud La Esperanza 8. Centro de Salud Costa Hermosa 9. Centro de Salud el Parque	Mobile units

The proximity of healthcare facilities is a critical factor in emergency response effectiveness. While the private Universidad del Norte Hospital is accessible within 10 min by car, the Juan Domínguez Romero Hospital, a public facility, requires more than 20 min of travel time (Figure 5). This disparity may impact the timeliness of emergency medical responses in the study area.

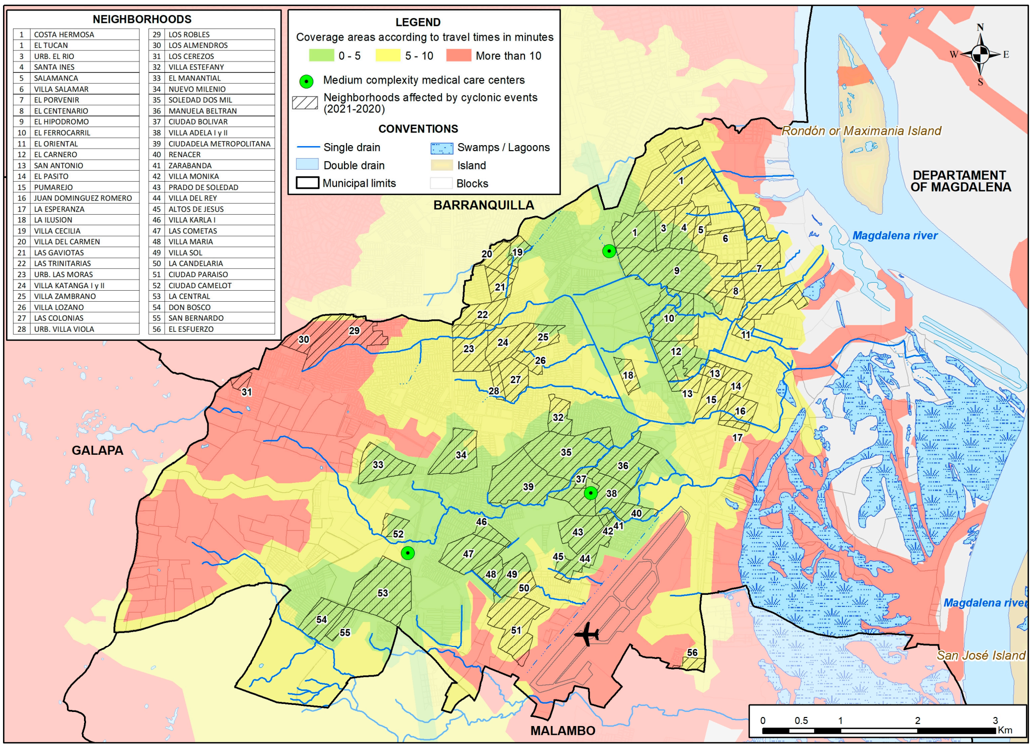

Figure 5. Second-level-complexity hospitals.

Despite the spatial coverage of the healthcare infrastructure in Soledad, challenges persist, particularly in terms of service quality. Many patients find it necessary to seek care in Barranquilla due to limitations in local healthcare provision. The demographic transition in Soledad, characterized by an aging population and declining youth demographics, underscores the importance of strategic planning for risk management and the establishment of a volunteer corps. Furthermore, healthcare coverage in Soledad is complex, with a significant portion of the population belonging to the subsidized public system. Forced migrations from internal Colombian conflicts and the Venezuelan crisis have strained the healthcare system, with many undocumented migrants facing challenges accessing healthcare services.

The resurgence of diseases in Venezuela, including measles, malaria, syphilis, and HIV [42,43], has posed additional challenges for host countries like Colombia, exacerbating the burden on healthcare systems. Venezuelan migrants, particularly vulnerable during the COVID-19 pandemic due to housing and economic instability [44], have further strained the healthcare infrastructure in cities like Soledad [45]. The spatial-temporal analysis reveals an optimal coverage of urban areas and historically cyclone-affected neighborhoods by public health centers. However, these centers lack hospital response capabilities, highlighting vulnerabilities in complex emergencies (Figure 6).

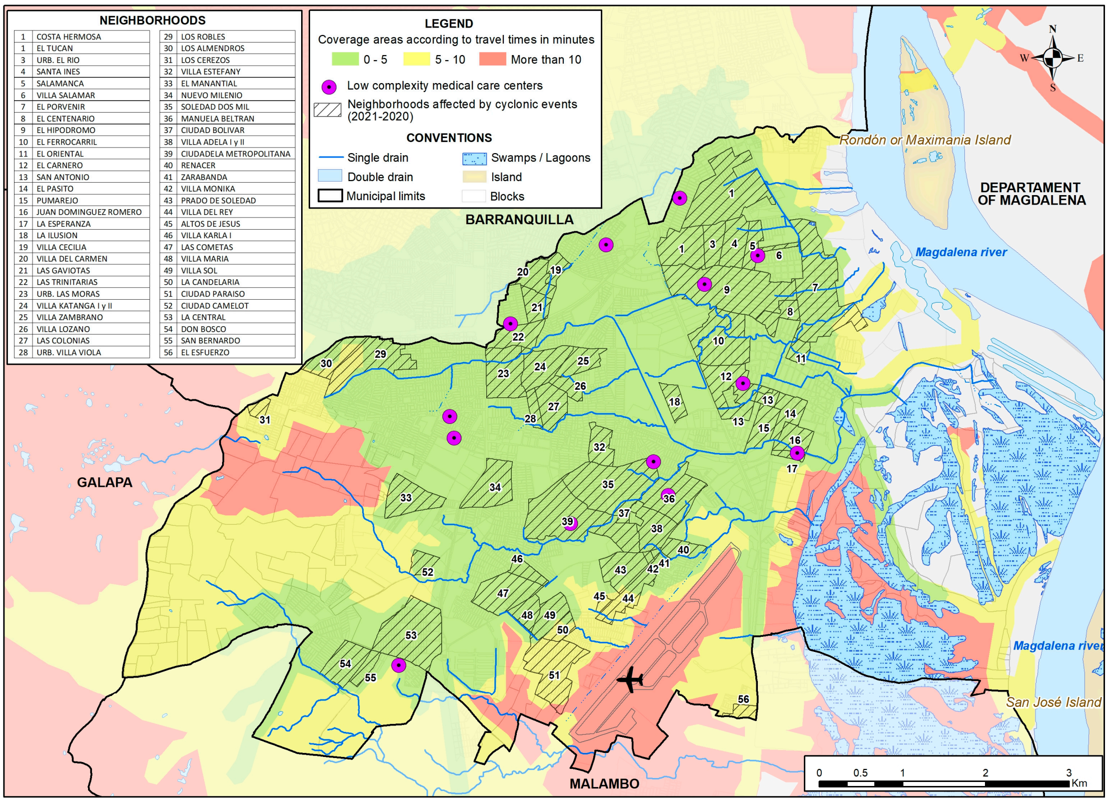

Figure 6. Low-complexity health centers.

3.3. Crowdsourcing in the Study of Strong Wind Risk in Soledad

The crowdsourcing methodology was applied to study strong winds in Soledad, focusing on neighborhoods with a high occurrence of such events over a 20-year interval. The sample encompassed five lower-middle-class neighborhoods (El Hipódromo, Costa Hermosa, El Río, Salamanca, and Santa Inés), characterized by formal urban growth and predominantly employed residents with educational attainment, primarily up to high school level (73%) (Figure 7). Professional training was prevalent among respondents, with technical occupations being the most common, followed by a marginal presence of postgraduate professionals (4%). Occupations such as housewives, students, merchants, self-employed individuals (informal salesmen), and retirees constituted 47% of household occupants.

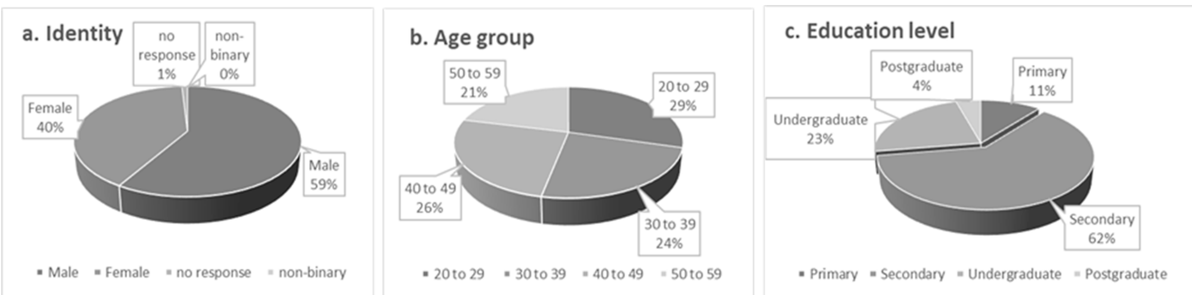

Figure 7. Sociodemographic characteristics of the sample.

Pérez-Arévalo et al. (2023) noted that strong wind events in Soledad are more associated with the rainy season than the high-wind season, often coinciding with atypically hot days featuring sudden rainfall. Citizens attribute the occurrence of strong winds to factors such as deforestation, urban morphology, and poor housing conditions, which align with scientific assessments. In the absence of advanced monitoring sources, crowdsourcing offers a means to collect information from dispersed sources, providing valuable insights into localized events. This study gathered relevant data on social characteristics and the community's potential response capacity for environmental emergencies. A significant majority (92%) of respondents perceived strong-wind events as a danger to the municipality, expressing limited trust in public entities' response capabilities (50.3%) and moderate trust in neighbors' assistance during emergencies (3.3/5) (Figure 8).

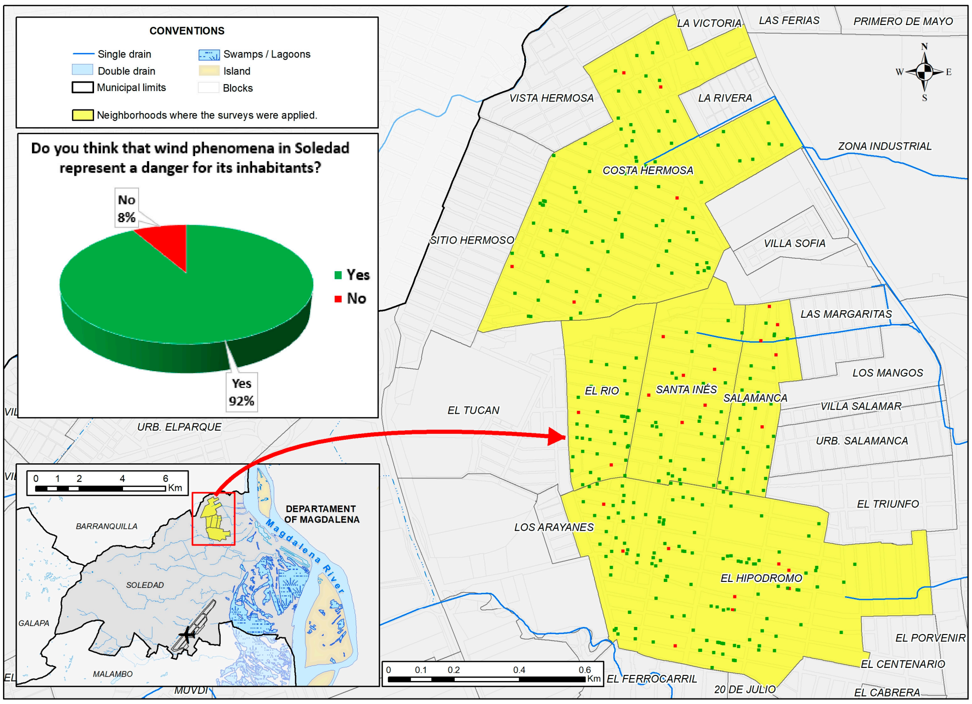

Figure 8. Hazard perception of strong-wind events in Soledad, Colombia.

Community social capital plays a crucial role in emergency responses and relief efforts, not only through volunteering but also through citizens' knowledge of the phenomena and how to address them [46]. In the data reported, 58% of respondents expressed a willingness to join a volunteer corps to respond to emergencies. Among these, 31.8% fell within an age range between 20 and 29 years, with lower interest observed among individuals over 50 years of age (15.7%) and housewives. Specifically, 73% of students surveyed (aged between 20 and 29 years) expressed readiness to join a volunteer corps, highlighting their potential as active contributors to emergency response efforts. In contrast, only 47% of individuals over 40 years old expressed interest in joining a volunteer corps, indicating a lower level of engagement among older age groups.

These findings underscore the importance of targeted outreach and engagement strategies, particularly among older demographics and housewives, to enhance community participation in emergency response initiatives. By harnessing the willingness of younger individuals, particularly students, and addressing barriers to participation among older age groups, communities can strengthen their social capital and improve their resilience to emergencies. Among individuals over 50 years old, there is compelling evidence of a more nuanced understanding of the problem and its effects, surpassing that of younger demographics, despite their educational background, including undergraduate and postgraduate training. This suggests that experience and accumulated knowledge play a significant role in shaping their awareness of risks and emergencies.

Furthermore, the data reveal that 8 out of 10 respondents expressed interest in receiving training on how to effectively manage risks and respond to emergency situations (Figure 9). This eagerness for training is promising as it contributes to the social construction of risk and enhances community resilience. By equipping individuals with the necessary skills and knowledge to handle emergencies, such initiatives have the potential to mitigate material damage, reduce injuries or fatalities, and alleviate psychological distress, thus safeguarding community spirit and identity [20].

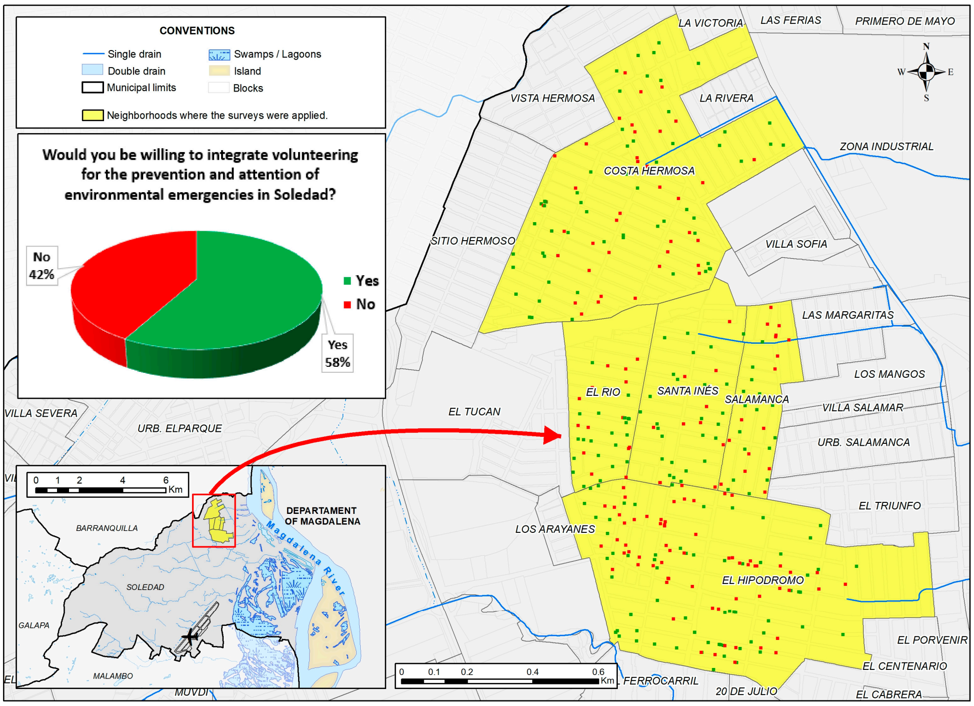

Figure 9. Volunteering for emergency responses in Soledad, Colombia.

In environmental risk events, integrating crowdsourcing data into urban monitoring initiatives contributes to the development of a "Smart City" [47]. Additionally, various measures can be implemented to bolster the response capacity, building upon the findings of the current study. These measures include the following:

- Incorporating webcams and sirens to enhance surveillance and early warning systems.
- Providing training programs to educate citizens on emergency preparedness and response strategies.
- Establishing dissemination platforms through social networks to disseminate timely information and instructions during emergencies.
- Assigning specific tasks to citizens as part of community-based response efforts.
- Developing mobile applications that allow residents to report information and incidents in real time [33].

By integrating these elements into existing disaster risk reduction strategies, communities can tap into the empirical knowledge of residents to effectively strengthen the response capacity. Collaboration between citizen science initiatives and research institutions, such as the Universidad del Atlántico (Colombia), the University of Córdoba (Colombia), and the University of Granada (Spain), can further enhance the implementation of disaster risk reduction strategies [42]. This synergy between citizen-driven initiatives and scientific research fosters a comprehensive approach to disaster management, ultimately improving community resilience and response effectiveness (Figure 10).

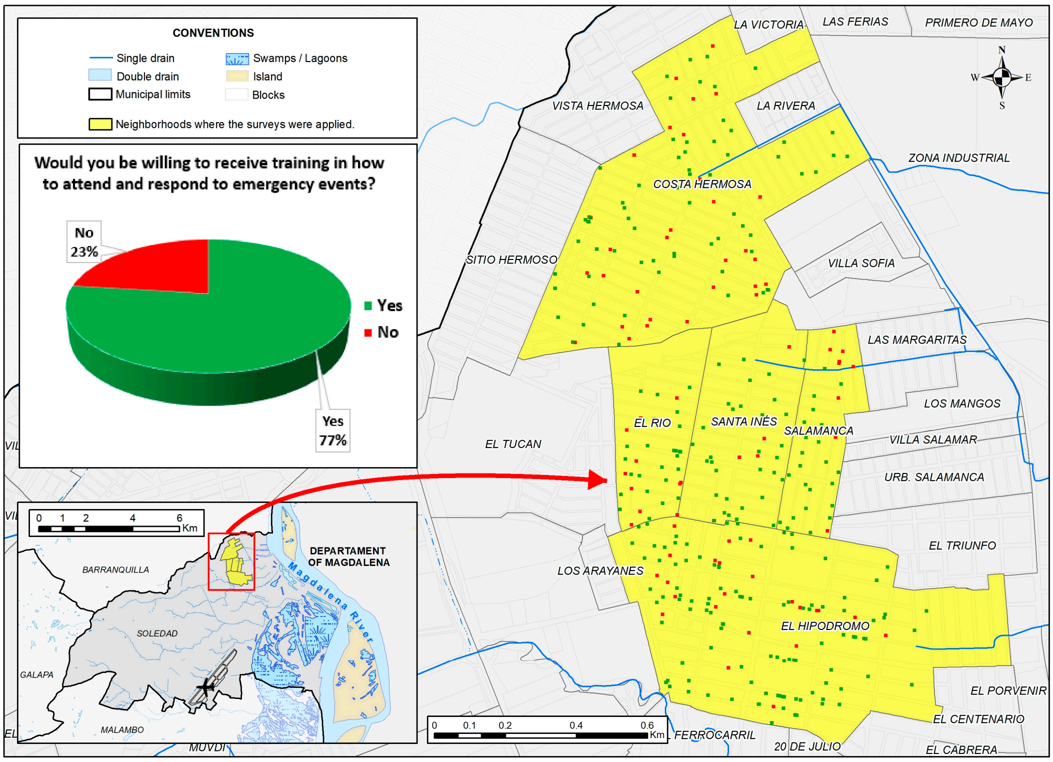

Figure 10. Citizen training for emergency responses.

In this case study, 8 out of 10 citizens expressed a willingness to acquire more knowledge about strong-wind phenomena, recognizing this as a crucial step to minimize damage during emergencies. It is recommended to preserve community intelligence by maintaining the geo-referenced volunteer corps online, thereby facilitating continuous engagement and knowledge sharing among residents. This approach combines a traditional top-down system with governmental public policies aimed at strengthening knowledge transfer among the inhabitants of vulnerable areas while also encouraging innovative bottom-up participation [48,49]. By establishing permanent connections between citizens and emergency response agencies, communities can act swiftly to mitigate the impacts of events as they occur.

Despite the widespread recognition of the benefits of crowdsourcing in the scientific community, emergency communication via social networks remains underutilized [50]. During the data collection process using mobile devices, distrust and rejection were observed among interviewees, attributed to both the security situation in the municipality of Soledad and a lack of familiarity with the procedure. To address these challenges, it is imperative to overhaul the social landscape of disaster management in Soledad, fostering innovation in emergency response strategies to effectively reduce negative impacts [50]. This may involve improving communication channels, enhancing public awareness, and implementing user-friendly technologies to facilitate citizen engagement and participation in disaster preparedness and response efforts.

4. Conclusions

This research fills a notable gap in the existing literature by evaluating public opinion in Soledad regarding the exposure to risk among inhabitants and their perspectives on mitigation strategies and the prevention of negative impacts caused by cyclonic events. By shedding light on these aspects, this study contributes to our understanding of the phenomena and paves the way for further research aimed at mitigating effects and managing risks through citizen participation.

Analysis of the installed capacity of Soledad's health system indicates the absence of spatial patterns that pose threats to health or emergency care. The strategic placement of health centers allows for diagnostic care and low-complexity interventions in a timely manner. However, this study also identifies the need to examine the endowment and instrumental capacity of these facilities, which could be the focus of future research endeavors; similarly, a better understanding of the vulnerability of buildings and the micrometeorological conditions of the case study could lead to site-specific solutions.

The implementation of crowdsourcing mechanisms has proven effective in generating empirical knowledge of atmospheric wind events in Soledad. Additionally, it has facilitated the establishment of a real-time, geo-referenced volunteer corps capable of responding to events promptly on-site. This approach not only enhances our understanding of local risk dynamics but also strengthens community resilience by leveraging citizen participation in emergency response efforts.

Crowdsourcing offers an effective approach to enhancing disaster management and risk reduction efforts by leveraging the collective intelligence and expertise of communities. By engaging citizens as active participants in data collection, analysis, and decision-making processes, crowdsourcing initiatives can improve the effectiveness and efficiency of disaster response efforts and build more resilient and adaptive communities.

The combination of geo-information technologies and crowdsourcing holds great promise for enhancing disaster management and risk reduction efforts in urban areas. By leveraging the power of digital citizen participation and collective intelligence, cities can improve their resilience to climate-related disasters and other hazards. However, realizing the full potential of these approaches requires addressing various technical, institutional, and social challenges. Future research and policy efforts should focus on overcoming these barriers and fostering greater collaboration between stakeholders to build more resilient and sustainable cities for the future.

Overall, this study underscores the importance of citizen engagement and collaborative approaches in disaster risk management. By harnessing the insights and contributions of residents, communities like Soledad can develop more effective strategies for mitigating risks and minimizing the impacts of natural disasters.

Considering the promising possibilities offered by crowdsourcing mechanisms and citizen science, this research opens the way for future research with which to obtain statistical parameters for monitoring high-wind phenomena; likewise, the implementation of a community network for micrometeorological assessment and monitoring is recommended.

The results obtained from the application of the crowdsourcing instrument in Soledad show that the formation of a volunteer corps to attend to emergencies from within is possible; however, the citizens themselves find it necessary to have training or more knowledge to act in times of risk. For this reason, it is suggested that government actors implement programs aimed at addressing these suggestions and intentions of the citizens.

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