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Priority Analysis of Community Preparedness for Megathrust Earthquakes Using Analytic Hierarchy Process (AHP): A Case Study of Warungboto Village, Yogyakarta

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ABSTRACT

The Special Region of Yogyakarta is highly vulnerable to megathrust earthquakes due to its proximity to an active subduction zone, posing significant risks to communities. While structural mitigation is important, community preparedness is critical to disaster risk reduction. This study aims to identify and prioritise factors influencing preparedness using the Analytic Hierarchy Process (AHP), with a case study in Warungboto Village. Data were collected from 30 respondents using pairwise-comparison questionnaires. Four main criteria were evaluated: Public Education and Awareness, Infrastructure Resilience, Emergency Response Management, and Social and Psychological Factors. The results show that Public Education and Awareness is the most influential factor (35.81%), followed by Infrastructure Resilience (24.10%), Emergency Response Management (20.20%), and Social and Psychological Factors (20.00%). Key sub-criteria include disaster drills, education programs, and awareness levels. All Consistency Ratio (CR) values are below 0.1, indicating reliable results. These findings highlight the importance of education-based strategies in enhancing community preparedness.

1. Introduction

Indonesia lies at the convergence of three major tectonic plates: the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate. This unique geological setting makes the country one of the most seismically active regions in the world, with frequent earthquakes along plate boundaries. The interaction between these plates, particularly through subduction processes, generates significant seismic energy that can result in large-magnitude earthquakes. One of the most critical and potentially catastrophic types of seismic events in this context is the megathrust earthquake, which originates from the rupture of large segments along subduction zones.

Megathrust earthquakes are characterised by their extremely large magnitudes and their potential to trigger secondary hazards, such as tsunamis, which can cause widespread destruction in coastal areas. Based on global earthquake records over the past 25 years, Indonesia has experienced several major megathrust events, including those on December 26, 2004; March 28, 2005; and October 25, 2010 [1]–[3]. These events not only resulted in significant loss of life and infrastructure damage but also highlighted the urgent need for comprehensive disaster risk reduction strategies, particularly in regions located along active subduction zones.

Most of Indonesia's southern coastal regions lie directly above active subduction interfaces, making them highly vulnerable to megathrust earthquakes and associated tsunami hazards. This includes the Special Region of Yogyakarta (Daerah Istimewa Yogyakarta/DIY), which is situated near the Java subduction zone. The vulnerability of this region has been clearly demonstrated by past seismic events, particularly the 2006 Yogyakarta earthquake, as well as by updated national earthquake hazard maps that indicate a high level of seismic risk [4]. Given these conditions, it is essential not only to focus on

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structural mitigation measures but also to strengthen non-structural measures, especially community preparedness.

Disaster risk reduction efforts have increasingly emphasised the importance of integrating both structural and non-structural approaches. While structural measures, such as earthquake-resistant buildings and infrastructure, are crucial in reducing physical damage, non-structural aspects—particularly community preparedness—play a vital role in minimising casualties and enhancing response effectiveness during disaster events. Communities with higher preparedness tend to respond more quickly, make better decisions, and adapt more effectively under emergency conditions, thereby significantly reducing potential losses. However, community preparedness is a complex, multidimensional concept influenced by interrelated factors, including education, infrastructure, governance, social dynamics, and individual perceptions of risk.

To analyse complex, multi-criteria problems, the Analytic Hierarchy Process (AHP) has been widely used as a decision-making tool. AHP is a structured multi-criteria decision-making method that allows researchers to decompose complex problems into a hierarchical framework consisting of objectives, criteria, and sub-criteria. Through pairwise comparisons, AHP enables the systematic evaluation of both qualitative judgments and quantitative data, yielding priority weights that support informed decision-making [5]. The flexibility and robustness of AHP make it particularly suitable for disaster management studies, where multiple interdependent factors must be considered simultaneously.

Previous studies have demonstrated the applicability of AHP in various disaster-related contexts. For instance, Wibowo and Khilmi [6] applied AHP to determine priority strategies for earthquake mitigation in Semarang City, while Pamungkas et al. [7] used the method to assess community preparedness levels in Cisarua District. Similarly, Hadi et al. [8] utilised AHP to map earthquake vulnerability in Bengkulu City, and Jena et al. [9] applied an integrated approach to assess earthquake risk in Aceh. On an international scale, Yariyan et al. [10] employed AHP to evaluate earthquake risk in Sanandaj, Iran. These studies highlight the versatility of AHP in addressing disaster-related decision-making problems across different spatial contexts.

Despite the growing body of literature, most studies have focused primarily on hazard assessment, structural vulnerability, and large-scale risk mapping. Relatively limited attention has been given to the quantitative prioritisation of community preparedness factors, particularly at the local or village level. In addition, many studies are conducted at regional or national scales, which may not fully capture the unique socio-demographic characteristics and local dynamics that influence preparedness at smaller spatial units.

Recent studies have further emphasised that megathrust earthquakes in Indonesia present not only significant structural challenges but also substantial non-structural risks, particularly in densely populated urban areas. The southern part of Java, including the Special Region of Yogyakarta, lies near an active subduction interface capable of generating large-magnitude earthquakes and tsunamis. Despite this high level of hazard exposure, preparedness at the community level often remains uneven, with variations in knowledge, awareness, and response capacity among different groups.

In this context, Warungboto Village represents a highly relevant case study. As an urban village characterised by relatively high population density and complex social interactions, Warungboto is exposed to significant earthquake risks and faces challenges in evacuation, communication, and coordination during emergencies. Understanding the priority factors that shape community preparedness in such settings is essential for designing targeted, context-specific disaster risk reduction strategies.

Therefore, this study aims to address the identified research gap by applying the Analytic Hierarchy Process (AHP) to systematically identify and prioritise the key factors influencing community preparedness for megathrust earthquakes at the village level. By focusing on Warungboto Village as a case study, this research seeks to provide both theoretical and practical contributions to disaster risk reduction, particularly in enhancing community-based preparedness strategies in earthquake-prone urban areas.

2. Methods

This study employs a quantitative approach using the Analytical Hierarchy Process (AHP) to determine community preparedness priorities for megathrust earthquakes. AHP was selected for its ability to evaluate complex decision-making problems involving multiple criteria systematically and to incorporate expert judgment in determining priority weights. Data analysis methods are the process of converting raw data into meaningful information through various statistical and non-statistical techniques to support decision-making or hypothesis testing [12].

2.1 Study Area and Data Collection

The study was conducted in Warungboto Village (Figure 1), an urban area in Yogyakarta City characterised by dense settlements and potential exposure to seismic hazards. The selection of this location was based on its vulnerability to earthquake risks and its relevance to urban disaster preparedness planning.

Primary data were collected through structured questionnaires distributed to respondents within the study area. The questionnaire was designed to obtain pairwise comparisons of criteria and sub-criteria related to community preparedness using the AHP scale.

2.2 Research Respondents

The study involved 30 respondents, consisting of 23 academics (76.7%) and 7 community representatives (23.3%). Respondents were selected through purposive sampling, targeting individuals with relevant knowledge and experience in disaster management and familiarity with local conditions.

The inclusion of academic respondents was intended to ensure analytical rigour, while community representatives contributed practical insights into local preparedness conditions. This combination is considered appropriate for AHP-based studies, where expert judgment plays a critical role in the evaluation process.

2.3 Development of AHP Hierarchical Structure

The AHP model in this study is structured into three hierarchical levels: objective, criteria, and sub-criteria.

1. Objective Level

The primary objective is to determine priority factors influencing community preparedness for megathrust earthquakes. Disaster preparedness policies have been established to strengthen Indonesia's disaster management system and increase capacity across various regulations and community guidelines, which were used to determine the criteria and sub-criteria in this article.

2. Criteria Level

The criteria were developed through a review of relevant policies and literature on disaster management in Indonesia, including:

Figure 1. Research Location [11].

- Law No. 24 of 2007 concerning Disaster Management [13]
- Disaster Preparedness Campus Guidelines by the Indonesian Red Cross (PMI), 2012 [14]
- Regulation of the Minister of Education and Culture (Permendikbud) No. 33 of 2019 concerning the Disaster-Safe Education Unit (SPAB) Program [15]
- Supporting literature from peer-reviewed journals and official policy documents [16]–[18]

Based on this review, four main criteria (N) were identified as: Infrastructure Resilience (A); Public Education and Awareness (B); Emergency Response Management (C); Social and Psychological Factors (D).

3. Sub-Criteria Level

Each criterion is further divided into several sub-criteria identified through content analysis of the selected references. The first sub-criterion is building structure, which refers to the structural condition and earthquake resistance of buildings. The second is evacuation routes and warning signals, which encompass the availability and accessibility of evacuation paths and early warning systems. Technology for mitigation is also considered, focusing on the use of technology to support disaster risk reduction and early warning mechanisms. In addition, disaster education programs are included to assess structured educational activities aimed at improving disaster-related knowledge within the community. Disaster drills and simulations represent practical exercises designed to train community responses during emergency situations.

Another important aspect is the level of public awareness, which reflects the community's understanding and awareness of disaster risks. Emergency response policy examines the existence of regulations and procedures related to disaster response, while coordination with stakeholders highlights collaboration among government agencies, communities, and relevant institutions. The availability of emergency facilities includes the provision of shelters, medical services, and logistical support during disasters. Community participation is also emphasized, referring to the involvement of local communities in preparedness activities. Furthermore, disaster risk perception evaluates how communities perceive earthquake risks and potential impacts. Finally, post-disaster psychosocial support addresses the availability of mental and emotional recovery assistance for affected communities after a disaster event.

2.4 Data Analysis Using AHP

The data processing in this study used the Analytic Hierarchy Process (AHP), which systematically evaluates decision-making problems through pairwise comparisons and priority weighting. The analysis stages are described as follows [5].

Preparation of a pairwise comparison matrix between criteria and subcriteria

The first step involves constructing a pairwise comparison matrix between criteria and sub-criteria based on respondents' judgments using Saaty's scale (1–9). This matrix reflects the relative importance of each element. The results of the pairwise comparison between the criteria examples are presented in Table 1.

Table 1. Example of a Pairwise Comparison Matrix of Criteria from Respondent 1

Criteria	A	B	C	D
A	1	1/3	5	9
B	3	1	3	7
C	1/5	1/3	1	5
D	1/9	1/7	1/5	1

Aggregation of Respondents' Judgments

Since the data were obtained from multiple respondents, the pairwise comparison values were combined using the Geometric Mean (GM), as shown in Equation 1.

$$GM = \sqrt[n]{(X_1)(X_2)\ldots.(X_n)} \quad (1)$$

which GM as geometric mean, X_1 as Respondent 1, X_2 as Respondent 2, X_3 as Respondent 3, GM is to obtain a representative value for each comparison, which is shown in Table 2.

Table 2. Geometric Mean of Criteria

Criteria	A	B	C	D	Total
A	1.000	0.717	1.326	1.126	4.169
B	1.395	1.000	2.572	1.360	6.326
C	0.754	0.389	1.000	1.501	3.644
D	0.888	0.735	0.666	1.000	3.290
Total	4.037	2.841	5.564	4.987	14.429

Normalization of the Matrix

The aggregated matrix is then normalised by dividing each element by the column's total. This step aims to standardise the values for subsequent calculations. The normalized matrix is presented in Table 3.

Table 3. Matrix normalization

Criteria	A	B	C	D	Total
A	0.248	0.252	0.238	0.226	0.964
B	0.345	0.352	0.462	0.273	1.432
C	0.187	0.137	0.180	0.301	0.804
D	0.220	0.259	0.120	0.201	0.799
Total	1.000	1.000	1.000	1.000	4.000

Priority Weight Calculation

The priority weights are calculated by averaging the values in each row of the normalized matrix. These weights represent the relative importance of each criterion. The results of the priority weights are shown in Table 4.

Table 4. Matrix Normalization

Criteria	Code	Weight	Presentase
Infrastructure Resilience	A	0.241	24.10%
Public Education and Awareness	B	0.358	35.81%
Emergency Response Management	C	0.201	20.1%
Social and Psychological Factors	D	0.200	20%
Total		1.000	100%

Eigenvalue (λ_{max}) Calculation

The maximum eigenvalue (λ_{max}) is calculated to assess the consistency of the pairwise comparison matrix. This is obtained by multiplying the pairwise matrix with the priority vector and averaging the results as Equation 2. The calculated λ_{max} was 4.099.

$$\lambda_{max} = \sum matriks \frac{\sum value\ of\ n\ row\ element}{N} \quad (2)$$

Consistency Test (CI and CR)

To ensure the reliability of the judgments, the Consistency Index (CI) and Consistency Ratio (CR) are calculated using Equation 3 and Equation 4.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

$$CR = \frac{CI}{RI} \quad (4)$$

Based on the calculation results, the CI value is 0.0365 (3.65%), which is less than the acceptable threshold of 10%. Therefore, the pairwise comparison matrix is considered consistent, and the analysis can proceed to the next stage.

Final Priority Analysis

The final step involves combining the priority weights across all hierarchical levels. This is done by multiplying the sub-criteria's weights by their respective parent criteria to obtain the global weights. The hierarchical structure and final weights are illustrated in Figure 2.

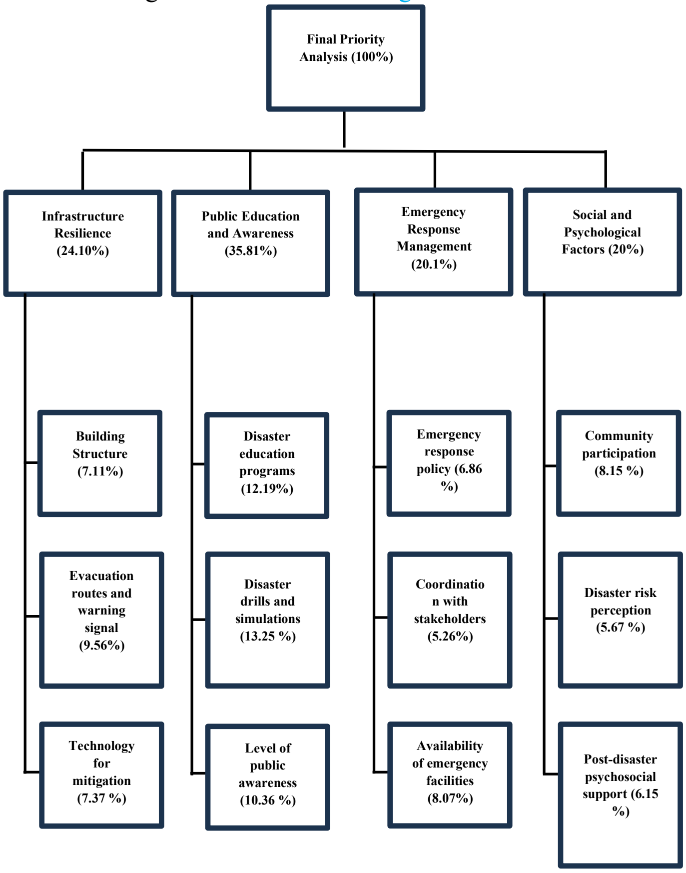

Figure 2. The hierarchical structure and final weights

2.4 Research Procedure

The overall research procedure, including data collection, AHP model development, analysis, and interpretation, is illustrated in Figure 3.

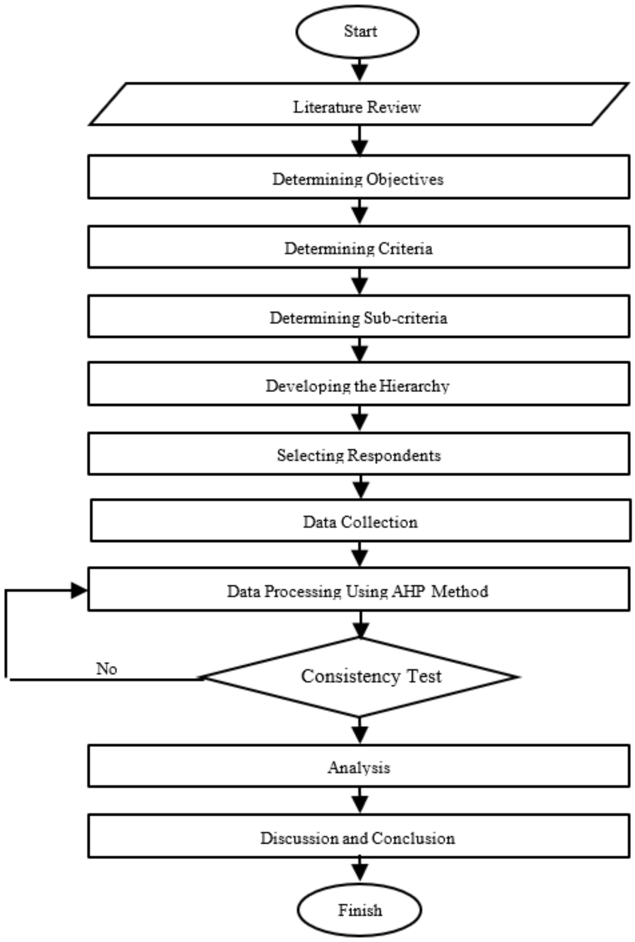

Figure 3. Research Flowchart

3. Results and Discussion

3.1 Main Criteria Weighting Results

The results of the weighting calculation for the main community preparedness criteria are presented in Figure 2. These results indicate that public education and awareness emerge as the most dominant factors in enhancing preparedness for megathrust earthquakes. With the highest weighting among all criteria, this finding demonstrates that knowledge-based and awareness-driven aspects play a central role in shaping the community's overall preparedness capacity.

A more detailed interpretation of these results suggests that the ability of individuals and communities to understand disaster risks, recognise early warning signs, and respond appropriately is strongly influenced by their level of education and exposure to disaster-related information. Public education and awareness not only improve individual preparedness but also facilitate collective action, which is essential in emergencies. In densely populated areas such as Warungboto Village, where rapid response and coordination are critical, the role of education becomes even more significant.

In comparison, other criteria such as infrastructure resilience, emergency response management, and social and psychological factors, although still important, have relatively lower weighting values. This does not imply that these factors are less relevant; rather, it indicates that their effectiveness is closely dependent on the community's level of awareness and understanding. For example, well-developed infrastructure may not function optimally if the community lacks the knowledge to utilise it during an emergency. Therefore, the dominance of public education and awareness highlights the foundational role of non-structural capacity in disaster preparedness..

3.2 Sub-Criteria Weighting Results

Based on the calculation of the total sub-criteria weights, the highest priority sub-criteria include: disaster drills and simulations, disaster education programs, and public awareness level. These sub-criteria are all associated with the Public Education and Awareness criterion, further emphasising the critical importance of strengthening non-structural aspects in disaster mitigation efforts. The prominence of these sub-criteria indicates that practical, continuous learning processes are essential for building an effective preparedness system at the community level.

Disaster drills and simulations, which rank as the highest priority, play a crucial role in providing hands-on experience and improving response readiness. Through simulation activities, community members can practice evacuation procedures, understand their roles during emergencies, and identify potential challenges in real-time scenarios. This experiential approach enhances not only technical skills but also confidence and decision-making capabilities under pressure.

Similarly, disaster education programs serve as a fundamental component in increasing knowledge and awareness. These programs can take various forms, including formal education, community training, workshops, and public campaigns. When implemented consistently and inclusively, such programs can significantly improve the community's understanding of disaster risks and appropriate response strategies.

The level of public awareness, as another key sub-criterion, reflects the extent to which individuals are conscious of potential hazards and motivated to take preventive actions. High levels of awareness are often associated with proactive behaviour, such as preparing emergency kits, participating in training activities, and disseminating information within the community. Therefore, enhancing awareness is not only about information dissemination but also about fostering a culture of preparedness.

Overall, the dominance of these sub-criteria underscores the strategic priority of strengthening human capacity through education, training, and awareness-building initiatives to improve disaster preparedness, particularly in urban village contexts.

3.3 Consistency Ratio (CR) Test

The Consistency Ratio (CR) for each pairwise comparison matrix in this study is below the acceptable threshold of 0.1. This indicates that respondents' judgments are consistent and reliable, and that the resulting priority weights can therefore be considered valid for decision-making purposes.

In the Analytic Hierarchy Process (AHP), consistency is a critical aspect that ensures the logical coherence of pairwise comparison judgments. A CR value below 0.1 suggests that the comparisons made between criteria and sub-criteria are not random or contradictory, but rather reflect a structured and rational evaluation process. This strengthens the credibility of the analysis and supports the robustness of the findings.

Furthermore, achieving a satisfactory level of consistency indicates that the respondents have a clear understanding of the criteria being evaluated. This is particularly important in studies involving subjective judgments, such as perceptions of preparedness and risk. The consistency of the results also implies that the prioritisation outcomes can be confidently used as a basis for developing disaster risk reduction strategies.

In addition, the acceptable CR values obtained in this study demonstrate that the AHP method has been properly applied, following standard procedures for pairwise comparisons and consistency testing. This reinforces the methodological validity of the research and enhances its contribution to the field of disaster preparedness analysis.

3.4 Discussion

The results of the Analytic Hierarchy Process (AHP) analysis clearly indicate that public education and awareness constitute the most influential factors in enhancing community preparedness, with a weighting value of 35.81%. This finding demonstrates that, among all evaluated criteria, education-related aspects have the highest priority in shaping the community's preparedness capacity. In particular, the results suggest that levels of knowledge, understanding, and prior experience in disaster management play a critical role in determining how individuals and communities respond to the potential threat posed by megathrust earthquakes. This is especially relevant in the context of Warungboto Village, where variations in educational exposure and access to disaster-related information may significantly influence preparedness levels.

A deeper interpretation of these findings reveals that individuals who possess adequate knowledge and understanding of disaster risks are more likely to take appropriate preventive actions, respond effectively during emergencies, and participate actively in preparedness programs. Prior experience with disaster events or training activities further strengthens this capacity, as experiential learning enables individuals to internalise response procedures and develop situational awareness. Therefore, education and awareness are not only theoretical constructs but also practical components that directly influence behavioural responses in disaster situations.

This finding is consistent with a growing body of literature indicating that well-informed and educated communities tend to respond more quickly, effectively, and appropriately during disaster events. Previous studies have highlighted that disaster education programs, public awareness campaigns, and community-based training activities are essential tools for improving preparedness and resilience [19]. Such programs are particularly effective when they incorporate participatory approaches, simulations, and continuous engagement, allowing community members to actively develop and reinforce their understanding of disaster risks and response mechanisms.

Furthermore, the results of this study indicate that infrastructure resilience and emergency response management remain important supporting factors in enhancing community preparedness. Although these factors do not rank as highly as education and awareness, their roles are nonetheless critical, particularly in facilitating evacuation processes, enabling efficient emergency response, and supporting post-disaster recovery. Infrastructure resilience, including the availability of safe evacuation routes, shelters, and communication systems, provides the physical foundation necessary for effective disaster response. Meanwhile, well-organised emergency management systems ensure coordination among stakeholders and enable timely intervention during critical situations.

In addition to structural and managerial aspects, social and psychological factors also contribute significantly to shaping community preparedness. Elements such as community participation, risk perception, awareness, trust, and social cohesion play a crucial role in influencing how individuals and groups respond to disaster threats. Communities with strong social networks and high levels of trust are generally better able to coordinate collective action, share information, and support one another during emergencies. These social dynamics enhance not only preparedness but also the community's overall resilience.

Several empirical studies have demonstrated that communities with higher levels of disaster knowledge and participation in preparedness training tend to exhibit faster and more effective responses, thereby reducing the adverse impacts of disasters. Training-based interventions, including evacuation drills, simulation exercises, and structured disaster education programs, have been shown to significantly improve response behaviour, decision-making capabilities, and overall preparedness levels [20]. Moreover, integrating local knowledge with formal disaster education further strengthens community capacity by ensuring that preparedness strategies are contextually relevant and culturally appropriate.

In addition, effective risk communication and public awareness strategies have been identified as key drivers of improved preparedness behaviour. Clear, consistent, and accessible communication enables communities to understand potential hazards better and take proactive measures to mitigate risks. Studies have shown that communities exposed to regular information dissemination and awareness campaigns tend to demonstrate higher levels of preparedness and a greater willingness to engage in disaster risk reduction activities [21]. This highlights the importance of not only providing information but also ensuring it is communicated and understood effectively by diverse segments of the population.

The dominance of public education and awareness as the highest-priority factor in this study indicates that non-structural factors play a crucial, and often decisive, role in enhancing community preparedness. This finding suggests that efforts to improve knowledge, understanding, and practical experience through education and training may yield more immediate and sustainable impacts than relying solely on physical infrastructure improvements. While infrastructure remains important, its effectiveness depends heavily on the community's capacity to utilise it appropriately during disasters.

In the specific context of Warungboto Village, this result is particularly significant due to its urban characteristics, including high population density, limited open spaces, and complex spatial arrangements. These conditions can complicate evacuation processes and increase the potential risks associated with disaster events. As a result, the community's ability to respond quickly and effectively depends heavily on its level of awareness, preparedness, and familiarity with emergency procedures. Education and simulation-based preparedness programs are therefore essential to ensuring that residents can act decisively and appropriately during emergencies.

The findings of this study are generally consistent with previous research indicating that disaster education and training significantly improve response capacity and reduce disaster impacts. However, compared with studies conducted in other regions, this study places greater emphasis on the role of education relative to infrastructure.

This difference may be attributed to specific local conditions, including socio-demographic characteristics, levels of access to information, and the existing state of infrastructure development in urban environments such as Warungboto Village. In areas where basic infrastructure is already relatively available, the marginal benefit of improving education and awareness may be more pronounced.

Nevertheless, infrastructure resilience and emergency response management should not be overlooked. Although they rank lower in priority, their contributions remain essential for supporting evacuation, facilitating emergency operations, and enabling effective recovery. This underscores the importance of adopting an integrated approach to disaster risk reduction, in which both structural and non-structural strategies are implemented in complementary ways.

Finally, social and psychological factors, including community participation, collective awareness, and social cohesion, continue to play a significant role in shaping preparedness behaviour. Communities characterised by strong interpersonal relationships and active participation are generally more resilient, as they are better able to coordinate actions, provide mutual support, and adapt to changing conditions during disasters. These findings reinforce the importance of fostering community engagement and strengthening social capital as part of comprehensive disaster preparedness strategies.

4. Conclusions

At the sub-criteria level, disaster drills and simulations, disaster education programs, and the level of public awareness are identified as the top priorities. These findings highlight that strengthening non-structural aspects, particularly through continuous education and training, is crucial to enhancing community preparedness for potential megathrust earthquakes.

The results of this study provide practical implications for policymakers and stakeholders in designing effective community-level disaster risk reduction strategies. Specifically, efforts should focus on implementing sustainable disaster education programs, conducting regular simulation exercises, and improving risk communication to increase public awareness.

Overall, this study confirms that a comprehensive approach integrating educational, technical, and social dimensions is essential to improving disaster preparedness and reducing potential impacts in earthquake-prone areas.

Further research is recommended to involve a larger number of respondents and a more representative proportion of the community, to combine the AHP method with other methods to enrich the analysis, to assess the implementation of priority outcomes through concrete programs, and to evaluate their effectiveness.

This study contributes to the existing body of knowledge by providing a structured prioritisation of community preparedness factors using the AHP method at the village level. Unlike previous studies that focus on broader scales, this research highlights the importance of local context in shaping preparedness strategies.

However, this study has several limitations, including a relatively small sample size and the dominance of academic participants over community representatives. Future research is recommended to involve a more balanced and larger sample, integrate additional decision-making methods, and evaluate the implementation of recommended strategies in real-world settings.

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