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Enhancing Disaster Preparedness Capacity and Multi-Stakeholder Coordination through Penta-Helix Collaboration: The Role of Kwarda DIY in Regional Resilience

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ABSTRACT

Background: Indonesia is famous for its disaster-prone status, having been situated along the Pacific Ring of Fire which makes areas like the Special Region of Yogyakarta vulnerable to various disasters such as earthquakes, floods, and volcanic eruptions. Nevertheless, disaster preparedness is still low; community and organizational preparedness, especially related to technical capacity and cross-sector coordination, continue to be a challenge. In terms of community-based disaster preparedness, such functions from intermediary civic organizations, such as *Kwartir Daerah (*Kwarda) of the Indonesian Scout Movement, have not been employed effectively.

Purpose of Study: It is the purpose of this study to formulate and evaluate a penta-helix collaborative disaster mitigation model for Kwarda, which would be intended to further the organization's preparedness capacity and, through cross-sector coordination, augment regional resilience.

Methods: The approach of community-based research (CBR) design with Kwarda and community stakeholders placed as active co-authors of the research. It is based on the penta-helix framework, which includes five actors: government, academia, private sector, community, and media. Research stages (problem identification, participatory planning, implementation, evaluation). Program interventions include disaster preparedness education, simulation-based exercises, coordination strengthening activities, and development of contingency planning mechanisms. A pre-test and post-test design, complemented by qualitative observation, measured the test scores of 50 subjects.

Results: These results include improvements in disaster preparedness capacity of the participants through improvements in knowledge score average, which increased from 58.2 (pre-test) up to 81.4 (post-test), or 39.9% increases. Moreover, qualitative findings show improved coordination capacity with faster response times, more systematic evacuation procedures, and stronger stakeholder cooperation during the simulation activities.

Keywords
Pentahelix; Disaster Mitigation; Disaster-resilient schools; Community-Based Research; Preparedness

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Introduction

Due to its geographical and geological condition that is located on the active tectonic plate borders and many volcanoes, Indonesia is one of most vulnerable country from natural disaster in the world. This scenario is manifested by the high frequency of disasters, earthquakes, flooding, volcanic eruption and so forth that will have cross-sectoral impacts particularly on Education. Disasters are not only a risk to human lives, but it also has the added circumstance of suspending the learning process for longer periods. The Special Region of Yogyakarta (DIY) is one of the most disaster-vulnerable areas. Type of earthquakes, floods and eruptions of Mount Merapi in this region. This high-risk level is well represented by the 2006 Yogyakarta earthquake, which resulted in over 6000 deaths and thousands more injured (Hanjarwati et al., 2024). Several schools are also still having limited disaster preparedness in flood-prone areas, this is endangering the safety of students as well as disrupting continuity of educational activities (Pradana et al., 2025). In addition, the threat of Mount Merapi eruptions also requires a higher level of awareness and ability among all school stakeholders in preparing for emergency response.

Disasters have a drastic influence on the education sector: they can stop learning for extended periods, with lasting effects on students' academic advancement. Hence, disaster education must be incorporated into the school curriculum — this is an actual strategic way of enhancing student resilience in a disaster-prone area. Disaster education prepares students in mitigation and emergency response, helping reduce interruptions to the educational process during disasters. Nonetheless, this strategy still has some problems to adjust with like the difficulty of releasing disaster materials in subjects course that already exist education (Kurniawan et al., 2023; Septikasari et al., 2024), adequate facilities, training, and limited community support for disaster education. As in additionless diverse teaching methods and the lack of partnerships with disaster management institutions has also contributed towards its ineffectiveness (Septikasari et al., 2024; Pambudi et al., 2025); Desilia et al., 2023).

In addition, school preparedness to face disasters in the region of the Special Region (DIY) still low. In fact, knowledge of students and educators in disaster mitigation is still low so as to hamper quick response in catastrophic events (Hutagalung et al., 2022; Lestari & Suwanto, 2024). This is further compounded by the absence of systematic disaster preparedness education programs (Balqis & Hasibuan, 2024). Moreover, the prepared safety infrastructure is still not sufficient as evidenced by the lack of defined evacuation route (EWL) maps, incomplete emergency plans and early warning systems (Fandayati et al., 2024; Hafida, 2019). Out of which only 11% of schools are disaster safety standards, physics together cause the main problem for this very necessarily (Fandayati et al., 2024).

The poor implementation of normal training and evacuation drills also compounds these challenges. While emergency documents are critical in preparing the whole institution for immediate responses to emergencies (Özmen et al., 2015), many schools have not yet prepared a fully-fledged contingency plan that has been subjected to rigorous testing. Implementation of existing plans is at best sporadic, which lowers the overall preparedness level (Özmen et al., 2015). However, the training and simulation activities have not been conducted regularly; therefore, school communities are currently less familiar with emergency response procedures (Kamaruddin, 2024; Rico, 2019). This aspect highlights the urgency to avert this condition by enhancing capacity rapidly, through continuous education and structured training programs, in order to be better prepared for disaster in schools (Kamaruddin, 2024).

In contrast, the levels of coordination among stakeholders in school-based disaster management are not well integrated. The best preparedness is possible only when the schools, government institution and society working collaboratively but at present until now it remains partial or fragmented actions (Ardiansyah et al., 2024). In the lack of emergency management system together, reaching out to crisis becomes difficult and inefficient. Likewise lack of structured communication and relationship between organizations can affect fast responses in disasters

(Curnin & Owen, 2020; Parkash, 2020). Building community-based disaster resilience requires multi stakeholder involvement. Within this scenario, organizations like scouting movement (Gerakan Pramuka) also have strategic potential to strengthen disaster education supported by their extensive networks. Studies on disaster education in schools demonstrate that it not only provides knowledge to students but also helps shape preparedness behavior and encourages them to become agents of change in their communities (Topno, 2021). In addition, the inclusion of disaster-related content into curricula, as well as regular conduct of simulation works, can effectively raise levels in preparedness (Roza et al., 2020). This is complemented by community engagement in collaborative learning-based programs (How et al., 2020).

As disasters have an extensive effect on education continuity, the demand for disaster-resilient school models is still urgently needs to be unfolded. Research from Pradana et al (2025) found that disaster education programs are well managed, which can have improved knowledge in the students by 78% The Sendai Framework for Disaster Risk Reduction stresses the need for disaster safe schools to prioritise community participation and sustainability (Laranjeiras & Ferrão, n.d.). But challenges still exist, such as poor alignment of programs with guidelines and policies, insufficient systemic or community-level engagement to provide program support (How et al., 2020). Taking these points into consideration, a model is needed that systematically and sustainably involves the different parties involved. The unique challenges of disaster preparedness make a collaborative pentahelix-based approach relevant, wherein government, academia, communities, the private sector and media can synergize their respective roles to establish a stronger disaster readiness mechanism. Thus, the collaborative pentahelix model is developed and it will help in achieving disaster-resilient schools by enhancing benefit regional resilience.

Method

This community service program was implemented using a Community-Based Research (CBR) approach. CBR is a service-oriented research method that positions the community as both the subject and an active partner throughout all stages of the process, from planning to evaluation. This approach emphasizes the importance of direct community participation in decision-making and program implementation, ensuring that the solutions generated are more contextual, relevant, and sustainable. Similar to Participatory Action Research (PAR), CBR promotes collaboration between researchers and the community in generating research-based social change. This paradigm also aims to empower communities to independently identify and address the challenges they face (Afandi et al., 2022). This program was designed among various stakeholders in a penta-helix collaborative context, the key stakeholders are; local government (through the Regional Disaster Management Agency/BPBD), academia, schools, community organizations (namely the Regional Scout Council *(Kwartir Daerah/Kwarda Gerakan Pramuka DIY))* and the private sector as supporting partners. The project team was an enabler supporting stakeholders at all levels in the programme, whereas the school community was the main participant in the implementation of the programme (teachers, pupils and scout instructors). A total of 50 participants were trained and involved in simulation sessions. This collaborative structure was intended to enhance the disaster preparedness capacity in a coherent and sustainable way. The implementation process was based on the CBR process model by Joanna Ochocka involving structured and participatory stages as problem identification, program planning, data collection, data analysis, interpretation and learning, implementation, evaluation and reflection. The problems were identified using focus group discussions (FGDs), observations, and interviews to evaluate the current preparedness scenario and key issues. This was followed by participatory program planning, which involved setting objectives, designing intervention strategies, distributing roles and responsibilities between stakeholders, and identifying resource requirements. Data collection was using surveys, observational assessments, and interviews to establish the baseline preparedness. Analysing the data collected by this method enabled a descriptive comparative analysis of gaps in practice as well as informed context-dependent interventions. The interpretation and learning stage involved

stakeholders reflecting together to transform findings into action strategies and shared community understanding. In the implementation phase, disaster preparedness training, simulations, and contingency planning procedures are implemented in coordination with penta-helix collaboration. The last stage, evaluation and reflection, was carried out, utilizing pre-test and post-test instruments to monitor changes in participants' knowledge and guided by a series of observational assessments during simulation activities and reflective dialogue with stakeholders. The evaluation findings were utilized to inform program improvement and sustain disaster preparedness implementation.

The implementation method followed the CBR model developed by Joanna Ochocka from the Center for Community-Based Research, which consists of several systematic and participatory stages as follows:

Figure 1. Flowchart of the CBR-Based Community Service Implementation Model in Strengthening Disaster-Resilient Schools

The figure shows the program implementation flow, which is organized into a structured process involving stakeholder involvement. Problem Identification: The first stage is performing problem identification through focus group discussions (FGDs), observation, and interviews to understand the phenomenon related to school disaster preparedness. The purpose of this stage is to carry out a thorough vulnerability, capacity and need mapping of the stakeholders. Program planning (includes setting program objectives, designing intervention strategies, allocating roles among stakeholders and establishing resource needs) Key activities are designed at this stage, including Disaster Preparedness Training, School Contingency Plan (SCP) creation, Evacuation simulations and preparation of disaster education media.

Stage 3: Data collection via surveys, observations of safety infrastructure, and interviews of teachers, students, and scout instructors. The collected data is utilized to evaluate the readiness

baseline and identify gaps that need to be addressed. Data analysis is the fourth step, where they process and interpret the data with the project team along with stakeholders. This research intends to identify priority issues and design context-specific interventions. Stage 5: Interpretation and learning: The results of the analysis are deliberated on with all stakeholders in order to provide program recommendations that can translate into real-world applications. The stage is also used to reflect about increasing common risks and how to mitigate together.

The sixth stage is the implementation of programs using a pentahelix collaboration method. Engagements include simulation training, actual practice of disaster preparedness i.e. Practice School Contingency Plan (SCP), mock evacuation procedures including the development and distribution of media information for Disaster Education When all are involved in these activities, we do with the engagement of the techniques from government and academic. Evaluation and reflection in the final stage: The aim is to help assess whether the program has been effective and how well it improves school readiness. Assessment is carried out via pre and post-test, observation of developmental simulations and reflective conversations with the stakeholders. Evaluation results inform program improvement and sustainability of future programming.

Result

Pre-test and Post-test Results

Table 1. Pre-test and Post-test Results of Disaster Preparedness Knowledge (n = 50)

Indicator	Pre-test	Post-test	Difference	Percentage Increase
Understanding of Disaster Concepts	60.1	83.5	+23.4	38.9%
Risk Identification Ability	57.3	80.2	+22.9	39.9%
Knowledge of Evacuation Procedures	55.8	82.1	+26.3	47.1%
Emergency Response Skills	58.9	79.8	+20.9	35.5%
Coordination and Communication Skills	59.4	81.0	+21.6	36.4%
Psychological Preparedness (Confidence Level)	57.6	82.0	+24.4	42.4%
Overall Mean Score	58.2	81.4	+23.2	39.9%

An assessment of the pre- and post-test in 50 participants was used to explore the effects of the intervention in enhancing knowledge of disaster preparedness. The test was deployed before and after the running of structured training sessions and simulation exercises to directly compare participants' cognitive gain. The results reflect a distinct and demonstrable increase of disaster preparedness knowledge from the intervention. In particular, the average pre-test score was 58.2, which increased to 81.4 for the post-test, which gave an absolute improvement of 23.2 points and an approximate 39.9% improvement.

This improvement represents a clear gain in participants' knowledge of the main concepts of disaster mitigation, including hazard identification, evacuation procedures, coordination mechanisms, and emergency response protocols. The increase was uniform across participants indicating that the learning was effective in providing both the base knowledge and applied skills.

Apart from the numerical enhancements, qualitative findings in training and simulation sessions corroborate these results, with participants being more comfortable with and more accurate in executing evacuation procedures and better coordinated to perform in simulated emergency situations. No inferential statistics, such as paired-sample t-test, were performed, but as compared, the size of the difference between pre- and post-test scores suggested a meaningful and practically significant change in learning.

A program evaluation would argue that the magnitude of the change is reasonable in order to demonstrate that the intervention works, especially for community-based disaster preparedness interventions. Moreover, as the observed behavioral changes appear to be in line with the quantitative improvements, thus validating the findings further. The pre-test and post-test results in combination show that participatory training and simulation-based learning are successfully integrated within the scope of the penta-helix collaborative system that allows improving disaster preparedness capacity. These results highlight the value of experiential and community-based approaches that enhance knowledge acquisition and operational preparation in disaster-prone settings.

Assistance Process Data

The community service program was organized in a graduated and organized way that followed the paradigm of a Community-Based Research (CBR) intervention for approximately three months. The intervention was a cluster of planned interventions, comprised of capacity building training, participatory planning meetings, and exercises. In total, four formal training sessions were organized, each lasting 2–3 hours in length, which consisted of thematic work on disaster risk awareness, hazard identification, evacuation procedures, contingency plans and inter-actor coordination. These sessions were conducted through a participatory learning mode, including lectures, group talks, and case-based problems to foster both theoretical and pragmatic understanding.

Alongside the training sessions, 2 complete simulation tasks were developed to measure the operational preparedness of respondents in handling emergency occurrences. These simulations were implemented in simulating actual disaster situations where participants exercise acquired knowledge in a controlled but dynamic scenario. They were simulated on evacuation drills, communications by stakeholders, and role-based coordination and thus gave opportunity for both individuals and collective response capability assessment. The program comprised 50 participants, which include *Kwartir Daerah* (Kwarda) members, scout leaders, and community representatives as core actors in the program implementation. Across all program activities, attendance rates were consistent and reached a level of approximately 90% per session average.

The extent of the engagement suggests significant institutional support and motivators of participants, both of which are key elements in designing community responses. The program not only achieved direct participation, but also expanded through partnership schools, via which the trained members shared knowledge and led simulation activities with teachers and students. Although these school-level actors were not part of the core sample (n = 50), they served as indirect beneficiaries, bringing disaster preparedness practices to community-level activities. Through this cascading model of knowledge transfer, the sustainability and scalability of the intervention have been improved. Operationally, the program faced a number of implementation

challenges.

This included: limited infrastructure capacity especially for simulating large-scale exercises, limited participants' time, due to overlapping institutional responsibilities, and a lack of initial coordination in the stakeholder's phase of the program execution. Variability in participants' baseline knowledge and preparedness levels forced adaptive facilitation approaches to ensure inclusive learning outcomes. To combat these limitations, the program implemented a series of dynamic measures including ad hoc scheduling of the various activities, in-depth iterations of coordination meetings for the actors of the penta-helix, and regular facilitation assistance from the project team. The relationship between coordination and stakeholder was improved as stakeholder engagement and accountability were reinforced through regular stakeholder consultation which in turn enhanced alignment with stakeholders in role and responsibility over time. With that in mind, coordination efficacy on implementation and participation improved with time.

The process of assistance provides an organized, participatory, and adaptive approach to implementation reflecting engagement, with engagement at an iterative and participatory level, a very high degree of stakeholder participation and learning cycle and teamwork. Meanwhile, the recognition of contextual and operational constraints offers valuable insights which will inform refinement of future interventions, particularly in resource allocation, institutional coordination, and scalability for programmes in disaster affected areas.

Pentahelix Synergy as the Foundation of Regional Resilience

Indonesia lies on the Pacific Ring of Fire, a centre point for three converging major active tectonic plates, making it one of the most disaster-prone countries in the world. Such a condition puts disaster mitigation as a fundamental need rather than just an option of the policy, especially in high risks areas like Special Region of Yogyakarta (DIY) (Pratama et al., 2024; Rahmat et al., 2024; BPBD DIY, 2021). The experience in managing the 2006 Yogyakarta earthquake which claimed more than 6,000 lives reminds us that disaster management needs to change from reactive to proactive preparedness through cross-sector collaboration (BPBD DIY, 2021). Here, this community service program applies a pentahelix collaboration model as a strategic approach to enhancing regional resilience. This model incorporates five key actors in producing a sustainable resilience ecosystem (government, academia, private sector, communities and media) (Pujiono Centre, 2022; Pratama et al., 2024). This strategy sees disaster management as a joint effort, where policy creation, scientific development, resource utilization, community involvement and knowledge sharing unite (Pujiono Centre, 2022; Nurdiansyah & Nurwati, 2025). Therefore, the theory of pentahelix in disaster mitigation is not only an effort to overcome the coordination of government bureaucracy but also efforts to equalize roles and awareness of all elements of society. The collaborative relationships among pentahelix actors in disaster mitigation are illustrated in Figure 2.

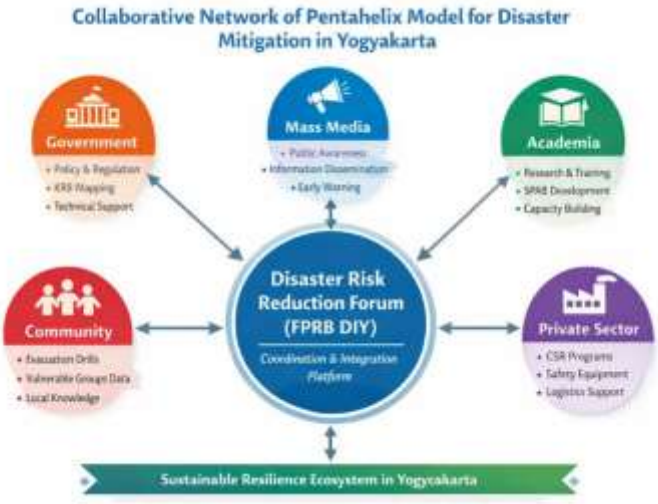

Figure 2. Collaborative Network of the Pentahelix Model for Disaster Mitigation in Yogyakarta

The diagram symbolizes the pentahelix collaborative network for disaster mitigation, which is centered around Disaster Risk Reduction Forum (FPRB) as one of the dominant nodes (central node) in the system. FPRB serves as an integrated platform that builds links between all actors in coordinated consortium. The network depicted in the above figure is a hub-and-spoke pattern, with all components directly linked to the central coordination point. The relationships connecting the elements are bi-directional, meaning that information, coordination and feedback is constantly exchanged between them. As such, the network is horizontal and interactive instead of hierarchical in nature. It also mirrors the systemic interdependency of the system: no element operates in isolation but rather as part of a self-reinforcing architecture. The establishment of this connectivity allows for processes to be interconnected through a single system from each stage of planning, implementation, and evaluation. This network structure builds a sustainable collaboration ecosystem, maximizing cross-sector coordination, and minimizing disaster risk management. The network also illustrates that the effectiveness of mitigations relies heavily on how well elements are connected and how much those connections are used. The figure ultimately conveys that the pentahelix is not only a multitude, rather it intends to be an active integrated collaborative network system focusing on sustainability.

Within the disaster management cycle, each actor plays a strategic and complementary role, as illustrated in Table 1.

Table 1. Contribution of Pentahelix Actors in Disaster Mitigation

Pentahelix Element	Strategic Contribution
Government	Policy formulation, disaster-prone area (KRB) mapping, and policy coordination
Academia	Scientific research, development of Disaster-Safe Education Units (SPAB), and capacity building
Private Sector	CSR support, logistics, and infrastructure
Community	Evacuation, vulnerable group data collection, and simulation activities

The roles of the actors in the pentahelix model as shown in Table 1 indicate a complementary division of responsibilities in collaborative disaster mitigation system. They are all interconnected in an integrated mechanism to achieve the goal of a successful disaster management, where no element works independent of each other. First and foremost, there is the part of regulatory and coordinative functions in case of use in the government sector. As for local

governments, it is their duty through related institutions such as the Regional Disaster Management Agency (BPBD) to formulate policies that include local regulations, contingency plans, and KRB mapping. Also, the government is an important factor in stakeholders' coordination process to maintain synergy, especially during emergencies. Therefore, this supports the government by providing mitigation documents for development and technical assistance on training and simulation activities as part of the community service.

On the other hand, academia acts as a supplier of knowledge and innovation. And they don't just conduct scientific studies on disaster risks, they're also involved in developing key concepts such as Disaster-Safe Education Units (SPAB) and implementing capacity-building programs. In this initiative, researchers serve as facilitators who impart knowledge to the school community through training in policies and evidence-informed mitigation tools. This function is pivotal in connecting the programs being rolled out to local contextual relevance and strong scientific roots. In the private sector, contributions are fundamentally supportive and strategic in nature, primarily addressing resource needs. The private sector Home can be part of CSR (Corporate Social Responsibility) programs, and it is possible to provide safety equipment for some infrastructure needs such as fire extinguishers, first aid kit, logistics support during emergencies etc. Moreover, this sector has important roles in advancing mitigation technologies including early warning systems based on digital means. While still relatively nascent, the promise of broader engagement by the private sector exists and should be developed in a more streamlined manner.

The community unit embodies a player with immediate contact to the populace and acts as the first line of implementation for disaster mitigation measures. In this context, community organisations like on the scouting movement (Gerakan Pramuka) become one of the active role in carrying out simulation evakuation in state schools, performing data vulnerable group collects and dissemination of disaster information inside school. It also cements a local wisdom perspective, which is an effective and critical aspect of disaster risk reduction. Active community engagement allows the clearly highlight that disaster risk mitigation do not only move from top to bottom but it also needs participatory approach from bottom to top. At the same time mass media is a communication channel that connects information from the government to the people and vice versa. Through news coverage, educational campaigns and the purchase of early warning information, the media has a more strategic role to play in raising public awareness around disaster risks. In the case of this community service program, while media is not directly involved on the field, it plays an important contribution in terms of reaching out to disaster education and developing it as a culture in society.

Given that the synergies at the pentahelix actor level can be seen more clearly in response to DRR, in the Special Region of Yogyakarta (DIY) there is a DRR Forum (FPRB) which is a cross-sectoral coordination platform facilitating DRR actors to formulate and implement mitigation action plans (Wardhani et al., 2024; Pramuka DIY, 2023). The FPRB allows for more committed and urgent engagement of relevant parties that can enable the mitigation programs to be constructed in a well-coordinated and demand-driven way within their community. Particularly, considering diverse and multi-dimensional nature of disaster risks in DIY—for example from the eruption of Mount Merapi in northern part to earthquake and tsunami hazard on southern coastal line—this exercise becomes even more important. In the absence of strong synergy, disaster response efforts fail and lead to a fragmented, uncoordinated, ineffectual initiative.

This community service result proves that the pentahelix model has created better and more integrated coordination among stakeholders, as well as developing working mechanisms in disaster mitigation that are more systematic. This is seen through enhanced engagement of stakeholders throughout the program, from planning to evaluation. Moreover, this partnership has yielded the construction of sustainable inter-institutional networks. These findings are consistent with various studies, which stress the importance of multi-actor collaboration for improving effectiveness in disaster risk reduction and building sustainable regional resilience resilience (Pratama et al., 2024; Nurdiansyah & Nurwati, 2025). As a consequence, the pentahelix model

could be conceived as having a strategic approach that is conceptually and syntactically specific to community-based disaster mitigation.

Implementation of SPAB through Strategic Collaboration in Community Service

Schools are strategic institutions in fostering a culture of disaster awareness, as they play a crucial role in shaping the knowledge, attitudes, and behaviors of younger generations. In this context, the Disaster-Safe Education Unit (SPAB) program serves as an essential instrument for integrating disaster mitigation into the education system. SPAB is built upon three main pillars: safe school facilities, school disaster management, and disaster risk reduction (DRR) education (PRB) (Oktavianto & Widodo, 2024; Pasaribu et al., 2025).

Figure 3. Implementation of Community Service Activities at the Regional Scout Council (Kwartir Daerah) of DIY

The implementation of this community service program demonstrates that the pentahelix approach is effective in accelerating the implementation of the School-Based Disaster Preparedness Program (SPAB) through synergy among internal and external school stakeholders. Academics play a role in providing training and technical assistance, the government contributes policy support and facilitation, while the Scout community acts as an agent of change by encouraging active student participation in mitigation activities. One of the main achievements of this program is the development of a School Contingency Plan (SCP) document, which serves as an operational guideline in responding to emergency situations. The preparation process was conducted in a participatory manner, involving teachers, students, and other stakeholders, ensuring that the resulting document is both contextual and practical.

In addition, the program resulted in the establishment of a school disaster response team, the development of evacuation Standard Operating Procedures (SOPs), and the implementation of regular simulation exercises. These simulation activities not only enhance technical skills but also build the psychological preparedness of the school community in facing disasters. Another innovation developed in this program is the implementation of the GEMA TANGGUH model, which integrates a technology-based early warning system with Psychological First Aid (PFA) training. This approach emphasizes not only physical preparedness but also mental readiness, which is often overlooked in disaster mitigation programs (Wijayanti et al., 2025; Rahmat et al., 2023).

Table 2. Implementation of SPAB Based on Pentahelix Collaboration

SPAB Component	Implementation
School Management	Establishment of a disaster response team and evacuation Standard Operating Procedures (SOPs)
Safe Facilities	Mapping of evacuation routes and designated assembly points
DRR Education *(Disaster Risk Reduction)*	Integration of disaster education materials and regular simulation exercises

The implementation of pentahelix collaboration based Disaster-Safe Education Unit (SPAB) in this community service program is promising, especially in three main features: school management aspect, safety facilities and disaster risk reduction (DRR) education. At the management level for schools, forming a disaster response team can be a tactical first step to creating an organized preparedness system. This team comprises of teachers, educational support staff and pupil representatives with defined roles and responsibilities in emergency situations. Second, the evacuation SOP (Standard Operating Procedures) was devised in inclusive processes of consultation with multiple stakeholders like Region Disaster Management Agency/ BPBD and local community. These SOPs include how to evacuate, where to carry out tasks, and ways of communications during an emergency as well as different situations that can arise from disasters. Presence of clear and standard SOPs makes crisis decision-making faster, more coordinated and free from errors.

The safe facilities component involved the activities with regards to mapping evacuation routes and identifying safe assembly points in school surroundings. This process was executed through an examination of the physical condition of the school, with particular attention to safety considerations and accessibility work. Evacuation routes were clearly marked such that they could easily be recognized by all members of the school community, and assembly points were placed in areas relatively safe from likely other risks secondary to the original event. While there are only limited interventions on aspects related to infrastructure due to budget constraints, this intervention is being undertaken as a key building block from which a more disaster-responsive school can be articulated. In the elements of disaster risk reduction (DRR) education it was implemented through integrating DRR materials on a variety of learning aspects and the conduct of community evacuation drills regularly. Disaster education was not only conducted in a theoretical manner but also planned by way of activities like earthquake response, fire evacuation drills and preparedness practices. It aims at developing a better moral understanding, and improve the psychological preparedness of students and teachers in case of emergencies.

More than one thousand educators were trained for the program, and evaluation results demonstrate substantial learning gains among school staff who participated in the initiative. Before this implementation, most participants had very little knowledge of disaster mitigation especially both concepts and technical terms. But following training sessions and simulation exercises, participants showed improvements in understanding evacuation procedures, identifying risks around them, and responding to emergency situations more methodically and cohesively. Such is not only evident in quantitative evaluation results such as pre-test and post-test scores, but also reflected behaviourally during simulations. Benefits such as improved response time, better accuracy when following evacuation routes, and stronger collaboration during a crisis. Participants also expressed greater confidence in disaster scenarios, signifying improved psychological preparedness.

Factor 2: Practice-based disaster education given at the community level (in-person or online) also has intrinsic merit in producing preparedness outcomes and this study's findings corroborates that of Tang et al.(2017), Ekmekci et al.,(2020) and Doran et al.(2024). The approach of experiential learning in disaster education can effectively convert knowledge into skills applicable to emergencies. With that, SPAB implementation based on pentahelix collaboration not

only increase individual capacity but also the school preparedness system overall. This indicates how important it is that managerial, structural and educational aspects are integrated in the process of building sustainable schools disaster-resilient until 2030.

Structural Challenges and Strategies for Strengthening Sustainable Mitigation

Although the implementation of the program has demonstrated positive outcomes, this community service initiative also identifies several challenges that need to be addressed to ensure its sustainability. One of the main constraints is limited funding, particularly in strengthening the school's physical infrastructure, such as evacuation routes, fire extinguishing equipment, and early warning systems. This condition indicates an imbalance between the enhancement of educational aspects and structural components. In addition, there are still challenges in cross-sectoral coordination, primarily caused by bureaucratic fragmentation and sectoral ego. This situation results in suboptimal program synchronization and the potential overlap of policies among institutions (Nasrun, 2024; Pujiono Centre, 2022). Another equally important issue is program sustainability. Without a structured monitoring and evaluation mechanism, there is a risk that the implemented program cannot be maintained in the long term. To address these challenges, a comprehensive strengthening strategy is required, including:

1. Strengthening regional regulations, including the development of policies that support disaster-resilient schools (BPBD DIY, 2025)
2. Optimizing the Merdeka Curriculum, through the integration of disaster education into the *Projek Penguatan Profil Pelajar Pancasila (P5)*.
3. Digitalizing mitigation systems, such as the development of IoT-based early warning systems.
4. Strengthening the institutional role of FPRB (Disaster Risk Reduction Forum), as a platform for coordination and continuous evaluation (Haksama et al., 2022; Arifiyanti & Millensyah, 2026).

These strategies are aligned with the **Sendai Framework for Disaster Risk Reduction,** which emphasizes the importance of multi-actor collaboration, strengthening local capacity, and ensuring program sustainability (How et al., 2020). Overall, strengthening pentahelix synergy not only enhances school preparedness but also ensures that investments in the education sector and community protection are sustained even in the face of disasters. The integration of local wisdom with modern approaches also serves as a crucial factor in building an adaptive and sustainable disaster mitigation culture (Rahmat et al., 2023; Setyaningrum et al., 2024). Comprehensively, the results of this community service demonstrate that the pentahelix approach based on Community-Based Research (CBR) is effective in improving preparedness, strengthening cross-sector collaboration, and developing a sustainable disaster mitigation system. This model is not only conceptually relevant but also proven to be implementable and adaptive to local contexts, thereby holding strong potential for replication in other regions with similar risk characteristics.

Discussion

Pentahelix Synergy as the Foundation of Regional Resilience

The findings of this community service initiative demonstrate that the implementation of a pentahelix-based collaborative model significantly contributes to strengthening disaster preparedness and regional resilience. In the context of the Special Region of Yogyakarta, which is highly vulnerable to multi-hazard risks, the shift from a reactive to a proactive and collaborative disaster management paradigm becomes increasingly essential. The results confirm that disaster

mitigation is not solely dependent on government intervention but requires the integration of multiple stakeholders in a systemic and sustained manner (Pratama et al., 2024; Nurdiansyah & Nurwati, 2025). The pentahelix model, as implemented in this study, demonstrates strong relevance in addressing the issue of fragmented governance often found in disaster management. The establishment of the Disaster Risk Reduction Forum (FPRB) as a central coordination node reflects a shift toward a more networked governance model, characterized by horizontal and interactive relationships among actors. This finding aligns with previous studies that emphasize the importance of collaborative governance in enhancing policy effectiveness and institutional coordination (Pujiono Centre, 2022; Wardhani et al., 2024). The hub-and-spoke network structure identified in this study further indicates that effective disaster mitigation relies not only on the presence of actors but also on the quality of their interactions and the intensity of coordination.

In the educational context, the implementation of the Disaster-Safe Education Unit (SPAB) highlights the strategic role of schools as agents of change in fostering a culture of disaster awareness. The integration of disaster risk reduction (DRR) into school systems through training, simulations, and contingency planning has proven effective in improving both technical capacity and psychological preparedness. These findings are consistent with prior research indicating that experiential learning approaches, such as simulations and drills, significantly enhance disaster preparedness at the individual and institutional levels (Roza et al., 2020; Pradana et al., 2025). Moreover, the development of the School Contingency Plan (SCP) and evacuation SOPs reflects the importance of structured and context-based preparedness mechanisms. Despite these achievements, several structural challenges remain evident. Limited financial resources constrain the development of disaster-resilient infrastructure, indicating a gap between capacity-building efforts and physical preparedness. Additionally, bureaucratic fragmentation and sectoral ego continue to hinder optimal cross-sector coordination, as also noted by Nasrun (2024) and Pujiono Centre (2022). These challenges highlight the need for stronger institutional frameworks and regulatory support to ensure the sustainability of mitigation programs. The absence of systematic monitoring and evaluation mechanisms further risks reducing the long-term effectiveness of the initiatives.

To address these limitations, this study underscores the importance of strengthening policy frameworks, optimizing educational integration through the Merdeka Curriculum, and leveraging digital technologies such as IoT-based early warning systems. These strategies are in line with the principles of the Sendai Framework for Disaster Risk Reduction, which emphasizes multi-stakeholder collaboration, capacity building, and sustainability (How et al., 2020). Furthermore, the integration of local wisdom with modern technological approaches emerges as a critical factor in ensuring the adaptability and contextual relevance of disaster mitigation strategies (Rahmat et al., 2023; Setyaningrum et al., 2024). Overall, this study confirms that the pentahelix approach, when combined with a Community-Based Research (CBR) framework, provides a robust and adaptive model for disaster mitigation. It not only enhances preparedness at the school and community levels but also fosters a sustainable collaborative ecosystem that can be replicated in other disaster-prone regions with similar characteristics.

And yet, despite these contributions, there are various limitations associated with the present study that justify consideration. First, the study was designed and carried out in a single regional context, the Special Region of Yogyakarta, which has more specific socio-institutional features, disaster characteristics as well as governance structures. This is a relevant context to focus on multi-hazard risk and collaborative mitigation, but it limits the external validity and generalizability of these findings to other regions with different levels of capacity for institutional response, resource availability, and stakeholders. Consequently, we need to conduct comparative research within various regions or provinces to evaluate the transferability and relevance of the pentahelix model in different contexts. Second, the intervention focused on capacity building, information transfer, and coordination enhancement with relatively little consideration of physical and infrastructural level of preparedness. While these non-structural supports are crucial to

increase awareness and facilitate organizational preparedness, disaster resilience is also highly contingent on access to and availability of infrastructure, including evacuation routes, early warning systems, and emergency facilities.

However, the study's lack of major infrastructure-related interventions indicates a partial level of coverage in the various dimensions of the disaster preparedness concept and a need for more integrative strategies combining both structural and non-structural approaches. Third, the evaluation design was executed within a short amount of time, and immediately assessed learning outcomes through pre-test and post-test, measuring immediate learning outcomes. Although these are effective measures of short-term cognitive gains, they cannot address long-term retention, behaviors, and sustained institutional impacts. Not having longitudinal follow-up data limits the ability to ascertain whether the observed improvements in knowledge and skills translate into long-term readiness. Thus, future research (and beyond) should incorporate longitudinal evaluation designs incorporating: delayed post-tests, repeated simulations, and tracking real-world response performance. Moreover, the study employed a small sample (n = 50), which was appropriate for community interventions, but may limit the statistical generalizability of the results. The analysis was also predominantly descriptive comparison making inferential statistical tests less available in order to detect statistical significance. However, it is recommended for the future studies to use bigger samples and more controlled analytic techniques to improve the empirical validity. The second limitation relates to the extent of stakeholder engagement in the implementation phase. The extent of direct involvement of the private sector and media actors during the implementation phase has yet to be determined.

As a result, although these actors were included as a theoretical component of the pentahelix framework, their effective contribution was less than that of government, academia, and community actors. An active involvement of all components of pentahelix must be improved to attain a more balanced and harmonized collaborative model. Considering all of these limitations, it is recommended for future research to focus on: (1) regional scale research through multi-centre or comparison studies; (2) linking infrastructure development to capacity building; (3) use longitudinal and mixed methods evaluation frameworks; and (4) to enhance the inclusiveness and operational involvement of all pentahelix parties. These approaches would help advance further comprehension of the efficacy, and the long-term sustainability, of disaster mitigation. In conclusion, this study validates the pentahelix approach is a strong and adaptable model for disaster response when integrated with a Community-Based Research (CBR) framework. And not only does it increase preparedness through the school and community level, but we also set the stage for a sustainable collaborative ecosystem with an underlying culture of shared responsibility, the cycle of learning, and collaborative action. Limitations of context notwithstanding, the model is highly promising for replication and flexibility across other disaster-prone zones showing similar outcomes, again for increased institutional arrangements and long-term assessment procedures.

Conclusion

The implementation of the pentahelix collaboration model underpinned by the Community-Based Research (CBR) approach is proving to be effective in solidifying disaster preparedness and regional resilience, especially in education. Indonesia’s high susceptibility to natural disasters can no longer be addressed with only a reactive disaster management, but needs to move to an approach which is proactive, collaborative, and multi-stakeholder. The pentahelix model maximizes the roles of five actors—government, academia, private enterprise, communities, and media—in constructing a cooperative and sustainable disaster prevention framework. This has enhanced stakeholder collaboration, increased program integration, and fostered the creation of community-based resilience ecosystems. Notably the program successfully accomplished its purpose of increasing disaster preparedness capacity as demonstrated by the pre-test and post-test evaluation results. The results show a 39.9% gain in knowledge of subjects and

a mean score increase from 58.2 to 81.4 in 50 subjects engaged in training and simulation. Beside cognitive gains, all the enrolled groups were offered the opportunity to develop and implement the main preparedness tools (School Contingency Plans (SCPs), evacuation Standard Operating Procedures (SOPs), and disaster response teams) together.

These effects result not only in increased personal knowledge and skill sets, but also in the institutional readiness and organisation and coordination of capacity building. In this context, implementation of the Disaster-Safe Education Unit (SPAB) program marks another step forward in the implementation of disaster risk reduction in education systems. Training and simulation exercises as well as contingency planning are combined to form the basis for measurable improvements in preparedness awareness, technical competences, and capacity for collaborative response. But there are still challenges, especially when it comes to the sustainability of the program. These are; limited monetary resources, disjointed coordination between sectors and lack of formal monitoring and evaluation practices. Strategically, these limitations should be addressed through enhancing regulatory structures (e.g., disaster education systems incorporated across regional curricula), leveraging new and emerging digital technologies (the introduction of IoT-based early warning systems, etc.), and building on existing institutional frameworks like Disaster Risk Reduction Forum (FPRB). In summary, the pentahelix model can provide both theoretical basis and empirical applications for the promotion of disaster preparedness and regional resilience. This model has a strong potential for replication within other disaster-prone areas with similar characteristics, given tailored responses to local contexts and persistent institutional support.

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Conflicts of Interest statement

The authors declare no conflict of interest.

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