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Participatory Geographic Information System Mapping for Strengthening Village Disaster Resilience: A Participatory Action Research Study

Sunarto[1*], Heru Santoso Wahito Nugroho[1], Sulikah[1], Suparji[1], Aries Prasetyo[2]

[1] Department of Midwifery, Poltekkes Kemenkes Surabaya, Surabaya, Indonesia
[2] Department of Environmental Health, Poltekkes Kemenkes Surabaya, Surabaya, Indonesia

*Correspondence: sunartoyahyamuqaffi@gmail.com

ABSTRACT

This study evaluated the implementation of an integrated framework combining the Quadrant of Difficulty–Usefulness Village Resilience (QoDU-VR), Participatory Action Research (PAR), and Geographic Information System (GIS) to strengthen community capacity in disaster mapping and to support village resilience assessment in Sumbersawit Village, Magetan Regency, Indonesia. Disaster risk mapping was prioritized on the basis of the QoDU-VR analysis because its usefulness was very high, although its implementation was very difficult. The study used a longitudinal PAR design through cycles of implementation, observation, and reflection. A total of 64 participants were purposively selected, consisting of village officials, community leaders, community protection units (Linmas), health cadres, youth organizations, neighborhood (RT/RW) heads, and disaster volunteers. The mapping covered hazards, vulnerabilities, capacities, disaster risk maps based on the integration of hazard, vulnerability, and capacity scores, as well as evacuation routes and final evacuation sites. Spatial information was validated through GIS, field verification, historical data, and available spatial data. Mapping competencies and self-reflection were assessed using six indicators, namely risk concepts and formulas (4 items), hazard mapping (4 items), vulnerability mapping (4 items), capacity mapping (3 items), evacuation routes and sites (4 items), and risk map utilization (6 items), arranged in a 25-item questionnaire. Each item was rated on a five-point scale, giving component score ranges of 3–15, 4–20, and 6–30 for the 3-, 4-, and 6-item components, respectively. The content validity index (I-CVI/Ave) was 0.96 for the observation instrument and 0.95 for the reflection instrument. The village resilience score increased from 39.45 to 79.22, with the category changing from Pratama (Primary) to Madya (Middle). Participants' mapping competencies improved across the PAR cycles, consistent with the self-reflection results, while the spatial products developed from initial identification into more detailed risk maps. The high whirlwind hazard zone covers approximately 22% (about 1.1 km²) of the 5.00 km² village area and is concentrated in RT 006–009, RW 002, while the remaining 78% is classified as moderate hazard. The implementation of QoDU-VR–PAR–PGIS was accompanied by improvements in mapping competency, spatial information, and village resilience assessment scores. These findings support the use of the framework to translate mitigation priorities into validated spatial information for disaster preparedness and management planning in disaster-resilient villages.

Keywords: Disaster risk mapping; Participatory Action Research; Participatory GIS; QoDU-VR; Village resilience

INTRODUCTION

Hydrometeorological disasters such as floods, flash floods, landslides, and strong winds pose increasingly complex risks to communities in rural areas. The impact of a disaster is determined not only by the magnitude of the physical threat (hazard), but also by the level of exposure, socio-economic vulnerability, and the community's capacity to respond to the crisis (Ramadhan et al., 2026). Within the Community-Based Disaster Risk Reduction (CBDRR) framework, the availability of spatially based risk information, such as maps of hazard distribution, vulnerable groups, local capacity availability, and temporary (TES) and final (TEA) evacuation routes and locations, is a crucial component underpinning mitigation and preparedness planning (Ravazzoli et al., 2025). An integrated approach combining Participatory Action Research (PAR) and Participatory Geographic Information System (PGIS) ideally complement each other to facilitate knowledge co-production (Salman & Ramsis, 2025). Through this integration, communities are no longer

merely passive objects or data sources but become active actors in identifying, verifying, and making disaster risk reduction decisions based on their local knowledge (Muyambo et al., 2025; Vasileiou et al., 2022).

However, in reality, technocratically developed Geographic Information System (GIS)-based risk mapping often ignores the dynamics and local knowledge of the community. Furthermore, current participatory mapping often stops at the production of maps (maps as the final/symbolic product) without ensuring that the information is understood, verified, or used effectively by the community and disaster response communities (Nefros et al., 2022). A key gap in current literature and practice is the limited integration of village resilience priority-setting mechanisms, participatory action learning (PAR) cycles, and spatial information (GIS) validation within a series of continuous interventions. This gap is clearly visible in Sumbersawit Village, Magetan Regency (with the status of a Primary Disaster Resilient Village), where, based on the Quadrant of Difficulty–Usefulness Village Resilience (QoDU-VR) assessment, risk mapping is considered to have very high benefits but is relatively difficult to implement. The fundamental problem in the field is not merely the absence of map documents, but rather the community's limited functional capacity to recognize, interpret, verify, and utilize spatial risk information for community action in disaster management (Akbar et al., 2021).

This issue urgently needs to be addressed because, if the gap remains, the documents and risk maps created will become passive administrative artifacts that will be ineffective when a disaster occurs. Consequently, when a hydrometeorological disaster strikes, village disaster preparedness teams will be confused, evacuation routes will be inaccessible, and communities will fail to conduct timely self-evacuation, ultimately increasing the potential for loss of life and massive socio-economic losses (Aeni & Khoirul Anwar, 2024; Ruslanjari et al., 2023). Conversely, addressing this issue will provide significant theoretical and practical benefits: communities can build their capacity for self-response based on local knowledge, while village governments will gain an evidence-based framework for sustainably integrating spatial information into village development planning and budgeting documents (RPJMDesa).

To address these issues, this study offers a sequential and iterative integrated solution that combines the QoDU-VR instrument (for prioritizing village resilience indicators in terms of usefulness and difficulties) (Sunarto et al., 2026), the PAR cycle (identification, planning, action, observation, and reflection)(Salman & Ramsis, 2025; Soedarwo et al., 2022), and PGIS (for analysis, visualization, and validation of spatial data) (Anggara et al., 2025; Yu et al., 2020). The novelty of this study lies in positioning mapping not as a static physical product, but as a continuous learning and action process that carries QoDU-VR priorities into the PAR cycle and PGIS mapping at the village level. The resulting contribution is not only in the form of a spatially accurate Village Disaster Risk Map derived from the integration of threat, vulnerability, and capacity assessments, but also in increasing the functional competence of participants in mapping and transforming the status of village resilience (Hutagalung, 2023; Maffi et al., 2026).

Based on this framework, this study aims to evaluate the implementation of the integrated approach of QoDU-VR, PAR, and PGIS in improving community competency in disaster risk mapping and in documenting changes in the resilience status assessment in Sumbersawit Village, Magetan Regency. Specifically, this study examines the level of change in participant competency in the participatory mapping process, the development of the quality of spatial risk information through the PAR stages, participant self-reflection (self-assessment) regarding the increase in understanding and independent confidence in risk mapping, and changes in the status of village resilience assessment after a series of interventions.

METHODS

The study used a longitudinal one-group Participatory Action Research (PAR) design to develop and validate village disaster risk maps. The study was conducted from April to July 2026 in Sumbersawit Village, Sidorejo District, Magetan Regency, East Java. Each PAR cycle consisted of needs identification, planning, implementation, observation, and reflection (Costello, 2016; McNiff & Whitehead, 2016). The same participants were involved in each cycle to ensure continuity of the process and iterative refinement of the maps. The study was oriented towards implementation, not a controlled intervention trial; therefore, changes in village competency and resilience are interpreted as changes during the implementation process and not as estimates of causal effects.

A total of 64 participants were purposively selected based on their involvement in the village disaster risk reduction forum. Participants included representatives from village officials, community leaders, community security officers (Linmas), health cadres, youth organizations, neighborhood association (RT/RW) heads, and disaster volunteers. Inclusion criteria included members of the forum and village disaster preparedness team who were actively involved in disaster risk reduction and emergency response activities, willing to participate in participatory mapping, and participating in the entire PAR series. Participants acted as co-researchers in identification, mapping, verification, and reflection, while the researcher acted as a facilitator and provided GIS technical support.

Each PAR cycle consists of the following stages: needs identification, planning, action, observation, and reflection. The needs identification stage is conducted using the Quadrant of Difficulty–Usefulness Village Resilience (QoDU-VR) approach, which indicates that disaster risk mapping is a priority need with a high level of implementation difficulty and a high level of utility. The planning stage includes determining the elements to be mapped, data sources, role allocation, data collection and verification methods, and GIS processing techniques. In

the action stage, participants carry out disaster risk mapping based on local knowledge and field observations according to an agreed schedule. The observation stage includes assessing participant capabilities, reviewing mapping results, assessing village resilience, and conducting field verification. Next, the reflection stage is conducted to identify deficiencies, evaluate results, and determine needs for improvement in the next cycle. The PAR cycle is repeated iteratively until a complete disaster risk map is obtained, validated in a participatory manner, and usable to support disaster preparedness and management planning at the village level.

Spatial data were processed using GIS through input, georeferencing, digitization, attribute classification, integration, overlay, field verification, and map production. The coordinate system used was WGS 84/UTM Zone 49S. Data included village and neighborhood unit boundaries, high-resolution satellite imagery at a scale of 1:5,000, digital elevation data, relevant national hazard datasets, and field observations (Viana et al., 2023). Risk was calculated using the equation Risk = (Hazard × Vulnerability)/Capacity and classified into low, medium, and high based on predetermined intervals (BNPB, 2012). The results of community mapping were compared and verified through consultation with participants, secondary administrative data, and field observations. The final product was a map of threats, vulnerabilities, capacities, risks, evacuation routes, and evacuation sites.

Mapping competencies and self-reflection were measured using a 25-item instrument covering indicators of risk concepts and formulas (4 items), hazard mapping (4), vulnerability (4), capacity (3), evacuation routes and locations (4), and risk map utilization (6). Each item was rated on a five-point scale (1–5), so component scores ranged from 3–15 for the 3-item component, 4–20 for the 4-item components, and 6–30 for the 6-item component. Content validity involved 10 experts in the fields of disaster management, GIS, environmental health, and community empowerment, with an I-CVI/Ave of 0.96 for the observation instrument and 0.95 for the reflection instrument. The pilot test produced a Cronbach's alpha of 0.89 (Mokkink et al., 2025; Polit et al., 2007; Roebianto et al., 2023).

In each PAR cycle, data were collected through direct observation, self-assessment in the form of reflection, and disaster risk mapping. Observation data were obtained through structured observation of participants' abilities in completing activities, conducted by enumerators using a structured checklist. Reflection data were obtained through a structured questionnaire completed at the end of each cycle to identify successes, obstacles, discrepancies, and needs for improvement in the next cycle. Mapping data were obtained through participatory mapping based on local knowledge, field observations, determination of points or boundaries of areas, and collection of supporting data from administrative sources and available spatial datasets. All mapping information was then integrated and processed using GIS, while the accuracy of locations, attributes, and completeness of information were verified with participants through consultation meetings, participatory discussions, and field inspections.

Participants' competency scores were analyzed descriptively in each cycle. A further cycle was conducted until most participants reached the capable threshold for competency and reflection scores, namely 11 for the 3-item component, 14 for the 4-item components, and 21 for the 6-item component (approximately 70% of the maximum component score). Data distribution was examined using the Shapiro–Wilk test, while changes in scores between cycles were analyzed using the Friedman test (J. Liu & Xu, 2022; Yang & Berdine, 2021). Village resilience scores were analyzed descriptively because they are institutional-level assessments. Spatial data were analyzed descriptively based on the completeness of elements, the suitability of field verification results, the integration of threat, vulnerability, and capacity scores, and the completeness of evacuation routes and locations. Mapping results are presented as thematic maps.

RESULTS AND DISCUSSION

Initial Needs Identification

The Quadrant of Difficulty-Usefulness Village Resilience (QoDU-VR) matrix analysis was used to map the priorities of Disaster Risk Reduction (DRR) interventions in Sumbersawit Village based on two main evaluation axes, namely the level of implementation difficulty (difficulty; value range 0.0 to −10.0) and the level of program usefulness (usefulness; value range 0.0 to 10.0). Mapping the position of these DRR indicators provides a comprehensive picture of action priorities in building sustainable community preparedness (Mawarti et al., 2026; Nugroho et al., 2020; Sunarto et al., 2024).

The Quadrant of Difficulty-Usefulness Village Resilience (QoDU-VR) matrix analysis in the initial stage identified priority Disaster Risk Reduction (DRR) interventions in Sumbersawit Village based on their level of difficulty and usefulness. The programs in Quadrant I (Priorities I) includes the preparation of Disaster Risk Maps and Evacuation Route and Location Maps, which are considered highly useful as emergency navigation instruments despite their high technical difficulty. Technical obstacles in Quadrant I were addressed through PAR and PGIS assistance. Meanwhile, Quadrant III (Priorities III) contains quick wins in the form of strengthening Early Warning Access and Mitigation Participation that are highly useful and easy for the community to execute independently. Windbreak Vegetation Strengthening activities occupy Quadrant IV (Priorities IV) with the lowest level of difficulty but with long-term impacts. The absence of indicators in Quadrant II (Low Usefulness, High Difficulty) indicates that all DRR programs designed with residents have practical utility (Nugroho et al., 2020) (Figure 1).

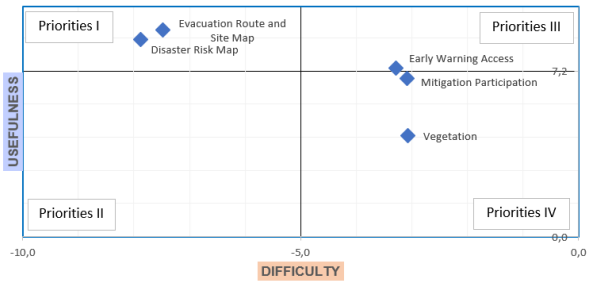


Figure 1. Difficulty–Usefulness Quadrant Matrix (QoDU-VR) of Mitigation and Preparedness Components in Sumbersawit Disaster-Resilient Village, Sidorejo District, Magetan Regency

The QoDU-VR analysis results indicate that DRR priorities in Sumbersawit Village are determined not only by their level of usefulness but also by the difficulty of their implementation. The Disaster Risk Map and Evacuation Route and Location Map fall into Quadrant I, indicating very high benefits but requiring more complex technical capabilities and collaborative processes. This finding reinforces the community-based disaster risk reduction and PGIS approaches, which position the community as actors in the identification, validation, and utilization of risk information. In this study, PAR serves as a learning mechanism that allows technical mapping barriers to be gradually overcome through a process of action, observation, and reflection (Moktan et al., 2026).

The presence of Early Warning Access and Mitigation Participation in Quadrant III indicates relatively easy-to-implement quick wins that still have high benefits, while strengthening windbreak vegetation in Quadrant IV indicates opportunities for simple interventions with long-term benefits. This pattern suggests that DRR strategies do not have to start with the most complex interventions, but can combine immediately feasible actions with interventions that require technical assistance (McAdoo et al., 2026). The absence of indicators in Quadrant II also indicates that participatory programs have practical relevance to community needs. Accordingly, QoDU-VR can be developed as a prioritization method that bridges resilience assessment with action planning, as it not only identifies DRR needs but also identifies interventions that require greater support and those that can be implemented immediately and independently (Dimitrova & Snair, 2024).

More broadly, the integration of QoDU-VR with PAR provides methodological and theoretical implications for the development of community-based DRR. Methodologically, QoDU-VR expands resilience assessment from measuring village conditions or capacities to a decision-making process regarding the sequence and strategy of interventions. Theoretically, these findings support the understanding that village resilience is an adaptive process formed through the interaction between intervention benefits, local capacity, level of difficulty, and collective learning. Thus, resilience status is understood not only as a final achievement, but also as a community's ability to select, implement, evaluate, and refine DRR actions according to its context (Nurmala et al., 2023).

Future research should test QoDU-VR in villages with varying risk and capacity characteristics and evaluate the longitudinal sustainability of intervention outcomes. Further development could include cost, time, resource requirements, inclusiveness of vulnerable groups, and institutional support as additional dimensions. A limitation of this study is that the difficulty and usefulness assessments were based on participant perceptions and local context, so the quadrant results are more appropriately understood as a contextual prioritization tool, rather than an absolute measure of program effectiveness.

Observation Results

Village Resilience Category

The series of participatory interventions was accompanied by a substantial improvement in the institutional resilience of Sumbersawit Village as a disaster-resilient village. The Sumbersawit Village Resilience Index more than doubled, from an initial score of 39.45 to 79.22 in the final assessment, raising the village's resilience category from Pratama (Primary) to Madya (Middle). The largest increases occurred in the Emergency Preparedness component, which increased from 0.10 to 0.80, and the Prevention and Mitigation component, which increased from 0.27 to 0.87. The Recovery Preparedness component also increased from 0.20 to 0.70, Disaster Management Regulations and Policies increased from 0.72 to 0.88, while Basic Services increased slightly from 0.69 to 0.71 (Table 1).

Table 1. Results of the Resilience Assessment of Sumbersawit Village before and after Disaster Risk Mapping Assistance

No	Resilience Component	Component Index		Village Resilience Index		Village Resilience Level	
		Initial	Final	Initial	Final	Initial	Final
1	Basic Services	0.69	0.71	39.45	79.22	Primary	Middle
2	Disaster Management Regulations and Policies	0.72	0.88				
3	Prevention and Mitigation	0.27	0.87				
4	Emergency Preparedness	0.10	0.80				
5	Recovery Preparedness	0.20	0.70				

The improvement in the Sumbersawit Village Resilience Index demonstrates that participatory interventions not only resulted in improved scores but also strengthened the village's institutional capacity to face, respond to, and recover from disaster risks. The largest improvements in Emergency Preparedness and Prevention and Mitigation demonstrate that the participatory process transformed previously relatively limited capacity into a

more structured preparedness mechanism. Therefore, the change in status from Primary to Middle can be understood as an indication that the village is beginning to move from administrative resilience to a more operational and adaptive capacity (Ahmadi et al., 2024).

Resilient village development requires maintaining intervention outcomes as a sustainable resilience system, not simply achieving scores during evaluations. Risk maps, evacuation routes and locations, early warning mechanisms, institutional capacity, and mitigation practices need to be integrated into village planning and budgeting to ensure they remain functional when risks change or management changes occur. The improvement in Recovery Preparedness also demonstrates the importance of strengthening village capacity not only to respond to events but also to restore social functions, basic services, infrastructure, the environment, and community life after a disaster (Horn et al., 2026).

Thus, these findings indicate that village resilience should be viewed as a dynamic process that is continuously built through learning, institutions, participation, and adaptation, rather than as a fixed status (Widianingsih et al., 2024). Sumbersawit's success in reaching the Middle level serves as a starting point for strengthening sustainable resilience toward a more independent and adaptive capacity, particularly through strengthening DRR institutions, regularly updating risk maps, preparedness exercises, empowering vulnerable groups, and post-event evaluation and learning. With this approach, improvements in the index can be translated into the village's actual ability to absorb impacts, respond effectively, adapt to changing risks, and recover quickly without losing key community functions.

Descriptive Analysis of Participants' Mapping Competency

Based on data on the development of participants' average competency scores across the six disaster risk mapping indicators, a consistent and gradual increase in capability was observed from Cycle I to Cycle III. The "capable" category is defined as meeting or exceeding the minimum score threshold for each indicator (dashed line in Figure 2).

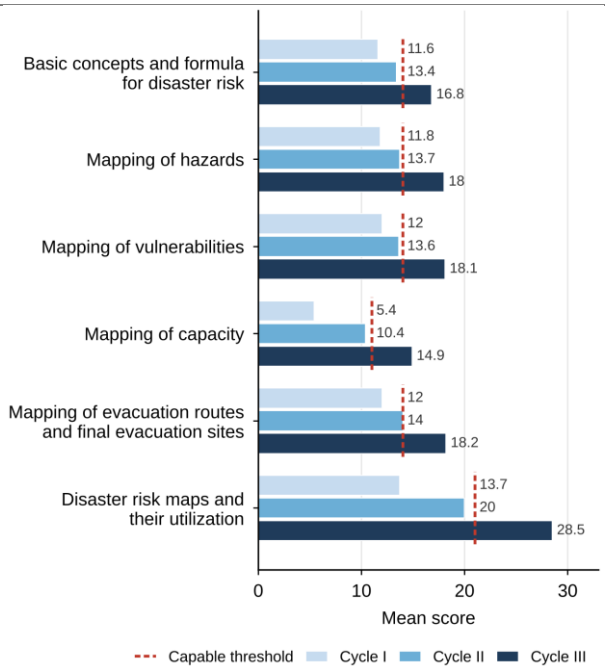


Figure 2. Development of Participants' Observed Competency Scores in Disaster Risk Mapping across Cycles

In line with the strengthening of village institutions, community competency in disaster risk mapping improved substantially. All participant competency indicators in Cycle I fell below the threshold for the capable category, with the lowest score being in capacity mapping. Entering Cycle II, participant competency increased gradually, and evacuation route mapping reached the passing threshold. In Cycle III, all competency indicators (100%) exceeded the minimum threshold for the capable category, with the highest achievement being in disaster risk mapping and utilization (Figure 2).

Inferential Analysis of Participants' Mapping Competency

Normality Test (Shapiro–Wilk Test)

Normality testing using the Shapiro–Wilk test on 64 respondents showed that the majority of data on the development of participant competency scores in the six components of disaster risk mapping across the three observation cycles were not normally distributed ($p < 0.05$). This departure from normality was reflected in the significance values that were consistently below the threshold of 0.05 for most indicators, such as capacity mapping, evacuation routes, and risk map utilization ($p < 0.001$). Because the assumptions of parametric tests were not met, differences between repeated measurements were analyzed using the non-parametric Friedman test (Table 2).

Table 2. Results of the Shapiro–Wilk Normality Test on Participants' Disaster Risk Mapping Competency Scores

No	Component	Cycle I		Cycle II		Cycle III	
		W	*p*	*W*	*p*	*W*	*p*
1	Basic concepts and formulas for disaster risk	.958	.029	.957	.027	.932	.002
2	Mapping of hazards	.950	.011	.970	.124	.821	<.001
3	Mapping of vulnerabilities	.959	.032	.966	.079	.816	<.001
4	Mapping of capacity	.662	<.001	.826	<.001	.135	<.001
5	Mapping of evacuation routes and final evacuation sites	.943	.005	.942	.005	.766	<.001
6	Disaster risk maps and their utilization	.713	<.001	.815	<.001	.750	<.001

Note: *W* = Shapiro–Wilk statistic; df = 64 for all tests. Most distributions deviated from normality ($p < 0.05$).

Repeated-Measures Comparison (Friedman Test)

The Friedman test yielded $\chi^2 = 810.480$ (df = 17; $p < 0.001$), leading to rejection of the null hypothesis (H_0). This result indicates a statistically significant difference in the level of disaster risk mapping competency of participants between intervention cycles. Substantively, the consistent increase shows that participants' understanding of disaster risk mapping improved from cycle to cycle during the implementation of PAR and PGIS (Table 3).

Table 3. Results of the Friedman Test on Participants' Disaster Risk Mapping Competency across Cycles

Statistic	Value
N	64
Chi-square (χ^2)	810.480
df	17
Asymp. Sig. (*p*)	<0.001

The improvement in disaster risk mapping competency from Cycle I to Cycle III suggests that PAR combined with PGIS can gradually build community capacity. This finding aligns with previous research showing that participatory mapping not only produces spatial information but also enhances community capacity to recognize hazards, vulnerabilities, capacities, and evacuation needs (Maffi et al., 2026). Direct community involvement in data collection, interpretation, validation, and utilization of spatial data makes the learning process more contextual than approaches that only provide theoretical material. The results of this study reinforce these findings by demonstrating that competency can develop cumulatively when the learning process is carried out through repeated cycles of action, observation, reflection, and improvement (Palinkas et al., 2025).

This improvement was influenced by several interrelated factors, particularly repeated learning, hands-on practice in the field, facilitator support, utilization of local knowledge, group work, and validation of mapping results in each cycle (Eldh et al., 2023). Participants not only learned the concept of risk, but also directly identified objects, determined locations, described spatial conditions, discussed results, and revised maps based on the findings of the previous cycle. This process allowed errors and competency gaps in Cycle I to become learning materials for Cycles II and III. Thus, the competency improvement demonstrated by the Friedman test results reflects not only an increase in theoretical understanding but also the development of practical skills in generating and using spatial information for DRR.

These findings imply that PAR–PGIS can be developed not only as a risk mapping method, but also as a method for strengthening community capacity and spatial literacy. Communities are positioned as co-producers of risk information, not simply recipients of maps created by external parties. This implication broadens the use of PGIS in DRR, as the success of interventions is measured not only by the availability of risk maps, but also by the community's ability to understand, validate, update, and use these maps for decision-making. Conceptually, these findings support the view that community competence is a capacity that can be built through a cyclical and reflective participatory learning process (Md Rami et al., 2026).

Further research is needed to test the sustainability of competencies after the mentoring program ends, particularly the ability of communities to independently update maps and use them in evacuation planning, simulations, and village development planning. Multi-site research is also needed to test the model's consistency across villages with varying social characteristics, digital literacy levels, disaster experiences, and institutional capacities. Further development can quantify the individual and institutional factors most influential in the success of PGIS learning, so that PAR–PGIS not only produces better maps but also builds community capacity to sustainably maintain and develop risk information systems.

Results of Participatory Disaster Mapping

Hazard Map

The whirlwind hazard map presents hazard zones divided into two main classes. The High Hazard Zone (red) covers approximately 22% of the village area (about 1.1 km² of the 5.00 km² village area) and is concentrated in the western part (RW 002: RT 006, RT 007, RT 008, and RT 009) due to the open topography of the landscape. The Moderate Hazard Zone (yellow) covers approximately 78% of the village area (about 3.9 km²), stretching from the northern, central, eastern, to southern sectors, namely RW 001, RW 003, and part of RW 002 (Figure 3).

The distribution of whirlwind hazard zones in Sumbersawit Village indicates that the risk is spatially heterogeneous, with high hazard zones concentrated in the western region, which has a relatively open landscape and is close to mountainous areas. This finding aligns with previous research showing that spatial mapping of wind hazards can identify variations in exposure levels based on topographic characteristics, land cover, and local environmental conditions (Gholami et al., 2020). Community-based mapping is important because it combines the physical characteristics of the area with the

community's experience of extreme wind events, thus producing more contextual information for DRR planning. In the context of Sumbersawit, the presence of high hazard zones in RW 002 demonstrates the need for a more targeted mitigation approach rather than applying uniform measures across the village.

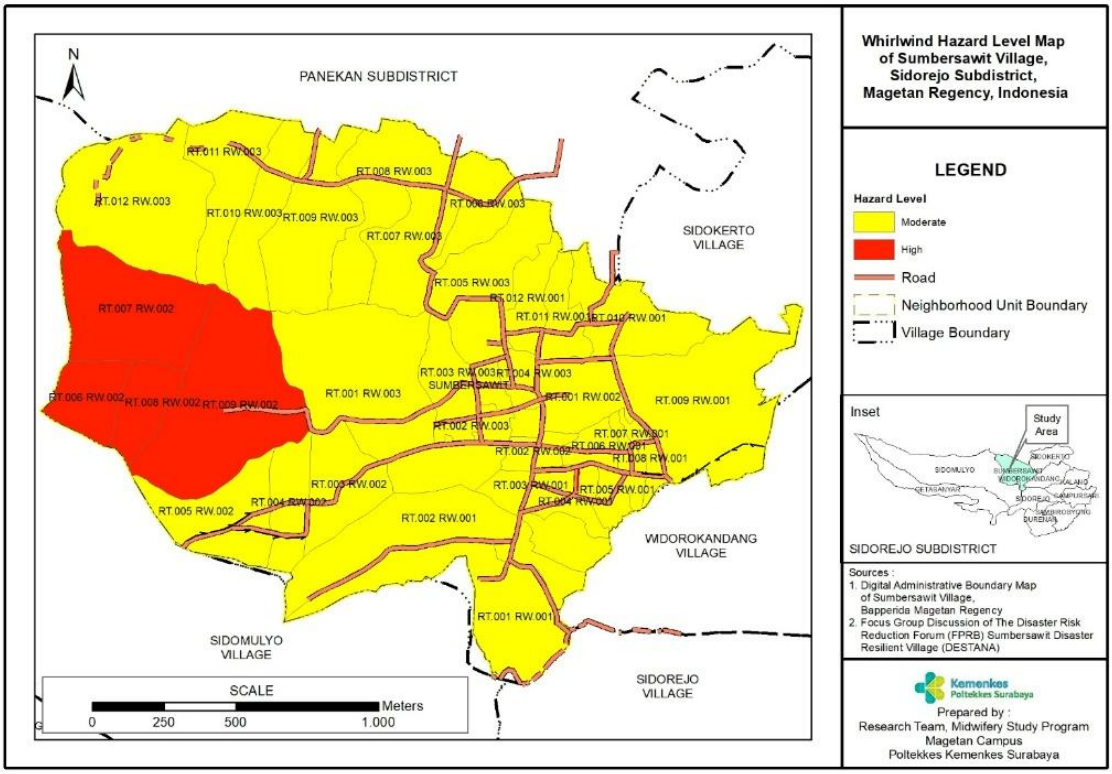


Figure 3. Map of Whirlwind Hazard Levels in Sumbersawit Village, Sidorejo District, Magetan Regency

Based on this zoning pattern, the Disaster Risk Reduction Forum (FPRB) needs to use the hazard map as a basis for determining mitigation and preparedness priorities, especially in RW 002, and specifically RT 006–009, which are in the high-hazard zone, by identifying vulnerable populations and at-risk facilities, increasing the capacity of communities and volunteers, placing early warning facilities, socializing and educating about mitigation, monitoring weather conditions, strengthening protective vegetation (windbreaks), environmental planning, determining safe temporary evacuation routes and locations, and implementing emergency response simulations. Areas with moderate hazards still need to be strengthened through early warning dissemination, family education, developing evacuation plans, and conducting regular exercises. From an empowerment perspective, the hazard map not only functions as a visual product, but also becomes an instrument for organizing and learning communities to build area-based volunteers, monitor environmental conditions, update data on vulnerable groups and important assets, and develop early warning procedures that are easily responded to by communities in affected areas (Pedoth et al., 2025). Thus, the community not only knows where the danger is, but is also able to determine what to do, who is responsible, and what resources need to be prepared (Gaillard & Mercer, 2013). The sustainability of the use of these maps needs to be strengthened through the integration of mitigation, preparedness, and disaster risk reduction activities into village development planning and budgeting, particularly the Village Medium-Term Development Plan (RPJM Desa).

Vulnerability Map

The Community Vulnerability Map visualizes the vulnerability conditions of the area into two categories. The Moderate Vulnerability Zone (yellow) covers approximately 75% of the village's residential area (mostly RW 001, RW 002, and RW 003) due to the high population density and the presence of vulnerable groups. The Low Vulnerability Zone (green) covers approximately 25% of the area, spread across points with lower building density and a lower ratio of vulnerable groups (Figure 4).

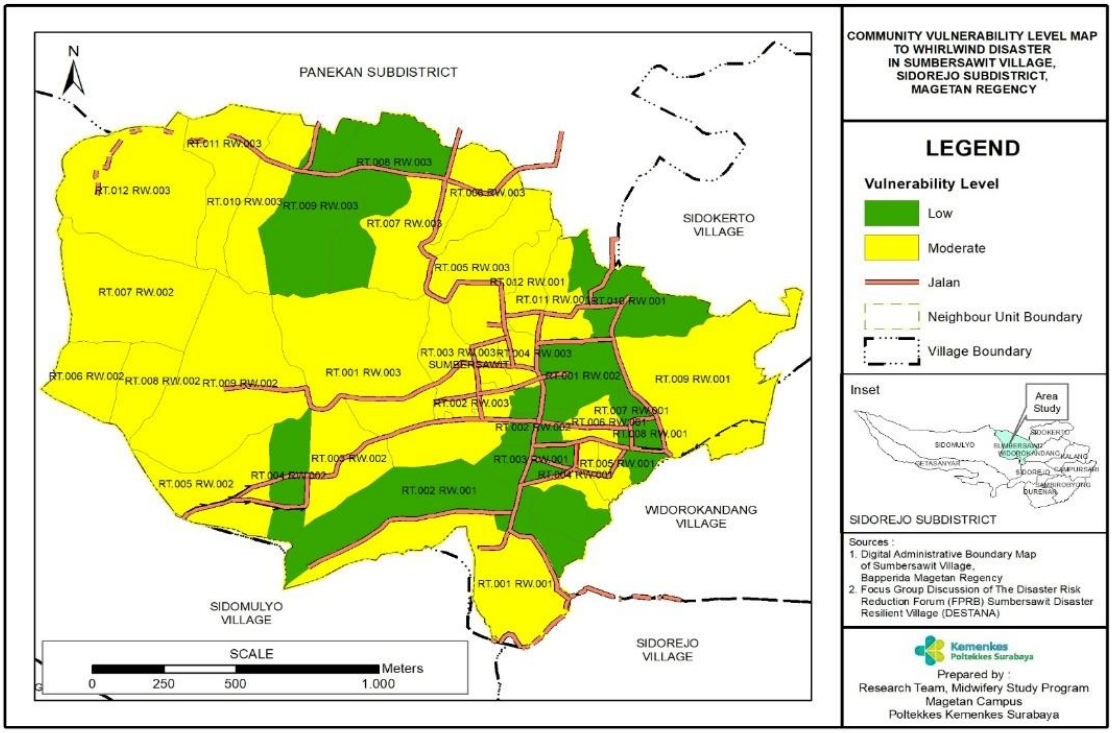


Figure 4. Map of Community Vulnerability Levels to Whirlwind Disasters in Sumbersawit Village, Sidorejo District, Magetan Regency

The dominance of vulnerability in the moderate zone indicates that vulnerability in Sumbersawit Village is spatial and related to population density, building density, socioeconomic conditions, and the presence of vulnerable groups. This finding aligns with previous research that places social vulnerability as a critical component in disaster risk assessment, as disaster impacts are determined not only by hazard intensity but also by the characteristics of vulnerable groups and the capacity of the exposed community (Rufat et al., 2025). Participatory mapping strengthens this approach by enabling communities to identify and validate vulnerable groups and environmental conditions often not reflected in aggregate data. Consequently, vulnerability maps can serve as a basis for village disaster management (FPRB) in establishing protection priorities, including updating vulnerable group data, determining evacuation needs and routes, providing preparedness education, providing an inclusive warning system, and assigning volunteer roles based on regional characteristics (Fagerholm et al., 2021).

Furthermore, vulnerability maps need to be developed from mere spatial products into decision-making and community empowerment instruments by integrating them with hazard and capacity maps to more comprehensively prioritize risks. Mapping results can be utilized in developing inclusive evacuation plans, simulations, resource allocation, and DRR planning and budgeting within the Village Medium-Term Development Plan (RPJM) (Muyambo et al., 2025). Future research should test the longitudinal use of these maps, particularly to determine whether updated vulnerability data and area-based interventions actually improve the protection capacity of vulnerable groups. Further development could also incorporate indicators of accessibility, adaptive capacity, and the specific needs of vulnerable groups so that the mapping not only shows where vulnerabilities exist but also the most appropriate interventions to mitigate them (van Heerden et al., 2022).

Capacity Map

The Capacity Map presents the distribution of local resources and institutions into three classifications. The Moderate Capacity Zone (yellow) covers the largest portion of the village area, which is around 80% (the majority of RW 001, RW 002, and RW 003). The High Capacity Zone (green) covers around 15% of the area in the southwest/north (RT 011 and RT 012 RW 003) with very active local institutions. On the other hand, the Low Capacity Zone (red) covers around 5% of the village area spread across certain residential pockets (RT 011 RW 001 and RT 004 RW 001) due to limited facilities and standby cadres (Figure 5).

The spatial findings on the Capacity Map, which divides the Sumbersawit Village area into Medium (80%), High (15%), and Low (5%) Capacity Zones, indicate that community capacity to face disasters is not evenly distributed, but rather forms micro-spatial variations based on the activeness of local institutions and the availability of facilities. The results of this study significantly strengthen the findings of Sulistyawan et al. (2018) and Cadag and Gaillard (2012), which emphasized that the integration of Participatory GIS (PGIS) is very effective in revealing the heterogeneity of local capacity that is often overlooked in top-down, macro-scale technocratic assessments. The existence of the High Capacity Zone is in line with similar

research in Sompok, Imogiri, which documented that the presence of disaster preparedness cadres and active community institutions are the main determinants in boosting spatial capacity scores. Conversely, the identification of Low Capacity Zones in certain residential areas proves the superiority of participatory spatial analysis in detecting capacity gaps (vulnerability–capacity gaps) at the site level with precision (Malawani et al., 2026).

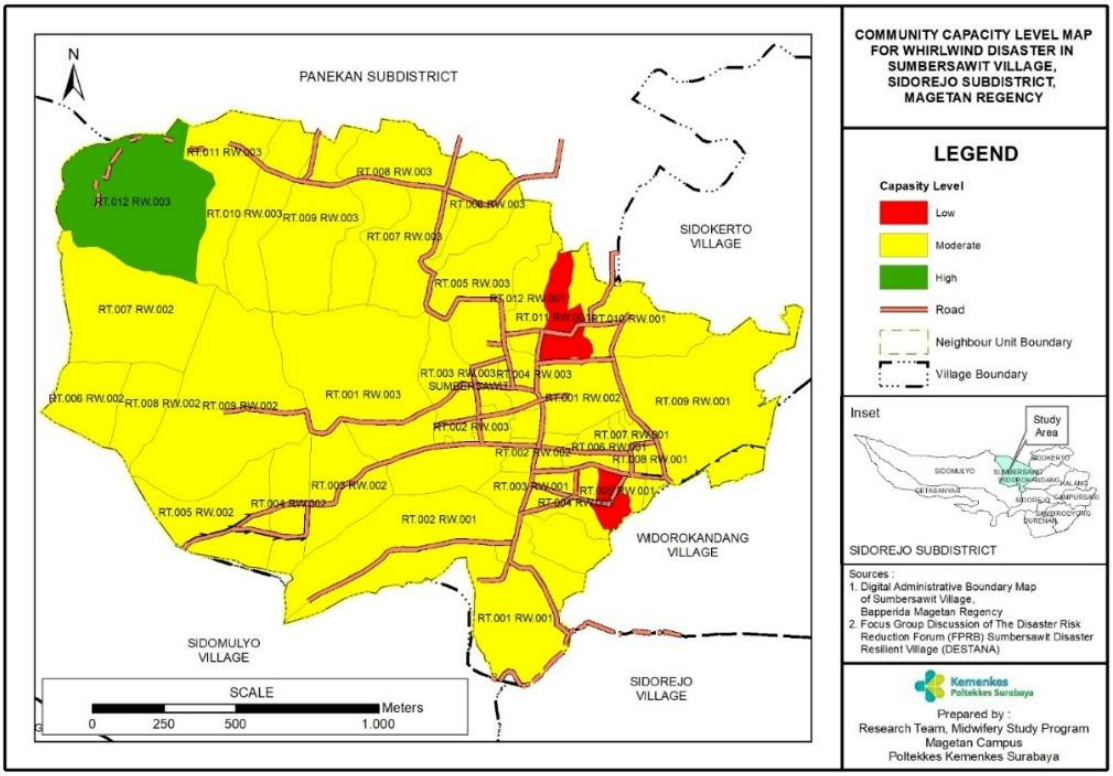


Figure 5. Map of Community Capacity Levels against Whirlwind Disasters in Sumbersawit Village, Sidorejo District, Magetan Regency

From an environmental health perspective, this Capacity Map reflects the extent of the capabilities and limitations of local communities in providing and maintaining healthy residential environments during emergency crises (Lü et al., 2021). The limited facilities and standby cadres in the Low Capacity Zone are directly correlated with high vulnerability to sanitation crises, limited access to clean water supplies, and unpreparedness for emergency waste management after a disaster. The absence of adequate sanitation infrastructure in these low-capacity settlements has the potential to trigger a surge in water-borne and vector-borne diseases in the event of a disaster (Riyadi et al., 2026). Conversely, areas in the High Capacity Zone demonstrate greater community independence in managing clean water facilities, organizing emergency sanitation, and maintaining a safe and hygienic threshold for residential environmental quality (Birgel et al., 2023).

The practical implications of these findings provide a rationale for village governments and the public health sector to undertake targeted interventions. Low-capacity areas should be prioritized for village budget allocations and health programs for the procurement of emergency sanitation facilities, portable clean water tanks, the formation of Village Disaster Preparedness Teams, and the training of environmental health cadres (Sphere Association, 2018). However, this capacity map still reflects a static assessment based on physical inventory and community perceptions. Therefore, further research should develop a Dynamic Spatial Capacity Index model that integrates real-time, crowdsourced data updates for community-based spatial data, expand ecosystem-based capacity variables (Eco-DRR) such as strengthening windbreak vegetation, and test the reliability of environmental health facilities and community response capacity through emergency drills under actual crisis conditions.

Village Disaster Risk Map

The Sumbersawit Village Whirlwind Disaster Risk Index Map presents the results of spatial integration between hazard level parameters (hazard, H), community vulnerability (vulnerability, V), and community capacity (capacity, C). The results of the integrative calculation ($R = H \times V/C$) on the Disaster Risk Index Map produce two risk classes. The Low Risk Zone (green) covers approximately 55% of the village area in the north, central, and south (RW 003, part of RW 001 and RW 002) due to the high local capacity value. In contrast, the Moderate Risk Zone (yellow) covers approximately 45% of the area in the west, east, and south of the village, which is the main priority area for preparedness interventions (Figure 6).

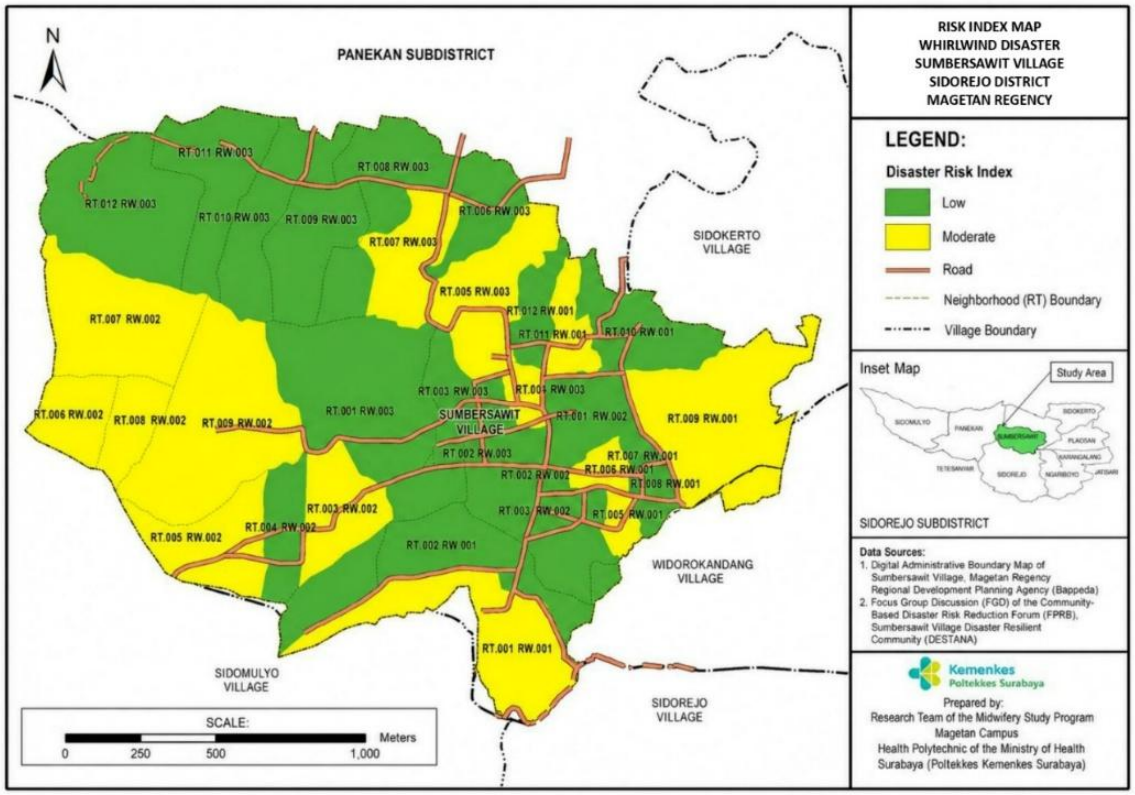


Figure 6. Whirlwind Disaster Risk Index Map of Sumbersawit Village, Sidorejo District, Magetan Regency

The dominance of Low-Risk Zones in the northern, central, and southern regions clearly demonstrates how high local capacity values can compensate for or reduce potential hazards and spatial vulnerability. This finding is highly relevant and confirms the conceptual framework of disaster preparedness as described by Cadag and Gaillard (2012) and the participatory mapping study in Sompok, Imogiri, which emphasized that disaster risk is not a static variable determined solely by exposure to physical hazards, but rather a dynamic function of the extent to which community capacity can reduce the level of vulnerability in their area (Malawani et al., 2026). The identification of Medium-Risk Zones in 45% of the village area (western, eastern, and southern) is also in line with the research results of Sulistyawan et al. (2018), which showed that Participatory GIS (PGIS) integration is highly reliable in isolating priority areas for intervention based on local-level geospatial objective conditions.

In the context of environmental health, this Disaster Risk Index Map provides a crucial spatial overview of potential threats to public health and village sanitation infrastructure during a whirlwind. Areas categorized as Medium Risk Zones are more vulnerable to physical damage to residential buildings, which could potentially trigger damage to clean water pipelines, contamination of residents' water sources due to fallen vegetation or whirlwinds, and damage to MCK (Bathing, Washing, and Toilet) facilities. Damage to sanitary infrastructure in these medium-risk zones is prone to triggering secondary environmental health crises after a disaster, such as the spread of water-borne diseases like diarrhea and skin diseases due to declining water quality and limited emergency sanitation facilities. Conversely, the high capacity in Low Risk Zones reflects institutional readiness and the presence of environmental cadres who are more responsive in protecting clean water facilities and organizing emergency sanitation management to maintain safe residential environmental health standards (Aziz et al., 2025).

The designation of the Moderate Risk Zone as a priority intervention area provides evidence-based policy guidance for village governments and the Regional Disaster Management Agency (BPBD) to focus their APBDes budget allocation on targeted mitigation and preparedness measures. Concrete steps that need to be prioritized in this zone include restructuring wind-resistant residential building structures, strengthening clean water supply and emergency sanitation networks, establishing field health posts, and pruning or planting ecosystem-based protective vegetation (windbreaks) (Reddy Anireddy, 2021). However, the risk index calculation in this study is still based on static spatial parameter weighting. Therefore, further research is recommended to develop dynamic disaster risk modeling that can account for climate change variables (climate change projections), integrate quantitative spatial simulations of wind speed and direction (meteorological spatial modeling), and test the resilience of environmental health facility networks through emergency response simulation exercises (drills/stress testing) in actual crises.

Evacuation Route and Evacuation Site Map

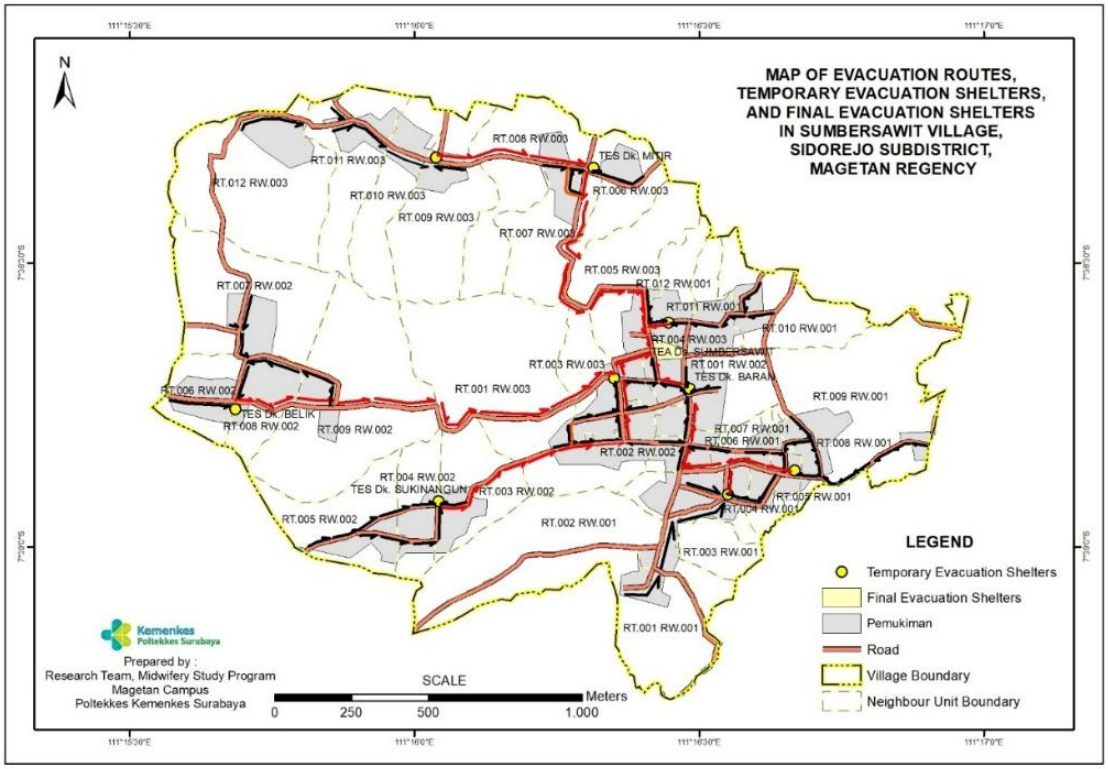


Figure 7. Map of Evacuation Routes, Temporary Evacuation Sites (TES), and Final Evacuation Sites (TEA) of Sumbersawit Village, Sidorejo District, Magetan Regency

The Evacuation Route and Site Map designates 5 Temporary Evacuation Sites (TES) based on hamlets in vulnerable areas (TES Belik, Sukinangun, Baran, Mitir, and Sumbersawit) with a travel radius of less than 500 meters, as well as communal Final Evacuation Sites (TEA) at the Village Hall and SDN Sumbersawit 2 located in the safe zone (green), with a travel radius of 1,000–2,000 meters from the TES. All residential areas are 100% connected through evacuation route corridors based on the main road network and village environment (Figure 7).

The mapping results show that all residential areas in Sumbersawit Village are connected by a network of evacuation routes to five hamlet-based TESs and two communal TEAs. The designation of TESs with a travel radius of <500 meters and TEAs in safe zones with a radius of 1,000–2,000 meters is in line with previous research, which emphasized that evacuation effectiveness is determined not only by the availability of safe places, but also by spatial accessibility, road network connectivity, and a clear hierarchy of evacuation locations. The participatory mapping approach also allows for the design of routes that take into account road conditions and local knowledge known to the community. Thus, the mapping in this study provides a more operational spatial basis than simply determining evacuation locations without considering accessibility from residential areas (Suwanno et al., 2023).

The implication for preparedness is the availability of maps that FPRB and Destana can use to define TES service areas, disseminate evacuation routes to the public, install directional signs and assembly points, and conduct regular simulations. During an emergency response, the TES-TEA structure can expedite decision-making by providing clear evacuation objectives before people move to safer final locations. However, 100% connectivity on the map requires regular field validation of road conditions, physical obstacles, TES/TEA capacity, access for vulnerable groups, and potential changes to the road network. Thus, the mapping results can develop into a community-based evacuation system that not only shows where people should move, but also who to assist, through which routes, and how the evacuation process will be managed in the event of an emergency (Moradi et al., 2025).

Reflection Results

The results of participant reflection and self-assessment showed an increase in self-efficacy and psychological preparedness in line with their improvement in technical competence. In Cycle I, participants' self-confidence in all mapping domains was below the Capable Category Score due to initial doubts. Participants' self-confidence increased rapidly in Cycle II, and finally in Cycle III, all self-assessment indicators (100%) significantly exceeded the Capable Category threshold, with the highest scores in the mapping and disaster risk map utilization domains. This positive trend confirms that the participatory action research approach contributed not only to preparedness documents on paper but also to residents' confidence in updating and managing their village disaster risk data sustainably (Figure 8) (Maffi et al., 2026).

The increase in participants' self-efficacy from Cycle I to Cycle III indicates that participatory learning not only

improves technical competence but also builds community confidence in their own ability to manage risk information. This finding is relevant to previous research on community-based disaster risk reduction, which shows that direct community involvement in risk identification, mapping, decision-making, and problem-solving can strengthen self-efficacy and the capacity to act (Ravazzoli et al., 2025). In this study, the increase in self-efficacy went hand in hand with the increase in technical competence, indicating that the experience of completing mapping tasks, obtaining feedback, and improving results in each cycle is an important part of the confidence-building process (Gale et al., 2021).

These changes were likely influenced by repeated practical experience, facilitator mentoring, collaborative work, validation of mapping results, and participants' success in seeing concrete products from their processes. In Cycle I, doubts arose because participants were unfamiliar with mapping concepts and techniques, whereas in subsequent cycles, successful experiences and opportunities to correct mistakes strengthened their confidence. However, reflection results need to be interpreted cautiously because self-assessment measures participants' perceptions of their abilities and does not fully reflect actual abilities. The study was also conducted in a single village and over a relatively limited intervention period, so it is not certain whether the increase in self-efficacy is sustainable over the long term or applicable to different community contexts.

The implication of these findings is that increasing DRR capacity should not only focus on technical knowledge and skills, but also on building community confidence to use these skills independently (Saputra et al., 2026). Increased self-efficacy can be a crucial asset for the sustainability of risk map management, particularly when communities need to update data, recognize changes in vulnerability, and use maps in disaster planning and response. Thus, PAR-PGIS has the potential to generate more sustainable capacity because communities are not only knowledgeable and capable, but also confident in implementing them (Brown & Fagerholm, 2015).

As a follow-up, these findings can be developed into a capacity-building model based on the competency-efficacy-action cycle. FPRB and Destana can conduct regular map updates, peer learning among residents, map-based simulations, and self-evaluations to maintain skills and confidence after the mentoring ends. Future research should test whether this increase in self-efficacy truly transforms into preparedness behavior and actual capabilities in disaster situations. If this relationship can be proven longitudinally, then increased self-efficacy could be an important finding in developing community capacity indicators, not only as a psychological outcome of mentoring, but as a mechanism bridging knowledge and skills development toward sustainable village resilience.

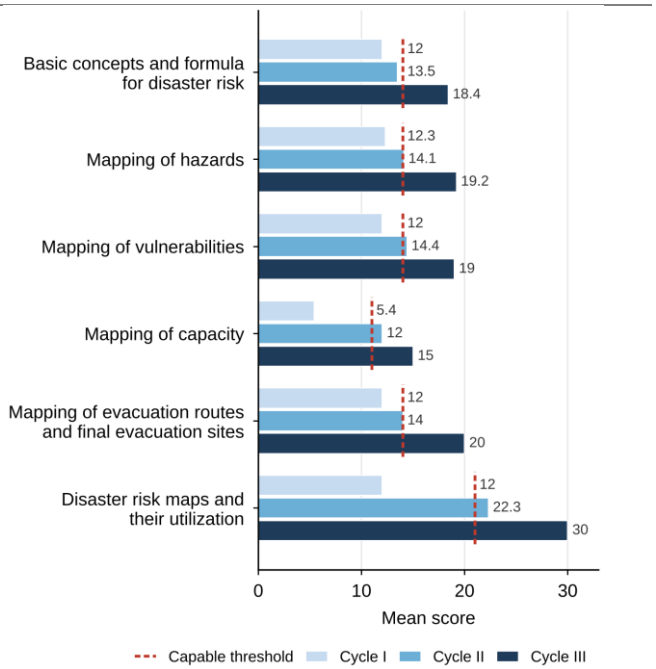


Figure 8. Development of Participants' Self-Assessment Scores in Disaster Risk Mapping across Cycles

This study demonstrates that the integration of QoDU-VR, PAR, and PGIS can be an integrated approach to improve the competency of the Disaster Resilient Village Forum in risk mapping while supporting the strengthening of village resilience. QoDU-VR functions to identify needs that need to be prioritized based on the level of difficulty and usefulness; PAR transforms these priorities into a process of learning and iterative action through planning, implementation, observation, and reflection, while PGIS provides a technical framework for building, validating, and using spatial information. Thus, the achievement of the research objectives is not only demonstrated by the formation of risk maps, but also by changes in the ability of participants to understand, compile, validate, and utilize spatial information for disaster risk reduction and improving the status of village resilience.

The main contribution of this research lies in how these three approaches are connected within a single intervention pathway, from prioritizing needs to developing capacities and spatial products that can be used in risk management. These findings expand the use of participatory mapping, which is generally oriented toward producing spatial information, into a capacity-building process that connects needs, learning, practice, reflection, and capacity change (Rong et al., 2023). Therefore, the risk map in this study is not positioned as an outcome, but as a learning and decision-making instrument that can be used by village Disaster Risk Reduction Forums (FPRB) to strengthen village mitigation, preparedness, evacuation, and DRR planning (Sarmiento et al., 2024).

The framework has the potential to be applied to other villages by maintaining its integration logic but adapting the stages, indicators, threats, forms of spatial information, and the intensity of assistance to each village's

initial conditions. Villages with low spatial capacity can begin with risk recognition and simple map interpretation, while villages with better capacity can be directed to vulnerability analysis, spatial validation, evacuation mapping, and utilization of the results in development planning. Replication with this adaptation principle allows the model to be used in different contexts without eliminating the key mechanisms of priority setting, participatory action, reflective learning, and spatial knowledge production (Moore et al., 2021).

Thus, this study yields novel findings that participatory risk mapping can serve as a capacity-building mechanism that simultaneously supports changes in village resilience, if preceded by priority setting and implemented through a structured action-reflection cycle (W. Liu et al., 2018). These findings can form the basis for model development in subsequent research through application to various village characteristics, involvement of more diverse community groups, and follow-up measurements to assess the sustainability of competency and map utilization after the mentoring ends.

CONCLUSIONS

The integration of Participatory Action Research (PAR), Participatory Geographic Information System (PGIS), and the Quadrant of Difficulty-Usefulness (QoDU-VR) framework transformed local knowledge into operational spatial data to strengthen village resilience in facing disasters. Together, the three components form a coherent chain of interventions: QoDU-VR filters priority activities based on difficulty and benefit analysis, PAR drives a learning cycle based on action-observation-reflection, while PGIS provides geospatial instruments to legitimize community knowledge. This integrated approach not only improved the community's collective spatial competence but also raised the village resilience category. Ultimately, the sustainability of this research's impact depends heavily on the commitment of local institutions to consistently institutionalize the results of participatory mapping into planning documents, village budgeting (APBDes), and preparedness simulations.

SUGGESTION

The Sumbersawit Village Government needs to utilize GIS-based risk maps as a dynamic instrument in development planning and disaster risk reduction through regular data updates, the installation of evacuation route and point information, the implementation of map-based simulations, and the strengthening of early warning systems and community environmental monitoring. The sustainability of the program needs to be supported through the integration of mapping results into the Village Work Plan (RKPDes) and Village Budget (APBDes), while the Regional Disaster Management Agency (BPBD), sub-district government, Community Health Center (Puskesmas), universities, and other stakeholders provide technical assistance, capacity building, and resource support so that the resilience of Sumbersawit Village can be maintained and continuously improved.

DECLARATIONS AND ETHICAL STATEMENTS

Ethical Approval and Consent to Participate

This study was approved by the Health Research Ethics Committee of Poltekkes Kemenkes Surabaya (No. EA/3177/KEPK-Poltekkes_Sby/V/2025). All participants received an explanation of the study and provided informed consent before taking part. Confidentiality of identity and data was maintained, and all activities were carried out voluntarily with due regard for participant safety and protection.

Conflict of Interest Disclosures

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Artificial Intelligence (AI) Usage Statement

AI-assisted tools were used only to improve the language and readability of the manuscript during editing. All study design, data, analyses, interpretations, and conclusions are the authors' own, and the authors take full responsibility for the content of this article.

Author Contributions

Sunarto conceptualized the study, designed the methodology, supervised the PAR cycles, and drafted the manuscript. Heru Santoso Wahito Nugroho developed the QoDU-VR analysis and contributed to data analysis and manuscript revision. Sulikah and Suparji facilitated the PAR cycles and contributed to data collection and data curation. Aries Prasetyo conducted GIS processing, spatial analysis, and map production. All authors read and approved the final manuscript.

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