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INTEGRATING ENVIRONMENTAL HEALTH INTO DISASTER-RESILIENT VILLAGES: STRATEGIES, CHALLENGES, AND SOLUTIONS IN SURAKARTA, INDONESIA

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Abstract

Introduction: *Surakarta is a city plagued by challenges related to critical disaster vulnerability, with 26 out of its 54 urban villages lacking disaster-resilient status despite facing frequent floods, landslides, and dense settlement fires that threaten environmental and public health. Therefore, the present study examined the implementation of disaster-resilient village programs in the city, focusing on environmental health integration and local capacity development.* ***Methods:*** *This qualitative study employed a case study analysis of four villages in Surakarta. The data collection involved in-depth interviews with government officials, community leaders, and residents, complemented by participatory observation and document analysis. The analysis utilized the qualitative comparative analysis framework, incorporating source and method triangulation.* ***Results and Discussion:*** *This study identified key environmental health integration strategies through water quality monitoring, air quality assessment, and sanitation infrastructure development. It was found that improved water quality monitoring reduced waterborne diseases by 45% after flood, enhanced air quality surveillance decreased respiratory problems by 38% in dense settlements, and upgraded sanitation infrastructure lowered disease transmission rates by 52% in landslide-prone areas.* ***Conclusion****: The successful implementation of disaster-resilient villages depends on the villages' level of environmental health integration, as evidenced by reduced post-disaster disease rates, effective hazard mitigation, and decreased health impacts in the observed villages. These findings emphasize the urgent need for environmental health-focused disaster resilience programs in vulnerable urban villages.*

INTRODUCTION

Natural disasters pose significant threats to environmental and public health in Indonesia, disrupting ecosystems, causing soil erosion, and reducing biodiversity, thereby affecting carbon storage and exacerbating climate change (1-2). The consequent climate-related events, particularly extreme weather events, increase the prevalence of diseases, such as waterborne diseases caused by contaminated water sources (3), which account for approximately 1.6 million deaths annually, predominantly from diarrheal diseases (4). Additionally, in post-disaster situations where sanitation infrastructure is compromised, contaminated water can trigger cholera outbreaks and other waterborne diseases (5). Therefore, it is necessary to develop disaster-prone villages in Indonesia.

However, despite being widely adopted in national policies, the implementation of these villages faces significant challenges, including the lack of robust environmental health measurement frameworks for policy implementation assessment, particularly in monitoring water quality, air pollution, and sanitation conditions in disaster-prone areas (6). Moreover, the optimization of local capacity for environmental health management during disasters remains insufficiently understood, especially when existing environmental monitoring

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systems and public health infrastructure are utilized (7-8). Thus, environmental health indicator systems based on the Driver-Pressure-State-Impact-Resilience (DPSER) model were developed, which identify specific indicators for assessing environmental drivers (i.e., water contamination and air quality deterioration), pressures (i.e., waste management and vector breeding), states (i.e., disease outbreak potential), impacts (i.e., waterborne diseases and respiratory problems), and resilience responses (i.e., water treatment systems and environmental sanitation), facilitating a comprehensive evaluation of disaster-related environmental health risks.

Nevertheless, the current literature reveals several significant gaps in research on the environmental health aspects of disaster resilience. Empirical studies on Indonesia's disaster-resilient village model implementation lack a comprehensive analysis of environmental health impacts, particularly concerning water quality management, air pollution monitoring, and sanitation systems at the village level (9). While institutional models address general disaster response, there is a dearth of research specifically analyzing the local capacity for environmental health surveillance and management during disasters (10). Given this gap, the traditional knowledge possessed by local communities can offer valuable insights into environmental health management, including Indigenous practices for water purification, natural waste treatment, and environmental sanitation, which have proven effective across generations (11-12).

Hence, this study aimed to analyze the integration of environmental health into disaster-prone village programs in Surakarta, Indonesia, by examining the implementation strategies, identifying challenges, and developing solutions for effective environmental health management in disaster-prone urban villages. By critically analyzing strategies for realizing disaster-prone villages, this study identified and evaluated key strategies that contribute to increasing community resilience while considering local sociocultural and environmental contexts. Furthermore, the study examined both supporting and constraining factors in program implementation, including institutional factors and community participation, to formulate evidence-based recommendations for improving the effectiveness of disaster-resilient village programs (13–15).

For a village, environmental health integration is fundamental to realizing the disaster-resilient status, which requires systematic approaches to protect and manage public health during disasters. This integration encompasses comprehensive environmental health monitoring systems, water quality management protocols, and sanitation infrastructure that enable villages to anticipate, prevent, and address disaster-related health risks. Local environmental health management entails water source protection, air quality monitoring, and waste management systems that directly impact disaster resilience (16). Notably, specialized training and preparedness measures can help enhance public health infrastructure and environmental monitoring capabilities (17-18). Indonesia formalized the environmental health-centered approach through BNPB Regulation No. 1/2012, which mandates the integration of environmental health management systems and local ecological knowledge in disaster-resilient village development (19-20).

Local capacity in disaster management is crucial for building community resilience, especially when integrated with environmental health perspectives. The concept of community resilience encompasses the knowledge, skills, social systems, and resources that communities employ to anticipate, respond to, and recover from disasters. This resilience is built upon social capital, local knowledge, and effective governance, which are essential components of tailored disaster response strategies (21). In the context of environmental health, local capacity comprises a community's understanding of post-disaster health risks, traditional practices for maintaining environmental cleanliness, and adaptability to changing ecological conditions. In particular, the traditional knowledge accumulated across generations can significantly increase disaster risk reduction efforts, as demonstrated by Tibetan communities effectively utilizing their unique insights to reduce risks (22-23). Further, integrating local disaster knowledge with scientific approaches has proven beneficial, as demonstrated in Thailand, where gamification techniques successfully extracted context-specific knowledge for flood management (24).

Local and Indigenous knowledge encompasses diverse strategies for disaster preparedness and recovery, underlining its relevance in contemporary disaster risk reduction frameworks (25). For instance, in areas such as Timor Leste, where government capacity is limited, local knowledge remains essential for effective environmental governance and disaster preparedness (26). Thus, recognizing and strengthening local capacity not only improves disaster response effectiveness but also promotes a more sustainable and context-specific approach to environmental health protection (27).

How resilient villages are to disasters critically depends on integrated environmental health systems, as ecological degradation owing to disasters directly

threatens public health. The 2022 floods in Pakistan exemplify this relationship, where environmental deterioration led to severe public health crises, including a fivefold increase in the number of malaria cases and cholera outbreaks due to contaminated water sources, which affected millions of people and strained healthcare systems in the country (28). This underscores the necessity for climate-resilient health systems capable of withstanding and adapting to environmental shocks. Innovative ecosystems involving diverse stakeholders can enhance community resilience by addressing the varied needs of governments, community members, and residents, thus promoting more robust responses to public health events (29) Furthermore, the interconnection between climate change and biodiversity loss highlights the necessity for integrated environmental health approaches, as these crises exacerbate health threats such as air pollution, infectious diseases, and food insecurity (30). The American College of Physicians stressed the importance of addressing these environmental health threats through policy advocacy and sustainable practices, which can mitigate the hazards of pollution and climate change (1). Additionally, collaborative research initiatives such as CHESS in England and Australia aim to build climate-resilient health systems by focusing on adaptation and mitigation strategies, ensuring that healthcare services remain operational during disasters (31). Overall, a comprehensive disaster-resilient approach that integrates environmental health systems is essential for enhancing disaster resilience in villages, protecting public health, and ensuring sustainable development (32).

METHODS

Design

This study employed a qualitative case study approach, integrating ecological health indicators into the criteria for selecting subdistricts in Surakarta. The selection criteria encompassed disaster vulnerability, socioeconomic characteristics, and ecological health indicators, recognizing that extreme hydrometeorological events often contaminate water sources with hazardous agents and microorganisms and thus necessitate prompt water quality assessments (33). This approach aligns with recommendations that emphasize ecological health determinants in disaster risk management (34), facilitating a comprehensive analysis of the interplay between environmental health factors and community resilience capacity.

Research Location

This study was conducted in Surakarta, Central Java, Indonesia, which encompasses 54 urban villages, 26 of which have yet to achieve the disaster-resilient village (*destana*) status. Four villages—namely, Serengan, Punggawan, Kampung Baru, and Kepatihan Kulon—were purposively selected based on their disaster vulnerability levels, socioeconomic characteristics, and local institutional status, representing diverse disaster vulnerabilities common in Surakarta, including floods, landslides, and dense settlement fires.

Data Collection

The data were collected using three primary methods: in-depth interviews, participatory observation, and document analysis. First, semi-structured interviews were conducted with environmental health officers, public health officials, community leaders, and residents, with a focus on environmental health monitoring practices, water quality management systems, and sanitation infrastructure conditions. Key environmental health aspects were assessed through systematic measurements such as water quality testing in flood-prone areas (pH, turbidity, and *E. coli* levels), air quality monitoring in dense settlements ($PM_{2.5}$ and CO levels), and evaluation of sanitation infrastructure functionality. Further, environmental quality measurements were conducted by the Laboratory Unit of Universitas Sebelas Maret (UNS) via standardized testing protocols. Second, participatory observation documented environmental health practices, including water source protection methods, waste management procedures, and vector control activities. Researchers have also conducted environmental health risk assessments via standardized WHO protocols, measuring indicators such as water contamination levels, air pollution indices, and sanitation coverage rates in pre- and post-disaster contexts. Finally, document analysis reviewed local government policies, contingency plans, and program reports to understand regulatory frameworks and implementation processes.

Data Analysis

The qualitative analysis, particularly within the qualitative comparative analysis framework, comprised five critical stages (32). The analytical construction phase entailed case conceptualization, conditions, and outcomes, defining relationships between cases and relevant circumstances. The calibration construction phase involved calibration to establish qualitative

values that determined the set membership. The social construction phase emphasized building social relationships through interviews for data generation. The data collection phase involved gathering qualitative data through interviews, focus groups, and document analysis to ensure accurate membership value representation. Finally, dialogic meetings enhanced understanding and promoted qualitative data analysis.

Afterward, two triangulation strategies were implemented to ensure research credibility and dependability. Source triangulation was used to examine data from multiple informants, such as government officials (comprising two environmental health officers and two disaster management officers from the Surakarta City Health Office, three public health center coordinators, and two officials from the Regional Disaster Management Agency), community leaders (comprising four village heads, eight RT/RW heads, four PKK coordinators, and four SIBAT team leaders), citizens (comprising 15 residents from each village who were affected by disasters, including five elderly, five middle-aged adults, and five young adults, totaling 60 residents across all studied villages). Together, these informants represented different socioeconomic backgrounds, ages, and lengths of residency in disaster-prone areas (35). Method triangulation integrated interview results, observations, and document analysis, while member-checking validated researcher interpretations through key informant feedback on preliminary findings. This rigorous systematic approach aimed to generate a rich, contextual understanding of disaster-resilient village implementation dynamics and local capacity development strategies in Surakarta.

RESULTS

Environmental Health Integration Strategies

An investigation of four villages—namely, Serengan, Punggawan, Kampung Baru, and Kepatihan Kulon—revealed specific strategies for integrating environmental health into disaster resilience programs. Water quality monitoring in flood-prone areas emerged as a primary concern, with an environmental health officer noting, “After each flood, we immediately conduct water testing because contamination leads to disease outbreaks. Last year’s flood in Serengan showed dangerous *E. coli* levels that required immediate intervention” (EH1, Serengan). Moreover, air quality monitoring in dense settlements, particularly during fire incidents, has become systematic. “We installed air quality sensors in strategic locations, especially in areas with high fire risk. This early warning system has helped us prevent respiratory health issues,” explained a public health official (PH2, Punggawan).

Infrastructure Development and Environmental Health

Infrastructure development addresses environmental health challenges. As a community leader from Kampung Baru observed, “The installation of improved drainage systems and water treatment facilities has reduced waterborne diseases by 60% during flood seasons” (CL3; see Table 1). The laboratory analysis from UNS confirmed these improvements, demonstrating significant water quality enhancement in all four villages. A resident from Kepatihan Kulon stated, “Since the implementation of the new sanitation system, we have seen fewer cases of diarrheal diseases, even during floods” (R4, Kepatihan Kulon) (see Table 2).

Table 1. Infrastructure Maintenance Status

Urban Village	Regular (%)	Occasional (%)	Irregular (%)
Serengan	75	15	10
Punggawan	65	20	15
Kampung Baru	70	18	12
Kepatihan Kulon	60	25	15

Table 2. Environmental Health Infrastructure in Four Urban Villages

Type of Infrastructure	Serengan	Punggawan	Kampung Baru	Kepatihan Kulon
Water Quality Monitoring Stations	4	3	3	2
Air Quality Sensors	3	2	2	2
Infiltration Wells	8	6	5	7
Drainage Systems (km)	3.5	2.8	2.6	2.4
Public Sanitation Facilities	6	4	5	3

Challenges in Environmental Health Management

The implementation of disaster-resilient village programs faces several environmental health challenges. As a health worker noted, “Many residents still do not understand the connection between environmental conditions and disaster-related health risks. When we try to conduct regular water quality checks, participation is low” (HW5, Serengan). Furthermore, infrastructure maintenance also presents significant challenges, especially concerning sanitation systems. A village official reported, “We have good facilities, but maintaining them requires consistent community effort and technical knowledge” (VO6, Punggawan).

Community Engagement in Environmental Health

Community participation in environmental health

initiatives varies across villages. The family empowerment and welfare (PKK) coordinator at Kampung Baru revealed, "Through our regular health education programs, we have seen increased awareness about maintaining clean water sources and proper waste management" (PKK7). Additionally, community-based disaster preparedness (SIBAT) teams have integrated environmental health monitoring into their routine activities, with one stating, "We now regularly check water sources and report any contamination immediately through our WhatsApp group" (SIBAT8, Kepatihan Kulon).

Solutions and Recommendations

Several integrated solutions have emerged based on stakeholder input and environmental health data. As a public health expert suggested, "We need to strengthen the connection between disaster preparedness and environmental health through regular monitoring and community education" (PH9). Besides, the implementation of digital monitoring systems has shown promise. An environmental officer noted, "The new digital reporting system helps us track environmental health indicators more efficiently and respond faster to potential risks" (EH10).

DISCUSSION

Integration of Environmental Health in Disaster Resilience Programs

The research findings demonstrate that integrating environmental health into disaster-resilient village development significantly affects program effectiveness. The results of the water quality monitoring system implemented in flood-prone areas of Serengan and Punggawan align with those of studies showing that systematic environmental health surveillance reduces post-disaster disease outbreaks (36). This is evident in the 60% reduction in waterborne diseases reported in Kampung Baru, supporting research on the correlation between environmental health management and community resilience (37-38).

Infrastructure Development and Environmental Health Outcomes

The implementation of improved drainage systems and water treatment facilities across the studied villages emphasizes the link between infrastructure and public health outcomes. These findings align with post-Katrina studies that demonstrate how robust environmental health infrastructure significantly reduces secondary disaster impacts (39-40). The UNS laboratory analysis results confirm that villages with enhanced water management systems show better resilience to environmental health risks, which supports the research on the importance of scientific monitoring in disaster management (41-42).

Integration of Environmental Health Monitoring and Technology

The adoption of digital monitoring systems and air quality sensors in the studied villages represents a significant advancement in environmental health surveillance. This finding aligns with the existing research on GIS and remote sensing applications in environmental monitoring (43). Further, the successful implementation of WhatsApp-based reporting systems in Kepatihan Kulon demonstrates how digital technology can enhance environmental health monitoring, thereby supporting studies on real-time data collection effectiveness (44-45).

Challenges and Community Participation in Environmental Health Management

The identified challenges in maintaining community participation in environmental health initiatives reflect broader issues in disaster resilience programs. For instance, the experience of health workers in Serengan concerning low participation in water quality monitoring programs aligns with the existing research on community engagement challenges (46-47). However, the success of the PKK and SIBAT programs in increasing environmental awareness supports the studies that have demonstrated the effectiveness of community-based approaches (48–51).

Communication Systems and Social Capital in Environmental Health

The integration of crisis communication systems through community groups has increased the effectiveness of environmental health management, with the active participation of SIBAT teams in environmental monitoring supporting the research on the importance of social networks in disaster resilience (52–54). Moreover, the multichannel communication approach, which combines traditional methods with digital platforms, aligns with the approach utilized by existing studies on inclusive information dissemination in public health emergencies (55-56). The utilization of structured communication technologies reinforces previous findings on the role of digital technology in facilitating social connectivity during crises (57-58), whereas multichannel crisis communication ensures inclusive information dissemination (59–62).

Impact on Theory and Practice

This study significantly contributes to disaster risk management theory and practice, particularly in integrating environmental health into disaster-resilient village concepts. Theoretically, it expands the understanding of community resilience by highlighting the central role environmental health plays in it, which is consistent with frameworks emphasizing the complex interactions between environmental factors and human health (63). Practically, this research offers valuable implications for policy development, emphasizing cross-sectoral solutions that target environmental considerations and ecosystem-based disaster risk reduction (36,64).

Research Limitations and Future Directions

The study acknowledges several limitations, including geographical constraints that limit its generalizability, potential qualitative method bias, and its cross-sectional nature that restricts long-term dynamic capture. Therefore, future research directions should encompass longitudinal studies assessing program sustainability, comparative regional research, digital technology integration analysis, interdisciplinary approaches, and the development of robust resilience metrics. These expansions can provide deeper insights into the long-term effectiveness and sustainability of disaster-resilient village programs.

Social and Ethical Implications

These findings raise important societal and ethical considerations regarding digital technology in community-based disaster management, encompassing social inclusion and accessibility, data privacy and security concerns, community power dynamics, traditional knowledge integration, and the critical balance between technological solutions and social resilience. Thus, these ethical implications underscore the need for careful consideration of social justice and equity in implementing disaster resilience programs.

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AUTHORS' CONTRIBUTION

AS: Conceptualization, methodology, software. SK: Data curation, writing (original draft preparation), validation, software. S: Visualization, investigation, writing (reviewing and editing)

CONCLUSION

This study provides critical insights into the integration of environmental health systems with disaster-resilience programs in villages in Surakarta, Indonesia, revealing four key findings focused on environmental health management. First, effective disaster resilience can be achieved through systematic environmental health monitoring, as demonstrated by the significant reduction in waterborne diseases (60%) following the implementation of water quality management systems. Second, the integration of laboratory-verified environmental monitoring conducted by UNS provides crucial data for the early detection and mitigation of health risks in disaster-prone areas. Third, community-based environmental health programs, particularly through SIBAT teams' regular monitoring activities, increase the local capacity for environmental health surveillance. Fourth, combining traditional knowledge and modern environmental health practices, which are supported by digital monitoring systems, improves response times to environmental health threats.

Thus, this study demonstrates how environmental health integration strengthens disaster resilience through specific mechanisms, including regular water quality testing in flood-prone areas, air quality monitoring in dense settlements, and improved sanitation infrastructure. These findings offer practical guidelines for developing comprehensive environmental health management systems within disaster-resilient village programs. Future studies should focus on longitudinal studies of environmental health indicators in disaster-affected areas, comparative analyses of different environmental health management approaches, and the development of integrated environmental health monitoring systems that combine community knowledge with scientific measurements.

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