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RESEARCH ARTICLE

Disaster Mitigation Strategies Based on Risk Matrix and House of Risk (HoR) Phase 2

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ABSTRACT

Wonogiri Regency, located in Indonesia, is an area susceptible to various types of natural disasters, such as floods, landslides, and hurricanes, which pose a significant risk to approximately 90% in this area. Therefore, this study aimed to identify the types of potential disasters in Wonogiri and propose effective strategies for disaster mitigation from 2021 to 2025. This study uses a risk matrix to quantify the risks associated with these potential disasters and utilizes House of Risk (HoR) phase 2 methodology to formulate strategies for disaster risk prevention. This comprehensive analysis has shown seven potential disasters for which nine mitigation strategies have been developed. Among these, the top three strategies, considering the effectiveness value and the degree of difficulty (EDRk) value, in order of priority, are “Increasing multi-stakeholder partnerships in disaster management” (EDRk value 176.20); “Strengthening the legal framework for disaster management” (EDRk value 167.40); and “Conducting socialization and education on disaster mitigation” (EDRk value 111.60). Implementing these strategies is expected to strengthen disaster risk reduction (DRR) in regencies, with a focus on prioritizing the most effective measures.

Introduction

A disaster is a significant problem and a challenge to society, which is detrimental to human survival [1]. Natural disasters are unpredictable and influenced by various factors, including seasonal variations. A disaster results in substantial material losses and loss of human lives, necessitating proactive efforts to address and prevent its occurrence [2]. Awareness of potential catastrophic risks in advance during the pre-disaster phase can help predict and reduce potential losses. Subsequently, the potential for loss of life, injury, and damage to assets in a system, society, and community over a specific period is referred to as disaster risk [3]. This definition underscores the concept of hazardous events and disasters arising from ongoing and current dangers. A hazard is a process, phenomenon, or human activity that has the potential to cause death, other adverse health effects, property damage, social and economic disruptions, or environmental degradation [3].

In addition to evaluating disaster risk, it is crucial to analyze the potential consequences of a disaster as part of pre-disaster preparedness to minimize significant losses when a disaster strikes. The combined outcome of a hazardous event or disaster is commonly referred to as the disaster impact [3]. Therefore, disaster mitigation or disaster risk reduction (DRR) involves a proactive approach implemented before an event, which involves conducting a thorough risk assessment. Disaster mitigation aims to reduce or eliminate the adverse effects of such events [4].

Wonogiri Regency, located in Indonesia, experiences a tropical climate characterized by two seasons, rainy and dry, with average temperatures ranging from 24 °C to 32 °C, and is situated between $7^0 32'–8^0 15'$South latitude and $110^0 41'– 111^0 18'$ East longitude. Subsequently, the natural landscape was dominated by

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limestone mountains as part of the Sewu Mountains [5,6]. Regency is also well-known as the location of the spring of Bengawan Solo [7–10]. However, these natural conditions also pose the potential for natural disasters, with floods, landslides, and hurricanes being common occurrences in the area. In 2021, the regency has an index value of disaster risk of 124.77 [11] and 108.91 in 2022 [12]. This categorizes it as having a medium level of disaster vulnerability in both years according to Indonesian standards.

Given the factors mentioned earlier, this research uses the risk matrix, as demonstrated in Kovačević et al. [13], and Li et al. [14], as well as the House of Risk (HoR) hase 2 framework, as outlined by Natalia et al. [15], Setiawan and Pramana [16], and Kristanto and Hariastuti [17], to assess potential disaster risks. This analysis will assist authorities in formulating and developing disaster mitigation activities in Wonogiri Regency from 2021 to 2025. The framework was selected because the study scope was tailored to BNPB (*Badan Nasional Penanggulangan Bencana*) framework of reference. This study is expected to contribute to DRR efforts in the context of regencies.

It is important to note that there have been few published studies on disaster mitigation consisting of all potential disasters in the Wonogiri Regency. For example, Darmawan et al. [18] determined the vulnerability level of soil movement and its distribution by using the Storie Method. Another study focused on an eco-drainage system for hydrometeorological disaster mitigation in the context of the Keduang Sub-Watershed, Wonogiri Regency [19]. Additionally, a terracing approach was used to analyze slope stability in Sendangmulyo Village, Wonogiri Regency by Pramudo et al. [20] and Surjandari et al. [21]. However, there is a lack of published scientific articles on the combined use of a risk matrix and HoR as a tool for disaster mitigation in the area. One of the closest studies in this area was carried out by Karningsih et al. [22] combining HoR phase 2 and a waste relationship matrix (WRM) and subsequently forming a new tool known as the lean assessment matrix.

Methods

Location and Time of Study

The observation and data collection for analyzing disaster risks in the regency and the formulation of disaster mitigation strategies were carried out from June 1st to June 30th, 2021. The steps included key persons at *Badan Penanggulangan Bencana Daerah* (BPBD or Regional Disaster Management Agency) in Wonogiri. The results were then contextualized by carrying out a comparison with previous studies and work in the field.

Data Collection Methods

Interview

Iterviews were carried out with two resources from the BPBD of Wonogiri Regency: The Head of the Emergency and Logistics Section (referred to as resource person 1) and the Head of the Prevention and Preparedness Section (referred to as resource person 2). The two officers were selected for several reasons. First, their capabilities are mostly relevant to this study. Second, they held the second-highest rank in the BPBD. Third, they adequately represented the 26 BPBD officers. According to Article 21 of Law Number 24 of 2007 on Disaster Management [23], one of the responsibilities of the BPBD is to establish guidelines and directions in accordance with local government and BNPB policies on disaster management strategies such as DRR, emergency management, rehabilitation, and reconstruction fairly and equitably.

Literature Study

This method of data collection was used to accumulate resources, references, data, and information that served as essential inputs for the study. The information required is the annual history of catastrophes in the regency, disaster categories, and the number of catastrophes in the regency.

Data Analysis Methods

In this study, data analysis was first performed by applying a risk matrix, which is a method used to rank and prioritize the risks associated with various events. In addition, HoR - a method that combines the principles of Failure Mode and Effect Analysis (FMEA) with House of Quality (HoQ) is also used. Specifically, this study uses the phase 2 framework of the HoR, selected because of its mechanism, which enables the formulation of strategies aimed at disaster risk prevention. Subsequently, the risk matrix was used as follows:

1. The step started with an interview with resource persons 1 and 2 to gather information on probable disasters that occurred (or potential disasters) in the Wonogiri Regency.

2. The next step involved calculating the Aggregate Risk Potential (ARP) value for each potential disaster. This step was carried out by the second author in collaboration with resource persons 1 and 2 and consists of three sequential parts:
    a. First, we calculated the frequency (the chance of occurrence during a given period) for each potential disaster. The frequency rating scale ranges from 1 (shallow events/occurs only in exceptional conditions) to 5 (extremely high occurrence/most likely to occur frequently).
    b. Second, we calculated the consequences (or effects) of each potential disaster. The consequence rating scale ranged from 1 (no impact) to 5 (major impact) (highly significant impact).
    c. Third, the ARP value is produced for each potential disaster. This is performed by multiplying the frequency and consequence values of the potential disaster.
3. Finally, the evaluation of each catastrophic risk frequency and consequence is incorporated into a risk matrix [2] to determine the risk value for each potential disaster. In this process, extreme risk is denoted by red, high risk is represented by orange, green signifies moderate risk, and low risk is characterized by yellow.

The implementation of HoR [24] phase 2 involves three major steps, as follows:

1. The first step included a discussion with resource person 2 to derive disaster mitigation strategies and the total value of effectiveness (TE_k). This consists of three steps.
    a. Producing disaster mitigation strategies.
    b. Determining the correlation between a particular potential disaster and the specified mitigation strategy. In this process, the alternatives for the correlation value are 0 (no correlation), 1 (low correlation), 3 (medium correlation), and 9 (high correlation).
    c. Calculate the total value of the effectiveness (TE_k) for each strategy.
2. The second step was to determine the degree of difficulty for each strategy, along with resource person 2. This is obtained by performing the following sub-steps:
    a. First, the criteria for assessing the difficulty of implementing mitigation strategies are determined.
    b. Second, the weights of the criteria were determined using a scale of 0.00 to 1.00.
    c. Third, we assessed the degree of difficulty in implementing a particular strategy in terms of a certain criterion: 0 (no difficulty at all), 1 (low degree of difficulty), 3 (medium degree of difficulty), and 9 (high degree of difficulty).
    d. Fourth, determining the total degree of difficulty (TD_k) of each strategy by summing up the multiplication of the degree of difficulty of the strategy and the weight of each criterion.
3. The third step includes determining the ratio of the total value of effectiveness to the total degree of difficulty (EDR_k), and the rank of the mitigation strategies (R_k) based on the ratio.

The implementation of HoR phase 2 produces a list of natural disaster mitigation strategies that will occur in Wonogiri between 2021 and 2025.

Results and Discussion

The number of disasters that have occurred in Wonogiri from to 2016–2021 is shown in Table 1. The potential disasters that can occur are listed in Table 2. The results of the assessment of the frequency, consequences, and aggregate risk potential (ARP) of each potential disaster are presented in Table 3. The risk matrix for potential disasters is shown in Figure 1.

Among the potential disasters that could occur, as presented in Table 1, landslides have the highest number of recorded events, followed by strong winds, floods, and land and forest fires. Based on the interviews, seven potential disasters were identified (Table 2). This is in line with the investigation carried out by Suyanto et al. [25], which shows that the five disasters frequently occurring in Wonogiri are drought, landslides, floods, and earthquakes. Subsequently, these potential disasters were similar to those mentioned in Law No. 24 of 2007 [23]. Furthermore, potential disasters in Wonogiri, such as floods, landslides, earthquakes, and tsunamis, were also found in Central Sulawesi [26]. Similarities can also be observed in the investigation conducted in the Kediri Regency [27], which identified potential disasters such as volcanic eruptions, floods, earthquakes, landslides, and cyclones. The difference in potential disasters depends on the geographical location and area characteristics.

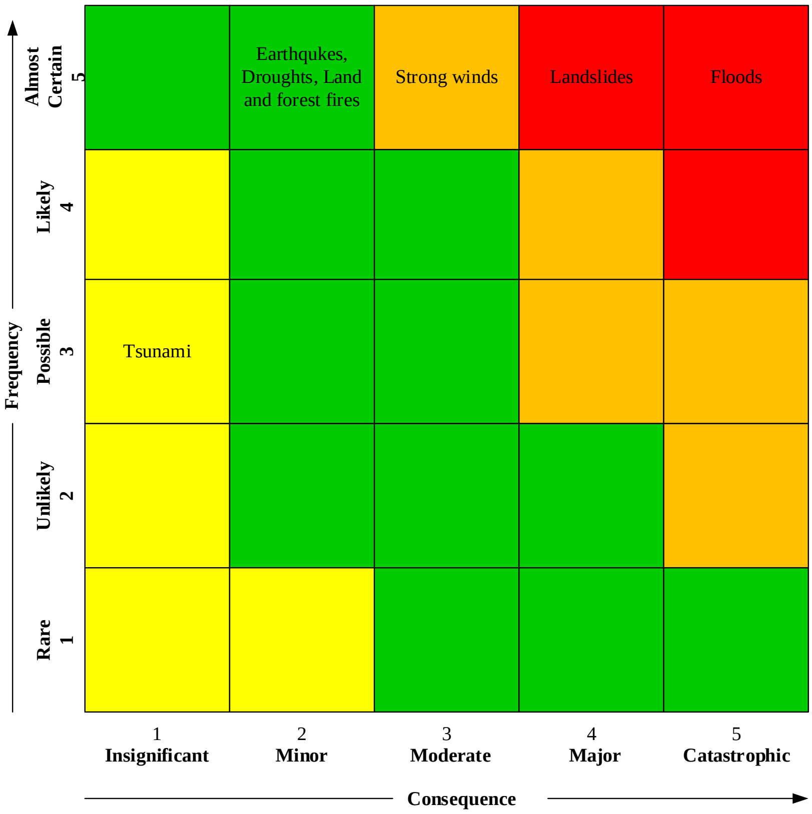

Figure 1. Risk matrix.

Table 1. Number of natural disasters in Wonogiri between 2016 and 30 June 2021[*)].

Natural disasters	Year						
	2016	2017	2018	2019	2020	2021	Total
Landslides	119	976	359	56	34	22	1566
Floods	131	267	64	134	95	23	714
Strong winds	195	51	119	498	93	34	862
Land and forest fires	24	23	62	60	5	2	176
Total	338	1317	604	748	227	81	

[*)] Source: [28]; data until 30 June 2021.

Table 2. Potential disasters in Wonogiri.

No.	Potential disasters	No.	Potential disasters
1	Floods	5	Tsunamis
2	Landslides	6	Forest/land fires
3	Strong winds	7	Droughts
4	Earthquakes		

Previous studies have identified the negative effects of potential disasters, as shown in Table 2. For instance, floods that occurred in Semarang resulted in loss of life and property [29], whereas landslides led to human casualties, property losses, environmental damage, and psychological impacts [30]. Strong winds affecting the Suramadu Bridge caused traffic congestion and accidents, posing risks to the surrounding communities [31]. Drought has adverse effects, including difficulties in accessing clean and irrigation water [32]. Furthermore, tsunamis have had a significant impact, leading to casualties and economic losses [33], which has resulted in numerous casualties and thousands of people being placed in refugee camps [34]. Forest fires affect the environment by contributing to irreversible degradation of the permafrost environment [35] and by affecting soil greenhouse gas emissions in upland boreal forests [36]. Considering these facts, mitigation efforts are needed to prevent and reduce the impact of disasters. Using the ARP values presented in Table 3, a risk matrix for potential disasters was produced, as shown in Figure 1.

Table 3. Aggregate risk potential (ARP).

Potential disasters	Frequency	Consequence	ARP
Floods	5	5	25
Earthquakes	5	2	10
Landslides	5	4	20
Strong winds	5	3	15
Droughts	5	2	10
Land and forest fires	5	2	10
Tsunamis	3	1	3

According to Table 3 and Figure 1, the risk assessment shows that floods and landslides in Wonogiri, with ARP values of 25 and 20, respectively, were classified as having extreme risks. Disasters of this nature take precedence in terms of mitigation, and regions exposed to these risks may face critical conditions if not promptly addressed. Strong winds, with an ARP value of 15, are categorized as high-risk, signifying a very high frequency of occurrence and significant impact, necessitating regular risk management and effective control. Subsequently, earthquakes, droughts, and land and forest fires were considered to be at medium risk (all three with an ARP value of 10). This suggests that disaster risk is characterized by a very high frequency of occurrence with a moderate impact. Tsunamis, on the other hand, were deemed to have a lower risk, as indicated by their ARP value of 3.

HoR phase 2 is used to generate mitigation strategies, and priorities are carried out based on various factors, including the time required for implementation, facility and infrastructure needs, human resource requirements, and financial resources. In HoR phase 2, the total value of mitigation strategy effectiveness (TE_k), the total degree of difficulty (TD_k) in implementing the strategy, the ratio of the total value of effectiveness and the total degree of difficulty (EDR_k) for each strategy, and the rank of the mitigation strategies (R_k) based on the ratio are produced. Table 3 lists the potential disasters in descending order, whereas Table 4 lists the corresponding ARP values along with their respective symbols. The results of the potential disaster identification were used as a reference for determining mitigation strategies (Table 5).

Table 4. Potential disasters in the order of ARP value.

Symbol	Potential disasters	Symbol	Potential disasters
R1	Floods	R5	Land and forest fires
R2	Landslides	R6	Droughts
R3	Strong winds	R7	Tsunamis
R4	Earthquakes		

Table 5. Mitigation strategies for potential disasters.

Symbol	Mitigation strategies	Symbol	Mitigation strategies
S1	Strengthening the legal framework for disaster management	S6	Developing early warning systems
S2	Establishing disaster-resilient villages	S7	Conducting socialization and education on disaster mitigation
S3	Conducting area mapping	S8	Increasing reforestation activities
S4	Installing evacuation points	S9	Creating and multiplying water catchment areas
S5	Increasing multi-stakeholder partnerships in disaster management		

Based on the interviews with resource person 2, nine mitigation strategies were proposed to deal with potential disasters in Wonogiri from 2021 to 2025 (Table 5). The results of potential disasters (Table 4) and mitigation strategies are subsequently processed into HoR phase 2, of which the final output, including the TE_k value for each strategy, is shown in Table 6. According to the results in Table 6, S1 (strengthening the legal framework for disaster management), S5 (increasing multi-stakeholder partnerships in disaster management), and S7 (conducting socialization and education on disaster mitigation) have the highest TE_k values of 837; S3 (conducting area mapping) has a TE_k value of 757; S2 (establishing disaster-resilient villages) has a TE_k value of 699; S8 (increasing reforestation activities) and S4 (installing evacuation points) have TE_k values of 435 and 432, respectively; and S9 (creating and multiplying water catchment areas) has a TE_k value of 255.

Table 6. House of Risk Phase 2.

Risk	Mitigation strategies									ARP
	S1	S2	S3	S4	S5	S6	S7	S8	S9	
R1	9	9	9	9	9	9	9	9	9	25
R2	9	9	9	9	9	9	9	9	0	20
R3	9	9	9	0	9	1	9	0	0	15
R4	9	3	9	0	9	3	9	0	0	10
R5	9	3	1	0	9	0	9	0	0	10
R6	9	9	9	0	9	3	9	3	3	10
R7	9	3	9	9	9	9	9	0	0	3
TE_k	837	699	757	432	837	507	837	435	255	

Table 7. Criteria for assessing mitigation strategies.

Symbol	Assessment criteria for mitigation strategies	Weight
C1	Time required to complete the strategy	0.25
C2	Requirement of facilities and infrastructure	0.25
C3	Requirement of human resource expertise	0.25
C4	Amount of funds required	0.25

According to the results of the interviews with resource person 2, four criteria (Cs) for assessing the degree of difficulty in dealing with the implementation of mitigation strategies are shown in Table 7. Based on the results of data processing obtained from interviews with the same resource person, the priority order of the mitigation strategies, R_k, was obtained, as shown in Table 8. Table 9 shows the mitigation strategies according to the order of priority implemented by the Wonogiri BPBD from 2021 to 2025. According to the results in Table 9, "Increasing multi-stakeholder partnerships in disaster management"; "Strengthening the legal framework for disaster management"; "Conducting socialization and education on disaster mitigation"; "Establishing disaster-resilient villages"; "Conducting area mapping"; and "Increasing reforestation activities" have a significant influence on DRR. These strategies show relatively small differences in *the* EDR_k values. "Developing early warning systems"; "Installing evacuation points"; and "Creating and multiplying water catchment areas" are the strategies with the three lowest priorities.

Table 8. The priority of the assessment criteria.

Criteria	Mitigation strategies									Criteria Weight
	S1	S2	S3	S4	S5	S6	S7	S8	S9	
C1	9	9	9	9	9	9	9	9	9	0.25
C2	1	9	9	9	0	9	9	9	3	0.25
C3	9	9	9	9	9	9	9	3	9	0.25
C4	1	3	9	9	1	9	3	3	3	0.25
TE_k	837	699	757	432	837	507	837	435	255	
TD_k	5.00	7.50	9.00	9.00	4.75	9.00	7.50	6.00	6.00	
EDR_k	167.40	93.20	84.10	48.00	176.20	56.30	111.60	72.50	42.50	
R_k	2	4	5	8	1	7	3	6	9	

Table 9. The order of priority of mitigation strategies.

Symbol	Mitigation strategies	EDR_k
S5	Increasing multi-stakeholder partnerships in disaster management	176.20
S1	Strengthening the legal framework for disaster management	167.40
S7	Conducting socialization and education on disaster mitigation	111.60
S2	Establishing disaster-resilient villages	93.20
S3	Conducting area mapping	84.10
S8	Increasing reforestation activities	72.50
S6	Developing early warning systems	56.30
S4	Installing evacuation points	48.00
S9	Creating and multiplying water catchment areas	42.50

The mitigation strategies listed in Table 9 are similar to the findings of other researchers. For example, Ruswandi Et al. [37] discussed disaster mitigation in Indramayu and Ciamis, demonstrating strategies such as community socialization, early warning systems, self-rescue systems, and improving regulations/laws. Galve et al. [38] and Galve et al. [39] demonstrated the importance of reforestation in reducing the occurrence of landslides. Martini [26] reported the importance of mitigation strategies, one of which is to collaborate with the government and community. Horhoruw et al. [40] mentioned a comprehensive set of disaster mitigation measures, including making evacuation locations and temporary shelters, establishing access points used to reach evacuation locations, drainage with adequate sizes following data on the type and absorption capacity of the soil, designing infiltration wells, river embankments to reduce flood risk, early warning systems, and construction of temporary garbage dumps. The following paragraphs provide a more detailed discussion of the top six mitigation strategies. This analysis is carried out by presenting results, opinions, and conclusions from various papers and manuscripts related to each of the proposed mitigation strategies or from similar proposals across different contexts.

Increasing Multi-Stakeholder Partnerships in Disaster Management (The Priority of Mitigation Strategy)

According to Parkash [41], one of the crucial aspects of disaster mitigation is fostering cooperation, coordination, and collaboration. Kapucu and Garayev [42] reported that cooperation with various stakeholders and mutual assistance between countries in disaster risk management was considered relatively satisfactory. Based on KRB (*Kajian Risiko Bencana* or Disaster Risk Study) of Central Java 2016–2020 [43], partnerships can be further enhanced through engagement with educational institutions. One example is the development of a localized curriculum for DRR at all educational levels, as this is considered capable of increasing efforts in the community from an early age. Concepts and practices regarding DRR and recovery can be included in the school curriculum. According to resource persons 1 and 2, Wonogiri BPBD has actively collaborated with various institutions such as the government, business people, the community, and the mass media in implementing disaster management. Increased partnerships with multiple parties are carried out to reduce the impact of potentially arising disaster risks.

Strengthening the Legal Framework for Disaster Management (The Second Priority of Mitigation Strategy)

The foundation for disaster management in Indonesia is Law Number 24 of 2007. This law serves as the principal guiding document for the execution of disaster management, which is followed by its implementing regulations in Government Regulation No. 21 of 2008 concerning the implementation of Disaster Management [44] and Government Regulation No. 22 of 2008 concerning the funding and management of disaster relief [45].

Based on the results of Susetyo [46], regarding the pressing need for disaster management laws at that time, one significant factor contributing to the ineffectiveness of disaster management in Indonesia was the absence of policies and regulations at the central level. These policies were not widely and comprehensively executed and were not in line with international disaster management practices or addressed the legal needs of the community. Consequently, Susetyo [46] stressed the urgency of enacting a disaster management law and emphasized the importance of harmonization following the implementation of Law No. 24 of 2007. This is in line with the investigation conducted by Anggono [47] regarding the harmonization of disaster management, which states that Law No. 24 of 2007 is closely related to other laws and regulations governing natural resources. Therefore, harmonizing Law No. 24 of 2007 with sectoral laws was deemed essential to prevent overlap or inconsistency and provide legal certainty. According to Kartika [48], one of the strengthening factors for disaster management policies in harmonizing legislation is to reinforce disaster management institutions and review and revise disaster management legal policies. Referring to Wibowo and Satispi [49], one of the implementations of Law No. 24 of 2007 concerning disaster management is fortifying regional disaster management planning based on the KRB. This approach enables more effective disaster-management planning.

Based on 2016–2020 Central Java KRB page 58 [43], strengthening the legal framework for disaster management includes maintaining the availability of budgetary reserves related to unexpected costs for the implementation of regional disaster emergency management at the provincial level. This ensures that basic needs are met and groups/communities/areas vulnerable to the impact of disasters can be protected. Additionally, these reserves can be allocated for the recovery of critical facilities. To ensure the availability of the reserved budget, it is necessary to formulate regulations regarding the mechanisms for providing and managing disaster emergency responses. This regulation is equipped with a supervisory mechanism to manage the availability of reserve funds. The availability of budget reserves must be synchronized with regional contingency plans to ensure that emergency management can be implemented more quickly and systematically. Therefore, budget reserves must also be considered at the regency/city level.

Conducting Socialization and Education on Disaster Mitigation (The Third Priority of Mitigation Strategy)

Education plays an important role in mitigating disasters and improving overall well-being [50]. Using Southeast Asian countries as a case study, Hoffmann and Blecha [51] found that education has a direct impact on disaster vulnerability. It is crucial to target disaster and emergency education for groups that are particularly susceptible to disasters [52]. Disaster socialization and education are critical factors in disaster management. This approach is carried out to increase public awareness, provide knowledge about recognizing disaster potentials in the respective areas, know what actions need to be taken when a disaster occurs, and know follow-up plans to lower the impact of disaster risks. Based on the interviews with resource persons, various disaster socializations and education have been carried out in areas prone to disasters in Wonogiri. These efforts have been carried out through sub-districts and by using posters, websites, and so on.

Establishing Disaster-Resilient Villages (Fourth Priority of Mitigation Strategy)

The strategy for establishing disaster-resilient villages is in line with other studies. Saroji et al. [53] conducted an empirical study of a disaster-resilient village program carried out by two different institutions on community resilience in dealing with the tsunami disaster. Oktari [54] dealt with capacity building for disaster-resilient villages. The importance of disaster-resilient communities has also been studied [55]. Habibullah [56] found that disaster-resilient villages could improve community understanding and awareness, allowing community members to build networks and organize and maximize potential and resources. According to Perka (*Peraturan Kepala*) BNPB no. 1 of 2012 [57], five out of 20 important indicators must be present in disaster-resilient villages: analysis, threats, vulnerabilities, capacities, and risks; maps, evacuation routes, and evacuation shelters; early warning systems; training for village governments; and training for villagers. Shaw et al. [50] reported that the importance of disaster education was widely recognized in reducing disasters and achieving security. Furthermore, Dufty [58] proposed disaster education as an important means of ensuring public safety. In 2021, the Wonogiri BPBD formed 170 disaster-resilient villages out of 294 recorded urban villages. These designated villages empower communities to independently identify, minimize, and control disaster risks.

Mapping the Area (The Fifth Priority of Mitigation Strategy)

One of the efforts to minimize the negative impacts of disasters includes providing maps of disaster-prone areas that can be used for planning, control, and early management [59]. Mishra et al. [60] recommended mapping disaster-prone areas to increase and strengthen disaster management. Subsequently, various investigations of disaster area mapping have been conducted. This includes the works by Harto et al. [61] on mapping disaster-prone areas using the Geographic Information System, the area mapping by Nuryanti et al. [59] using remote sensing and geographic information, and the risk mapping of storm flood disasters based on heterogeneous data and a machine learning algorithm in the Xinjiang, China context carried out by Liu et al. [62].

Increasing Reforestation Activities (The Sixth Priority of Mitigation Strategy)

The concept of using reforestation to reduce a variety of disaster risks has been supported by many investigations. In line with the investigation by Kirno and Sarwono [63], the most efficient way of controlling erosion is reforestation of highlands and forests. Demirel et al. [64] reported that among the alternatives of reforestation, terracing, windbreaks, and farming techniques, reforestation was the most optimal choice for preventing soil erosion. Marden et al. [65] recommended that, regarding the Waipaoa catchment, New Zealand, reforestation could reduce erosion by 51%. Veldkamp et al. [66] suggested that many of the effects of deforestation, including soil erosion, can be reversed by reforestation. Tidball et al. [67] suggested that community-led reforestation and resilience in disaster-interrupted social–ecological systems had the probability of consulting each other.

According to Locatelli et al. [68], tropical reforestation can mitigate climate change and reduce susceptibility to climate change. Istijono et al. [69] proposed reforestation as a cost-effective measure to reduce vulnerability to landslides in the Maninjau Lake area of West Sumatra, Indonesia. Galve et al. [39] suggested reforestation as the most effective action for stabilizing slopes in an area of northwest Italy that experienced a rainfall-induced landslide event in 2011. In the context of lands primarily cultivated with winter wheat in south-central Italy, Ricci et al. [70] reported that reforestation in combination with contour farming was the most effective method for erosion control among reforestation, no-tillage, contour farming, and reforestation with contour farming.

Reforestation activities in Wonogiri Regency play an important role in maintaining the balance of nature. An example of these efforts is the DRR forum, a collective initiative of the community across Wonogiri Regency committed to disaster awareness and prevention. Additionally, one of the key activities in this forum is reforestation, which includes establishing nurseries and cultivating prioritized plants for land and water conservation. The plants are *banyan* trees (*Ficus benghalensis*), *trembesi* trees (*Samanea saman*), *talok* (*Muntingia calabura*), *duwet* (*Syzygium cumini*), tamarind (*Tamarindus indica*), and vetiver grass or *akar wangi* (*Chrysopogon zizanioides*).

Conclusion

Based on the results and discussion, it was found that, first, the disaster risks with potential to occur in Wonogiri Regency, Indonesia, include floods, landslides, strong winds, earthquakes, land and forest fires, drought, and tsunamis. Second, the risk categories, along with their ARP values for each risk, were as follows: floods were categorized as an extreme risk with an ARP value of 25, and landslides had an ARP value of 20, falling into the extreme risk category, high risk for strong winds (ARP value of 15), moderate risk for earthquakes, drought, land, and forest fires (ARP value of all three 10), and low risk for tsunamis (ARP value of 3). Third, nine mitigation strategies were proposed according to the order priority, namely “Increasing multi-stakeholder partnerships in disaster management”; “Strengthening the legal framework for disaster management”; “Conducting socialization and education on disaster mitigation”; “Establishing disaster-resilient villages”; “Conducting area mapping”; “Increasing reforestation activities”; “Developing early warning systems”; “Installing evacuation points”; and “Creating and multiplying water catchment areas.” These strategies are expected to strengthen Wonogiri BPBD’s efforts to reduce disaster risks in the regency by identifying prioritized strategies that need to be implemented. In this context, this study is in line with the BPBD plans for reducing disaster risks in Wonogiri from to 2021–2025. However, due to the absence of the first rank officer of Wonogiri BPBD from the resource persons, it is recommended that the results be presented to a wider audience of BPBD (where there is the first rank officer of the agency) first in order to obtain stronger support and understanding.

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