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Updating Risk Level on Housing Resettlements of Mount Merapi Using a Visual Chart Examination

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Abstract

Permanent housing resettlement (*Huntap*) on the slopes of Merapi from the 2010 great eruption supposedly has experienced development progress. Undergoing adjustments due to environmental circumstances, hazard knowledge, and people's understanding are inevitable and affect the safety performance of the shelter against volcanic hazards. Many dwellings are still in the most dangerous area, while the hazards will strike again sooner or later. This research intends to update Merapi *Huntap's* safety risks to mitigate volcanic disasters. We assessed the safety of 15 settlements and focused on calculating five selected *Huntaps* for their spatial and formal configuration to the dwellers' awareness. Detailed observation by a proposed visual chart method based on the hazard and degree of vulnerability discovered from hazard-prone zones (KRB). Resilience factors to safety, including access for evacuation, the dwelling, and community consciousness of disaster, discovered the disaster risk level. We found that disaster risk in Merapi's resettlement is still high; thus, the people and stakeholders need to pay more attention to the need for precautions. Mitigation should address the potential safety threats related to (1) Hazard-prone levels, (2) Spatial confusion for up-to-date disaster zones, (3) less consideration of evacuation barracks and routes, and (4) people's lower understanding and awareness. Through this research, we also discovered the proposed simple and easy-use method suitable for classifying the risks. The research was limited to Mount Merapi's resettlement housing after the 2010 eruption by examining five *Huntaps* with higher hazard susceptibilities. This study contributes to reevaluating the risk-hazard-resilience by practical measures for driving higher disaster awareness in the future. The proposed method proved its appropriateness in testing the risks and has the prospect of being used in further applications in more massive cases.

Keywords:
Housing safety, Huntap Merapi, Disaster mitigation, Visual chart, Volcanic hazards.

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INTRODUCTION

Mount Merapi is one of Indonesia's most active volcanoes, periodically causing volcanic hazards and often resulting in disaster in Yogyakarta. Its volcanic activity lasts about 2-7 years, and a major eruption is likely to occur every 100 years, with deadly pyroclastic flows up to 15 km (PVMBG, 2014). This volcano was also suspected of causing many disasters, including the fall of the great Javanese Kingdom Mataram in 1006 (Kusumayudha et al., 2019). The fatalities were caused mainly by clouds of super-heated gases (*wedhus gembel*) at 200-300 °C with a speed of 200 – 300 km/h. The deadliest eruption occurred in 1672, with a death toll 3,000 (Dove, 2008). From 26 October to 5 November 2010, Mount Merapi erupted eight times with a high intensity of the Volcanic Explosion Index (VEI) ≥ 4 (Bawole, 2015). The eruptions spread a disaster within a radius of 20 km, causing loss of life, property damage, and changing the mountain landscape. The pyroclastic flows downed towards the Southeastern sector, mainly via the Gendol River, reached up to 17 km away, the Southwestern area on the Krasak Rivers via Bebeng 11.5 km and Bedog 8.5 km, and other rivers less than 8 km (ESDM, 2010). The eruption was the largest in this century after previously recorded in 1822, 1872, 1930-1931, and 1961 (Muktaf et al., 2018). The 2010 disaster claimed the lives of 367 people, displaced no less than 400,000 residents, and 3,931 families lost their homes (Mei et al., 2016; Sukhwani et al., 2021). Although most displaced people returned to their homes after the event, the losses from the eruption of Merapi 2010 were about Rp. 2.14 Trillion or USD 142,7 Million (BNPB, 2011).

The government previously provided resettlement programs by moving the people from dangerous areas, yet mostly failed. Though supported by a world-class scientific service, monitoring, and dissemination, Merapi's problems were still in the intake (Mei et al., 2013). In most cases, people refuse house relocation (Dove, 2008; Griffin & Barney, 2021; Juniansah et al., 2018; Mei et al., 2013). The transmigration of 1905 villagers followed the 1961 eruption, resetting the affected villagers of Turgo in 1978 failed, and relocation of the slope villages in 1994 was unsuccessful likewise. Due to the 2010 eruption, the government completed housing replacement or *Huntap* in 2014. The *Huntap*s, *mainly* spread over 15 sites in Yogyakarta, have been built, with each family getting about 100 m2 of land and 36 m2 of houses in the lower and safer sites (*see Figure 1*). The permanent housing costs Rp 30 million up to Rp 50 million per family for the house and residential facilities (Bawole, 2015). A community engagement project scheme adopted from REKOMPAK (Community-based settlement for rehabilitation and reconstruction) has built 2,750 shelters as in the 2006 Yogyakarta earthquake (Sukhwani et al., 2021). This project has succeeded in resetting thousands of residents to relatively safer settlements.

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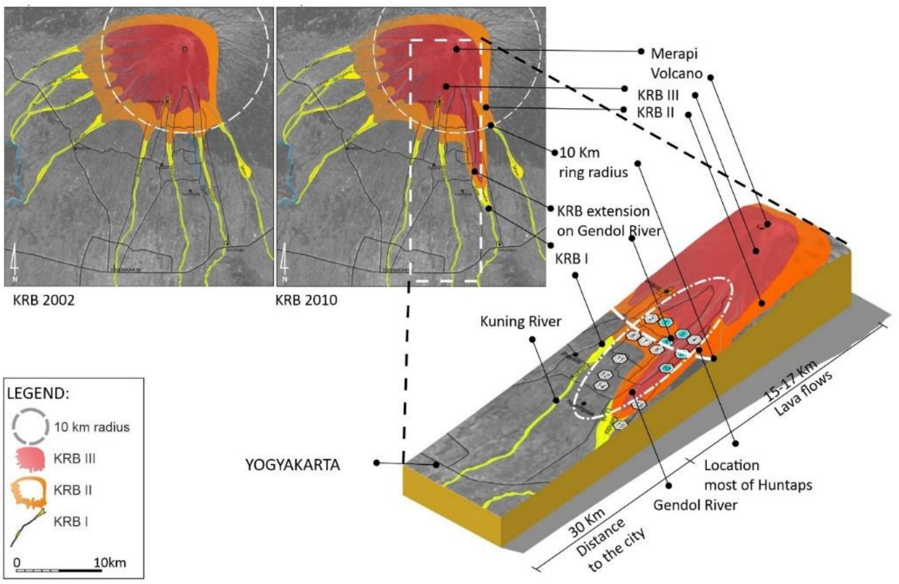

Figure 1. Merapi Hazard-prone extension and impact on the *Huntaps* vulnerability levels.

Nevertheless, the Merapi hazard-prone area or *Kawasan Rawan Bencana* (KRB) has shifted since the unprecedented 2010 great eruption, corresponding to the disaster risk and vulnerability levels. The extended pyroclastic flows have defined more expansive hazard-prone areas and increased the danger status of the Gendol River line 15-17 km down (Geological Agency, 2018; BPBD-DIY, nd; ESDM, 2010; Sayudi et al., 2010). KRB Merapi divides three level zones, from higher to lower threats, namely KRB III, II, I, and an unsafe area inside a radius 10 km from the peak with the potential attack by 2-6 cm flame-rock bombardiers and heavy ash rain (ESDM, 2010; Sayudi et al., 2010). KRB III, or high-hazard zone, is the most dangerous area, which mostly encounters pyroclastic flows in the form of super-heated clouds, ballistic debris, falling ash, and toxic gas. KRB II, or intermediate-hazard zone, is the area surrounding as an extension of KRB III with similar risks in more enormous eruptions. KRB I, or low-hazard zone, is sideways along the main rivers, possibly filled by flooding lahars mainly by cold materials. Dwelling should stand away from the KRB III. Changing the zone status increases disaster exposure and will seriously impact safety.

Huntap Merapi spreads mainly in the Sleman Regency on the southern slope of Merapi, starting from the highest point adjacent to the vent, sideways to the lava flows, or resting in the lower area. All the resettlement locations are close to existing villages nearby, which have proven to be less affected by the 2010 eruption. However, the extension of the KRB puts many dwellings in various zones at KRB III and II, likely increasing the risk of disaster (*see Figure 2*).

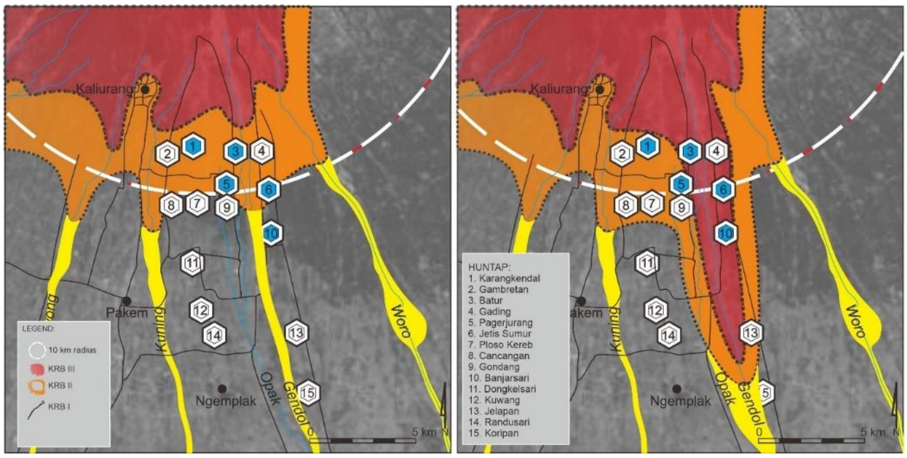

Figure 2. The change in Merapi's hazard-prone zone related to *Huntaps* before and after the 2010 eruption. The blue points indicate the five study locations from 15 resettlements.

The government released the map immediately after the eruption, dated 2010, but its dissemination needed to be better than the residential redevelopment process. Many areas previously considered safer zones are now found in a red zone or KRB III. Five of them, Karang Kendal, Gambretan, Batur, Gading, and Pagerjurang, are still inside the 10 km peak radius. Batur and Gading, together with Jetis Sumur, Banjarsari, and Jelapan, are now also in KRB III primarily because of the path of the main pyroclastic flows along the upstream of the Gendol River (*see Table 1*). Other *Huntaps* are still in relatively safe areas, although the Lahar floods swept down to 25 km away - 500 meters wide, such as in the Putih River, which destructed 22 dams (Hadmoko et al., 2018). The total number of resettlement households was 1709, with more than 7000 inhabitants making up the vulnerable population. The side is the most dangerous area, up to 20-25 km from the summit, threatening more than 400.000 people (Global Volcanism Program, 2011).

The *Huntap* aims not only to provide physical post-disaster resettlement but also to comprehensively mitigate the disaster with the people. Previously, the evacuation of the people was also not easy because of many complicated local factors (Maharani et al., 2016; Mei et al., 2013; Muir et al., 2020). Furthermore, the government still tolerates low-density settlements in the disaster zone, including KRB III, which may result in confusion and complications in the future (Fathurrohmah & Kurniati, 2017). Housing resettlement has been reconstructed to new locations relatively far from the peak. However, it does not mean being free from danger. Some research confirms that most people near Merapi eruption-prone need to be aware of the risk (Donovan, 2010; Dove, 2008; Kusumayudha et al., 2019; Lavigne et al., 2008). People commonly do not consider Merapi eruptions significant threats (Lavigne et al., 2008; Sopha et al., 2018). Potential hazard neglect is also common in other places in the rest of the world. People mostly do not perceive that they are under safety threat and are reluctant to evacuate when hazards are about to strike (Bird et al., 2009; Cashman & Cronin, 2008; Haynes et al., 2007; Sopha et al., 2018).

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Table 1. List of Huntap Merapi in the Sleman Regency area.

No	*Huntap*	Number of households	Area (m2)	Distance to the peak (km)	Distance to the main river (km)	Danger zone (KRB)
1.	**Karang Kendal**	81	13,365	8.0	1.8	II
2.	Gambretan	21	1,890	8.2	2.6	II
3.	**Batur**	204	33,660	8.3	0.6	III
4.	Gading	62	11,282	8.5	0.5	III
5.	**Pagerjurang**	301	49,665	9.5	1.4	II
6.	**Jetis Sumur**	81	12,559	10.2	0.6	III
7.	Ploso Kereb	84	17,922	10.5	1.6	II
8.	Cancangan	92	*8,280*	10.5	2.7	II
9.	Gondang	125	20,972	10.7	0.7	II
10.	**Banjarsari**	178	28,000	11.7	0.6	III
11.	Dongkelsari	147	24,690	12.0	2.2	-
12.	Kuwang	138	23,250	14.7	1.9	-
13.	Jelapan	48	4,320	14.8	0.1	II
14.	Randusari	109	16,387	15.0	2.0	-
15	Koripan	38	5,900	17.5	0.6	I

Settlements' progress is always related to the changes in its citizens' physical and social circumstances, which will affect the level of safety. Unfortunately, the government released the up-to-date hazards-prone mapping while *Huntap* development was in the process without appropriate dissemination. Although the government has promoted international scientific research devoted to Merapi for decades, it was very least involving local knowledge (Dove, 2008). Even in many hazardous events, traditional and local knowledge has saved countless lives (Griffin & Barney, 2021). Thus, safety continuing examination is critical in establishing Mount Merapi shelter progress related to distancing the volcano, avoiding the eruption path, handling evacuation safely, and ensuring the facilities. The people themselves are also vital. This research examines the up-to-date Merapi's disaster risk level in an integrated but simple way of the settlement's evaluation considering the zoning, spatial arrangement, evacuation facilities, housing qualities, and people awareness.

STATE OF THE ARTS

Scholars have discussed Mount Merapi's physical and social issues. Many focused on social aspects, such as how the Javanese deal with volcanic hazards (Donovan, 2010; Dove, 2008; Griffin & Barney, 2021; Lavigne et al., 2008). While on environmental aspects, some studies engaged on physical condition, spatial configuration, and hazard possibilities (Astari et al., 2022; Fathurrohmah & Kurniati, 2017; Muktaf et al., 2018; Pratama et al., 2014; Sari, 2019). In housing subjects, research focuses on the resettlement and its post-occupancy issues (Bawole, 2015; Maly et al., 2015; Mei et al., 2016; Prawitasari et al., 2019). A deeper study on evacuation safety at the Merapi's 2010 eruption has been well explained (Mei et al., 2013). Disaster risk reduction in the aftermath of volcanic eruptions in Merapi was also studied, but financial aid was focused on it (Muir et al., 2020). However, research on safety related to the hazard risk level has been rare since the settlement progressed. This study focuses on Merapi's risk level regarding resettlement for disaster mitigation. It also fills the gap by updating the recent risk evaluation with a proposed visual chart method for ease of examination and user convenience.

RESEARCH METHOD

The research investigates disaster risk levels on the most exposed *Huntaps* in different areas of Mount Merapi by proposing a simple yet unique graphic examination method. The authors initially evaluate the 15 dwelling complexes based on their position according to the new Merapi's disaster-prone zones KRB. KRB is the sole tool to define the risk levels, which is too general yet only based on physical aspects, despite its revision after the 2010 explosion. We intensify five resettlements by considering their capacity to cope with the hazards, or resiliencies, on physical and social aspects. Evacuation facility and accessibility, the houses and environment, the people's understanding, and safety awareness are the four most considered resilience factors. Three settlements, namely Karang Kendal, Batur, and Pagerjurang, represent the closest *Huntaps* to the volcano under the ring of a 10 km radius. At the same time, Jetis Sumur and Banjarsari characterize the dwelling adjacent to the pyroclastic flows zone in the Gendol River (*Figure 3*).

Face-to-face interviews of 59 targeted occupants from the five locations, with 10 to 12 respondents each, confirmed environmental and social aspects and fit to interpret the social resilience levels. The head of neighborhoods (*Dukuh*/RT/RW), the head of families, and their members are interviewed personally to catch their genuine views. Understanding KRB, how and where to evacuate, how to self-protection, and whether they have the initiative to deal with the disaster are the basic questions to confirm their resilience.

Figure 3. The situation of the dwelling of five *Huntaps* for the sample of the research.

The risk level calculates the hazards and their correlation with the resilience capacity, which follows the formula (1).

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$$\textbf{Risk} = \frac{\textbf{Hazard x Vulnerability}}{\textbf{Resilience}} \quad (1)$$

The level of disaster risk thus follows the chart developed from a linear function of minimum to maximum hazard versus minimum to maximum resilience. A unique chart visualizes the risk level (*Figure 4*). The visualization simplifies the complicated and underlying factors, which will be easier to comprehend and the most effective tool (Li & Qin, 2020; Singh et al., 2023). A scale of 0 – 4 represents the hazard and the resilience magnitude. The upper right-hand side direction of the diagonal line is the function of the balance of the risks, the so-called risk limit or risk cut-off. The higher the hazard level, the more resilience is needed to deal with the risks. The line, which always has value 1, divides the risks into two side zones: disastrous and manageable. On the other side, the opposite diagonal is directing risk extremities from the highest on the upper left to the least on the lower right-hand side. Divided triangles represent the area of risk levels. The chart also shows that remedial effort should bring the object from the upper to the lower AND OR from the left to the right-hand section. It means that bringing the disastrous dwelling to a safer state reduces the hazard-prone AND OR increases the level of resiliencies. The risk classification follows:

Safety areas < 1 < Risky areas, *thus*: (2)
Lowest risk < 0.5 < 1 < 1.5 < 2.5 < Highest risk, *thus*: (3)
INSIGNIFICANT < LOW < MODERATE < SERIOUS < SEVERE (4)

The safety and risky areas are divided by accepted level or risk cut-off with value 1 (2). Further, the risky area divides three zones by values 1.5 and 2.5. Conversely, the safety area split into two by 0.5 value (3). The risks thus come to five levels (4).

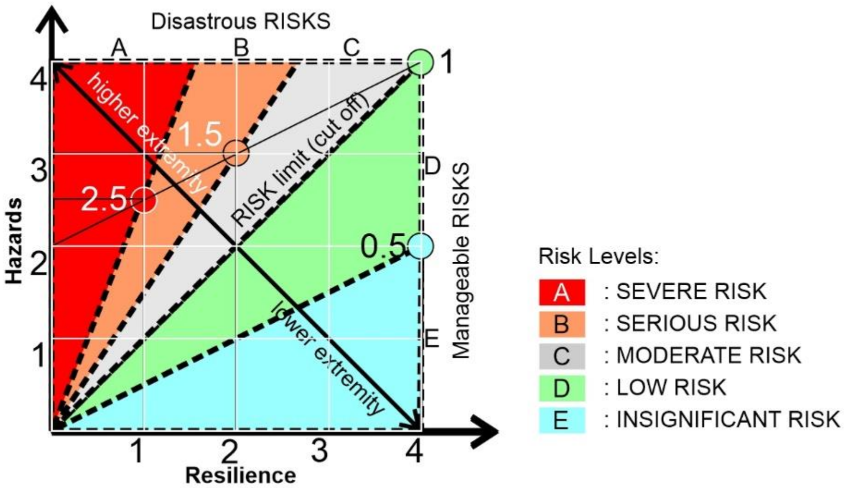

Figure 4. Hazard Risk-Vulnerability Zones Chart.

The result examination of an object will occupy either a disastrous area on the upper left-hand side or a manageable sector on the lower right-hand side. The position on the chart identifies a level correlated with the five risk magnitudes: SEVERE, SERIOUS, MODERATE, LOW, and INSIGNIFICANT. The first three, in the disastrous area, are further defined as correlations with the safety factors resulting from the accepted level 1, which is from 4/4 to the medium of hazard level 2. As a result, the severe risk starts at 2.5, linked with the lowest resilience 1, while the serious risk starts at 1.5, linked with mid-resilience 2. On the other hand, for the last two manageable risks, the insignificant risk below 0.5 from the middle hazard of 2 correlated with the highest resilience 4. The risk level assessment categorizes potential disaster risks and their possible significance to settlement conditions as follows (*Table 2*):

Table 2. Risk levels and their meanings.

Risk levels	Values	Meanings in risks
SEVERE RISK	> 2,5	**Far beyond the limit** (cut-off) The dwellings have too high hazard level but with very low resilience
SERIOUS RISK	≥ 1.5 – 2.5	**Upper the limit** The dwellings have higher hazard level with low resilience or too high hazard level but with very high capacity to coupe
MODERATE RISK	> 1 – 1.5	**Slightly upper the limit** The dwellings have intermediate hazard level with very high resilience or lower hazard level with higher capacity to coupe
LOW RISK	≥ 0,5 – 1	**Below the limit** The dwellings have intermediate hazard level with high capacity in resilience or low hazard with high capacity to coupe
INSIGNIFICANT RISK	< 0.5	**Far below the limit** The dwellings have no significant hazard level but still have capacity in resilience

Grading applies to scaling the degree of potential risks. A specific form is also developed based on most aspects of the vulnerability: hazards exposure and resilience levels of the Huntap. Hazard is danger proximity; consider the hazard-prone zones (KRB) by how close the location is to the source: the volcano and the main river Gendol (*see Table 3*). Resiliencies include both physical and social factors. Physical resilience links the aspects of the evacuation capacities, including the distance and approaching process, to the permanent barracks for evacuation, the access road, and the building itself. The condition of the structure, renovation, and replacement rate the level of physical quality (*Table 4*). Reducing disaster risk also increases people's ability to respond and recover from hazards (Cashman & Cronin, 2008). People's knowledge and awareness determine social resilience (*Table 5*). Each object's value alternates with the applicable options based on their magnitudes.

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Table 3. Hazard levels of Merapi taken from the hazard-prone KRB.

Hazards zones	Hazards exposure	Max Value (=4)	Object Value
KRB III	The most dangerous area which mostly encounter pyroclastic flows in form of super-heated cloud, lava flow, flaring ballistic debris, and toxic gas	3	
KRB II	The area surrounding as an extension of KRB III with similar risks in bigger eruption	2	
KRB I	Sideways along the main rivers whichispossibilityfilled by flooding lahars and probably hit by hot-cloud extension	1	
KRB -	Safe area outside KRB	0	
10 Km radius ring	The area near the crater which is most probably ruined by ballistic debris in >2-6 cm diameter and heavy ash rain	KRB+1	
			0

Table 4. Physical resilience aspects.

Physical Aspects	Physical Aspects	Physical Aspects	Max Value (=2)	Object Value
Evacuation safety	Access	In range and safe (3-7 km)	0.5	
		In range with potential hindrance	0.25	
		Out range	0.1	
	Barracks	Outside KRB	0.5	
		KRB II	0.25	
		KRB III	0	
Housing safety	Housing environment	Evacuation facilities exist	0.5	
		Evacuation facilities limited	0.25	
		No facilities	0.1	
	House	Strenghtened	0.5	
		Original	0.25	
		Decreasing quality	0.1	
				0

Table 5. Social resilience aspects.

Social Aspects		Level of procentage of the population:	Max Value (=2)	Object Value
Knowledge & Awareness	KRB zones	Understanding their location	0.5	
	Evacuation	Know how location and access	0.5	
	Housing/house	Know how the protection	0.5	
	Safety precautions	Self-initiative for safety	0.5	
				0

RESULTS AND DISCUSSION

Merapi's volcanic disaster depends on the risk vulnerability determined by the degree of susceptibility and resilience of the community and environment on the *Huntaps*. Merapi eruption, which triggers hazard threats, puts the community at risk. However, the risk levels will decide whether a hazard becomes a disaster (Smith, 2013). The five *Huntaps* risk levels are generally beyond the "safe line" or cut-off diagonal. We can see on the hazard risk-vulnerability zones chart application that none of these five samples is in a safe zone (*Figure 5*). According to the chart, the highest to the lowest risk from the five *Huntaps* are **Batur, Jetis Sumur, Karangkendal, Banjarsari**, and **Pagerjurang**. This result comes to light, and we can see elaborately in the following chart for each settlement (*Figure 6*).

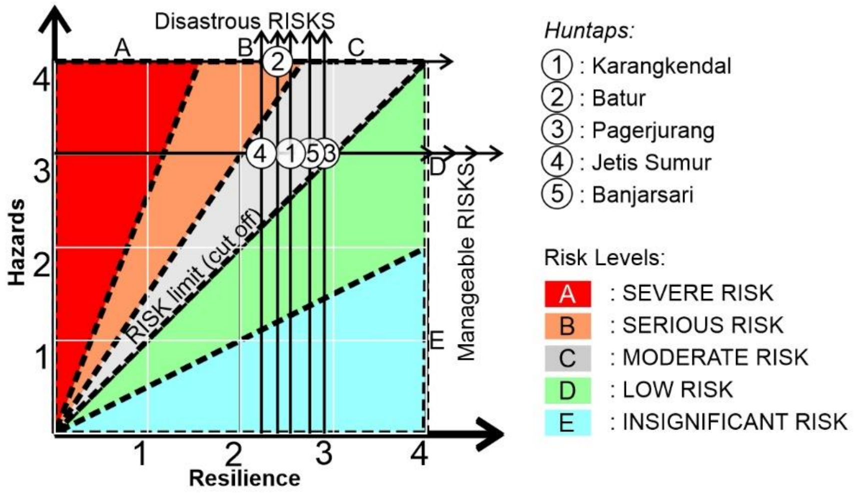

Figure 5. The application of the Hazard Risk-Vulnerability Zones Chart for the five *Huntaps*.

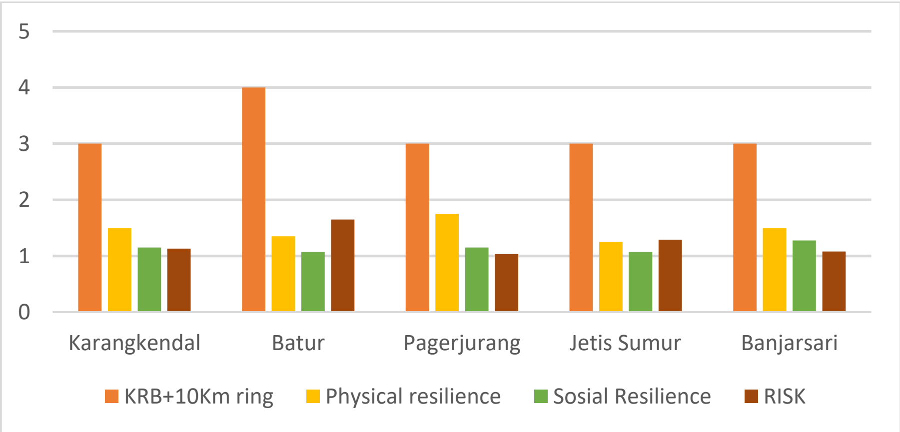

Figure 6. Risk levels between the five *Huntaps* with their components.

Hazard Exposures

According to the regulation, KRB III does not reserve for any settlement. This restriction is also relevant inside a 10 km radius of the peak. However, there is a significant difference in application between KRB mapping zones and their markings in the field. In most cases, the hazard zone map and its development are treated loosely by the authorities and not followed by the people even understood (Haynes et al., 2007). Though KRB III and the 10 km ring area differ, people mostly assume they are identical. Even the ring for them is smaller, only a radius of about 8 km where restriction signs stand in the field. The advanced sloping site near the 8 km radius misleads the signages. As a result, there are still many settlements within KRB III and the 10 km radius areas. This distorted KRB zone is even more apparent with the extended 2010 version. Recently, to confirm the actual position related to Merapi disaster-prone, it has become even more practical to use recent information technology such as Google Maps via http://bit.ly/CekPosisiMerapi. Nevertheless, most people need to utilize it.

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The dwelling sites are among the main rivers for the eruption flows: the Gendol, the Opak, and the Kuning rivers. Most *Huntaps* are still in the dangerous zones caused by their KRB status, under a radius of 10 km from the ring or too close to the lava flowline on the Gendol River 15 – 17 km south. Of the 15 dwellings, five residential locations are still in the zone of flaming rock falls and heavy ash rain at a radius of 10 km from the summit, namely **Karangkendal, Gambretan, Batur, Gading,** and **Pagerjurang**. Six dwellings are very near the riverbanks of the Gendol, including **Batur** and **Gading, with Jetis Sumur, Gondang**, and **Jelapan**. Furthermore, four *Huntap*s are in KRB III**: Batur, Gading, Jetis Sumur,** and **Banjarsari**; seven in KRB II**: Karangkendal, Gambretan, Pagerjurang, Ploso Kereb, Cancangan, Gondang,** and **Jelapan**; and one in KRB I: **Koripan**. Only three are outside the dangerous area**: Dongkelsari, Kuwang, and Randusari** (*Figure 7*).

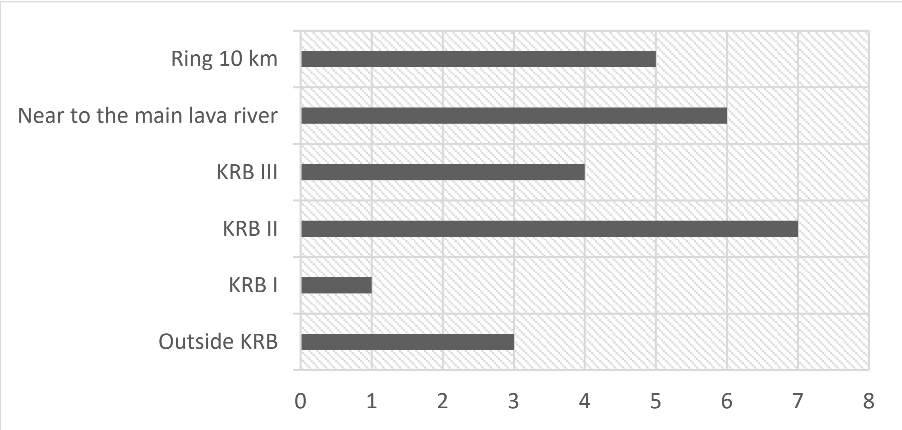

Figure 7. Number of *Huntap* exposure to the hazard.

By focusing on the five *Huntaps,* the chart locates Batur as the most exposed to the hazard. Its location inside KRB III and under the radius 10 km ring makes it the most dangerous site compared to the others. Jetis Sumur and Banjarsari are also in KRB III but slightly less exposed since the location is outside the ring. However, Jetis Sumur's risk is higher and almost touching the next level as Batur. By contrast, Karang Kendal and Pagerjurang are both in KRB II but still inside the ring. Pagerjurang is the least exposed to risk since environmental and social resilience are relatively high. This finding provides the recent levels of hazard vulnerability for the five *Huntaps,* which were rarely available.

Evacuation Route Safety

Accessibility is one of the main aspects of the rescue process, where distance and access are essential. Each *Huntap* has a definite evacuation barracks (TPA). The distance of the evacuation points provided is relatively diverse. Most accesses to evacuation points range between 3-7 km and are still in good condition, though generally, they are narrow in size, 3-4 meters. 76 % of the refugees used trucks and motorbikes for self-evacuation (Mei et al., 2013). Thus, the time needed to evacuate also varies. There is also a potential hindrance to be considered, such as

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crossing a river or moving along the road near a river potentially affected by flowing lava. From the five dwellings examination, the evacuation safety can be explained below (*Table 6*).

Table 6. Occupancy and location distribution of evacuation barracks and their distance.

No	Residential	Evacuation Barracks	Distance (km)	Time foot/motorbike/car (minute)	Potential hindrance
1	Karangkendal	Brayut, Wukirsari	5.5	49/9/10	exposed road
2	Batur	Kuwang, Randusari	8.0	90/13/14	cut off road
3	Pagerjurang	Kiyaran, Wukirsari	4.9	57/11/12	n/a
4	Jetis Sumur	Gayam, Argomulyo	3.6	37/7/7	exposed road
5	Banjarsari	Koripan, Sindumartani	5.6	61/10/10	exposed road

Batur, which has barracks in Brayut, Wukirsari, also has a high potential obstruction. The evacuation road is longer than the others, and the safety level is potentially lower when crossing the bridge on the Opak River. The three other refugee lines for Karangkendal, Jetis Sumur, and Banjarsari face the lava flow from the river near the road to the barracks. Only Pagerjurang has relatively lower interference.

Housing Safety

A house within its complex is the first line of protection against disasters at unexpected events, though evacuation is a primary procedure for safety under volcanic hazards. Housing facilities related to the evacuation process, such as a meeting point and signage, are very substantial and should be specific for each case (Bektaş & Sakarya, 2020). The quality of the house for hazard defense is also needed to protect people inside. Merapi resettlement housing has a standard of brick walls with concrete frames and terracotta roof tiles completed by public facilities. The structure quality, in general, is better than that of the previous houses. The people beforehand built houses with various materials ranging from wood to concrete frames, and the quality varied. *Huntaps* have been built almost uniformly in every residential location, although there are slightly different applications.

Materials' use greatly determines the level of building safety against volcanic disasters. Concrete frames and brick walls are generally relatively resistant to volcanic earthquakes and ash rain. However, terracotta tiles are still vulnerable to disasters in locations that are reachable by throwing stones because they break easily. Regarding thermal comfort, terracotta roof tiles are very efficient in creating air comfort because they are suitable for the climate and cheap, but they cannot withstand the onslaught of hail. Sheet metal roofing, in this case, is much better for that purpose, though less comfortable. A reinforced concrete roof is ideal for increasing safety, even though it is more expensive. The abundant availability of sand is beneficial for this purpose. The use of glass windows can also reduce building safety. Volcanic tremors will occur continuously, and the glass material will easily shatter.

Some changes also occurred in Merapi housing according to the needs of its residents. Due to economic growth, people increase their housing

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lifestyle, from replacing the finishing layer to adding rooms and terraces. The abundance of sand is also one of the driving forces behind the renovation of residential units. Many minor additions are made by beautifying the facade or terrace of the house. Renovated houses are generally built with good quality materials, although the impact on building structure may vary. Batur has experienced the least changes, while Jetis Sumur houses have experienced the most transformations. Renovation generally does not affect the strength and ability of the house to protect the occupants inside.

People's Understanding and Awareness for Safety

People's understanding and awareness of disasters also greatly influence building safety. Knowing actions before and after the eruption is essential for mitigating the Merapi Volcanic disaster. Furthermore, knowledge parallels awareness to avoid risks (Wulandari et al., 2023). Apart from the several deficiencies in *Huntaps*, most residents feel that their dwellings are safe. They believe this because they moved from their previous house, which was damaged by the eruption, and moved further down from the peak. Replacement housing provided by the government and donors has fulfilled their sense of security (Muir et al., 2020). Fortunately, a similar event has not happened again since the 2010 eruption. So, in the past 13 years, they have felt safe living in their new settlement. The community also considers that using a better reinforced concrete structure can protect them from eruptions. They said it was easier to deal with an eruption event as a group, including when they should immediately evacuate family members and their belongings.

Public understanding and safety awareness should rely on government information as the most trusted source. Their obedience to evacuation must increase since many neglected the warning, causing hundreds of fatalities in 2010 (Mei et al., 2013). On the other hand, the government has also issued various regulations and renewed hazard-prone areas for KRB mapping. The progress of the regulation and the indefinite field implementation have caused misleading information. Their understanding of hazard-prone zoning is high, but their awareness of the hazards' risks needs to be more profound. This negligence includes the fact that the new settlement is mostly considered safe and will protect them. They mostly needed to follow the evacuation order of the authorities. Though the massive monitoring and emergency plans supported them, the people eventually neglected the official warnings and declined evacuation (Donovan, 2010). They also have a system based on domesticating the threat and see it as a routine catalyst for natural productivity (Dove, 2008). The community has proven to need more awareness related to safety. Providing a regular understanding of volcanic disasters and how to deal with them is very necessary.

SAMPLE APPLICATIONS

Case 1: Karang Kendal

Karang Kendal is a replacement housing still very close to the peak of Merapi, with a radius of only 8 km. Though this residence is the closest to the peak, it stands in KRB II. The site is located relatively far from Gendol River at 1.77 km but only about 600 meters from the Opak River and may become a future threat. For this reason, their hazard prone is in the middle but added with the risk of materials falls graded 3 out of 4. The Karangkendal residence has a refugee facility in Brayut Barracks in the village of Wukirsari, about 5.5 km. The dwellers can reach it easily in 49 minutes on foot or 9-10 minutes by motorcycle or car. However, the facility is very close to the Kuning River, about 170 meters. This facility's vulnerability is relatively high because the river often flows eruption materials from Merapi. Karangkendal refugees do not have to cross a large river to evacuate. There is a less significant issue related to the dwelling, but because the location of the barrack and its track are very close to the river, it could trigger a disaster. Thus, its physical resilience is down to 1.5 out of 2. In the social aspect, the people's understanding of the KRB zone tends to be low, but their knowledge of evacuation is high. However, their self-initiative to have safe precautions could be much higher. For this reason, their level of social resilience is lower by 1.15 out of 2. The total risk level is in MODERATE RISK by 1.13 beyond the acceptable risk line of 1 (*see Figure 5*).

Case 2: Batur

Batur housing site is very close to the source of the disaster, within a radius of 8.28 km from the summit and only 0.56 km from the main lava flows of the Gendol River. The site is also in KRB III, the most dangerous zone, though further from nearby settlements. In addition, Batur is also very near, about 0.35 km to the Opak River headwaters, one of Merapi's principal rivers. This position makes Batur *Huntap* the most vulnerable to Merapi volcanic disasters, graded by 4 out of 4. For resilience, Batur has a permanent evacuation in Kuwang Barracks located in the village of Randusari, about 8 km. People must take about 90 minutes to walk or 13-14 minutes to ride a motorbike on an appropriate-condition pavement road 3 to 4 meters wide. Kuwang Barracks has a significant distance, which is relatively safer because it is far below, but the drawback is its long distance. However, to access it, the resident must cross the Opak River, which can suffer an obstruction if the lava damages the bridge. The access along the banks also has high potential obstacles. The situation and acceptable housing conditions put Batur on 1.5 out of 2 in physical resilience. As for social, the people also need a better understanding and awareness of safety, graded by 1.07 out of 2. The people depend on the government only and, at the very least, on initiative safety precautions. The Batur grade is 1.55 or in SERIOUS RISK for all these conditions, which is relatively far above the acceptable risk line (*see Figure 5*).

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Case 3: Pagerjurang

Located within a radius of 9.45 km from the summit, Pagerjurang is also in a dangerous zone. The residence is further from the headwaters of the Gendol River by 1.4 km to the West but still very close, about 200 meters to the Opak River. The site is also right below the open golf lawn. Pagerjurang is fortunately in KRB II, just outside the red zone; thus, the physical resilience is in 2 out of 4. One significant consideration is that this settlement also has the highest number of residents, about 301 households. The population's vulnerability to disaster is another aspect of their ability to evacuate. Fortunately, the residents have a definite and accessible evacuation shelter, Kiyaran Barracks in Wukirsari Village, 4.9 km away. Rescue access for the occupants is relatively safer, with roads 3 to 4 meters wide also in good condition. The people need about 57 minutes on foot or 11-12 minutes by motorcycle to reach the barracks. They do not have to cross a large river, so their access is relatively free of potential obstacles due to the threat of lava flows in the river. Pagerjurang dwelling is also mostly of acceptable quality, making this Huntap's resilience 1.75 out of 2. Like most of the Huntaps, however, the people have a relatively low understanding and awareness of the danger, having 1.15 points out of 2. For all these reasons, Pagerjurang occupies a MODERATE RISK level with a point of 1.03, just slightly over the acceptable risk line (*see back to Figure 5*). The dwelling has the lowest risk level, almost touching safe line 1.

Case 4: Jetis Sumur

Jetis Sumur is a residence far from the peak of Merapi and is outside the ejection zone, about 10.2 km. However, the location is very close to the headwaters of the Gendol River, about 600 meters. This location situates this residence in KRB III and is graded 3 out of 4. Jetis Sumur also has an evacuation point of the Gayam Barracks in Argomulyo Village to the east of the headwaters of the Gendol River. This barracks is 3.6 km away and can be reached from Jetis Sumur for 37 minutes on foot or 7 minutes by motorcycle. Unfortunately, the safety risk for evacuation is relatively high since the barrack is in KRB II, though the barracks are on the downslopes. The barracks and their access are close to the Gendol River, about 500 meters, making safety potentially highly threatened. Altogether, with the dwelling quality, which is still acceptable, the physical resilience of Jetis Sumur drops to 1.25 out of 2. Another consideration aspect is that this complex is on the east side of the Gendol River. Thus, if there is a significant eruption, there will be a potential accessibility cut-off from the Yogyakarta Province area. However, the people's understanding and awareness need to increase by a grade of 1.07 out of 2. Many people understand their dwelling in KRB III and know where the evacuation point is. Nevertheless, their self-initiative for safety could be much higher. Jetis Sumur's risk is at a MODERATE RISK, but with

1.29 points almost touching the higher risk area, this dwelling is the second highest risk after Batur (*see Figure 5*).

Case 5: Banjarsari

Banjarsari's residence is just down south of Jetis Sumur, approximately 600 meters from the Gendol River and far from the top, about 12 km. Like Jetis Sumur, Banjarsari is also in KRB Zone III because of its proximity to the main lava flow. Its hazard level is graded similarly by 3 out of 4. *Huntap* Banjarsari is also on the east side of the Gendol River, with the same risks as Jetis Sumur. Banjarsari residence has an evacuation Koripan barracks site about 5,6 Km away, reach by walking for about 60 minutes or by motorcycle for 10 minutes. The shelter is in the form of a permanent functional barracks dedicated building like other *Huntap*s. Reaching this refugee camp is undoubtedly easy. However, the barracks and access are also exposed to the Gendol River, resulting in a higher hazard risk. The potential disruption of the rescue may rise in extreme conditions. Combined with the dwelling, which is relatively acceptable in good condition, the physical resilience is 1.5 out of 2. Unfortunately, though the level of people understanding KRB is also high, their awareness of safety precautions is shallow. The people feel very safe and tend to neglect the threat of hazards. Their social safety resilience is down to 1.27 out of 2. All these facts put Banjarsari also in a MODERATE RISK by 1.08 points, slightly exceeding the acceptable risk line (*see also Figure 5*).

RISK LEVEL VALIDATION TEST

To confirm the result from the proposed method, we apply an alternative examination for the four resiliencies of the five *Huntaps.* A different approach utilizes a risk due to the accumulative threats from the hazard level of KRB and the 10 km radius, incorporating potential risks from the barracks, the accessibility, the dwelling, the knowledge, and the awareness. Three levels of quality, which are high, medium, and low, mark the values. The result is quite similar: Batur is the highest, Pagerjurang is the lowest, Jetis Sumur and Karangkendal are at the upper level, and Banjarsari is at the lower level of the risk rank. However, we cannot easily decide the accepted level from this verification method since the accumulative calculation has no correlation function (*Figure 8*).

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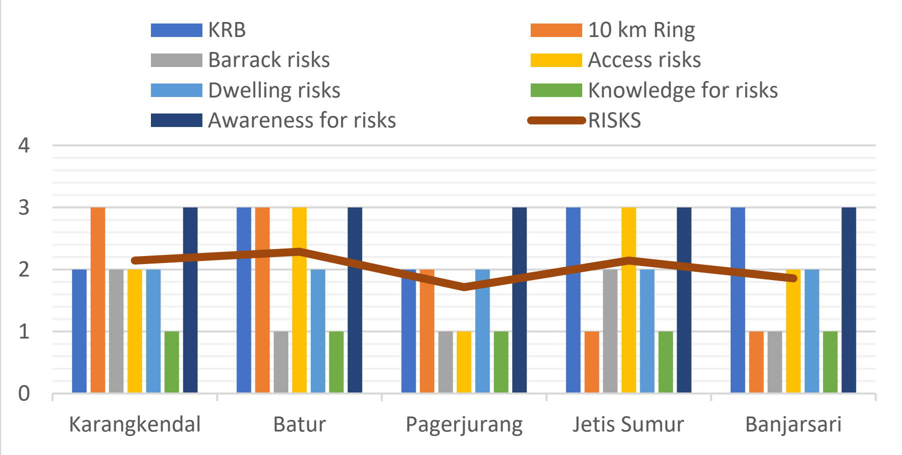

Figure 8. The confirmation chart of the risk level of five *Huntaps*.

CONCLUSION

Huntap Merapi, constructed after the 2010 eruption, is scattered in several areas on the slopes, which vary in safety. Generally, the housing complexes are in better condition and relatively improved in safety compared to the previous settlement in the higher danger zone. Unfortunately, because of the need for immediate shelter, the location determination did not consider the latest hazard-prone zone progress. We discovered that many dwellings are even in dangerous areas, such as KRB III-II, and inside the 10 km ring. Some *Huntaps* are too near the Gendol River, including some of their evacuation barracks and their accesses. Five dwelling samples in this study represent substantial conditions related to safety, starting from too near the peak to the downslope area. From the analysis done by the proposed method, their risk levels are higher beyond the safe line as the minimum level resulted from the degree of balance of hazard and resilience.

Most hazard levels are high because of their higher KRB zone, which directly faces the source of the hazard. Four out of 15 dwellings are in the highest hazard-prone, making the people most vulnerable to disaster. The vulnerability of the people is even higher since this study did not consider the existing villages nearby, which are in a similar zone and have more significant population numbers. Likewise, resilience capabilities were low because physical facilities, including the refugee barrack, were found to have risky access. Even though their building quality is decent, their locations are still in danger. Although the people's understanding is acceptable, their awareness must be higher. Since they feel safer and more comfortable, the awareness of the risks must be more profound. People also need to increase their initiatives to take precautions from potential hazards. Together with the social conditions, five *Huntaps* found themselves at higher risks.

The conditions of the *Huntaps* as replacement settlements, including their evacuation preparedness, are still in good condition, complete with various facilities. Most houses have experienced minor changes without influencing their function and structural integrity. The addition of the front and rear terraces and the completion of the facade finishing are done mainly by residents, along with enhancing the social need for identity. The authority should develop guidance for house renovation for safety.

The method has successfully proved its practical use in calculating risk levels. Visual charts locate the object in a specific zone related to the risk levels. The accepted level, which results from the balance between threats and resilience, strongly defines whether they are at risk or in safe status. The extremity caused by the hazards or resilience defines the further evaluation needed in safety. This technique also proves that the physical facilities and the community's understanding and awareness are vital to the hazard risk associated with disaster vulnerability.

The government rarely updates the risks, especially when the hazard tends to be less than ever, although a volcanic eruption like Merapi just in time. The risk evaluation is needed not only when the mountain has just erupted. This study found reasonable results by providing a simple way to assess the risk of Merapi's resettlements involving physical and social aspects. Since this study was only limited to specific samples, the application for further massive investigations is needed. Furthermore, we must pay more attention to more detailed aspects of improving safety and mitigating disaster vulnerability.

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Resume

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