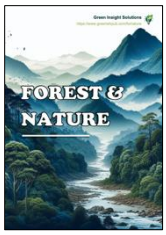
E-ISSN: 3110-1380 Vol. 1(4): 170-180, October 2025

FOREST AND NATURE

Homepage: https://www.greenishpub.com/fornature



RESEARCH ARTICLE

Risk Assessment for Sustainable Hiking: A Conservation-Based Approach on the Cibodas–Gede Trail using Hazard Identification, Risk Assessment, and Determining Control (HIRADC)

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ARTICLE INFO

Article History:
Received: 5 August 2025
Revised: 20 September 2025
Accepted: 3 October 2025

Keywords:
Conservation
Hiking
HIRADC
Risk assessment
Mount Gede Pangrango National Park

Citation: Miftah, B., Hasibuan, R. S., & Rusli, A. R. (2025). Risk Assessment for Sustainable Hiking: A Conservation-Based Approach on the Cibodas–Gede Trail using Hazard Identification, Risk Assessment, and Determining Control (HIRADC). *Forest and Nature*, *1*(4), 170-180. https://doi.org/10.63357/fornature.v1i4.18

ABSTRACT

Special interest hiking tourism involves risks that can be minimized through thorough preparation and effective management. This study aims to identify potential hazards, assess risks, and propose control measures to enhance climbing safety within Mount Gede Pangrango National Park (TNGGP). The Hazard Identification, Risk Assessment, and Determining Control (HIRADC) method was employed, involving interviews with experienced trail managers, including two porters, two guides, and TNGGP officials with over one year of trail management experience. The results indicate seven vulnerable points along the Cibodas–Gede Peak Trail, where potential hazards have been identified. Based on assessments of probability and severity, five locations were categorized as high-risk zones: The Gayonggong Swamp Bridge, Hot Water Trail, Sela Crater Trail, Rante Climbing Trail, and the Bayangan–Gede Peak segment. These risks can be mitigated through a hierarchy of controls, including elimination, substitution, administrative controls, engineering controls, and the use of personal protective equipment. With a planned and conservation-based risk management approach, hiking activities in TNGGP can be conducted safely and sustainably, without compromising ecosystem functions or disturbing protected wildlife habitats. Such an approach is crucial for maintaining the delicate balance between conservation objectives and the sustainable use of ecosystem services for nature-based tourism.

1. Introduction

Hiking activities in open natural environments, particularly in active volcanic regions, entail potential hazards that may result in a range of risks, from minor injuries to severe incidents. A hazard refers to any condition or situation with the potential to cause harm, whereas risk is defined as the combination of the likelihood of a hazardous event occurring and the severity of its consequences (She et al., 2019; Cui, 2022; ILO, 2025; MOHR, 2020). According to research by Soulé et al. (2014) in France, since 2012, there have been 1,172 deaths and 33 missing persons (and 3,385 injuries). In Switzerland, between 2000 and 2012, there were 45 deaths per year during climbing activities, while in Indonesia from 2013 to 2024, as many as 155 people died (Redaksi Jelajah Lagi, 2024). According to Zhang et al. (2024), mountain climbing has become the most popular and engaging hobby in China since the COVID-19 pandemic, with more than 20 million people taking up the sport.

Accidents on trails remain prevalent, even within conservation areas equipped with monitoring and surveillance systems. A notable incident occurred on 21 June 2025, when a Brazilian climber, Juliana Marins, was reported to have died after falling into a ravine on Mount Rinjani, West Nusa Tenggara (Santosa, 2025). This event highlights the urgent need for a more systematic, conservation-based risk management framework, particularly on trails with high visitor volumes. As a form of special interest tourism, hiking necessitates particular attention to occupational safety and health considerations. It is,

therefore, imperative for site managers to prioritize visitor protection—not only to uphold the reputation of the destination, but also to reinforce public confidence in the quality and safety of the tourism products provided (Arifin et al., 2023; Aziza et al., 2024; Rotinsulu et al., 2023).

One of the most popular trails due to its accessibility is Mount Gede Pangrango (TNGGP). TNGGP is a key conservation area on the island of Java, known for its high ecological value and rich biodiversity. It comprises a mountainous tropical rainforest ecosystem that remains relatively undisturbed. The park's main attraction lies in its two prominent peaks: Mount Gede (2,958 masl) and Mount Pangrango (3,019 masl) (Taman Nasional Gunung Gede Pangrango, 2022). Administratively, the park spans three regencies—Cianjur, Sukabumi, and Bogor—which contribute to the diversity and accessibility of the hiking routes leading to both summits (Mulyanto et al., 2015). Official trails include the Cibodas, Mount Putri, and Selabintana routes. However, hikers often encounter steep, rocky, slippery, and overgrown terrain, along with rapidly changing weather and low temperatures. These conditions pose significant hazards and risks, particularly for those with limited knowledge or inadequate preparation. As noted by She et al. (2019), understanding potential risks is crucial when engaging in mountain climbing activities. Risk analysis methods are techniques and tools used to identify a type of hazard and then assess it, allowing for an analysis of how much the risk can threaten a management system. This enables the determination of appropriate and efficient control measures. An organization must establish, create, implement, and maintain procedures for hazard identification, risk assessment, and the determination of necessary controls for hazards and risks (MOHR, 2020).

Based on statistical data from the Mount Gede Pangrango National Park Office (Taman Nasional Gunung Gede Pangrango, 2023), the number of climbers visiting the area during the 2018–2023 period reached 179,992 people. During the same period, 126 minor accidents, 9 moderate accidents, 3 serious accidents, and 5 deaths were recorded. The high number of visits and the frequency of accidents indicate that climbing activities in this area carry a high level of risk. Therefore, this study is necessary to analyze the potential hazards along the Cibodas–Gede Peak Trail. The main objective of this research is to identify hazards, assess risks, and control risks to improve climbing safety in the TNGGP area.

2. Materials and Methods

2.1. Study Area and Tools Used

The research was conducted from October to December 2022 on the Cibodas climbing route to Gede Peak–TNGGP, Cianjur Regency (**Fig. 1**). The tools used are a GPS, a camera, and a HIRADC tally sheet.

2.2. Data Collection

This research used the HIRADC approach to support systematic, conservation-based risk management in hiking areas. The HIRADC method consists of three stages: hazard identification, risk assessment, and risk control (Rifai et al., 2020; Rotinsulu et al., 2023).

1. Hazard Identification
   Hazard identification was conducted by directly observing potential danger points on the climbing route, based on guidelines for OSH risk management (MOHR, 2020). Sampling was carried out using a purposive technique (intentionally), namely agreeing on danger points, through interviews with managers who have experience managing climbing routes (2 porters and 2 guides) and TNGGP managers who have more than one year of experience managing climbing routes in TNGGP.
2. Risk Assessment
   The hazard level assessment was carried out by TNGGP researchers and managers. The hazards and risks assessed comprise the likelihood and severity components, with the risk level evaluated on a scale of 1 to 5. The component categories are shown in **Tables 1** and **2**. The assessment of the measurement results will be carried out by multiplying the likelihood and severity by Equation 1 (MOHR, 2020).

$$Risk = Likelihood\ (L)\ X\ Severity\ (S) \quad (1)$$

The multiplication results between the categories are then entered into a risk matrix, as shown in **Table 3**, to determine the risk level. The identified risk level will then be used as the basis for accepting the hazard and proposing actions to control it, as presented in **Table 4**.

3. Risk Control

Control measures were determined through discussions with management, taking into account the danger points encountered along the trail. These controls are also based on management input and suggestions tailored to the danger points on the trail. The following risk control measures are recommended (Aziza et al., 2024; MOHR, 2020):

- Elimination: This control is carried out by eliminating the source of danger (hazard).
- Substitution: This control involves replacing the process and its inputs with those of lower risk.
- Control/Engineering: This control is implemented on tools, machines, infrastructure, the environment, and/or buildings by modifying them to reduce the risk to a low level.
- Administrative Control: This control is implemented through administrative procedures, rules and regulations, as well as the installation of safety and warning signs, training, standard operating procedures (SOPs) for climbing, personal identification, health certificates, and checklists for clothing and food logistics.
- Personal Protective Equipment (PPE): Risk reduction control involves the use of personal protective equipment, such as jackets, socks, hiking boots, helmets, raincoats, flashlights, thermal blankets, and other necessary items. PPE is the final level when the previous four hierarchies of control are insufficient to control a hazard.

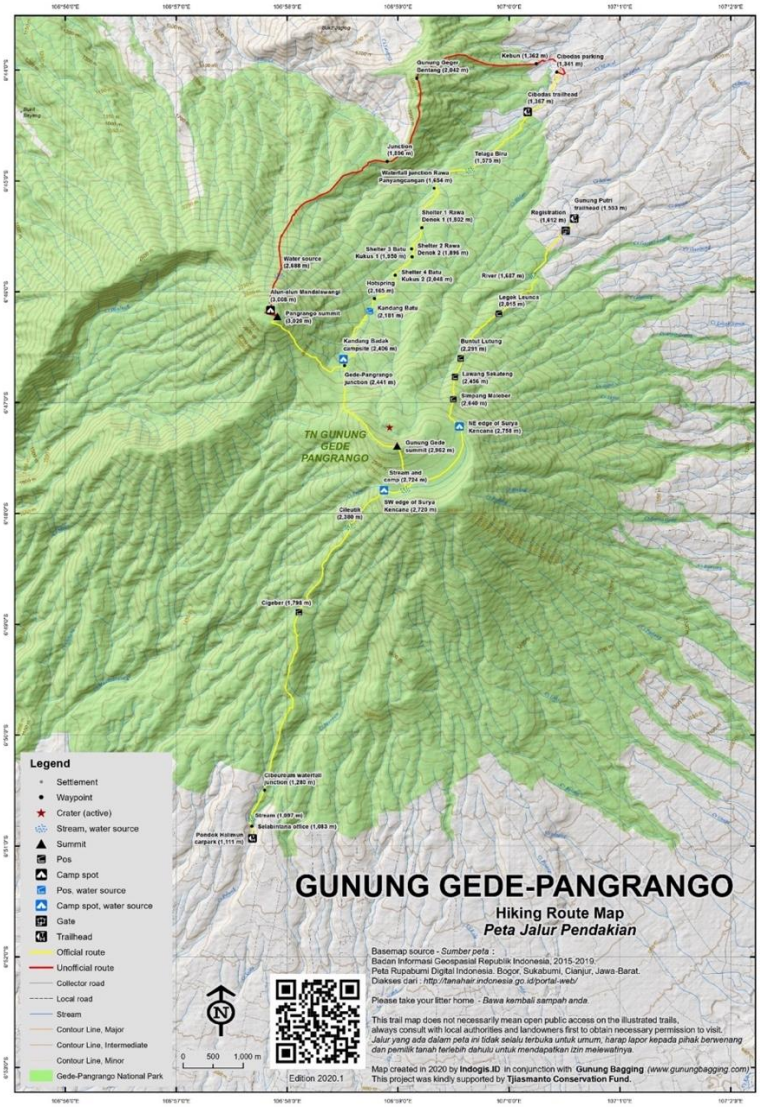

Fig. 1. Mount Gede Pangrango climbing route (Geospatial Information Agency, 2020).

Table 1. Components of the likelihood value (MOHR, 2020)

Component	Score	Information
Most likely	5	The most likely outcome of the hazard
Possible	4	Has a good chance of happening and is not common
Conceivable	3	It may happen sometime in the future
Remote	2	It is not known what happened after all these years
Inconceivable	1	It is practically impossible, and it never happens

Table 2. Severity value components (MOHR, 2020)

Component	Score	Information
Catastrophic	5	Many serious bodily injuries, or many life-threatening activities and or illnesses (e.g., occupational cancer or acute poisoning)
Major	4	Serious bodily injury involving permanent disability or life-threatening occupational disease involving one person
Moderate	3	Injuries involving permanent disability or ill health requiring medical treatment (including lacerations, burns, sprains, minor fractures, dermatitis and work-related upper extremity disorders)
Minor	2	Causes minor injuries, minor losses, and does not cause serious impacts, only requires first aid for accidents (including minor cuts and bruises, irritation, pain with temporary discomfort)
Negligible	1	The incident did not result in any loss or injury to humans

Table 3. Risk matrix (MOHR, 2020)

Likelihood / Severity	Inconceivable (1)	Remote (2)	Conceivable (3)	Possible (4)	Most likely (5)
Catastrophic (5)	5 (Medium)	10 (Medium)	15 (High)	20 (High)	25 (High)
Major (4)	4 (Low)	8 (Medium)	12 (Medium)	16 (High)	20 (High)
Moderate (3)	3 (Low)	6 (Medium)	9 (Medium)	12 (Medium)	15 (High)
Minor (2)	2 (Low)	4 (Low)	6 (Medium)	8 (Medium)	10 (Medium)
Negligible (1)	1 (Low)	2 (Low)	3 (Low)	4 (Low)	5 (Medium)

Table 4. Risk acceptance level and control actions (MOHR, 2020)

Risk level	Risk acceptance	Action
15–25 (High)	Not acceptable	HIGH risk requires immediate action to control the risk to the extent practicable for medium risk levels or low risk levels
5–14 (Medium)	Tolerance	MEDIUM risks may require a planned approach to control the hazard as far as practicable for low risk levels and implement temporary measures (if necessary)
1–4 (Low)	Acceptable	Risks identified as LOW can be considered acceptable, and further reduction may not be necessary

3. Results and Discussion

3.1. Identification of Potential Hazards

According to ISO 45001 (Dentch, 2018), risk management is a systematic process for identifying, analyzing, and evaluating risks to minimize the likelihood and potential negative impacts. In the context of natural areas such as national parks, the implementation of risk management is not only aimed at protecting human safety but also at mitigating negative impacts on the environment and vulnerable ecosystems. A hazard is defined as a source that has the potential to cause injury or health problems (MOHR, 2020). Therefore, forest activities, especially hiking, require careful planning, physical and mental preparedness, and a thorough understanding of potential hazards in the field.

Hazardous conditions in the open air cannot be eliminated. However, through proper identification, these potential hazards can be recognized, and mitigation measures can be designed to reduce the risk level that may occur (Rifai et al., 2020). In this study, the results of hazard identification on the Cibodas–

Gede Peak Trail indicate seven vulnerable points that pose a high level of risk to climber safety (**Table 5**). These seven points include the Gayonggong Swamp Bridge, which is prone to slippery and fragile terrain; the path between the Batu Kukus II Shelter and the Pondok Pemandangan Shelter, which has a slope and loose rocks; the Hot Spring Trail, which has the risk of extreme temperatures and slippery surfaces; the Panca Weuleuh Trail, which is steep and narrow; the Sela Crater Trail, which is close to volcanic activity; the Tanjakan Rante Trail, which is steep and muddy during the rain; and the trail from Shadow Peak–Gede Peak Trail, which is often covered in thick fog and has the potential to cause disorientation. These findings underscore the importance of implementing location-based risk management to improve climbing safety and maintain the sustainability of nature tourism activities in conservation areas such as the TNGGP.

Table 5. Potential hazards and risks of climbing on the Cibodas–Gede Peak Trail

No.	Activity	Danger condition	Danger factors	Altitude coordinates
1	Gayonggong Swamp Bridge	a. Broken security features b. Threats to wild flora and fauna c. Ergonomic conditions. d. Incomplete personal protective Equipment features	Physical, biological, and ergonomics	S 06.4459° and E 106.5925° 1,600 masl
2	Track Shelter Batu Kukus II–Shelter Pondok Pemandangan	a. Steep track conditions b. Threats to wild flora and fauna c. Psychological condition of climbers d. Ergonomic conditions	Physical, biological, and ergonomics	S 06.7643° and E 106.9828° 2,000 masl
3	Hot Water Route	a. Steep track conditions b. Condition of the route through the hot spring river c. Condition of the side of the ravine path d. Inadequate security features e. Ergonomic conditions	Physical and ergonomics	S 06.7672° and E 106.9804° 2,138 masl
4	The Weuleuh Route	a. Steep track conditions b. Condition of the route at several landslide-prone points c. Threats to wild flora and fauna d. Ergonomic conditions e. Psychological conditions	Physical, biology, ergonomics, and psychology	S 06.7717° and E 106.9774° 2,250 masl
5	Sela Crater Trail	a. Steep track conditions b. The condition of the path is near a crater that emits sulfur gas c. Threats to wild flora and fauna d. Ergonomic conditions	Physical, chemical, biological, and ergonomics	S 06.7779° and E 106.9756° 2,415 masl
6	Rante Uphill Trail	a. Broken security features b. Steep track conditions c. The slope condition is 70°–90° d. Ergonomic conditions	Physical and ergonomics	S 06.78404° and E 106.9751° 2,638 masl
7	Shadow Peak–Gede Peak Trail	a. The condition of the path is steep, gravelly, and sandy b. Condition of the side of the ravine path c. The condition of the path is near a crater that emits sulfur gas d. Sun exposure e. Extreme temperature conditions, low air pressure and strong winds	Physical, chemical, and ergonomics	S 06.7881° and E 106.9793° 2,910–2,958 masl

Accidents can occur on the Cibodas–Gede Peak climbing route, including those that can cause climbers to sprain, fall, slip, fall into the Gayongong Swamp, be thrown, cut, scratched, injured, bruised, or gored by wild boar, wild animals, insect stings, snake bites, contact with poisonous plants, or skin irritation. Poison gas poisoning, loss of consciousness, shortness of breath, slipping, falling into a ravine, getting lost/climbers lost, and death. The same thing was mentioned by Rahman et al. (2018) where physical activity accidents in mountain climbing are also caused by two factors, namely (a) Internal

factors (climbers), including inadequate planning and preparation, fatigue, congenital internal diseases, and getting lost, (b) External factors (natural conditions), including path conditions, weather or climate, mountain illnesses, such as hypothermia and hypoxia, and wild animal attacks.

Based on **Table 5**, threats from flora in the TNGGP area include falling branches caused by wind gusts, which may injure climbers, and the presence of poisonous plants such as stinging nettle (*Toxicodendron radicans*) and jimpi-jimpi (*Dendrocnide moroides*), which can induce allergic contact dermatitis characterized by itching, redness, and blistering. Both of these plants are generally classified as herbaceous or shrubby species. Additionally, potential disturbances may arise from wild fauna, including snakes, monkeys, and other animals, as reported by Jasthin et al. (2024). As a designated conservation area, TNGGP enforces management policies focused on biodiversity protection, explicitly prohibiting activities that threaten ecosystem integrity, such as logging and wildlife capture. These conservation measures not only safeguard flora and fauna but also ensure the long-term sustainability of ecosystem functions and promote the responsible use of natural resources within the area.

3.2. Risk Assessment

Risk refers to the combination of the likelihood of a work-related hazardous event or exposure occurring and the severity of injury or illness that may result from that event or exposure (MOHR, 2020). Climber safety theory can be used to rank potential risks at tourist attractions, helping tourism managers to take further action to mitigate these risks (Brillhart et al., 2025). Risk level assessments are necessary in all tourist areas, including the Cibodas–Gede Peak Trail and the TNGGP trail, to identify hazardous conditions and ensure the safety and security of climbers, thereby ensuring the sustainability of the hiking tour itself. Based on the results of the potential hazard identification, the risk levels are as shown in **Table 6**.

Table 6. Risk levels based on likelihood and severity on the Cibodas–Gede Peak Trail

No.	Activity	Hazard	Risk			Risk status
			L	S	L× S	
1	Gayonggong Swamp Bridge	• Stumble • Falling • Slipping • Trapped • Scrape • Injury • Muscle spasms/cramps • Sprains	4	4	16	High
2	Track Shelter Batu Kukus II – Shelter Pondok Pemandangan	•Falling •Slipping •Thrown •Scrapes •Bites •Stabs •Sprains •Skin irritation due to plant toxins	4	3	12	Medium
3	Hot Water Route	• Slipping • Being thrown • Being hit • Being sprained • Being swept away by the current of a hot spring • Falling into a ravine	4	4	16	High
4	The Weuleuh Route	• Slipping • Falling • Cuts • Grazes • Injuries • Sprains	4	3	12	Medium

No.	Activity	Hazard	Risk			Risk status
			L	S	L× S	
		• Bruises • Stung				
5	Sela Crater Trail	• Poison gas poisoning • Loss of consciousness • Shortness of breath • Slipping • Fall • Lost/disappearance • Death	5	5	25	High
6	Rante Uphill Trail	• Falling • Sprain/dislocation • Imputation • Cut • Strike • Strike by a rock/object falling from above • Flung • Death	4	4	16	High
7	Shadow Peak–Gede Peak Trail	• Slipping • Falling into a ravine • Missing • Bruises • Sprains/dislocations • Contusions • Broken skin • Hypothermia • Death	4	5	20	High

3.3. Risk Control

According to MOHR (2020), the presence of hazards necessitates control efforts to prevent detrimental consequences. **Table 7** shows the types of hazards and relevant risk controls recommended by researchers to the Cibodas Trail managers. Risk and hazard control must consider various conditions that could potentially arise in the field, and proactively implement preventive measures to ensure the sustainability of the TNGGP climbing route. General controls implemented by management include providing bathrooms with good water and sanitation to facilitate climbers' access to water and the ability to clean themselves during or after climbing. Available water can also be boiled for drinking to prevent thirst. Climbing can be physically demanding, so it is essential to drink plenty of fluids to prevent dehydration. The management has provided emergency response equipment, including first aid kits and emergency rescue supplies, that meet the safety and security standards for mountain climbing. Training has been conducted for officers and partners, such as guides and porters, regarding procedures for handling natural disasters and fires, as well as handling unexpected events such as climbers being injured or falling into ravines, and handling wildlife encounters, as implemented by Welter et al. (2015) and Yue et al. (2018) in their research.

Technical controls can be implemented through various means, such as repairing bridge guardrails, installing warning signs in bumpy areas of the bridge, or displaying signs that read "Caution, Risk of Tripping!" These steps align with those implemented by Jasthin et al. (2024) in their research on the Sembalun-Senaru trail in Mount Rinjani National Park, West Nusa Tenggara. Furthermore, control through elimination can be implemented by directly eliminating the source of the hazard, for example, by repairing or closing holes in bridges that pose a potential danger. Meanwhile, substitution control can be implemented by diverting overly steep paths to gentler alternative routes, even if they are slightly more circuitous and longer. Two separate paths could be built—one for climbers going up and one for climbers going down—to minimize crowding, considering that the existing paths are only about 1–2 meters wide. This strategy has proven quite effective in reducing the risk level without compromising the safety of climbers.

Table 7. Types of risk control

No.	Activity	Risk	Control stages	Risk control
1	Gayonggong Swamp Bridge	• Safety risks	• Elimination • Engineering controls • Administrative controls • Personal protective equipment (PPE)	• Repair of potholes on bridges • Repair of handrails • Inspection and briefing on climbing POS • Inspection of PPE and supplies • interpretation boards
2	Track Batu Kukus II Shelter–Pondok Pemandangan Shelter	• Safety risks • Health risks	• Substitution • Engineering controls • PPE	• Maintaining visible paths • Installing warning signs (interpretation boards) • Using PPE
3	Hot Water Route	• Safety risks	• Engineering controls • PPE	• Installing a “Caution, Slippery Path!” warning sign • Repairing the railings • Using PPE
4	The Weuleuh Route	• Safety risks	• Engineering controls • PPE	• Installation of warning signs and directional signs (interpretation boards) • Using PPE
5	Sela Crater Trail	• Health risks	• Elimination • PPE	• Close the crater rim by posting a no-trespassing sign. • Use PPE and bring a life-saving mask
6	Rante Uphill Trail	• Safety risks	• Elimination • Substitution • Engineering controls • PPE	• Close the trail route • Create an alternative route • Repair the handle of the chain ramp when it is reopened • Using PPE
7	Shadow Peak–Gede Peak Trail	• Safety risks • Health risks	• Engineering controls • PPE	• Repairing the barrier railings, • Using PPE and bringing life jackets, life masks, and trekking poles

However, all forms of control must remain within reasonable limits, considering that TNGGP is a conservation area that serves as a habitat for various protected and endemic wildlife, such as the Owa Jawa (*Hylobates moloch*), Lutung Jawa (*Trachypithecus auratus*), Macan Tutul (*Panthera pardus*), Elang Jawa (*Nisaetus bartelsi*) and various bird species (Mustari and Haris, 2023). Therefore, the risk management approach in this area must strike a balance between human safety and ecosystem preservation to ensure the area’s sustainability.

Administrative control involves managing risks and hazards in the workplace by implementing policies and regulations related to occupational safety and health. Its implementation, such as identity documents and permits, requires an IDR 10,000 stamp for those under 17 years old, a minimum age limit of 5 years, a maximum of 60 years, a health certificate, SIMAKSI (Conservation Area Entry Permit), 1 group of at least 3 people, and a maximum of 10 people. Actually, this can be done online using an Android smartphone or tablet. Hazard management can also be done by providing online information related to climbing activities, such as the availability of climbing route maps for visitors, the height and characteristics of each location, to emergency calls in the event of an accident, this is in accordance with the research of (Jasthin et al. 2024), which presents climbing routes via Android on the Rinjani trail.

TNGGP must have a dedicated internal team to ensure safety and security procedures are carried out in accordance with established regulatory mechanisms. Have insurance, regularly monitor the implementation of guidelines and safety regulations at special interest mountain climbing tourist sites (Rifai et al., 2020). Prepare human resources, including managers and trained officers, to develop and implement safety mechanisms on climbing routes. Provide information on safety implementation guidelines at mountain climbing tourist sites, where visitors receive information on emergency safety

and security conditions (Kemenparekraf, 2020). Provide severe sanctions for climbers who behave dangerously and violate regulations, as well as for illegal climbers who do not have SIMAKSI.

With planned, conservation-based risk management, hiking activities in the TNGGP can continue safely and sustainably without disrupting ecosystem functions or damaging protected wildlife habitats. This approach is key to maintaining a balance between preserving conservation areas and utilizing environmental services for nature tourism activities. Furthermore, implementing appropriate risk management can be an integral part of a conservation-based nature tourism management strategy, ensuring the area continues to provide long-term educational, recreational, and economic benefits. These efforts also support the achievement of the Sustainable Development Goals (SDGs), particularly in the areas of terrestrial ecosystem protection (SDG 15), sustainable tourism, and increasing environmental awareness.

4. Conclusion

There are seven locations observed to have medium to high potential hazards and risks, namely the Gayonggong Swamp Bridge, along the route from Batu Kukus II Shelter to Pondok Pemandangan Shelter, the hot water route, the Weuleuh route from Kandang Batu post to Kandang Badak post, the dangerous gas route around the crater above Kandang Badak post, the Rante Climbing Route, and the route from the top of the shadow to the top of the big cliffside. The risks include sprains, falls, slips, falls into the Gayonggong Swamp, being thrown, cuts, scratches, injuries, bruises, being gored by wild boars, insect stings/contact with poisonous plants, and skin irritation. Poisonous gas poisoning, loss of consciousness, shortness of breath, slips, falls into the ravine, lost/lost climbers, and death. The risks that arise can be addressed with the hierarchy of control. Elimination, substitution, administrative control, technical control, and the use of personal protective equipment (PPE): the determination of control implementation is adjusted to the decision maker's policy.

Acknowledgments: The author would like to thank the management of Mount Gede Pangrango National Park, who permitted data collection, and all parties who helped with this research.

Author Contributions: B.M.: resources, data curation, writing – original draft preparation; R.S.H.: supervision, funding acquisition, conceptualization, methodology, investigation, validation, writing – review and editing; A.R.R.: conceptualization, data curation, writing – review and editing.

Funding: The authors received no financial support for this article's research, authorship, and/or publication.

Data Availability Statement: The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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