Riset Geologi dan Pertambangan
Earth science journal · Open access · BRIN Earth Sciences & Maritime · BRIN Publishing
ISSN 0125-9849 e-ISSN 2354 6638

RESEARCH ARTICLE
OPEN ACCESS

Riset Geologi dan Pertambangan (2026) Vol. 36, No. 1, 27–40
DOI: 10.55981/risetgeotam.2026.1384

Keywords:
Geotourism
Degradation Risk
Hazard Identification
Waluran
Ciletuh Geopark

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Article history:
Received: 16 April 2025
Revised: 30 September 2025
Accepted: 17 October 2025

Author Contributions:
Conceptualization: SDP, MHM
Data curation: SDP, MHM, RK
Formal analysis: SDP, MHM, RK, NNP, NNS, MFR
Funding acquisition: MFR, SDP
Investigation: SDP, MHM
Methodology: SDP, MHM, RK, NNP, NNS, MFR
Supervision: SDP, MFR
Visualization: MHM, RK
Writing – original draft: SDP, MHM, RK, NNP, NNS, MFR
Writing – review & editing: SDP, MHM

Citation:
Pratiwi, S.D., Maulana, M.H., Khoerunisa, R., Putri, N.N., Silalahi, N.N., Rosana, M.F., 2026. Degradation risk assessment and hazard identification on geotourism site of Waluran District, Ciletuh Palabuhanratu UGGp. J. Ris. Geol. Pertamb., 36 (1) 27–40, doi: 10.55981/risetgeotam.2026.1384

Degradation risk assessment and hazard identification on geotourism site of Waluran District, Ciletuh Palabuhanratu UGGp

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Abstract

Geotourism in Waluran District, part of the Ciletuh–Palabuhanratu UNESCO Global Geopark (UGGp), is exposed to potential degradation and safety risks if its management remains inadequate. This study assesses the sustainability of three geosites, including Taman Batu Cukcrukan, Taman Batu Sarongge, and Lorong Tengah, through an integrated approach combining Degradation Risk Assessment and Hazard Identification, Risk Assessment, and Determining Control (HIRADC). The first method was applied to evaluate site vulnerability to several factors using standardized scoring criteria, while the latter was applied to recognize hazards by considering their likelihood and severity, followed by determining control measures in line with the ISO 45001 framework. The results indicate that none of the sites can yet be categorized as threatened. Nevertheless, Taman Batu Cukcrukan attained the highest risk score (4.25), largely linked to its relative accessibility and proximity to problematic areas. Field observations also revealed recurring safety concerns, such as steep and slippery trails, unsafe bridges, deep river holes, and unstable rocks, with 60% of hazards in Taman Batu Cukcrukan categorized as high risk. The methodological strength lies in combining degradation assessment with HIRADC, which not only highlights governance and conservation weaknesses but also converts them into practical safety measures. This integrated approach provides structured prioritization of risk control and management. The findings underscore the importance of targeted mitigation measures, including infrastructure improvements, slope stabilization, routine maintenance, and visitor education. Overall, this study demonstrates that proactive risk management is essential to preserve geodiversity, enhance visitor safety, and secure the long-term sustainability.

1. Introduction

A geopark, as defined by UNESCO, is an integrated area that contains unique geological sites and landscapes of international significance, managed through a holistic concept of protection, education, and sustainable development (UNESCO, 2015). This concept highlights geodiversity as a key foundation for advancing geotourism, alongside natural and cultural diversity (Ansori, 2018; Pratiwi et al., 2019). Geodiversity encompasses the entire range of non-living nature elements, such as rocks, minerals, fossils, soils, and also geological features like folds and faults. Furthermore, it encompasses the dynamic processes that continuously shape our landscapes, which serve as the basis for natural ecosystems. These processes range from sedimentation and soil formation to tectonic activity and volcanism (Gray, 2004). Geodiversity holds significant value across many fields, and as it faces growing threats from human activities, its protection becomes essential (Gray, 2005). Geotourism sites located within complex geological settings demand comprehensive hydrogeological investigations to anticipate degradation processes and design effective mitigation measures (Mareta et al., 2021).

The Ciletuh-Palabuhanratu UNESCO Global Geopark is located in the southwest of Sukabumi Regency, West Java of Indonesia. It covers an area of 126,000 hectares, features a unique amphitheater-like landscape that overlooks Ciletuh Bay, with white sandy beaches facing the Indian Ocean. This area consists of a wide variety of rocks, including metamorphic and igneous (mélange) rocks formed by subduction, as well as Tertiary sedimentary and pyroclastic rocks deposited above them (Hardiyono et al., 2015). The Ciletuh mélange complex is mainly composed of metamorphic rocks belonging to the greenschist facies and retrograde amphibolite types (Ikhram et al., 2023). Waluran District, part of the Ciletuh-Palabuhanratu UNESCO Global Geopark (UGGp), showcases its geodiversity in terms of scientific, aesthetic, and tourism value. It includes distinctive subaqueous volcanic rocks from the Early Miocene, which make up the Jampang Formation, specifically the Cikarang Member and Ciseureuh Member (Sukamto, 1975; Martodjojo, 1984; Rosana et al., 2019; Pratiwi et al., 2024). This complex geological phenomenon has ultimately produced intriguing geosites, such as Taman Batu Cukcrukan, Taman Batu Sarongge, and Lorong Tengah, all formed through millions of years of geological processes in the Waluran District area. These features not only enhance the area's tourism potential but also demand special attention for their protection, management, and development.

The geodiversity site documentation in geotourism areas not only enhances educational and scientific value but also supports early identification of degradation risks and natural hazard potentials (Titisari and Azzaman, 2019). The existence of those geotourism sites is at risk if they are not consistently maintained and developed. Threats to these sites can come from both natural factors and human activity (Fuertes-Gutiérrez et al., 2016). These challenges may include inadequate state or regional funding for their management, acts of vandalism, uncontrolled vegetation growth, and societal pressures regarding the ways the sites are utilized (Kubalíková et al., 2021; Selmi et al., 2022). Based on data published by Center of Volcanology and Geological Hazard Mitigation (PVMBG) in 2025 concerning the map of potential landslide areas in West Java, the Sukabumi area is classified as a medium to high risk zone for landslides. In this zone, landslides can occur if rainfall is above normal, especially in areas bordering river valleys, cliffs, road embankments, or if slopes are disturbed (PVMBG, 2025). Furthermore, according to Sugianti et al. (2016), the spatial-temporal analysis of landslide susceptibility in Sukabumi Regency demonstrates that variations in lithology, slope gradient, and land use significantly influence the distribution and frequency of mass movement events.

The risks faced by geotourism sites in Waluran are not only shaped by management and human activities but also closely tied to the physical setting. Previous assessments in the Ciletuh–Palabuhanratu UGGp highlight rockfalls and slippery rock surfaces as the most prominent physical hazards, while landslides, snakes, bees, and poisonous plants are considered lower risks (Herlinawati et al., 2025). The geological structure and landforms of the area, including elongated ridges and steep amphitheater-like cliffs, further contribute to its geomorphological vulnerability (Ummah et al., 2018). Supporting this, the official landslide susceptibility map indicates that Waluran is dominated by low to moderate susceptibility, though localized risks remain along river valleys, escarpments, and road cuts. Localized soil displacements may develop during heavy rainfall as a result of erosional

processes, steep topography, and unstable soil structures that are highly prone to landslides (PVMBG, 2025). Accessibility conditions add another layer of concern, as field-based studies in different geosites within the Ciletuh area show that paths are generally steep and uneven, creating fall hazards that may lead to serious injuries such as fractures, often complicated by the presence of wild animals (Surahman and Pratiwi, 2024). Moreover, poorly maintained dirt roads that are frequently overgrown with vegetation and rocky trails heighten the risks of slips and falls for visitors (Herlinawati et al., 2025).

Considering these conditions, hazard identification and risk assessment are urgently needed to ensure sustainable geotourism in Waluran District. Geopark development must prioritize accessibility, safety, and visitor protection through systematic management. Identifying and mitigating hazards not only safeguards visitors and local communities but also supports enjoyable and safe tourism experiences (Herlinawati et al., 2025). This requires hazard control based on the ISO 45001 hierarchy, including elimination, substitution, engineering controls, administrative measures, and personal protective equipment (ISO 45001, 2018), applied through Hazard Identification, Risk Assessment, and Determining Control (HIRADC) tailored to local geosites. Such measures enhance visitor confidence, sustain geotourism growth, and address risks of site degradation by anticipating anthropogenic impacts, thereby ensuring long-term preservation of natural and educational values (Newsome and Dowling, 2006; Newsome et al., 2012).

To address these challenges, this study aims to identify and classify the degradation risks and potential hazards at several geotourism sites in Waluran District and formulate appropriate control measures. The results are expected to support management and conservation efforts while enhancing the quality of a safe and sustainable tourism experience in the Ciletuh-Palabuhanratu UNESCO Global Geopark (UGGp).

2. Geologic setting

Physiographically, Waluran District is part of the Southern Mountain Zone of West Java, which is mainly composed of volcanic rocks intercalated with volcaniclastic sedimentary rocks ranging in age from Oligocene to Miocene (Koesoemadinata, 2020). More specifically, the area belongs to the Ciletuh High Subzone. One of the features that exist in this subzone is the Jampang Plateau. The plateau is bounded to the north by the ENE-WSW Cimandiri Fault Zone, which also marks the northern boundary of the Ciletuh High (Haryanto and Sudradjat, 2018; Koesoemadinata, 2020).

The morphology in Waluran District is generally characterized by plains and hilly terrain with gently to moderately steep slopes (Khansa et al., 2024), with elevations ranging from 0 to 400 meters (BPS Kabupaten Sukabumi, 2024). These morphologies are primarily shaped by tectonic and volcanic activities, resulting in structural and volcanic morphogenetic origins. This interpretation is supported by the distribution of volcanic rock outcrops, the presence of joints, and the river drainage patterns observed in the area, which are predominantly rectangular and sub-dendritic (Khansa et al., 2024).

Based on the Regional Geological Map of the Cikadal – Lengkong Sheet (Rosana et al., 2019), the study area is composed of several rock units, including the Jampang Formation, Cikarang Member, and Ciseureuh Member (Figure 1). The origin of these rock units is associated with volcanic processes that have been active since the Late Eocene (Koesoemadinata, 2020). These three units consist of a variety of rocks, including volcanic rocks that interfinger with volcaniclastic and carbonate sedimentary rocks. Nannofossil distribution studies within volcaniclastic and clastic sedimentary rocks exposed in the Ciletuh area indicate that these rocks were deposited during the Late Oligocene to Early Miocene (Pratiwi et al., 2024; Ramdhani et al., 2024; Pratiwi et al., 2022). In addition, more recent stratigraphic studies in Waluran identified five lithological units, including sandstone, altered tuff, basalt lava, tuff, and volcanic breccia, with volcanic breccia showing evidence of unconformity. These variations indicate multiple volcanic and tectonic episodes from the Early to Late Miocene, accompanied by structural features such as joints and normal faults that further reflect the region's complex geological evolution (Farela and Fachrudin, 2025).

The rocks of the Cikarang Member represent deposits formed through turbidite flow mechanisms, resulting from turbulent currents that contributed to the development of a deep marine fan system (Anhaer et al., 2024). Meanwhile, the volcanic rocks of the Ciseureuh

Member were generally formed through interactions between lava, water, and sediments, producing distinctive structures such as pillow lavas, peperites, and hyaloclastites (Djafar et al., 2024). These features suggest that volcanic activity influencing rock formation in the Ciletuh-Palabuhanratu UGGp area during the Early Neogene occurred in a submarine environment.

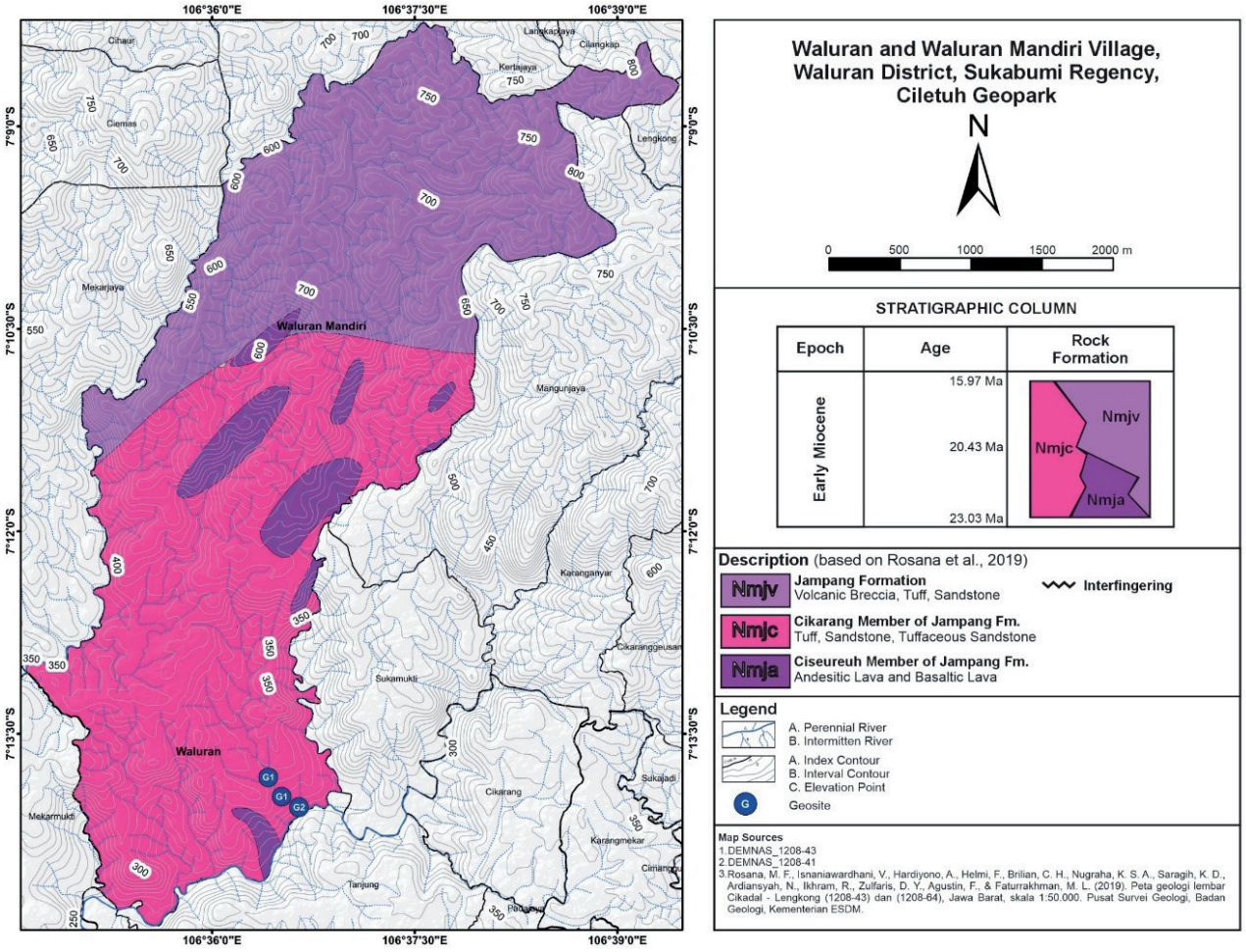

Figure 1. Geological map and stratigraphic column of the study area, Waluran District. G1= Taman Batu Cukcrukan, G2= Taman Batu Sarongge, G3= Lorong Tengah.

3. Data and methods

Our research was carried out in Waluran Village, Waluran District, Sukabumi Regency (Figure 2). This region is renowned for its distinctive geological formations, including volcanic and sedimentary rock formations, which significantly contribute to its geotourism potential. This research focuses on three key geosites in Waluran, such as Taman Batu Cukcrukan, Taman Batu Sarongge, and Lorong Tengah, which are significant due to their scientific, educational, and recreational value. The research utilized both primary and secondary data. Primary data were obtained through interviews with local stakeholders and direct field observations, which included qualitative insights and quantitative measurements such as hazard values and severity levels. Secondary data were derived from literature reviews and previous studies that provided additional context for the geological and geotourism characteristics of Waluran. In this research, we applied degradation risk assessment analysis following the approach of Kubalíková et al. (2023) and conducted Hazard Identification and Risk Assessment to formulate appropriate control measures for each geosite based on the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) method.

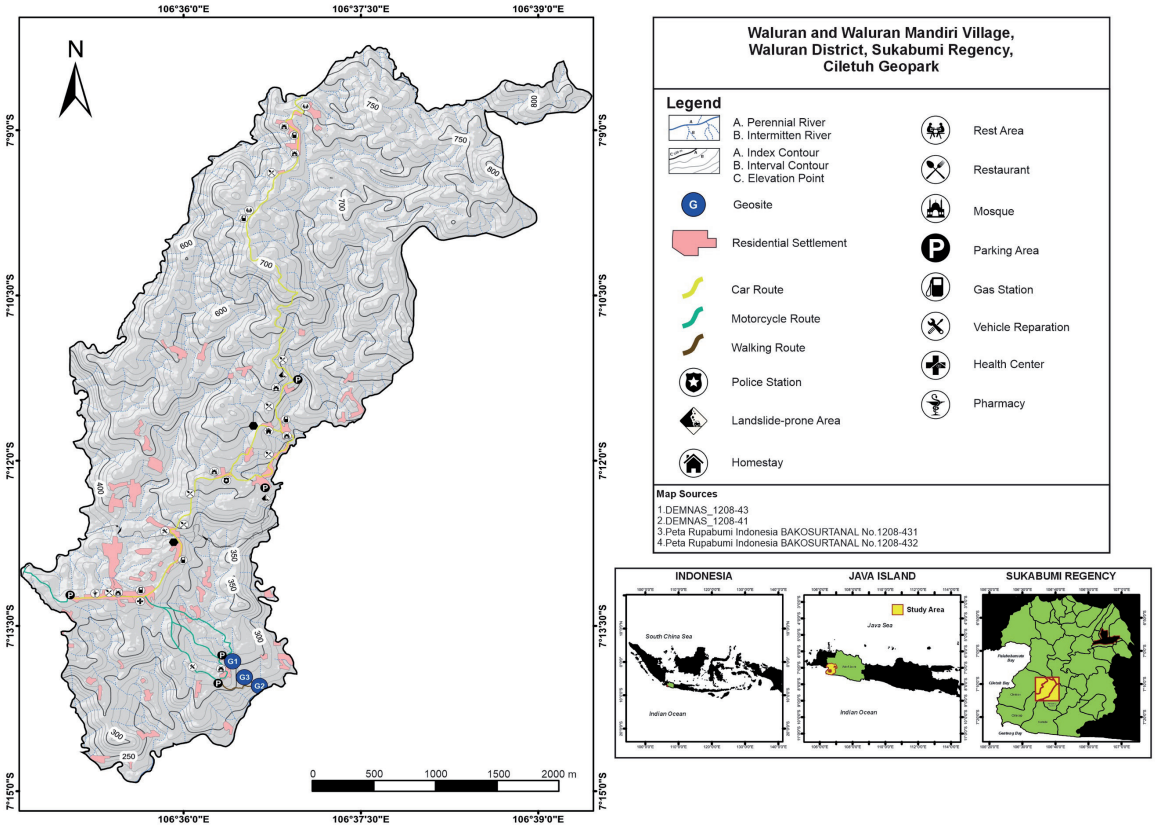

Figure 2. Map of the study area and geotourism site locations. G1= Taman Batu Cukcrukan, G2= Taman Batu Sarongge, G3= Lorong Tengah.

3.1 Degradation Risk Assessment

Degradation risk assessment evaluates the level of threats to geotourism sites, using a 0–1 point scale for each criterion as adapted from the approach of Kubalíková et al. (2023) (Table 1). A site can score up to 10 points, with scores above 5 indicating a threatened status, as determined by expert judgment. While this approach may involve some subjectivity, using a quantitative scale and engaging more experts can help reduce bias. The final score reflects a site's risk susceptibility. However, site-specific characteristics must always be considered in the interpretation. To reduce subjectivity, standardized scoring criteria and matrices can be applied, as they combine probability and impact values to evaluate site vulnerability (Kubalíková and Balková, 2023; Kubalíková et al., 2023). In addition to data limitations, the use of statistical measurement was not applied because this method is designed as a tool for field observation rather than a complex analytical model. This assessment helps prioritize sites needing urgent attention and guides the development of targeted management strategies.

Table 1. Degradation Risk Assessment (Kubalíková et al., 2023)

Criterion	Scoring
Integrity	0 = excellent conditions; 0.25 = good conditions; 0.5 = medium, average conditions; 0.75 = bad conditions, but with a possibility to recover; 1 = bad conditions, site is damaged
Accessibility	0 = more than 1 km from a parking place and stop of public transport; 0.5 = the stop and/or parking in the distance 0.2 and 1 km; 1 = the stop and/or parking place no more than 0.2 km from the site
Current Threats and Management	0 = site practically not endangered; 0.25 = low anthropic and natural threats; 0.5 = potential threats, but managed well or possible to decrease; 0.75 = current anthropogenic threats, but existing plans to decrease them; 1 = existing and ongoing processes leading to the destruction of the site with no plans to recover

Criterion	Scoring
Legal Protection	0 = protected on national level; 0.25 = protected on regional level; 0.5 = protected on municipal level; 0.75 = ongoing monitoring of the site; 1 = no legal protection
Proximity to Problematic Area	0 = site located less than 1 km of a potential degrading area/activity; 0.5 = site located less than 0.5 km of a potential degrading area/activity; 1 = site located less than 0.2 km of a potential degrading area/activity
Current Use	0 = 1 activity; 0.5 = 2 different activities; 1 = 3 and more different activities
Visitation	0 = low; 0.5 = medium; 1 = high
Number of Threats	0 = no threat; 0.25 = 1 threat; 0.5 = 2 threats; 0.75 = 3 threats; 1 = 4 and more different threats
Use Limitation	0 = the use is very hard due to limitations difficult to overcome (legal, permissions, safety, etc.); 0.5 = the site can be used occasionally after overcoming limitations; 1 = no limitations for public use

3.2 Hazard Identification, Risk Assessment, and Determining Control (HIRADC)

Hazard identification, risk assessment, and determining control refer to the HIRADC standard. Hazard identification, risk assessment, and determining control (HIRADC) is a method used to identify potential hazards by defining their characteristics and evaluating associated risks using a risk assessment matrix (Susihono, 2012). In accordance with OHSAS 18001 clause 4.3.1 (2007), workplaces in the tourism sector must integrate HIRADC into their occupational health and safety management systems. HIRADC is flexible, as it allows risks to be evaluated either quantitatively through a risk matrix or qualitatively using descriptive categories such as low, medium, and high. Another key advantage is that it supports compliance with occupational health and safety standards such as OHSAS 18001. However, the process is highly subjective, as the quality of the risk assessment depends greatly on the assessor's experience, knowledge, and personal judgment.

Risk is defined as a combination of the likelihood of an event occurring and its impact, such as injury or illness. Organizations are required to develop, implement, and maintain procedures for hazard identification, risk assessment, and necessary controls (Ningsih and Hati, 2019). Hazards can be categorized into occupational safety hazards, including risks such as mechanical, electrical, fire, and explosion hazards, as well as occupational health hazards, encompassing physical, chemical, ergonomic, biological, and psychological risks (Wisudawati and Patradhiani, 2020).

The assessment proceeds by first observing potential hazards associated with activities conducted around the geosites. Each hazard is then evaluated in terms of its likelihood and severity, from which both the risk level and maximum severity can be determined using a risk matrix. Based on these results, hazard control must be implemented in line with the ISO 45001 hierarchy, which prioritizes elimination, substitution, engineering controls, administrative measures, and personal protective equipment (ISO 45001, 2018). This process is operationalized through Hazard Identification, Risk Assessment, and Determining Control (HIRADC), adapted to the specific conditions of local geosites.

In the context of geotourism, HIRADC is crucial for ensuring visitor safety and ecosystem preservation. Risk assessment involves evaluating the likelihood of accidents occurring and the severity of their impacts. Likelihood measures the probability of a hazard occurring, while severity assesses the level of harm it may cause (Wisudawati and Patradhiani, 2020). A risk relative matrix is also reviewed to determine the risk level of potential hazards, allowing for the identification and prioritization of hazards that require more attention and action (Susihono, 2012). Applying HIRADC to geotourism sites, such as those in Waluran District, aims to identify potential hazards like steep paths or rocky areas, enabling appropriate mitigation measures to be implemented. This approach ensures that geotourism activities remain safe while retaining their educational and recreational value.

4. Results

4.1 Degradation Risk Assessment

The degradation risk assessment conducted using the Kubalíková et al. (2023) model shows that none of the three Waluran geosites are categorized as threatened, as none have a score exceeding 5 (Figure 3). Taman Batu Cukcrukan emerges with the highest total (4.25), largely due to its Problematic Areas score of 1.00, indicating proximity to human activity, hazard, and elevated susceptibility (Table 2). This aligns with broader observations in Ciletuh-Palabuhanratu UNESCO Global Geopark, where physical hazards such as rockfalls and slope instability have been identified as key risks to visitor safety and site integrity (Herlinawati et al., 2025). In addition, the landslide susceptibility map of West Java by PVMBG shows that all three geosites are located within a moderate-risk zone, where slope movements may occur along river valleys, escarpments, and road cuts, especially when slope stability is disturbed by intense rainfall and erosion. In comparison, Taman Batu Sarongge and Lorong Tengah both obtained a score of 3.75, with a Current Use factor of 0.50 (Table 2). This indicates the influence of human activities, primarily agricultural practices with limited formal development, which may pose potential challenges to the long-term sustainability of these sites. Although these activities are less intensive, they still mirror a wider pattern in global geoparks, where human use without management structures gradually erodes site quality (Selmi et al., 2022; de Lima et al., 2010).

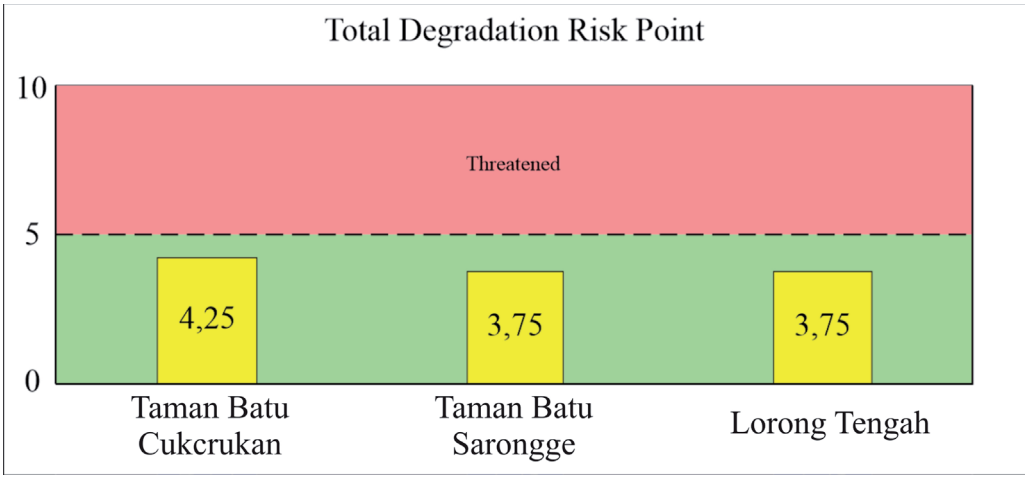

Figure 3. Bar chart representation of the total degradation risk point of 3 geosites observed in Waluran District.

Across all sites, Integrity is consistently low (0.50), indicating that while geological features remain intact, systematic maintenance is lacking (Table 2). This mirrors broader weaknesses in the Ciletuh geoconservation program, which remains underdeveloped despite its unique mélange, ophiolitic, and pre-Tertiary exposures (Hengky, 2022). Accessibility further differentiates the sites, as improved access enhances their tourism potential but also increases vulnerability to degradation when protection and monitoring are limited (Selmi et al., 2022). At the same time, the uniform scores for Current Threats (0.50) and Legal Protection (0.75) indicate a moderate regulatory framework, but one weakened by poor on-site enforcement, supporting findings that inadequate management and limited legal protection are key drivers of geosite degradation (de Lima et al., 2010).

Visitation remains effectively minimal (0.00), with no official records available since the sites lack direct management. Interviews with local stakeholders suggest that visitation rarely exceeds 50 people per week and may fluctuate significantly, while during our field observations, no visitors were recorded. Although this confirms that anthropogenic pressures are currently minimal, it paradoxically raises a different form of risk, where sites with very low visitation and limited community engagement are more prone to neglect, and therefore receive little attention in terms of conservation, monitoring, or funding (de Lima et al., 2010; Selmi et al., 2022).

Table 2. Degradation risk assessment result

Criterion/Site	Taman Batu Cukcrukan	Taman Batu Sarongge	Lorong Tengah
Integrity	0.50	0.50	0.50
Accessibility	0.75	0.25	0.25
Current Threats	0.50	0.50	0.50
Legal Protection	0.75	0.75	0.75
Problematic Areas	1	0.50	0.50
Current Use	0	0.50	0.50
Visitation	0	0	0
Number of Threats	0.25	0.25	0.25
Use Limitations	0.50	0.50	0.50

The risk assessment indicates that Waluran's geosites, although not currently classified as threatened, face vulnerabilities coming from low visitation, accessibility, weak management, and insufficient legal protection. Unlike studies that emphasize tourism pressure and visitor threats, the main concern in these geosites lies in neglect, where the absence of consistent maintenance and governance may accelerate degradation despite their location within the geopark. These conditions highlight the need for proactive measures, such as natural hazard monitoring, regular maintenance, and clearer legal protection, to safeguard their long-term integrity and ensure their potential for education, recreation, and conservation can be realized.

4.2 Hazard Identification, Risk Assessment, and Determining Control (HIRADC)

4.2.1 Taman Batu Cukcrukan

Taman Batu Cukcrukan, located in Waluran Village at coordinates 7°13'49.3" S and 106°36'24.9" E, is a striking area featuring rock outcrops forming a small rocky waterfall (Figure 4). Field observations identified five potential hazards in the vicinity, with risk assessment categorizing three as high (60%) and two as moderate (40%) (Table 3). The detailed analysis of these hazards, including their identification, risk evaluation, and recommended control measures, is provided in Table 3. High-risk categories are predominantly mobility-related, such as walking and driving on steep roads and narrow tracks, where slips and falls are likely and may cause severe injury. Moderate risks, including uneven roads and rockfalls, are more localized but remain significant, particularly during visitor activities involving driving and walking. These hazards arise from a combination of natural conditions (e.g., rockfall from weathered slopes) and human activities (e.g., navigating small tracks or walking on slippery roads), with visitors most vulnerable during movement across uneven terrain.

The findings indicate that immediate interventions are necessary to mitigate accident potential and enhance site accessibility. Recommended measures follow the ISO 45001 hierarchy, including elimination (removing slippery leaves), engineering (paving roads, slope stabilization), and administrative actions (warning signage and routine maintenance). Implementing these controls not only minimizes accident likelihood but also supports long-term conservation by reducing human-induced pressures on fragile landforms.

Table 3. HIRADC Analysis Results in Taman Batu Cukcrukan

HIRADC Analysis in Taman Batu Cukcrukan									
No	Activity	Hazard	Description	Risk Assessment (Susihono, 2012)		Risk Level	Risk	Maximum Severity	Risk Control
				Likelihood	Severity				
1	Driving	Uneven road	There are potholes on the road	Possible	Moderate	Moderate	Fall	Severe Injury	Engineering: Construct non-slippery roads by paving the road
2	Driving	Steep road	The road slope is steep	Possible	Major	High	Fall	Severe Injury	Administration: Place warning signs for caution
3	Walking	Small track	The small track at the edge of the rice field	Almost Certain	Minor	High	Slip	Minor Injury	Administration: Place warning signs for caution
4	Walking	Dried leaves	There are slippery, dry leaves around the rock	Likely	Moderate	High	Slip	Minor Injury	Elimination: Cleaning the dry leaves

HIRADC Analysis in Taman Batu Cukcrukan									
No	Activity	Hazard	Description	Risk Assessment (Susihono, 2012)		Risk Level	Risk	Maximum Severity	Risk Control
				Likelihood	Severity				
5	Walking and sightseeing	Falling weathered rocks (rockfall, landslide)	Loose and weathered rocks that are prone to falling	Rare	Catastrophic	Moderate	Hit by falling rocks	Minor Injury	Administration: Place warning signs for caution Engineering: Slope stabilization with a geotechnical approach

Figure 4. Geosite condition of Taman Batu Cukcrukan, highlighting potential hazards such as uneven roads, narrow paths, dry leaves covering trails, and weathered rocks.

4.2.2 Taman Batu Sarongge

Taman Batu Sarongge, Goa Maung, and the Waluran Pillow Lava are geotourism sites located within the same complex area in Waluran Village, at coordinates 7°14'03.8" S and 106°36'40.1" E (Figure 5). Field observations identified three potential hazards in the vicinity, with risk assessment categorizing one as high (33,3%) and two as moderate (66,7%). The detailed analysis, including hazard identification, risk evaluation, and recommended control measures, is presented in Table 4. The high-risk category is mainly associated with walking activities on slippery rocks around the river, where the likelihood of slipping is considerable and may cause minor injury. Moderate risks include crossing a small wooden bridge without handrails and walking near areas with loose or fallen rocks, both of which present hazards ranging from falls with severe injuries to potential rock strikes that could be fatal in extreme cases. These risks stem from a combination of natural factors (e.g., unstable slopes and weathered rocks) and insufficient infrastructure (e.g., the absence of handrails on bridges). Visitors are particularly vulnerable during activities requiring balance and movement across unstable or slippery terrain.

The findings emphasize the importance of immediate risk mitigation to ensure visitor safety while maintaining the site's natural integrity. Recommended interventions follow the ISO 45001 hierarchy, including engineering measures (improving the wooden bridge structure and adding handrails), administrative actions (installing clear warning signs to increase visitor awareness), and substitution strategies (rerouting paths to avoid areas prone to falling rocks). Implementing these measures can substantially reduce accident potential and enhance the overall safety of geotourism activities.

Table 4. HIRADC Analysis Results in Taman Batu Sarongge

HIRADC Analysis in Taman Batu Sarongge									
No	Activity	Hazard	Description	Risk Assessment (Susihono, 2012)		*Risk Level*	Risk	Maximum Severity	Risk Control
				Likelihood	*Severity*				
1	Crossing the river	A small and narrow wooden bridge	There is a small wooden bridge without any handrails.	Possible	Moderate	Moderate	Fall	Severe injury	Engineering - The crossing bridge is constructed using more bamboo and adding handrails to the bridge.
2	Walking and sightseeing	Slippery rocks	Slippery rocks around the river	Likely	Moderate	High	Slip	Minor injury	Administrative - Provide warning signs to make tourists more cautious.
3	Walking and sightseeing	Fallen or sliding loose rocks.	There are loose rocks that might fall again.	Rare	Catastrophic	Moderate	Struck or buried by the rocks	Death	Substitution - Find an alternative path that is not blocked by rocks.

Figure 5. Geosite condition of Taman Batu Sarongge, highlighting potential hazards such as a narrow wooden bridge without handrails, slippery moss-covered rocks, and weathered rocks

4.2.3 Lorong Tengah

Lorong Tengah, an erosional landform resembling a canyon, is located in Waluran Village at coordinates 7°13'58.0" S and 106°36'30.8" E (Figure 6). Field observations identified three potential hazards in the vicinity, with risk assessment categorizing two as high (66,7%) and one as moderate (33,3%). The detailed findings, including hazard identification, risk evaluation, and proposed control measures, are outlined in Table 5. The high-risk hazards are mainly associated with deep holes around the river, where accidental falls or drowning could occur, posing a potentially fatal outcome. Moderate risks include slippery vegetation and obstructive tree branches along walking paths, which may result in minor injuries from slipping or severe injuries from physical contact with branches. These hazards are influenced by natural site characteristics, such as riverbank morphology and dense vegetation, combined with limited visitor management infrastructure.

The results emphasize the urgency of implementing appropriate risk control measures to minimize accident likelihood while maintaining safe access for visitors. Recommended interventions align with the ISO 45001 hierarchy, including administrative measures (installing warning signs near river holes), as well as elimination strategies (conducting regular track cleaning to remove slippery vegetation and clear obstructive tree branches). Such measures not only enhance visitor safety but also support sustainable geotourism by reducing physical disturbances and maintaining the natural conditions of the site.

Table 5. HIRADC Analysis Results in Lorong Tengah

HIRADC Analysis in Lorong Tengah									
No	Activity	Hazard	Description	Risk Assessment (Susihono, 2012)		*Risk Level*	Risk	Maximum Severity	Risk Control
				Likelihood	*Severity*				
1	Walking and sightseeing	Deep holes around the river.	There are holes in the river with a depth of more than 1 meter.	Possible	Catastrophic	High	Fall or drown	Death	Administrative - Provide warning signs to make tourists more cautious.
2	Walking	Vegetation	There are slippery, dry leaves and living plants.	Likely	Minor	Moderate	Slip	Minor injury	Elimination - Conduct regular cleaning of the track.
3	Walking	Tree branches	Tree branches are blocking the path.	Likely	Minor	Moderate	Pricked by a branch.	Severe injury	Elimination - Conduct regular cleaning of the track

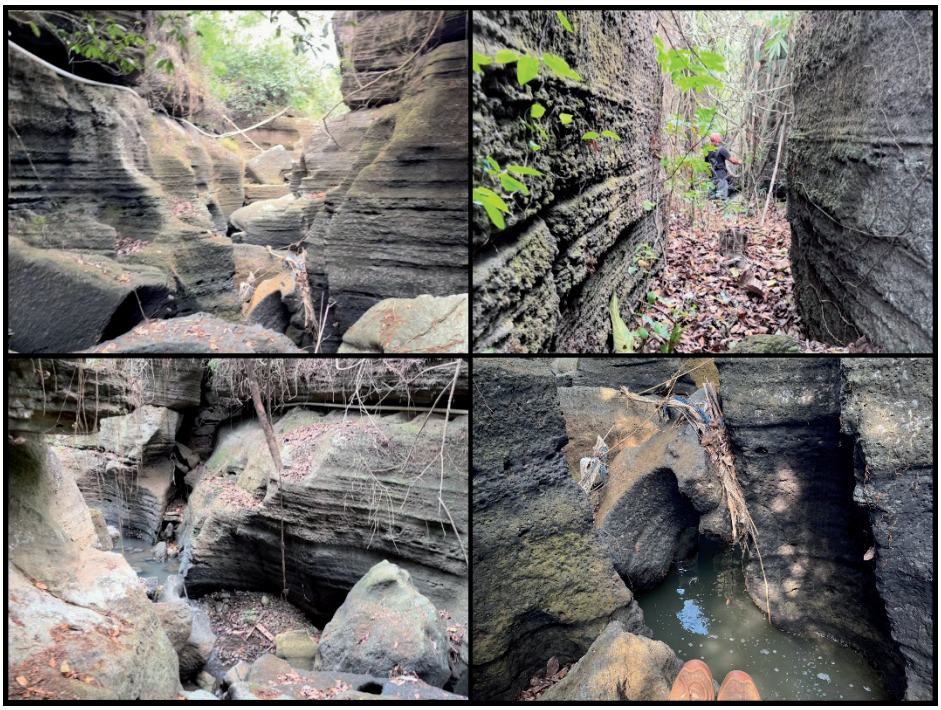

Figure 6. Geosite condition of Lorong Tengah, highlighting potential hazards such as deep holes around the river and obstructed tracks caused by vegetation, slippery dried leaves, and fallen branches.

5. Discussion

The integration of Degradation Risk Assessment and Hazard Identification, Risk Assessment, and Determining Controls (HIRADC) in this study provides a holistic framework to evaluate the sustainability of geotourism sites in Waluran. Although none of the assessed geosites are currently classified as threatened, the results highlight significant vulnerabilities, particularly at Taman Batu Cukcrukan, which obtained the highest score (4.25), exemplifying how better accessibility and proximity to problematic areas increase susceptibility, reflecting broader findings that accessibility and insufficient legal protection increase geoheritage degradation risks (Selmi et al., 2022). This highlights the need for continuous monitoring and targeted management plans, as fragility and anthropic vulnerability shape the sustainability of geosites and their scientific, educational, and recreational value (Fuertes-Gutiérrez et al., 2016).

The HIRADC results indicate that most hazards are mobility-related, including steep trails, slippery surfaces, unsafe bridges, and deep river holes, with Taman Batu Cukcrukan recording 60% of hazards in the high-risk category, consistent with previous safety assessment research by Herlinawati et al. (2025) in Ciletuh–Palabuhanratu UGGp that highlighted rockfalls and unstable paths as primary hazards. Mitigation requires adherence to the ISO 45001 hierarchy through infrastructural measures such as slope stabilization, paving, and guardrail installation, complemented by administrative controls like signage and visitor education, which have proven effective in reducing accident likelihood while maintaining conservation values (Newsome and Dowling, 2006; Kubalíková et al., 2023). Importantly, the linkage between Degradation Risk Assessment and HIRADC lies in how site vulnerabilities escalate safety risks, where limited legal protection, unclear management, and natural hazards, such as slides or rockfalls, are compounded by maintenance and infrastructure quality, leading to mobility-related hazards, including unsafe trails and crossings. This shows that degradation and hazard risks are interdependent and require integrated risk control.

Low visitation at the observed geosites currently reduces direct anthropogenic pressure, but it also results in neglect, underfunding, and weak legal protection, which over time may compromise conservation (Kubalíková et al., 2021). To address this, strengthening participatory management with local communities, securing stronger legal protection, and conducting regular reassessments are essential to maintain sustainability. In this regard, the combined application of Degradation Risk Assessment and HIRADC provides a comprehensive framework, showing how degradation risks and hazard risks are interconnected dimensions of the same sustainability challenge. Addressing both aspects in an integrated manner is therefore critical not only to safeguard visitor safety and preserve geodiversity but also to reinforce the role of the Ciletuh–Palabuhanratu UNESCO Global Geopark as a model of sustainable geotourism in Indonesia.

6. Conclusions

The results of this study conclude that the three geosites in Waluran are not classified as threatened based on the applied assessment method. The main vulnerabilities are low visitation, weak management, accessibility, and only moderate legal protection, which indicate neglect rather than direct tourism pressure. Despite not being classified as threatened, these conditions increase the potential for the geosites to become more vulnerable over time, where the absence of consistent maintenance and protection may accelerate degradation. The HIRADC results show that most hazards are mobility-related, with high-risk categories recorded in all sites. Control measures include slope stabilization, paving, warning signs, bridge improvements, and regular track maintenance to reduce accident likelihood while supporting conservation.

The integration of the two methods provided a clear and complementary framework to evaluate geosite sustainability in Waluran. The degradation risk assessment highlighted where governance and protection remain weak, while HIRADC translated those vulnerabilities into practical safety measures. This approach proved effective in addressing the research objectives and can be applied in other geotourism areas with similar conditions to strengthen management, enhance visitor safety, and support sustainable use of geoheritage within the Ciletuh-Palabuhanratu UNESCO Global Geopark.

Acknowledgments

We would like to express our sincere gratitude to Universitas Padjadjaran, Indonesia, for research funding support provided through the *Hibah Riset Unpad* (HRU), under the *Hibah Riset Kompetensi Dosen Unpad* (RKDU) 2024 scheme (Contract No. 1955/UN6.3.1/PT.00/2024). The authors also extend their appreciation to the Waluran District community and the Ciletuh–Palabuhanratu UNESCO Global Geopark Management for their kind cooperation and assistance during field data collection. This study also forms part of the implementation of the *Hibah Pengabdian Pada Masyarakat "Unpad Bermanfaat"* program (2023-2024).

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