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QUALITY AND CARRYING CAPACITY OF KLAYAR COASTAL BEACH TO ENHANCE SUSTAINABLE MANAGEMENT IN GLOBAL GEOPARK GUNUNG SEWU, INDONESIA

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Abstract: Klayar Beach, a key site within Indonesia's Gunung Sewu UNESCO Global Geopark, faces growing tourism pressures threatening its ecological integrity. This study evaluates sustainable visitation thresholds by integrating carrying capacity analysis with beach quality assessment, addressing critical gaps in coastal geopark management literature. Using a descriptive-quantitative method, the study integrates beach carrying capacity analysis, including Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC), and Effective Carrying Capacity (ECC), with beach quality indicators, such as accessibility, environmental quality, comfort, and infrastructure. Data were collected using field observations, surveys, GIS mapping, and stakeholder interviews. The result showed that while the beach has high environmental quality (score: 0.93), optimal water quality (1), and no industrial pollution, vendor waste management requires improvement. Poor facilities (score=0.5) are due to inadequate restrooms, limited shade, insufficient safety equipment, and significant limitations in facilities and comfort. Although the PCC exceeds 113,000 visits/day, the ECC is significantly lower at 6,060 visits/day, showing a gap between physical capacity and management capability. The beach was divided into five zones with distinct characteristics and capacities: Zones 1-2 show high development potential (ECC 547-256 visits/day), while Zones 4-5 require strict conservation measures (ECC 105-68 visits/day). The study shows the need for visitor limits, improved infrastructure, and community-based tourism strategies to balance conservation with economic growth. By aligning visitor management with zone-specific capacities, Klayar Beach can mitigate over-tourism and enhance sustainable use. This approach can serve as a model for other coastal geoparks facing similar challenges, promoting long-term environmental and socio-economic resilience. In this regard, a novel framework was provided for integrating carrying capacity and beach quality assessments in geopark contexts, contributing to more sustainable coastal tourism management in Indonesia and beyond.

Keywords: sustainable coastal tourism, carrying capacity, beach quality, UNESCO Global Geopark, Klayar Beach

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INTRODUCTION

Coastal areas are essential for economic development, cultural heritage, and biodiversity conservation hubs. However, unmanaged tourism growth significantly pressures fragile coastal ecosystems, leading to habitat degradation, pollution, and overcrowding (Milano et al., 2024). Recently, coastal tourism has been a rapidly growing sector, driven by increasing global demand for nature-based experiences (Da Mota & Pickering, 2021). Sustainable tourism's challenge was balancing economic benefits with environmental and social sustainability (Williams & Lemckert, 2023).

Indonesia is home to some of the world's most visited coastal destinations and the country faces overtourism issues in places such as Bali, Yogyakarta, and Lombok (Faiz & Komalasari, 2020; Purwandani & Pakan, 2022; Utama et al., 2024). Although these popular destinations have attracted significant attention in tourism studies, lesser-known yet ecologically valuable coastal sites, such as Klayar Beach in Pacitan, remain understudied regarding their carrying capacity and long-term sustainability. Klayar Beach, part of the UNESCO-designated Gunung Sewu Global Geopark, is renowned for its unique karst formations, white sandy shores, and geological heritage. Despite the growing appeal, drawing over 300,000 visitors annually, there is limited understanding of how increased tourism impacts its environmental integrity and visitor experience.

Assessing beach quality in Klayar Beach is essential for safeguarding its UNESCO Global Geopark status by protecting unique geological formations while monitoring human impacts (Pérez-Romero et al., 2023). It complements carrying capacity calculations by revealing how conditions affect visitor distribution and experience quality, aligning with UNESCO's sustainable tourism guidelines (Rocha et al., 2021). Regular quality monitoring establishes climate resilience benchmarks and provides management tools to prevent heritage degradation. This integrated approach offers a

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model for coastal geoparks worldwide to balance preservation with responsible tourism development (Wu et al., 2022). Beyond visitor thresholds, sustainable coastal tourism also depends on a broader evaluation of beach quality indicators, which provide a holistic measure of sustainability. Previous studies have identified several key factors influencing beach quality, including accessibility, environmental quality, comfort, infrastructure, and safety (Prisco, 2021).

Accessibility is crucial in determining visitor flow and distribution, with well-designed infrastructure facilitating a more even dispersal of tourists while reducing congestion in sensitive areas (Dash & Sharma, 2021). Environmental quality, including water cleanliness, waste management, and pollution control, are important factors in maintaining the ecological integrity of coastal destinations (Peña-Alonso et al., 2018). Visitor satisfaction and tourism experience are influenced by comfort and infrastructure, including rest areas, public facilities, and security measures (Hanaee et al., 2025).

Sustainable coastal management strategies need to account for beach carrying capacity (BCC), the maximum number of visitors an area can sustain without causing environmental degradation or compromising visitor satisfaction (Cisneros et al., 2016). Previous studies have assessed carrying capacities of tourist beaches in Argentina and the Dominican Republic (Cisneros et al., 2016; Cortés-Useche et al., 2021), but there remains a study gap in applying carrying capacity frameworks to Indonesian UNESCO Geopark sites, particularly in integrating environmental indicators with visitor management strategies. Furthermore, while global studies showed the importance of sustainable coastal tourism (Defeo et al., 2021), there are limited empirical reviews on the accurate and effective carrying capacities of Indonesian beaches facing increasing tourism demand. There is a significant gap in studies that integrate both methods within the Indonesian tourism context despite the extensive investigation of carrying capacity and beach quality assessments. Previous studies have primarily focused on carrying capacity calculations or general sustainability assessments, with only a few attempting to merge these methodologies into a comprehensive evaluation framework (Arinta et al., 2022; Cisneros et al., 2016; Insani et al., 2020).

This lack of study challenges local policymakers and tourism stakeholders, who require data-driven insights to develop effective management strategies. This study addressed these gaps by conducting an integrated assessment of Klayar Beach's tourism sustainability, combining carrying capacity calculations (PCC, RCC, and ECC) and evaluating beach quality indicators. By applying this comprehensive framework, valuable insights were provided into the environmental thresholds of Klayar Beach and strategic recommendations for sustainable tourism planning.

MATERIALS AND METHODS

The study used a cross-sectional descriptive-quantitative design to evaluate various aspects of Klayar Beach. This method enables systematic collection and analysis of numerical data, facilitating comparisons and statistical evaluations.

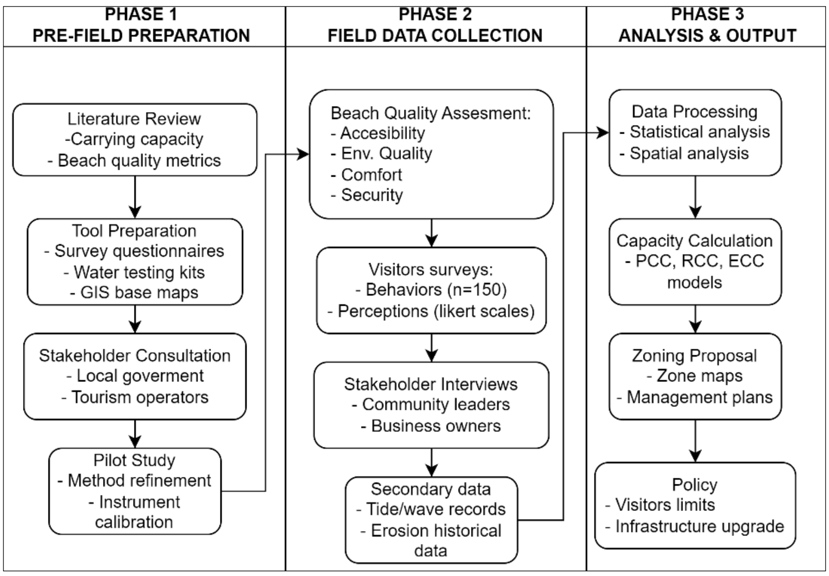

Figure 1. Research flowchart Quality and Carrying Capacity of Klayar Coastal Beach (Source: Author, 2024)

This study was conducted at Klayar Beach, Donorojo District, and Pacitan Regency, Indonesia, focusing on beach quality and carrying capacity assessment. Klayar Beach (approximately 8.123°S, 111.456°E) lies along the southern coast of Java Island, facing the Indian Ocean, and is renowned for its unique coastal geomorphology, including limestone cliffs, white sand, and tidal wave erosion features. Primary data were collected in the field using the direct measurement method. Secondary data were also collected by studying the literature and information on assessing the carrying capacity of the tourism environment. The research flow is shown in Figure 1.

Assessing the beach uses the Beach Quality Assessment indicator (Table 1) and scoring for analysis (Table 2).

Table 1. Beach Quality Assessment Framework ((Peña-Alonso et al., 2018)

Indicator	Parameters Assessed	Measurement Criteria	Data Collection Method
Accessibility (Acc)	-Disabled parking; -Public parking; -Accessible pathways; -Public transport; - Signage	0-4 scale (0=None, 4=Excellent)e.g., "Disabled parking: 0=Absent, 4=Available"	Observation GIS mapping

Environmental Quality (EnvQ)	- Noise pollution; - Odors; - Algae blooms; - Water pollution; - Waste accumulation	Binary (Yes/No) and frequency scales e.g., "Algae blooms: 0=>5/yr, 4=<2/yr"	Water sampling Visual surveys
Water Quality (WatQ)	- Microbiological safety	0=Unsuitable, 4=Suitable	Laboratory analysis
Comfort (Comf)	- Wave energy; - Wind speed; - Temperature; - UV index; - Animal nuisance	Categorical scales e.g., "Wave energy: 0=>1.5m, 4=<0.5m"	Meteorological instruments
Scenic Beauty (SceQ)	- Water clarity; - Landscape integration; - Coastal vegetation	0-4 scales e.g., "Water transparency: 0=Muddy, 4=Clear"	Expert appraisal Visitor surveys
Human Activity Infra. (HumAI)	- Carrying capacity; - Structures; - Urbanization level; - Illegal activities	Mixed scales e.g., "Permanent infrastructure: 0=>75%, 4=0%"	Spatial analysis Official records

Table 2. Beach Quality Classification System

Class	Score Range	Description	Management Implications
Excellent	145-192	Pristine conditions with full facilities and minimal human impact	Maintain current status; focus on monitoring and minor improvements
Good	97-144	Minor issues in 1-2 indicators but generally well-managed	Targeted enhancements (e.g., waste management, accessibility upgrades)
Fair	49-96	Significant deficiencies in multiple indicators require intervention	Major infrastructure investments and visitor management are needed
Poor	0-48	Severe degradation; unsafe or unsuitable for sustainable tourism	Immediate restoration required; potential temporary closure

The carrying capacity assessment framework for tourist attraction zones considers three levels of focus, namely Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC), and Effective Carrying Capacity (ECC). Physical Carrying Capacity (PCC) shows the maximum number of tourists a space can hold at a specific time and was calculated using the preceding formula (Cifuentes, 1992). This measure provides the limit for tourist numbers based on available space.

$$\mathrm{PCC} = \frac{A}{A_U} * T_f,$$

where A is the size of the study area, Au represents the available area based on occupancy criteria, Tf shows how often an individual can visit the area in a day, considering scheduled visits and the time needed for each visit. The occupancy criterion (Au) was based on Norma Cubana's model, which identified three situations, namely high, medium, and low, with 5, 10, and 25 m² of space per visitor, respectively. The study estimated Tf values using data from questionnaires, as described by Cisneros et al. (2016). The Real Carrying Capacity (RCC) is the number of visitors allowed to visit a tourist attraction with a correction factor (CF) obtained from the object features applied to the PCC. The equation used to calculate RCC is as follows (Cifuentes, 1992):

$$\mathrm{RCC} = \mathrm{PCC} * \frac{100 - Cf_1}{100} * \frac{100 - Cf_2}{100} * \frac{100 - Cf_3}{100} * \cdots * \frac{100 - Cf_n}{100}, \qquad Cf_i = \frac{Ml_i}{Mt_i} * 100,$$

RCC is part of the PCC with some external factors, and Cfi is the correction coefficient for each generic factor. All Cfi factors were expressed as percentages using the equation. Mli represents the measured value for each generic factor i, and Mt_i is the maximum allowable value. These factors, including rainfall, strong winds, sunshine, periods of temporary closure, and beach were selected due to the influence on recreational activity (Table 3).

Table 3. Correction Factor Applied in the Research (Source: Cifuentes, 1992; Defeo et al., 2021; Peña-Alonso et al., 2018)

Component	Definition	Units
Rainfall (CF_1)	Percentage of days when precipitation limits beach activities	% days/yr
Strong Winds (CF_2)	Days with wind speeds >20 knots (23 mph) creating safety hazards	% days/yr
Sunlight (CF_3)	Excessive UV index (>8) reducing comfort during peak hours	hours/day
Closure Periods (CF_4)	Scheduled maintenance or ecological recovery periods	days/yr
Erosion (CF_5)	Beach area reduction from sediment loss (≥5% annual change)	m²/year

$$\mathrm{ECC} = \mathrm{RCC} * \frac{\mathrm{MC}}{100}.$$

The equation defines the ECC, where MC is the management capacity of the zone under consideration (Cifuentes, 1992). For the estimation of MC, the factors considered were institutional support (information services, beach management plans, building regulations, access regulations), services (tent rental, restaurants, drug stores), personnel (lifeguards, people trained for natural disaster response) and infrastructure (bathrooms, public lighting, beach buildings, wayfinding/beaches, beach access, recreational areas, lifeguards and fire stations, vehicles and means for natural disaster relief). Qualitative information, such as beach access, accommodation, recreational areas, parking, fishing, dunes, and rock zones, was also included, as shown in Table 4.

Table 4. Classification of BCC qualitative variables: Beach facilities (Source: Cisneros et al., 2016)

Qualitative variable	High (H)	Medium (M)	Low (L)
Beach access	H (>4)	M (between 2 and 4)	L (1)
Accommodation	H (>10)	M (between 4 and 10)	L (<4)
Recreation places	H (4)	M (between 2 and 4)	L (<2)
Parking places	H (>500)	M (between 100 and 500)	L (<100)

The carrying capacity calculation provides the number of tourists allowed per day. Studies calculated PCC, RCC, and ECC, then compared the values with the number of tourists who visit daily (JKr). When the number of tourists per day is greater than the carrying capacity, then the threshold of sustainable tourism is exceeded. However, when the number remains below the carrying capacity, then the value is within the limit, and further development opportunities are suggested. This method ensures accurate assessments for sustainable tourism management (Table 5).

Table 5. Recommended Tourism Classification and Supportability (Source: Cifuentes, 1992)

Type of Tourism Support		**Supportability Classification**	**Recommendation**
PCC>JKrRCC>JKr	ECC>JKr	Great Opportunity	Can be developed
PCC<JKrRCC<JKr	ECC<JKr	Overrated	Control and organization
PCC=JKrRCC=JKr	ECC=JKr	Optimal	Effective and Efficient

ANALYSIS AND RESULTS

Klayar Beach is located in the Donorojo Sub-district, about 35 km from Pacitan City (Figure 2). The beach classification was based on the category of Cisneros et al. (2016), namely urban, semi-urban, or natural. The Klayar Beach falls under the semi-urban category. This area has moderate to low population density and limited accessibility.

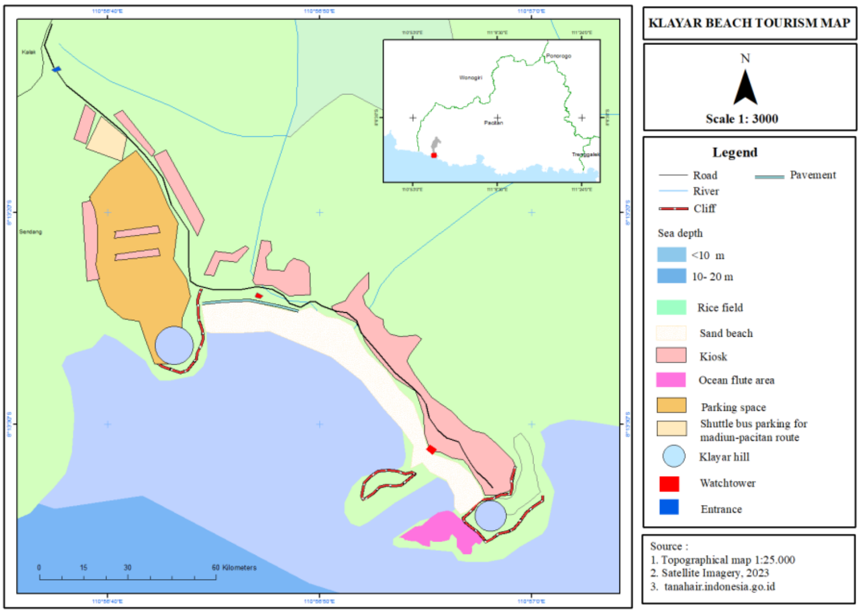

Figure 2. Klayar Beach Map (Source: The authors, 2025)

There is also a moderate presence of visitors and fewer artificial structures compared to urban beaches. The beach offers limited facilities and services, while the permanent residences have sparse essential services, such as primary schools, religious centers, shops, and cafes. The Klayar Beach quality index in this study is described in Table 5.

Table 5. Klayar Beach Quality Index

Indicator	**Category**					**Score**
	0	**1**	**2**	**3**	**4**	
Accessibility (Acc)						
1. Disabled parking	No.	-	-	-	Yes	0
2. Public car park	Insufficient	-	-	-	Simply	4
3. Access to the bathing area for users with disabilities	Zero	-	Without personnel	-	Customized	0
4. Access to beach facilities	0	-	Partially	-	Adapted	4
5. Access points customized for users with disabilities	0	-	1 every >200m	-	1 every <200m	0
6. Transport	No.	-	-	-	Yes	4
7. Fulfilment of transit facilities	It fails	-	-	-	It meets	4
8. Fulfilment of access to the sea	It fails	-	-	-	It meets	4
9. Possibility of access to the beach by public transport	No.	-	1 h/day	-	>2 h/day	2
10. Signs to the beach	0	-	<200m	-	>200m	2
11 . Information signs	No.	-	-	-	Yes	4
Environmental quality (EnvQ)						
1. Permanent noise	Yes	-	-	-	No.	4
2. Permanent anthropogenic odor	Yes	-	-	-	No.	4
3. Episodic algae and/or jellyfish blooms	>5 per year	-	2-5 per year	-	<2 per year	4
4. Episodic water pollution	>2 per year	-	1-2 per year	-	None	4
5. Waste sand	>40%	25-40	15-25%	5-15%	0-5%	4

6. Sewers	>2 in 1 km	-	1-2 in 1 Km	-	None	2
7. Particles/debris floating in water	Yes	-	-	-	No.	4
Water quality (WatQ)						
1. Microbiological water quality	Not suitable	-	-		suitable	4
Comfort (Comf)						
1. Drift current/shore drift	Common	-	Occasional	-	Non-existent	0
2. Wave energy	High (>1.5m)	-	Moderate (0.5-1.5m)	-	Low (<0.5m)	1
3. Wind speed	High	-	Moderate	-	Low	2
4. Air temperature (midday) (^{o}C)	<15/>38	-	15-27/32-38		27-32	2
5. Water temperature. (^{o}C)	<21 C/>27	-	-	-	21-27	4
6. Meteorological conditions	Rainy	Stormy	Overcast	Cloudy	Sunny	4
9. Nuisance animals	Common	-	Occasional	-	Non-existent	4
10. Thermal sensation	Very cool/Hot	-	Cool/Warm	-	Mild	0
11. UV Radiation	>6	-	6	-	<6	2
Scene quality (SceQ)						
1. Water transparency	Muddy	-	-	-	Transparent	4
2. Field of view	3/4 y 1/4	-	-	-	1,5/4- 2/4	4
3. Specific changes by humans	None	-	Rare	-	Very often	2
4. Integration of buildings into the landscape	Low/dense buildings	-	Low/rare Building	-	Moderate density	2
5. Integration of facilities into the landscape	Low integration	-	Partial	-	High	2
6. Integration of access to the landscape	Low integration	-	Partial	-	High	2
8. Contrast of coastal vegetation	Un-vegetated	Low	-	Moderate	High	1
9. Type of sea horizon	Indust/Port/Slum	-	Agricultural/ Islands	-	Natural or free	4
Human activity and infrastructure (HumAI)						
1. Physical carrying capacity	<8 2	-	8-12 2	-	>122	4
2. Dykes and breakwaters	Some/several	-	Only one	-	No.	2
3. Permanent infrastructure (%)	>75	75-50	50-25	25-1	0	2
4. Temporary structures (%)	>75	75-50	50-25	25-1	0	2
5. Degree of urbanization (%)	>75	75-50	-	25-50	<25	4
6. Disturbances	Frequent	-	Occasional	-	No.	4
7. Unauthorised activity	Non-fulfillment	-	Occasional	-	Fulfill.	4
8. Illegal dumping point within 1km	>2	-	2-1	-	None	2
9. Type of environment (urban, industrial)	Industrial	-	Urban	-	Natural	3
Total						**125**
Class						**Good**

The Beach Quality Index (BQI) assessment revealed significant variations across indicators, highlighting strengths and critical challenges for sustainable tourism management. Klayar Beach demonstrated excellent environmental quality (0.93/1.0), optimal water quality (1.0/1.0 for microbiological safety and salinity at 30.9 ppt), and minimal industrial pollution. However, litter management near vendor areas required improvement, as evidenced by episodic waste accumulation (score: 2/4 for sewers within 1 km). Accessibility scored moderately (0.63/1.0), constrained by steep terrain and inadequate disabled facilities (0/4 for customized beach access). Conversely, public parking and transport links scored well (4/4), reflecting localized infrastructure investments. Comfort levels were suboptimal (0.53/1.0) due to strong winds (score: 2/4) and high UV exposure (score: 2/4), while swimming restrictions further reduced recreational appeal. The scenic beauty index (0.66/1.0) benefited from transparent waters (4/4) and dramatic karst landscapes (4/4 for sea horizon aesthetics), though human-made structures partially compromised visual integrity (2/4 for building integration). Human activity infrastructure scored 0.81/1.0, with well-organized parking (4/4) but unauthorized vendor stalls (2/4 for disturbances). The Klayar Beach quality assessment is rated as good, scoring 125. The calculation of carrying capacity starts with identifying zone classifications (Figure 3).

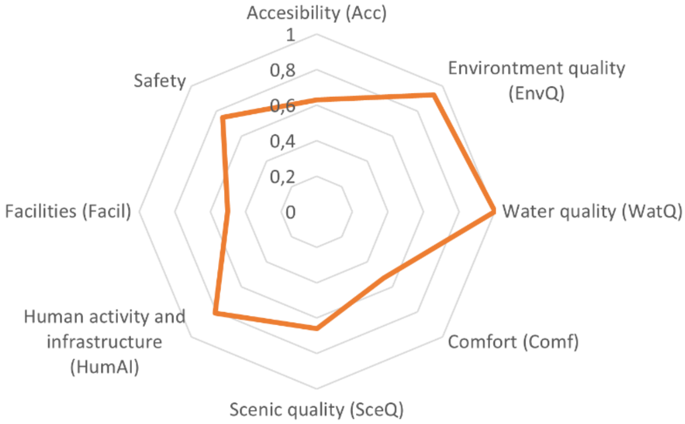

Figure 3. Results of Beach Suitability Index Calculation (Source: author's analysis)

Klayar Beach's zoning as presented in Figure 4 adheres to UNESCO Global Geopark guidelines, dividing the area into Core Zones (4–5) for protecting key geological features, Buffer Zones (2–3) for regulated tourism, and Transition Zones (1) for low-impact infrastructure (Vandenberghe, 2020). This structure ensures conservation while supporting sustainable tourism. The approach balances ecological protection with socio-economic benefits. Zone 1 (A–B) features a paved pathway with safety railings, offering panoramic ocean views and hosting a souvenir market (Figure 5a). Zone 2 (B–C) includes a motorbike parking area, viewing tower, and ATP post, where visitors enjoy a mix of sandy and rocky shores with wave-carved formations (Figure 5b). Zone 3 (C–D) combines lodging, food stalls, and coconut-shaded paths near the beach. Zone 4 (D–E) showcases dramatic karst cliffs and wave-eroded rocks, attracting photographers (Figure 5c).

Zone 5 (E–F), accessible only on foot, features a hilltop gazebo with sweeping views of the Ocean Flute - a geological marvel where waves create flute-like sounds through crevices (Figure 5d). Each zone balances tourism infrastructure with natural preservation, aligning with UNESCO Geopark zoning principles.

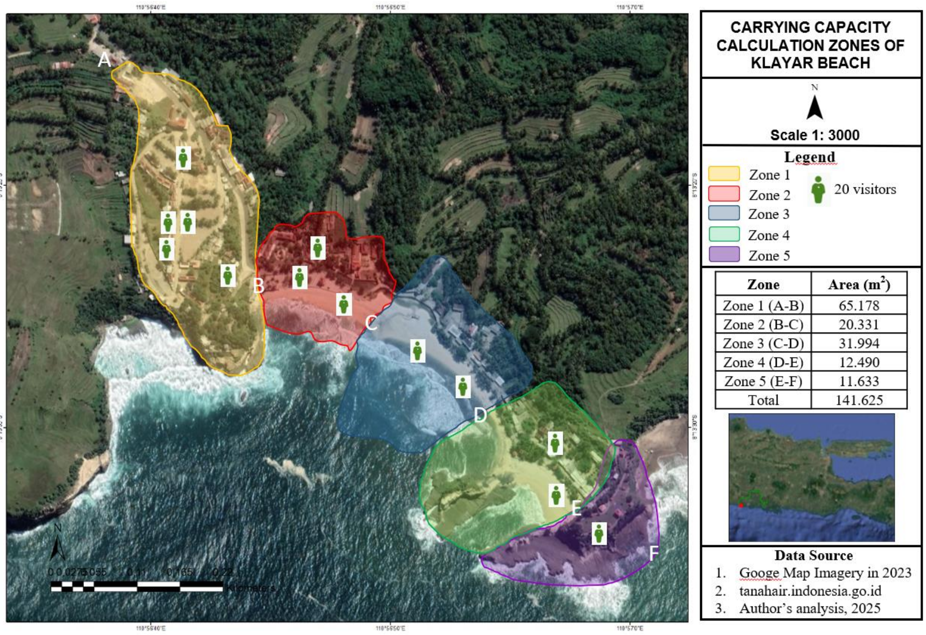

Figure 4. Zones of Klayar Beach (Source: The authors, 2025)

Figure 5. The landscape of the Klayar coastal area (a) Exposed beachrock formations at Klayar Beach. (b) All-Terrain Vehicle (ATV) rental in Zone 2 (IDR 100,000/hour for coastal tours) (c) The 'Sphinx van Java' is a locally designated karst formation shaped by prolonged marine abrasion processes. (d) A natural coastal phenomenon where waves compress water through narrow karst fissures, creating a high-pitched whistling sound reminiscent of a flute (Sea Flute) (Source: The authors, Klayar, December 4-20, 2024)

In this study, the Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC), and Effective Carrying Capacity (ECC) were calculated, and the results are shown in Table 8. PCC, RCC, and ECC were calculated using the three occupancy criteria. Each zone's area, external factors, special zones, and urban capacity management were considered. The five zones have a total planimetric area of 141.625 m² and the PCC values were 113,300, 56,650, and 22,660 daily visits for high, medium, and low occupancy, respectively. These values were calculated using a rotation factor 4 (Ariza Solé, 2007). The RCC values include 11,883, 5,941, and 2,377 visits per day. These values show the maximum number of visitors after applying the correction factor. Finally, ECC was calculated based on information from the MC and the results were 6,060, 3,030, and 1,212 daily visits. These numbers represent the effective capacity for daily visitors. The analysis shows that external factors affecting Klayar Beach record 59 rainy days and 170 windy days per year. The correction percentages for these factors are 16% and 47%, respectively. The beach receives approximately 5,110 sun hours annually, contributing to a correction factor. Klayar Beach loses about 42,000 m³ of sediment annually, reducing the total beach area by 12,000 m² annually. This leads to an erosion correction percentage of 14%. The result shows that Klayar Beach has an average MC score of five across all five zones.

Table 8. PCC, RCC, and ECC for Klayar Beach Beach Supportability Management

ZONE	PCC			RCC			ECC		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Zone1	10428	26071	52142	1094	2734	5469	109	273	547
Zone2	3253	8132	16265	341	853	1706	51	128	256
Zone3	5119	12797	25595	537	1342	2684	48	121	242
Zone4	1998	4996	9992	210	524	1048	21	52	105
Zone5	1861	4653	9306	195	488	976	14	34	68

The study assesses facilities, equipment, human resources, and institutional support. Zones 1, 2, and 3 focus on essential services like shops, hotels, and car parks. These zones also have the highest concentration of beach access. Zones 4 and 5 offer limited services, which correlates with fewer users. Other activities, such as fishing, occur frequently in Zones 3 and 4. The study lists PCC, RCC, and ECC values in Table 9 to support effective beach management.

Table 9. Variables considered for the estimation of MC at Klayar Beach (Source: Authors, 2025)

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Zone 1		v	v	v	v		v		v	v		v	v	v				
Zone 2	v	v	v	v	v	v	v	v	v	v	v	v	v		v		v	
Zone 3	v	v	v		v			v	v		v	v	v					
Zone 4	v	v	v		v			v	v	v	v	v	v					
Zone 5			v				v		v		v	v	v	v				

Type: 1: Lifeguard. 2: Bathroom. 3: Public lighting. 4: Information service. 5: Coastal building. 6: Tent hire. 7: Road/beach signage. 8: Beach access. 9: Wastebasket. 10: Restaurant, drugstore. 11: Recreational area. 12: Coastal management plan. 13: Building regulations. 14: Access regulations. 15: First aid. 16: New police and offices. 17: People trained in natural disaster response. 18: Vehicles and facilities for disaster relief

The PCC results in Table 8 show that visitor capacity in all categories is ECC > JKr, showing great opportunity. The actual daily visits to Klayar Beach are only in the hundreds, suggesting that several aspects need improvement to increase the number of visitors. Zones 1 and 2 serve as beach access points, and the carrying capacity offers excellent opportunities for further development. However, in Zones 5 and 6, visitor numbers can exceed ECC, which leads to overcapacity.

DISCUSSION

The assessment of Klayar Beach using the proposed indicators highlights its current strengths and areas needing improvement, aligning with the broader sustainability goals of Gunung Sewu UNESCO Global Geopark. The findings contribute to the geopark's management framework by ensuring that tourism development remains balanced with geological conservation, environmental protection, and community well-being. Klayar Beach's excellent scores in water transparency, low pollution, and minimal anthropogenic disturbances reinforce its role in preserving the geopark's unique karst landscapes and coastal ecosystems. The natural sea horizon and moderate building integration ensure that tourism infrastructure does not degrade the aesthetic and geological value of the area, a core principle of UNESCO Global Geoparks.

Klayar Beach, a popular tourist destination, offers unique geological and scenic features but faces challenges in accessibility and visitor management. The sloping or steep access road and limited facilities for individuals with disabilities, the elderly, and young children showed the need for improvements. Dash & Sharma (2021) defined accessibility as a term that measures the ease of reaching a location, considering time, cost, and effort. Furthermore, Wang et al. (2021) stated that tourism efficiency must account for both economic indicators, such as visitor numbers and revenue, as well as psychological indicators, including comfort and experience. Klayar Beach does not fully accommodate individuals with disabilities. The beach provides vehicle access, parking, and pedestrian pathways, but the steep road requires assistance for specific groups. Accessibility reflects how quickly visitors can access and enjoy the destination, making it a critical factor for improving visitor satisfaction and tourism efficiency. Measures to enhance accessibility can address current limitations and support sustainable development.

Klayar Beach's current conditions significantly influence visitor comfort, which is shaped by physical, psychological, and socio-environmental factors (Zhen et al., 2025). While sunny weather and minimal rainfall enhance comfort, swimming restrictions, high temperatures, and weak winds—except on hilltops—reduce satisfaction, reflecting tourists' subjective environmental evaluations (Lai et al., 2020; Tian et al., 2022; Yung et al., 2019). Facilities score poorly due to unregulated development, including coastal degradation from stalls, parking areas, and private constructions, exacerbating anthropogenic pressures and biodiversity loss (Ştefănică et al., 2021). Despite sustainability mandates, community prioritization of short-term economic gains over environmental management weakens governance, necessitating stricter building standards to align tourism growth with long-term ecological goals.

While the beach has a high Physical Carrying Capacity (PCC), the much lower Effective Carrying Capacity (ECC) indicates that current management practices limit overcrowding, preventing ecological degradation. The division into Core, Buffer, and Transition Zones ensures that high-conservation areas (Zones 4–5) remain protected, while Buffer and Transition Zones (1–3) allow controlled tourism activities. This zoning aligns with UNESCO's approach through protection use. The low urbanization score and absence of industrial disturbances support community-based tourism, a key strategy in Gunung Sewu's development. While some accessibility features (e.g., disabled access) need improvement, public transport and information signs enhance inclusive tourism, benefiting local livelihoods.

Visitor restrictions offer a solution to keep these zones sustainable. Managers limit visitation time as part of conservation efforts. This method helps restore the rehabilitation function of the ecosystem (Al Dilwan & Astina, 2019). Klayar Beach, as part of the geopark, requires maintenance during its development. Sustainable tourism development balances environmental preservation and infrastructure opportunities (Wirahayu et al., 2022).

According to a previous study, community-led initiatives also focus on improving economic welfare (Sumarmi & Shrestha, 2022). This harmonious balance between community benefit and environmental conservation is exemplified by Geopark, which shows tourism principles that promote sustainable development. The ecotourism principle helps coastal areas develop while promoting environmental sustainability (Sumarmi et al., 2022).

A previous study reported that geological phenomena are essential resources for geopark-related tourism (Ruban, 2018). However, resource management often combines geological features with other resources, reducing its uniqueness. Tourism development at Klayar Beach needs to focus on preserving geological heritage.

Ha Long Bay in Vietnam limits motorized vehicles in sensitive areas. The management promotes using environmentally friendly transportation, such as non-motorized boats (Nguyen, 2020). Dry Tortugas National Park in the US applies a reservation system, which limits the number of daily visitors. This system reduces anthropogenic impacts on ecosystems and improves the quality of the tourism experience (Defeo et al., 2021). Edu-eco-tourism concepts maintain the sustainability of the Gunung Sewu Geopark. According to (Baloch et al., 2023), sustainable ecotourism addresses environmental issues caused by poorly planned tourism development. Edutourism helps maintain the cleanliness and sustainability of physical resources at tourist sites (Sumarmi et al., 2023).

Zoning of Geo-Eco Tourism at Klayar Area

The zoning of Klayar Beach integrates geological, ecological, and sustainable tourism principles while supporting the Gunung Sewu UNESCO Global Geopark framework (Figure 6). The five zones (Geological Education, Ecological Conservation, Sustainable Recreation, Tourism and Public Facilities, and Hill and Panorama) balance education, conservation, and community benefits (Nguyen, 2020).

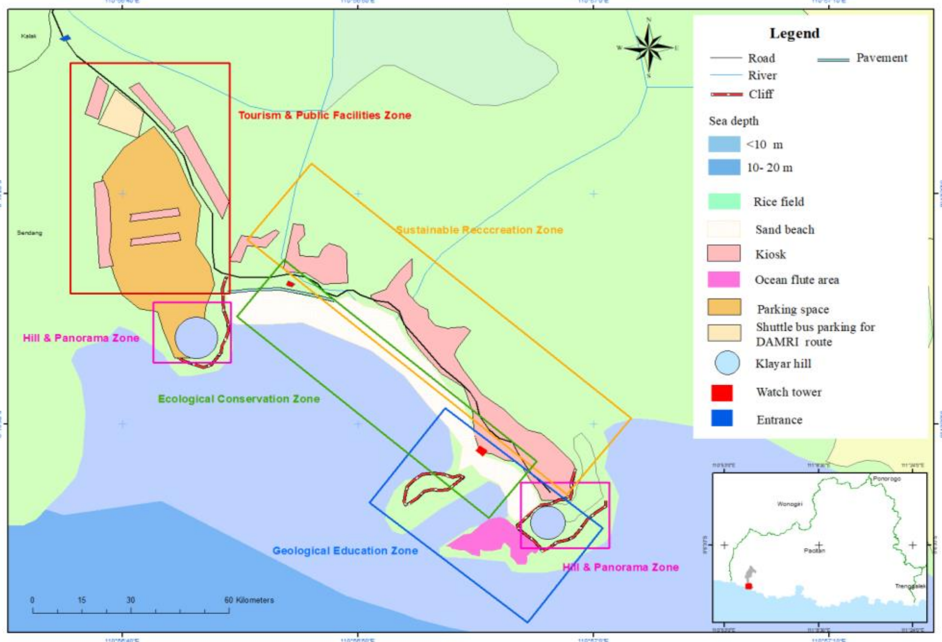

Figure 6. Zoning of Geo-Eco Tourism at Klayar Area

The Geological Education Zone, featuring karst cliffs and ocean flutes, serves as a key geosite for geopark-based learning, using digital tools and guided tours to minimize degradation (Zafeiropoulos, 2024). Meanwhile, the Ecological Conservation Zone protects coastal biodiversity through community-based methods, aligning with global geopark goals. The remaining zones prioritize low-impact recreation, local economic growth (Dłużewska & Giampiccoli, 2021), and scenic trekking with ecological markers (Karuppiah et al., 2022), ensuring holistic sustainability. This zoning model strengthens Klayar's role in the Gunung Sewu Geopark by designating areas for geoheritage education, biodiversity protection, and community-led tourism. The Geological Education Zone, for instance, functions as an outdoor classroom, while the Tourism and Public Facilities Zone mirrors geopark visitor centers, enhancing waste management and stakeholder engagement. Such structured zoning simplifies management (Nguyen, 2020) while advancing the geopark's mission—offering a replicable template for coastal geotourism within UNESCO-designated sites. Future studies should refine participatory mapping to optimize Klayar's integration into the geopark network.

CONCLUSION

Klayar Beach faced several challenges: limited infrastructure, accessibility issues, environmental degradation risks, and inadequate visitor management strategies. Despite the growing popularity, there was a lack of empirical studies on balancing tourism growth with environmental sustainability in this unique coastal ecosystem.

The results of this study provided a data-driven method for sustainable tourism planning, integrating Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC), and Effective Carrying Capacity (ECC) assessments with beach quality indicators, such as accessibility, environmental health, and visitor satisfaction.

According to the results, Klayar Beach had high tourism potential, but existing infrastructure and management strategies were insufficient to support long-term sustainability. Specific challenges included poor accessibility, lack of inclusive facilities, unregulated tourism activities, and risks of overcrowding in sensitive ecological zones.

To address these issues, the study showed five key areas of intervention, namely (1) infrastructure improvements to enhance accessibility and visitor experience, (2) visitor management policies, such as quota systems and controlled entry to prevent overcrowding, (3) environmental conservation measures to protect the beach's fragile ecosystems, (4) community engagement to foster local economic benefits and environmental stewardship, and (5) regulatory frameworks to ensure consistency between tourism development and conservation priorities.

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REFERENCES

Al Dilwan, M., & Astina, I. K. (2019). Community Based Wakatobi Tourism Management Strategies. *1st International Conference on Social Knowledge Sciences and Education (ICSKSE 2018)*, 51–54. https://doi.org/10.2991/icskse-18.2019.9

Arinta, D., Sumarmi, Deffinika, I., Arif, M., & Putri, I. W. (2022). Quality and Carrying Capacity of Beaches for Recreational Activities in Ampelgading District, Malang Regency, Indonesia: High or Low? *Geojournal of Tourism and Geosites*, *40*(1), 64–70. https://doi.org/10.30892/GTG.40107-803

Ariza Solé, E. (2007). *A system of integral quality indicators as a tool for beach management*. Universitat Politècnica de Catalunya. http://doi.org/10.5821/dissertation-2117-93711

Baloch, Q. B., Shah, S. N., Iqbal, N., Sheeraz, M., Asadullah, M., Mahar, S., & Khan, A. U. (2023). Impact of tourism development upon environmental sustainability: A suggested framework for sustainable ecotourism. *Environmental Science and Pollution Research*, *30*(3), 5917–5930. https://doi.org/10.1007/s11356-022-22496-w

Cifuentes, M. (1992). *Determinación de capacidad de carga turística enáreas protegidas [Determination of tourism carrying capacity in protected areas]* (Issue 194). Bib. Orton IICA/CATIE (in Spanish).

Cisneros, A. H., Sarmiento, N. V. R., Delrieux, C. A., Piccolo, M. C., & Perillo, G. M. E. (2016). Beach carrying capacity assessment through image processing tools for coastal management. *Ocean & Coastal Management*, *130*, 138–147. https://doi.org/10.1016/j.ocecoaman.2016.06.010

Cortés-Useche, C., Hernández-Delgado, E. A., Calle-Triviño, J., Blasco, R. S., Galván, V., & Arias-González, J. E. (2021). Conservation actions and ecological context: optimizing coral reef local management in the Dominican Republic. *PeerJ*, *9*, e10925. https://doi.org/10.7717/peerj.10925

Dash, S. B., & Sharma, P. (2021). Reviving Indian Tourism amid the Covid-19 pandemic: Challenges and workable solutions. *Journal of Destination Marketing & Management*, *22*, 100648. https://doi.org/10.1016/j.jdmm.2021.100648

Defeo, O., McLachlan, A., Armitage, D., Elliott, M., & Pittman, J. (2021). Sandy beach social–ecological systems at risk: regime shifts, collapses, and governance challenges. *Frontiers in Ecology and the Environment*, *19*(10), 564–573. https://doi.org/10.1002/fee.2406

Dłużewska, A., & Giampiccoli, A. (2021). Enhancing island tourism's local benefits: A proposed community-based tourism-oriented general model. *Sustainable Development*, *29*(1), 272–283. https://doi.org/10.1002/sd.2141

Faiz, S. A., & Komalasari, R. I. (2020). The assessment of tourism carrying capacity in Lombok Island. *IOP Conference Series: Earth and Environmental Science*, *592*(1), 12002. http://doi.org/10.1088/1755-1315/592/1/012002

Hanaee, T., Dincă, I., Moradi, Z., Sadegh Eghbali, P., & Boloor, A. (2025). Reflecting the Effect of Physical–Perceptual Components on Increasing the Anxiety of Inner-City Rail Transit's Users: An Integrative Review. *Sustainability*, *17*(9), 3974. https://doi.org/10.3390/su17093974

Insani, N., Ariani, Y., Arachman, F. R., & Wibowo, D. A. (2020). Carrying capacity estimations to support tourism coastal management in Ungapan Beach Indonesia. *IOP Conference Series: Earth and Environmental Science*, *485*(1), 12036. http://doi.org/10.1088/1755-1315/485/1/012036

Karuppiah, N., Hussin, R., Shah, J. M., Latip, N. A., & Afrizal, T. (2022). Maragang hill trekking through community based ecotourism (cbe): The tourist guides responsibility and challenges in Kundasang, Sabah, Malaysia. *Planning malaysiA*, *20*. http://doi.org/10.21837/pm.v20i23.1156

Lai, D., Lian, Z., Liu, W., Guo, C., Liu, W., Liu, K., & Chen, Q. (2020). A comprehensive review of thermal comfort studies in urban open spaces. *Science of the Total Environment*, *742*, 140092. https://doi.org/10.1016/j.scitotenv.2020.140092

Milano, C., Novelli, M., & Russo, A. P. (2024). Anti-tourism activism and the inconvenient truths about mass tourism, touristification and overtourism. *Tourism Geographies*, *26*(8), 1313–1337. https://doi.org/10.1080/14616688.2024.2391388

Nguyen, C. D. (2020). Key Factors Affecting Sustainable Tourism in the Region of South Central Coast of Vietnam. *Journal of Asian Finance, Economics and Business*, *7*(12), 977–993. https://doi.org/10.13106/JAFEB.2020.VOL7.NO12.977.

Peña-Alonso, C., Ariza, E., Hernández-Calvento, L., & Pérez-Chacón, E. (2018). Exploring multi-dimensional recreational quality of beach socio-ecological systems in the Canary Islands (Spain). *Tourism Management*, *64*, 303–313. https://doi.org/10.1016/j.tourman.2017.09.008

Pérez-Romero, M. E., Álvarez-García, J., Flores-Romero, M. B., & Jiménez-Islas, D. (2023). UNESCO Global Geoparks 22 years after their creation: Analysis of scientific production. *Land*, *12*(3), 671. https://doi.org/10.3390/land12030671

Prisco, I. (2021). A bridge between tourism and nature conservation: boardwalks effects on coastal dune vegetation. *Journal of Coastal Conservation*, *25*(1). https://doi.org/10.1007/s11852-021-00809-4

Purwandani, I., & Pakan, S. P. (2022). Local habitus and temporal overtourism in Yogyakarta. *Consumer Behavior in Tourism and Hospitality*, *17*(4), 544–560. http://dx.doi.org/10.1108/CBTH-07-2021-0177

Rocha, C. H. B., Fontoura, L. M., Vale, W. B. do, Castro, L. F. de P., da Silva, A. L. F., Prado, T. de O., & da Silveira, F. J. (2021). Carrying capacity and impact indicators: analysis and suggestions for sustainable tourism in protected areas–Brazil. *World Leisure Journal*, *63*(1), 73–97. https://doi.org/10.1080/16078055.2021.1888000

Ruban, D. A. (2018). Karst as important resource for geopark-based tourism: Current state and biases. *Resources*, *7*(4). https://doi.org/10.3390/resources7040082

Ștefănică, M., Sandu, C. B., Butnaru, G. I., & Haller, A. P. (2021). The nexus between tourism activities and environmental degradation: Romanian tourists' opinions. *Sustainability*, *13*(16), 9210. https://doi.org/10.3390/su13169210

Sumarmi, S., Ensiyawatin, A. Z., Astina, I. K., Kurniawati, E., & Shrestha, R. P. (2022). The management of bangsring underwater as conservation-based ecotourism for international tourism destination. *Geo Journal of Tourism and Geosites*, *41*(2), 393–399. http://doi.org/10.30892/gtg.41208-842

Sumarmi, S., & Shrestha, R. P. (2022). The Management Of Bangsring Underwater As Conservation. *Based Ecotourism For International Tourism Destination Aminatus Zuhro Ensiyawatin*. *41*(2), 393–399. https://doi.org/10.30892/gtg.41208-842

Sumarmi, S., Tanjung, A., Putra, A. K., Zubaidah, S., Shrestha, R. P., & Suprianto, A. (2023). How Eco-Spatial Edutourism Support Sustainability in Coastal Areas in South Malang, Indonesia? *Anuário Do Instituto de Geociências*, *46*(June 2023), 1–14. http://doi.org/10.11137/1982-3908_2023_46_47725

Tian, Y., Hong, B., Zhang, Z., Wu, S., & Yuan, T. (2022). Factors influencing resident and tourist outdoor thermal comfort: A comparative study in China's cold region. *Science of the Total Environment*, *808*, 152079. https://doi.org/10.1016/j.scitotenv.2021.152079

Utama, I., Suardhana, I. N., Sutarya, I. G., & Krismawintari, N. P. D. (2024). Assessing the impacts of overtourism in Bali: Environmental, socio-cultural, and economic perspectives on sustainable tourism. *TourismSpectrum: Diversity & Dynamics*, *1*(2), 10–56578. https://doi.org/10.56578/tsdd010202

Vandenberghe, K. (2020). *Operational Guidelines for transnational UNESCO Global Geoparks*. https://policycommons.net/artifacts/1601726/operational-guidelines-for-transnational-unesco-global-geoparks/

Wang, Y., Wang, M., Li, K., & Zhao, J. (2021). Analysis of the relationships between tourism efficiency and transport accessibility—A case study in Hubei province, China. *Sustainability*, *13*(15), 8649. https://doi.org/10.3390/su13158649

Williams, P., & Lemckert, C. (2023). Beach Carrying Capacity Has it been exceeded on the Gold Coast ? *Beach Carrying Capacity : Has it been exceeded on the Gold Coast ? 50*, 21–24. *https://www.jstor.org/stable/26481548*

Wirahayu, Y. A., Sumarmi, S., Arinta, D., Islam, M. N., & Kurniawati, E. (2022). Developing a sustainable community forest-based village ecotourism in Oro-Oro Ombo, Malang: What is the effect of Batu's West Ring Road? *Revista Turismo & Desenvolvimento*, *39*, 425–437. https://doi.org/10.34624/rtd.v39i0.26473

Wu, K., Chen, K., Gao, Y., Jiang, S., & Huang, H. (2022). Applying a set of potential methods for the integrated assessment of the marine eco-environmental carrying capacity in coastal areas. *Sustainability*, *14*(8), 4416. https://doi.org/10.3390/su14084416

Yung, E. H. K., Wang, S., & Chau, C. (2019). Thermal perceptions of the elderly, use patterns and satisfaction with open space. *Landscape and Urban Planning*, *185*, 44–60. https://doi.org/10.1016/j.landurbplan.2019.01.003

Zafeiropoulos, G. (2024). *The importance of Geoenvironmental Education in understanding Geological Heritage and promoting Geoethical Awareness: Development and Implementation of an innovative assessment method, with a case study of the Southeast Aegean islands*. Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών (ΕΚΠΑ). Σχολή Θετικών Επιστημών. http://doi.org/10.12681/eadd/57905

Zhen, M., She, X., Xia, W., Lu, R., Geng, Z., Shang, D., Zhang, M., & Nan, K. (2025). Comparative study of outdoor thermal comfort: Residents vs. tourists at Xi'an Ming Dynasty Ancient city wall scenic area. *Building and Environment*, *267*, 112195. https://doi.org/10.1016/j.buildenv.2024.112195

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