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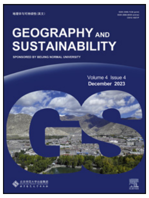

Research Article

Evaluation of the potential of coastal cliffs as geosites for the promotion of geotourism

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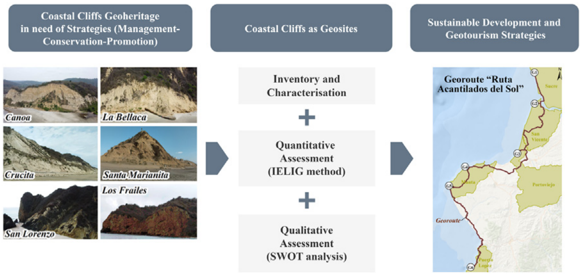
HIGHLIGHTS

- Manabí (Ecuador) has favourable coastal geoheritage for its use in geotourism.
- Beach-cliff systems were characterised and assessed as geosites.
- The strategies involve geotourism, geoconservation and geoeducation actions.
- The georoute takes into consideration tourist and cultural attractions.
- This work provides a method for the assessment of beach-cliff systems as geosites.

GRAPHICAL ABSTRACT



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ABSTRACT

Coastal zones, with their significant geodiversity, are vital areas for geotourism. Effective management is crucial to harness the geological interest of these sites as geotourism resources while ensuring their conservation. Manabí Province is one of the most representative regions along the Ecuadorian coast due to its beaches and coastal cliffs, offering a wealth of tourist attractions and cultural elements. This study aims to evaluate the geosite potential of six cliffs in Manabí Province through quantitative and qualitative analyses to propose geotourism promotion strategies. The methodology involves (i) inventory and characterisation of the cliffs, (ii) assessment of the sites by the Spanish Inventory of Places of Geological Interest method (IELIG), and (iii) qualitative evaluation through focus group discussions and Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. The results reveal that all six sites boast diverse geological assets, including geomorphological, stratigraphic, sedimentological, and tectonic elements. They are characterised by "high" scientific, didactic, and tourist interest, while also being susceptible to degradation due to natural and anthropic threats. The SWOT analysis demonstrates that the valuable geological and geomorphological heritage of potential geosites provides an opportunity to foster geotourism and boost the province's economy, incorporating geoconservation and geoeducation strategies. This study proposes a georoute called "Ruta Acantilados del Sol", a 245 km journey encompassing all six sites, incorporating diverse tourist and cultural activities. Our research lays the foundation for fostering geotourism along the Manabí coast and strengthening the connection between nature, heritage, and the welfare of residents within a global resilience plan.

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1. Introduction

Coastal cliffs are distinctive landforms characterised by steep slopes and diverse rock formations (Mörner, 2016; Sunamura, 1992). Their origin can be attributed to the erosive geomorphological processes experienced by high coasts, mainly caused by coastal and gravitational forces (Castedo et al., 2017; Hampton et al., 2004; Tarbuck et al., 2005). The geomorphological features of cliffs include steep, often vertical or nearly vertical slopes, typically exceeding 40°, and occasionally protruding rocks (Bird, 2016). Coastal cliffs are widespread, accounting for approximately 80%–93% of oceanic coastlines globally (Emery and Kuhn, 1982; Young and Carilli, 2019).

Coastal cliffs serve as valuable sites for geological, geomorphological, palaeontological, biological, and ecological education and research (Bird, 2016; Doody and Rooney, 2015; Strumia et al., 2020). Additionally, they provide habitats for plants and animals, and are popular destinations for recreation and tourism (Fisher et al., 2019). From a geological and geomorphological perspective, some of these cliffs offer insights into local lithostratigraphic sequences and various coastal forms such as raised/submerged shore platforms, natural tunnels and sea caves, joints and faults, escarpments, boulder screes, arches, stacks, shoreline platforms extending offshore into shoals, and blowholes (Camanni et al., 2021; Dickson and Woodroffe, 2005; Government of Malta, 1998; Lace, 2008; Stephenson and Kirk, 2000; Warne and Soutar, 2012). Moreover, they often preserve evidence of different geological epochs through the occurrence of fossils and palaeosols (Kruczkowska et al., 2019).

However, the erosive context of coastal cliffs makes them susceptible to threats such as coastal retreat (Rodríguez Guitián et al., 2020; Stanchev et al., 2018), physical and chemical weathering (Andriani and Walsh, 2007; Duszyński et al., 2019; Sallenger et al., 2002; Short, 1982; Trenhaile, 1987), mass movements (Domínguez-Cuesta et al., 2022; Trenhaile, 1987), tectonism (Komar and Shih, 1993; Minor et al., 2022; Orchard et al., 2020; Quezada et al., 2010), climate change (Griggs et al., 2019; Trenhaile, 2014), and human activity (Di Stefano et al., 2013; Guerrera et al., 2021; Jabaloy-Sánchez et al., 2010). In addition, Bird (2016) observed that intense waves during storms, extended periods of rain, thawing soils, and earthquakes are also primary natural causes of cliff recession.

Throughout history, coastal areas have been attractive for human settlement (Gravel-Miguel et al., 2022). However, inadequate control of coastal ecosystems linked to anthropic activities (e.g., tourism) can lead to deterioration and imbalances (Anthony and Sabatier, 2012; Bunicontro et al., 2015; Ferrer-Valero et al., 2017; Gerivani et al., 2020; McMillan and Larson, 2002). Initiatives to protect and conserve coastal zones have been promoted through management policies (Cai et al., 2009; Portman, 2018) and the establishment of coastal reserves and national parks (Bird, 2016, 1982).

Geoparks present a promising strategy for local social and economic development based on sustainable management of natural areas with geological (geosites) or geomorphological (geomorphosites) value, such as mountains, cliffs and caves, and on the development of geotourism activities (Farsani et al., 2014; Németh et al., 2021; UNESCO, 2006). Geotourism focuses on geological and geomorphological assets to provide entertainment and education, stimulate visitor interest (Chen et al., 2020), and promote local development and the tourism industry (Duarte et al., 2020).

Geotourism also seeks to minimize the negative impacts of mass tourism on geographically or geologically sensitive tourism ecosystems while supporting sustainable rural development (Xu and Wu, 2022). It aims to enhance the well-being of the neighbouring population through the generation of employment and the growth of local businesses, while respecting the natural and cultural heritage of the population (Gursoy et al., 2002; Gursoy and Rutherford, 2004; Stolz and Megerle, 2022). Adequate tourism can also enhance inhabitants' perception of their heritage, promoting awareness and encouraging environmental care (Abdel Maksoud et al., 2021).

Geotourism often encourages the creation of georoutes that enable tourists to visit places of interest and develop itineraries that highlight geological potential by linking different geosites (Carrión-Mero et al., 2021b; Meléndez et al., 2012). These routes can be guided or self-guided (Hose, 2020). Geosites are natural places that are part of the geological heritage of a territory (Fuertes-Gutiérrez and Fernández-Martínez, 2012). Brilha (2016) defines them as in situ elements of geodiversity with high scientific value. They may also have additional values (such as educational, aesthetic, and cultural value), making them valuable and beneficial to society. According to Carrión-Mero et al. (2021b), georoutes can illustrate the geodiversity of a region by incorporating predetermined stops and explanatory materials to enhance the understanding of the natural features of the visited locations.

The technical assessment of geosites play a crucial role in promoting geotourism and geoconservation (Herrera-Franco et al., 2022a; Kubalíková and Kirchner, 2016). Such assessments can use qualitative, semi-quantitative, or quantitative methods to identify the geological interest of the geosites and evaluate parameters of interest related to education, science, tourism, functionality, culture, economy, ecology and protection (Herrera-Franco et al., 2022b; Tamang et al., 2023). The recognition of geosites in the scope of geotourism research has made it possible to identify places of significant value and to design strategies or plans for their proper management that facilitates their sustainable use (Carcavilla et al., 2014; Tessema et al., 2021), with an emphasis on their conservation as geological heritage (Moura et al., 2017; Sisto et al., 2022). Noteworthy methods for evaluating geosites include the "Spanish Inventory of Places of Geological Interest" (IELIG, acronym in Spanish) method (García-Cortés et al., 2013), the Brilha method (Brilha, 2016), the Geosite Assessment Model (GAM) (Vujičić et al., 2011) and the Pereira et al. (2007) method.

Ecuador, renowned for its abundant natural resources and diverse geological and geomorphological features, stands as one of the most diverse countries in the world and a popular destination for international tourists (Brehm et al., 2008; Rieckmann et al., 2011). Ecuador has several geosite evaluation works (Berrezueta et al., 2021). Within the context of geotourism, relevant studies assessed geosites in the Andes Mountains (Carrión-Mero et al., 2021a), the Cajas National Park (Navarrete et al., 2022), Puyango Petrified Forest (Morante-Carballo et al., 2020), as well as El Oro and Santa Elena regions (Herrera-Franco et al., 2021). The characterisation of geosites in Ecuador have facilitated the development of strategies tailored to the natural and sociocultural environment within a comprehensive management framework, resulting in proposals for georoutes such as the "Ruta Escondida" (Carrión-Mero et al., 2020), the "Ruta del Oro" and routes in Santa Elena (Herrera-Franco et al., 2022b).

The Ecuadorian coastal landscape, characterised by high cliffs connected to beaches (Boothroyd et al., 1994), provides an ideal setting for geosite assessment projects. A previous geodiversity evaluation study at the regional level in Ecuador by Carrión-Mero et al. (2022) identified the coastal region as an area of considerable geodiversity, with hotspots of high geodiversity along the central coast owing to the presence of fault systems, marine fossils, and prominent relief features such as the Ecuadorian Coastal Cordillera.

Amongst the coastal regions, Manabí Province stands out as a geologically diverse area where landforms like beaches and cliffs constitute vital landscape components, making them major tourist attractions (Andrade, 2021; Cantos, 2020). In April 2016, Manabí was struck by a magnitude Mw 7.8 earthquake (named the 16A earthquake) (Ye et al., 2016) that impacted the province's social, economic, tourism, and environmental assets (García Reinoso et al., 2019; Guerrero-Miranda and Luque González, 2021; Solíz et al., 2018). The earthquake also caused alterations to the landscape, including coastal landslides in beach-cliff systems (Chunga et al., 2019). In response, civil society and local governments implemented strategies to restore infrastructure (Félix Mendoza et al., 2021) and promote tourism through gastronomic festivals, solidarity tours, cultural and sporting events, and social media campaigns to attract national visitors (Félix Mendoza et al., 2017; Félix Mendoza and Rivera Mateos, 2018).

In Manabí Province, cliffs possess geological and geomorphological features that are highly relevant to geotourism, offering opportunities to advance science, education, and tourism in the region. Consequently, the following research question arises: What is the impact of assessing the potential of the Manabi cliffs as geosites on developing geotourism promotion strategies in the province?

This study aims to evaluate the potential of six cliffs, located on the most representative beaches of the province of Manabí, as geosites. The assessment uses the IELIG semi-quantitative method and the Strengths, Weaknesses, Opportunities, and Threats (SWOT) matrix to propose geotourism promotion strategies. By considering geotourism as a resilience and development strategy within the coastal sector of the province, this initiative is of critical importance. Moreover, implementing geotourism strategies will add value to these sites, revitalizing tourism adversely affected by the 16A earthquake.

2. Materials and methods

2.1. Case study

2.1.1. Geographical setting

Manabí Province is situated in the northwest of Ecuador, on the second westernmost salient of the country along the Pacific Ocean (Fig. 1(a)). It covers an area of 18,939.6 km^2 (INEC, 2010). It has a population of 1,585,372 inhabitants (INEC, 2021). The province consists of 22 cantons, with its principal city being Portoviejo. The Manabí coastline stretches for 354 km with a general north-south orientation (GAD Manabí, 2015). As part of Ecuador's coastal region, Manabí is home to various coastal ecosystems, including beaches and cliffs. The climate in the study area ranges from dry subtropical to humid tropical, with temperatures varying between 24°C and 30°C. From January to May, the weather is hot and rainy, followed by cooler and dryer conditions from June to December (MAE, 2013). The annual precipitation is approximately 610 mm (INAMHI, 2017). The province's primary economic activities include agriculture, livestock, fishing, and mining (GAD Manabí, 2021). In addition, sun and beach tourism has emerged as an alternative for economic growth, utilizing the coastal heritage and natural and cultural elements of the territory to attract tourists (Arroyo, 2018). This study focuses on the cantons of Puerto Lopez, Manta, Portoviejo, Sucre and San Vicente, where the beach-cliff systems of Los Frailes, San Lorenzo, Santa Marianita, Crucita, La Bellaca and Canoa are located, respectively (Fig. 1(b)).

2.1.2. Geological setting

In the geological context, the Ecuadorian coast lies adjacent to an active subduction zone, where the oceanic (Nazca) plate subducts beneath the continental (South American) plate (Lynner et al., 2020; Tamay et al., 2018). The Coastal Region has an igneous basement of oceanic origin covered by volcanic and volcanoclastic rocks associated with volcanic island arcs from the Upper Cretaceous to the Lower Paleocene. During this period, forearc basins also developed (Jaillard et al., 1995; Reynaud et al., 1999). Tectono-stratigraphically, the coastal terrain comprises several units separated by faults with a consistent orientation of SSW-NNE (Luzieux et al., 2006).

Fig. 1(c) presents the generalised lithology of the central-western area of Manabí Province (Chunga et al., 2019), simplified from the geological map by Reyes and Michaud (2012). Five predominant lithologies can be identified: (i) basaltic basement (BB), composed of gabbros, basalts, volcano-sediments, and pillow lavas belonging to the Cretaceous Piñon Formation (Fm.), and volcano-sedimentary sequences of the Late Cretaceous Cayo Fm. outcropping mainly to the south, in the Chongon-Colonche Cordillera; (ii) sandstones (SS) formed by a clastic sequence of volcanic sandstones, tuffaceous shales, and conglomerates with abundant marine fauna of the Miocene Angostura Fm., thick massive sandstones of the lower clastic member of the Pliocene Borbon Fm., and sandstones and conglomerates of the Eocene San Mateo Fm. that outcrop mainly in the Coastal Cordillera; (iii) Miocene flintstones (FS) formed by shales, mudstones, sandstones and calcareous concretions of the Dos Bocas and Villingota Fm., and by shales, mudstones, volcanic tuffs, and sandstone strips of the Onzole Fm.; (iv) Quaternary (Pleistocene) volcanic rocks (VV) formed by volcanoclastic deposits of breccias and tuffs belonging to the upper volcanic member of the Borbon Fm.; and (v) alluvial materials (AL) of Quaternary (Pleistocene) age formed by loose fluvial and alluvial deposits with a composition of fine- to coarse-grained coastal silts, sands, gravels and estuarine clay.

Geomorphologically, most of the Ecuadorian coastal profile is relatively flat, with local reliefs that do not exceed 100 m and some elevations of more than 300 m (Feininger and Bristow, 1980), such as the Chongon-Colonche Cordillera and the Coastal Cordillera (Alemán et al., 2021). According to Winckell (1982), Manabí's coastal geomorphology can be grouped into two types: 1) coasts of high cliffs, interspersed with small bays in the zones of tertiary sedimentary relief from Pedernales to the south of Manabí, and 2) medium to low shores, with small cliffs and large rectilinear beaches, originated from the deposit of Quaternary materials of transgressive origin, located near Manta.

2.1.3. Natural hazards

Manabí is situated close to an active subduction zone and is susceptible to natural hazards, mainly of tectonic origin, such as earthquakes and tsunamis (Demoraes and D'Ercole, 2001). In its history, notable earthquakes occurred in 1896 and 1998, causing adverse effects in Bahia de Caraquez, Portoviejo and Canoa. These seismic events led to the formation of cracks, uplifts and landslides on hills and slopes (Beauval et al., 2013; Egred, 2009). The most recent earthquake, known as the 16A earthquake, occurred on 16th April 2016 between the towns of Pedernales and Cojimies, with a magnitude of Mw 7.8. It caused significant damage to infrastructure (Furtado et al., 2021). It resulted in injuries, loss of human life, and a range of other effects such as the opening of cracks, soil liquefaction, tsunami waves, coastal landslides and uplifting of the beach and abrasion platforms (Pedernales and Crucita) (Chunga et al., 2016).

2.2. Assessment stages

The IELIG method is applied for the semi-quantitative evaluation of the selected case study sites. In addition, expert criteria are used to formulate strategies for the protection and sustainable tourism development of the cliffs. The study comprises three phases (Fig. 2): (i) inventory and general characterisation of the selected cliffs, (ii) semi-quantitative evaluation of the sites by the IELIG method, and (iii) qualitative evaluation through focus group discussion and SWOT analysis to plan strategies for geotourism development.

2.2.1. Phase I: Inventory and general characterisation of the cliffs

In the first phase, we conducted an inventory and general characterisation of the sites of geological interest (SGI) using bibliographic information, photointerpretation and fieldwork.

To compile the inventory of sites of geological interest, we gathered data from various sources, including national catalogues of tourist attractions, theses, national technical reports, and scientific publications. These sources provided valuable insights into the Manabí coastal area for the preliminary selection of potential geosites based on geological-geomorphological, socioeconomic, cultural and tourist characteristics of the territory. The selection criteria for the preliminary sites included prior recognition as a tourist or geotourism attraction, the possibility of observing geomorphological elements and processes (specifically,

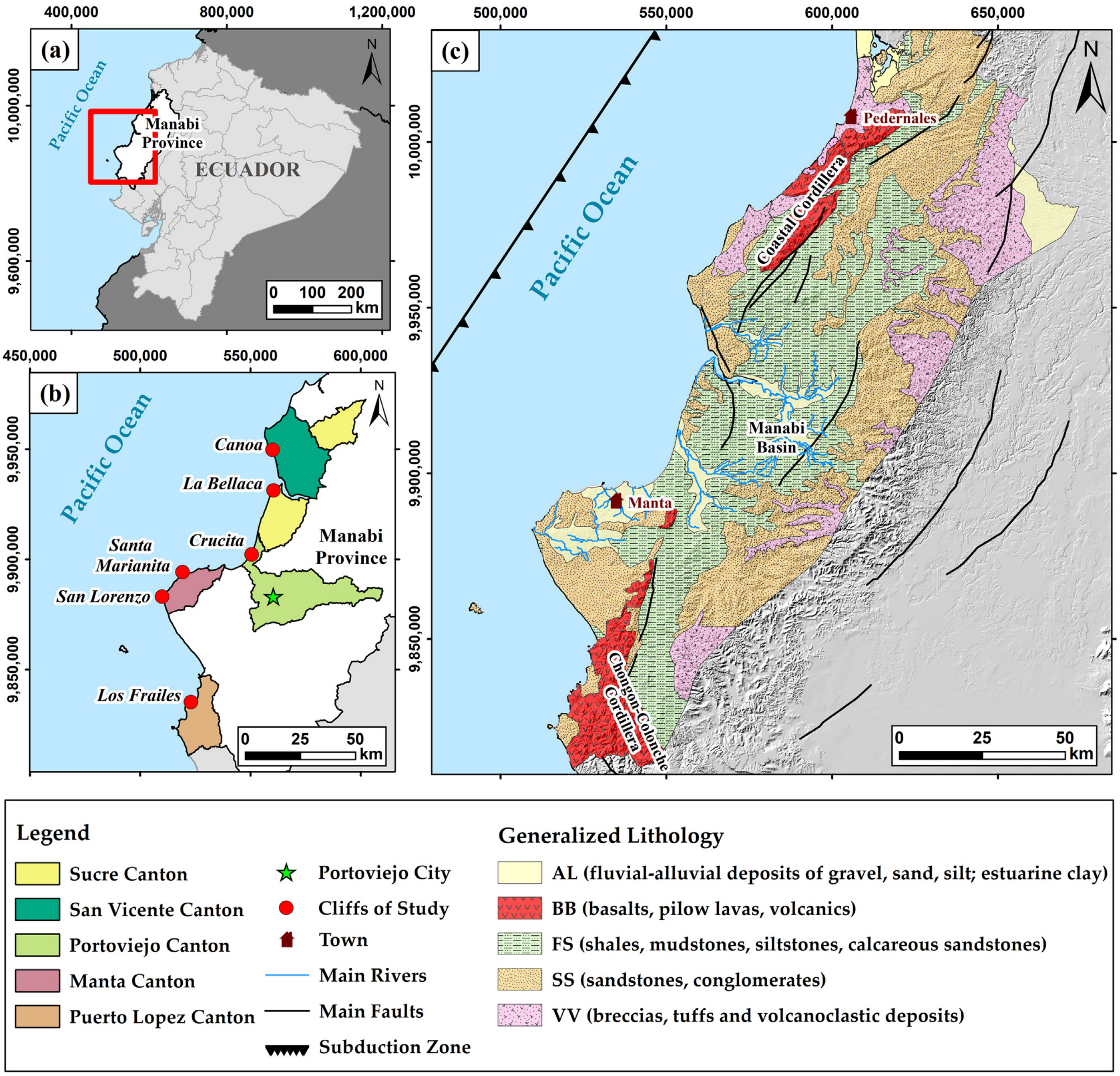

Fig. 1. (a) Location of Manabí Province within Ecuador; (b) location of the coastal cliffs of study in the Province of Manabí, from north to south: Canoa, La Bellaca, Crucita, Santa Marianita, San Lorenzo and Los Frailes; (c) geological setting showing the subduction zone and the generalised lithological map of the western and centre part of Manabí Province defined by Chunga et al. (2019). Map simplified and modified from Reyes and Michaud (2012). Abbreviations: AL: alluvial, BB: basaltic basement, FS: flintstones, SS: sandstones, VV: volcanic.

coastal dynamics and changes resulting from the 16A earthquake), proximity to economically vulnerable towns, cultural richness, and the presence of accessible routes to facilitate visits by tourists. The inventory also accounted for the identification of the type of interest of each potential geosite in terms of its geological content (e.g., stratigraphic, sedimentological, tectonic, hydrogeological, and geomorphological characteristics); its use according to its capacity for the development of scientific (e.g., research), didactic (e.g., dissemination and teaching), tourist (e.g., leisure and recreation activities) and economic activities; and its relevance at different levels (local, provincial, national).

For photointerpretation, the study used satellite images from the Google Earth platform between 2018 and 2022 to identify geomorphological elements of the sites. In addition, field campaigns were conducted to verify the geology, geomorphology and additional data specific to each site (conservation status, accessibility, tourist attraction and type of interest of each site analysed). Finally, the gathered information was consolidated into a descriptive table of the SGIs, encompassing geographic, geological, geomorphological, cultural, and tourist-related information (Paz-Salas et al., 2022).

2.2.2. Phase II: Semiquantitative assessment as geosites

For the geosite assessment, Phase II applied the updated 2018 version of the IELIG method (García-Cortés et al., 2013; García-Cortés et al., 2018). The IELIG method assesses the intrinsic characteristics of the places of interest, considering their scientific, didactic, and touristic-recreational potential. This method employs a set of distinguishable parameters for each site of geological interest. Experts specializing in geomorphology and geotourism conducted the assessment. Three main types of interest were evaluated: scientific interest (Si), didactic interest (Di) and touristic interest (Ti). Each site received individual valuations

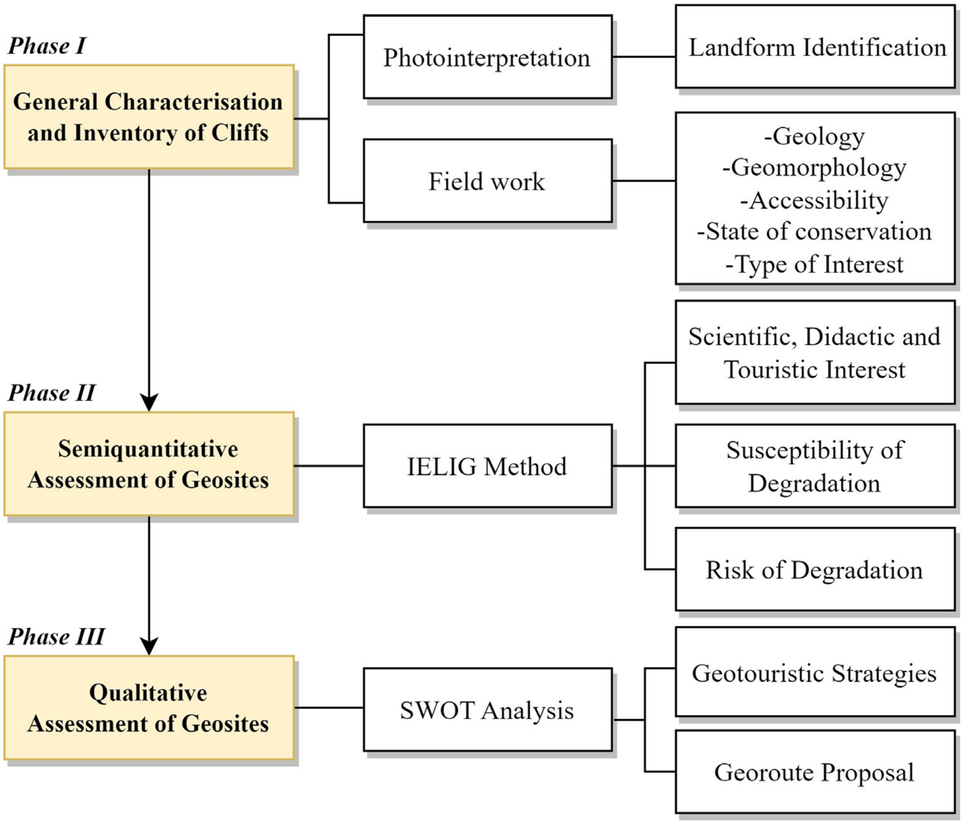

Fig. 2. Scheme of the methodology used in the study. Abbreviations: IELIG, Spanish Inventory of Places of Geological Interest; SWOT, Strengths, Weaknesses, Opportunities, and Threats.

for Si, Di, and Ti. These values were then averaged to derive the global interest value (Gv) for that particular site (Eq. (1)). The overall interest value was classified into three rating ranges: Very High (> 6.65), High (3.33–6.65), and Medium (< 3.33).

$$\text{Global Interest Value (Gv)} = \frac{\text{Si} + \text{Di} + \text{Ti}}{3} \tag{1}$$

Subsequently, the Susceptibility to Degradation by natural threats (SD_{NT}) and anthropic threats (SD_{AT}) were calculated. These calculations considered various parameters, such as the size of the geological interest site (S_{F}), its fragility (F), its natural vulnerability (V_{N}), or its vulnerability due to anthropic causes (V_{A}). Fragility (F) evaluates the alterability of the site due to intrinsic characteristics such as lithology, weathering, and associated tectonism. Natural vulnerability (V_{N}) evaluates the possibility of site alteration resulting from ongoing natural processes. The relationship between the fragility parameter (F) and natural threats (N_{T}) parameter is established by (Eq. (2)). On the other hand, vulnerability due to anthropic causes (V_{A}) evaluates the possibility of site alteration due to human activity and emphasises the need for adopting adequate protection measures. For its calculation, the broken-down vulnerability is considered, which relates to mining interest (V_{M}), looting (V_{L}), proximity to infrastructures (V_{I}) and other general anthropic factors (V_{GA}).

To determine the susceptibility values (SD_{NT} and SD_{AT}), the above factors were related according to Eqs. (2) and (3). The obtained values were classified into the following rating ranges: Low (< 0.75), Medium (0.75–1.5), High (1.5–3.5) and Very High (> 3.5).

$$\text{SD}_{\text{NT}} = S_{\text{F}} \cdot V_{\text{N}} = S_{\text{F}} \cdot F \cdot N_{\text{T}} \tag{2}$$

$$\text{SD}_{\text{AT}} = S_{\text{F}} \cdot V_{\text{A}} = S_{\text{F}} \cdot \left(V_{\text{M}} \cdot V_{\text{L}} \cdot V_{\text{I}} + V_{\text{GA}}\right) \tag{3}$$

After evaluating the interests and susceptibility of degradation values, the next step was to calculate the Risk of Degradation by Natural Threats (RD_{NT}) and Anthropic Threats (RD_{AT}). These factors combine the susceptibility of degradation with the value of interest, measuring the potential damage to the geological heritage based on the magnitude of the consequences of degradation. To calculate RD_{NT} and RD_{AT}, the values of Si, Di, and Ti parameters for each site were related to their corresponding degradation susceptibility values (SD_{NT} and SD_{AT}, respectively). This process allowed for the determination of the maximum risks of degradation values for both RD_{NT} and RD_{AT}, according to Eqs. (4) and (5), selecting the maximum values. The obtained values were classified into the following rating ranges: Low (< 0.5), Medium (0.5–1), High (1–2.5) and Very High (> 2.5).

$$\text{RD}_{\text{NT}} = \max\left(\frac{1}{10}\text{Si} \cdot \text{SD}_{\text{NT}},\ \frac{1}{10}\text{Di} \cdot \text{SD}_{\text{NT}},\ \frac{1}{10}\text{Ti} \cdot \text{SD}_{\text{NT}}\right) \tag{4}$$

$$\text{RD}_{\text{AT}} = \max\left(\frac{1}{10}\text{Si} \cdot \text{SD}_{\text{AT}},\ \frac{1}{10}\text{Di} \cdot \text{SD}_{\text{AT}},\ \frac{1}{10}\text{Ti} \cdot \text{SD}_{\text{AT}}\right) \tag{5}$$

2.2.3. Phase III: Qualitative assessment

In the final phase, a qualitative analysis was conducted. A focus group was assembled comprising researchers and experts with specialised knowledge in geomorphology and geotourism to assess the current state of the beach-cliff systems and their potential as a geotourism destination. This analysis used a SWOT matrix (Wang et al., 2022) of the sites, considering the internal (EFI) and external (EFE) factor evaluation matrices to establish strategic lines of action (David, 2011). As a result of this phase, the authors formulated geotourism strategies for the valuation, protection, adaptation, and promotion of sites through the development of a georoute featuring geomorphological points of interest.

3. Results

3.1. Characterisation of the selected cliffs

This work revealed six potential geosites that met the selection criteria: the beach-cliff systems of Canoa, La Bellaca, Crucita, Santa Mar-

Fig. 3. Satellite images of the six beach-cliffs systems of the study and main landforms identified on them: cliff walls (polygon), abrasion platforms (arrow), sea stumps (circles). Red marks indicate photographic points for the images in Fig. 4. (a) Canoa Cliff; (b) La Bellaca Cliff; (c) Crucita Cliff; (d) Santa Marianita Cliff; (e) San Lorenzo Cliff; (f) Los Frailes Cliff. *Source of images*: Google Earth.

Table 1
Quantitative information of the geomorphological elements identified in the sites of study.

Name	Beach	Cliff				Abrasion platform	Sea stumps
	Length (m)	Length (m)	Altitude range (m)	Area (m^2)	Slope (°)	Outcropping area (m^2)	Outcropping area (m^2)
Canoa Cliff (Fig. 3(a))	650	580	10–50	9,200	>70	3,800	–
La Bellaca Cliff (Fig. 3(b))	1,200	1,180	30–90	56,000	>70	2,300	–
Crucita Cliff (Fig. 3(c))	1,900	1,900	20–40	46,400	<60	2,600	–
Santa Marianita Cliff (Fig. 3(d))	440	280	20–35	10,225	<70	6,200	1,700
San Lorenzo Cliff (Fig. 3(e))	580	577	20–50	22,580	>70	4,200	2,160
Los Frailes Cliff (Fig. 3(f))	1,560	800	10–40	52,760	>80	7,715	1,205

ianita, San Lorenzo, and Los Frailes. The selected sites have intrinsic scientific, aesthetic, cultural, and tourist values that will be detailed in the following sections.

3.1.1. Photointerpretation: landform identification

Fig. 3 illustrates the results of the photointerpretation of the satellite images of the Google Earth platform. The photointerpretation aimed at identifying geomorphological elements, such as escarpments or cliff walls, abrasion platforms and sea stumps in the beach-cliff systems. For further insight, Table 1 provides quantitative data on the dimensions of the identified elements. During the photointerpretation process, specific attention was drawn to the occurrence of debris flow processes on the cliffs of Canoa, La Bellaca and Crucita.

3.1.2. Sites of geological interest (SGI): Description

Table 2 shows the six SGIs corresponding to the cliffs considered in this study (Fig. 1(b)). The table includes their respective types of interest and the main characteristics identified at each site. All the sites exhibited notable geomorphological, stratigraphic, tectonic, and sedimentological features. Moreover, their importance reaches both the local and provincial levels, highlighting their significance within the broader geographical context. Fig. 4 showcases photographs of the six SGIs evaluated in the study.

3.2. IELIG: Global interest, susceptibilities and risks

3.2.1. Assessment of interests (scientific, didactic, touristic)

The results of the evaluation of the six sites of geological interest are illustrated in Fig. 5. Fig. 5(a) presents the scientific, didactic, touristic, and global interest results. All the cliffs obtained global interest values (Gv) within the “high” range. Los Frailes and San Lorenzo cliffs had the highest Gv values (5.65 and 5.6, respectively) due to their impressive geomorphological elements, such as semi-vertical and vertical cliffs, abrasion platforms, sea stumps, bays, arches, and capes. These captivating

Table 2
List of six sites of geological interest (SGI) evaluated in the study.

No.	SGI	Types of interest			Main features
		Content	Use	Influence	
SGI 1	Canoa Cliff (Fig. 4(a))	Gm St Tc Sd Hg	*T* *S* *D* Ec	Lc Pv	• The lithology includes calcareous sandstones (calcarenites) and clays associated with the Borbon Fm. in a soft and brittle state. • The predominant geomorphological features are escarpments of cliffs and abrasion platforms. • State of conservation: favourable with some minor impacts. • Accessibility by paved road. • History/culture: There are nearby occurrences of ceramic fragments attributed to the Manteña Culture (500–800 A.D.) and some remains of natural fishing weirs on the shoreline, a form of ancestral fishing technique in the area, which consists of circular structures that use tidal variations for the capture of fish (Medranda et al., 2020; Salomón, 2018). • At the tourist level, the site offers a captivatisng scene characterised by majestic cliffs, beautiful beaches, and the river-mouth of the Canoa River flowing towards the Pacific Ocean. In addition, it provides opportunities for recreational activities such as cycling, sport fishing, surfing, and paragliding. • Nearby attractions: The Mystic Caves of Canoa and Canoa Beach.
SGI 2	La Bellaca Cliff (Fig. 4(b))	Gm St Tc Sd	*T* *S* *D* Ec	Lc Pv	• The lithology includes clays, sandstones and conglomerates associated with the Borbon and Onzole formations in a soft and brittle state. • The predominant geomorphological features are escarpments of cliffs and abrasion platforms. • State of conservation: degraded. • Accessibility by unpaved road. • History-culture: In the surroundings, there are occurrences of archaeological vestiges, especially ceramic objects, from the Valdivia and Jama-Coaque cultures, near a pre-Columbian settlement (Chirije) (Bouchard et al., 2006). • At a tourist level, the relief and the beaches are the principal attractions. There are opportunities for surfing and hiking. • Nearby attractions: Corazon Island, Las Caras Bridge, Bahia de Caraquez Museum, Cerro Seco Biological Reserve and Punta Gorda Nature Reserve.
SGI 3	Crucita Cliff (Fig. 4(c))	Gm St Tc Sd	*T* *S* *D* Ec	Lc Pv	• The lithology includes tuffaceous to calcareous shales belonging to the Villingota Fm., in a soft and brittle state. • The predominant geomorphological features are escarpments of cliffs and abrasion platforms. • State of conservation: partially affected. • Accessibility provided by unpaved and paved roads. • History-culture: There is an archaeological site of local relevance: La Boca Mangrove Estuary, which is a trail with tolas (mounds for ceremonial use) and is home to 40 species of native birds of the area (Sanchez and Vallejo, 2009). • At the tourist level, the topography of the cliffs offers a natural viewpoint, and the vast beach is a prominent feature. On-site activities include surfing, paragliding, and hiking. • Nearby attractions: Tortuga and Crucita Beaches.
SGI 4	Santa Marianita Cliff (Fig. 4(d))	Gm St Tc Sd	*T* *S* *D* Ec	Lc Pv	• The lithology includes fine-medium-coarse sandstones, localised shales (upper part), and conglomerates (lower part) associated with the San Mateo Fm. in a hard and compact state. • The predominant geomorphological features are escarpments of cliffs, abrasion platforms, and sea stumps. • State of conservation: favourable with affectations. • Accessibility provided by unpaved roads. • History-culture: The sector was a pre-Hispanic culture “Manteña” settlement. Some remains of natural fishing weirs in the shoreline area appear as vestiges of ancestral fishing techniques (Ávila, 2022; Favier Dubois et al., 2019). • At the tourist level, the landscape featuring the impressive topography and extensive beach stands out as major attractions. Visitors can engage in various activities on-site, including paddle-boarding or surfing, kiteboarding, and hiking. • Nearby attractions: La Tiñosa Lighthouse, La Tiñosa Islet, La Tiñosa Beach and San Mateo Dock.
SGI 5	San Lorenzo Cliff (Fig. 4(e))	Gm St Tc Sd	*T* *S* *D* Ec	Lc Pv	• Geographically, it is part of the San Lorenzo Cape. • The lithology includes modern alluvium (Quaternary) and volcanic rocks (basalt) of the Piñon Fm., in a hard and compact state. • The predominant geomorphological features are escarpments of cliffs, abrasion platforms, and sea stumps. • Conservation status: favourable. • Accessibility by paved roads and trails. • History-culture: This site has historically served as a natural landmark for navigation along the coast, being the most prominent point of the Manabí coastline. The area also boasts great wealth in archaeological remains of the Manteña culture (GADP San Lorenzo, 2016). • At a tourist level, the site has a natural viewpoint with breathtaking scenery, local flora, and fauna that attract many visitors. • Nearby attractions: San Lorenzo Lighthouse, San Lorenzo Natural Arches, La Botada Beach, San Lorenzo Waterfall and Pacoche Coastal Marine and Wildlife Refuge.

(*continued on next page*)

Table 2 (*continued*)

No.	SGI	Types of interest			Main features
		Content	Use	Influence	
SGI 6	Los Frailes Cliff (Fig. 4(f))	Gm St Tc Sd	*T* *S* *D* Ec	Lc Pv	• Cliffs situated at both sides of Los Frailes Bay. • The lithology comprises layers of green sandstone, clay and greywacke belonging to the Cayo Fm., in a hard and compact state. In addition, alluvial deposits composed of sands and debris of Quaternary origin are evident. • The predominant geomorphological features are escarpments of cliffs, abrasion platforms, and sea stumps. • Conservation status: favourable. • Accessibility by paved roads and trails. • History-culture: The cliff and its beaches are within the Machalilla National Park, a protected area, with evidence of pre-Hispanic cultures, where the reference is the Manteño – Huancavilca culture (Calva and Rosado, 2021; MAE, 2015). • At a tourist level, the site's attractions include captivating rock formations, pristine white sand beaches, and panoramic views of the green-blue waters of the sea. There is strict control of park rangers and technicians to avoid damage in the area. In addition, hiking and whale watching activities are available for visitors. • Nearby attractions: Las Fragatas Viewpoint, Coral Beach, Tortuguita Beach, Prieta Beach, Machalilla Beach, and Machalilla National Park.

Note: Gm*:* Geomorphological; St*:* Stratigraphic; Tc*:* Tectonic; Sd*:* Sedimentological; Hg*:* Hydrogeological; *T:* Touristic; *S:* Scientific; *D:* Didactic; Ec*:* Economic; Lc*:* Local; Pv*:* Provincial.

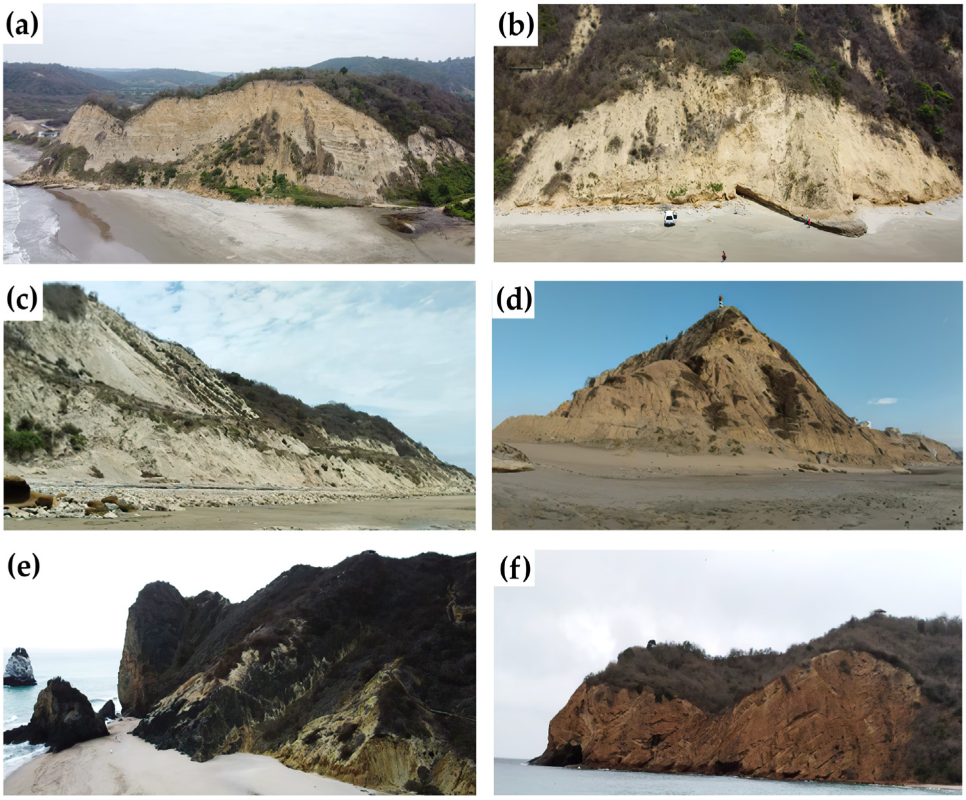

Fig. 4. Photographs of the sites of geological interest (SGI) considered in the study. (a) Canoa Cliff (SGI 1); (b) La Bellaca Cliff (SGI 2); (c) Crucita Cliff (SGI 3); (d) Santa Marianita Cliff (SGI 4); (e) San Lorenzo Cliff (SGI 5); (f) Los Frailes Cliff (SGI 6).

geological formations make them attractive tourism and scientific exploration resources. On the other hand, Crucita Cliff received the lowest score (3.83) because of the presence of debris flows, which negatively impact the area's aesthetics and hinder the visibility of its stratigraphic and geomorphological characteristics.

3.2.2. Assessment of susceptibility to degradation by natural and anthropic threats

All sites fall within the "high" range of susceptibility to degradation due to natural threats (SD_{NT}) (Fig. 5(b)). The main natural threats to cliffs include coastal erosion and earthquakes. Amongst the sites, Canoa, Crucita, and La Bellaca cliffs were the most susceptible to natural degradation, with a value of 3. This susceptibility is associated with the lithology of soft sedimentary rocks, such as calcareous sandstones, poorly consolidated fine sandstones, clays, and tuffaceous shales, which contribute to the weakening of the cliff structure and the occurrence of landslides, which are evident towards the base of each cliff. In contrast, in the cliffs of Santa Marianita, San Lorenzo, and Los Frailes, the susceptibility value was lower due to the presence of erosion-resistant conglomerates, shales, and medium to thick sandstones, forming high and vertical cliffs. However, these sites are still exposed to natural threats over extended periods. The structural arrangement of rocks, faults and folds in various cliffs also contribute to natural degradation by weakening the terrain.

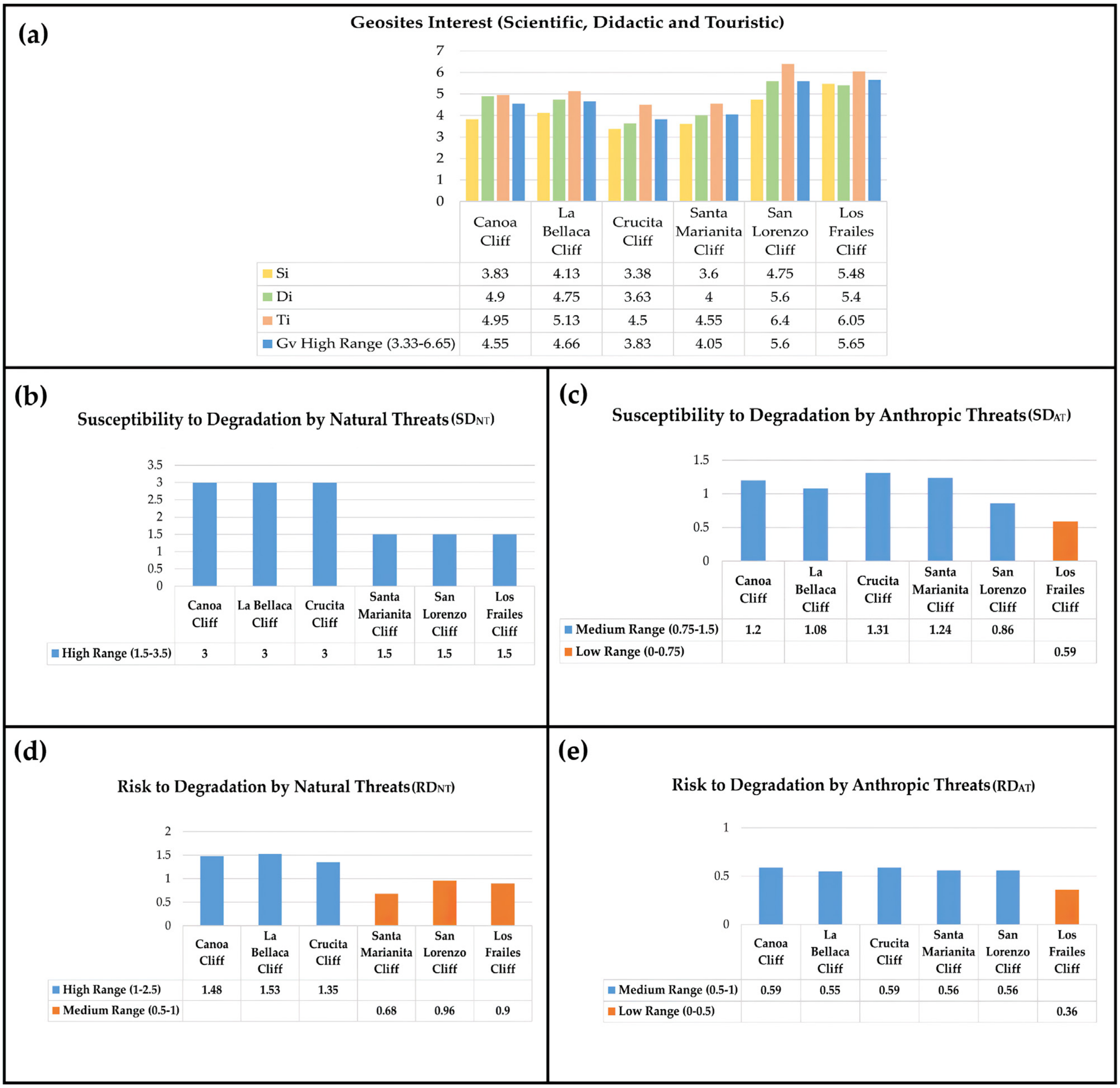

Fig. 5. (a) Global value (Gv) assessment for the sites of geological interest according to the type of interest – scientific (Si), didactic (Di), and touristic (Ti); (b) susceptibility to degradation by natural threats assessment; (c) susceptibility to degradation by anthropic threats assessment; (d) risk to degradation by natural threats assessment; (e) risk to degradation by anthropic threats assessment.

Fig. 5(c) shows the results obtained from analysing susceptibility to degradation by anthropic threats (SD_{AT}). Five out of six sites received a "medium" degradation value, indicating that they are subject to anthropic impacts (mass tourism, recreational activities, urban expansion, vehicle circulation) that alter the entire beach-cliff system. Crucita Cliff obtained the maximum SD_{AT} value within the medium range, with a score of 1.31. This cliff is currently affected by building construction along its edge, which has caused landslides in the area. In addition, access to beaches allows pedestrians and vehicles to move in unstable zones. Canoa, La Bellaca, Santa Marianita, and San Lorenzo also obtained high SD_{AT} values due to their use for outdoor sports and tours without adequate conservation practices. Only the Los Frailes Cliff obtained a minimum SD_{AT} value of 0.59, corresponding to the low range, owing to its official protection status (Machalilla National Park), which seeks to control recreation activities and the use of the area to prevent deterioration.

3.2.3. Assessment of risk to degradation by natural and anthropic threats

For the risk to degradation by natural threats (RD_{NT}), three out of the six sites obtained values within the "high" risk range: Canoa (1.48), La Bellaca (1.53) and Crucita (1.35). These results reflect the significant damage affecting the morphology of the cliffs, requiring short-term protection measures. The other three sites obtained values falling within the "medium" range: Santa Marianita (0.68), San Lorenzo (0.96) and Los Frailes (0.9). These sites also require protective measures to ascertain sustainable geoconservation and geotourism development, but the timeframe for implementation can be more extended (Fig. 5(d)).

The results obtained for the risk of degradation by anthropic threats (RD_{AT}) indicated that five out of six sites (Canoa, La Bellaca, Crucita, Santa Marianita, San Lorenzo) fall within the "medium" range, indicating the urgent need for protection measures concerning their susceptibility to anthropic phenomena. Only Los Frailes Cliff is within the "low" range due to its active protection measures (Fig. 5(e)).

Table 3
External factors evaluation matrix (EFE matrix) and internal factors evaluation matrix (IFE matrix) for sites of study.

External factors Opportunities (O)	Weight (W)	Rating (R)	Weighted Score (WS)
Development of specific projects in the geological zone to benefit surrounding communities.	0.20	1	0.20
Interest of government entities to promote natural resources.	0.15	3	0.45
Promotion of geomorphological sites to boost the local economy.	0.2	2	0.4
Threats (T)	Weight (W)	Rating (R)	Weighted Score (WS)
Need for private financial resources to conduct geotourism projects.	0.1	1	0.1
Constant impacts by natural phenomena and aggressive climatic changes.	0.30	1	0.30
Potential competition.	0.05	1	0.05
Total	1.00		1.5
Internal factors Strengths (S)	Weight (W)	Rating (R)	Weighted Score (WS)
Valuable geological and geomorphological heritage.	0.2	4	0.8
A large variety of landscape resources.	0.05	3	0.15
High potential for geotourism development.	0.1	4	0.4
Presence of erosive processes that reveal geological structures for observation and the development of future research.	0.2	4	0.8
Good conditions of main and secondary roads.	0.05	3	0.15
Weaknesses (W)	Weight (W)	Rating (R)	Weighted Score (WS)
Landforms exposed to anthropogenic and natural erosion.	0.15	1	0.15
Lack of knowledge of natural potential.	0.05	1	0.05
Lack of conservation plans in geomorphological sites.	0.1	1	0.1
Non-existent marketing for geotourism.	0.05	1	0.05
Lack of interpretative signage in most natural attractions.	0.05	1	0.05
Total	1.00		2.7

IFE Scoring system: Major strong point—4; Strong point—3; Weak point—2; Major weak point—1.
EFE Scoring system: Score 4—appropriate answer; Score 3—above average answer; Score 2—the answer is average; Score 1—the answer is below average.

Table 4
Proposed strategies matrix.

Strategies: Strengths + Opportunities	Strategies: Weaknesses + Opportunities
$S_3.O_3$. To design proposals for the valuation and promotion of geomorphological sites to illustrate environmental importance. $S_5.O_2$. To improve accessibility for visiting and observing geomorphological resources. $S_3.O_1$. To raise community awareness about geomorphological sites and their importance in the geotourism sector.	$W_1.O_1$. To provide training to the community and tourism entities on the importance of promoting geological resources. $W_4.O_3$. To create informative panels and promotional material showcasing the most important characteristics of the geomorphological site. $W_5.O_3$. To improve site accessibility with roads, paths, safety indicators, and safety bars.
Strategies: Strengths + Threats	Strategies: Weaknesses + Threats
$S_1.T_1$. To initiate research projects supported by funding from public and private organisations. $S_3.T_3$. To promote the recognition of geomorphological sites through cooperation with government entities. $S_4.T_2$. To implement protective measures against natural threats to safeguard geological heritage.	$W_3.T_2$. To organize monitoring campaigns by experts on preservation and conservation issues to prevent deterioration and enhance tourism quality. $W_2.T_1$. To implement fundraising programs to support the evaluation of geological elements.

3.3. *Geotouristic strategies development*

3.3.1. *SWOT analysis*

Tables 3 and 4, respectively, summarize the SWOT analysis results and the strategies formulated by the focus group members for all sites.

The SWOT analysis involved the design of the internal and external factor evaluation matrices (Table 3). The weight (W) is associated with the level of importance given to each factor by the evaluator. At the same time, the rating (R) represents the value the evaluator assigns to the factors based on the concrete situation. The weighted score (WS) is calculated by multiplying each factor's weight and rating.

The internal analysis (strengths and weaknesses) resulted in a score of 2.7, indicating favourable qualities of the beach-cliff systems for promoting geological tourism. This evidence is crucial for the comprehensive development and enhancement of the sites. On the other hand, the external analysis (opportunities and threats) yielded a score of 1.5, indicating favourable prospects for developing geotourism capacities. However, effective strategies are required to leverage geotourism and mitigate existing threats concerning the beach-cliff systems. The evaluation of internal and external factors suggests the potential for emerging development of the geotourism capacities at the studied sites.

The main strategic lines derived from the SWOT analysis are as follows:

- Promoting geo-education and raising geological awareness regarding beach-cliff systems and the impact of geological threats.
- Fostering community-academy-government-company collaboration to jointly develop geotourism and geoconservation initiatives.
- Improving the infrastructure associated with sites of geological interest.
- Establishing a link between geotourism and the socioeconomic development of the communities surrounding the beach-cliff systems.

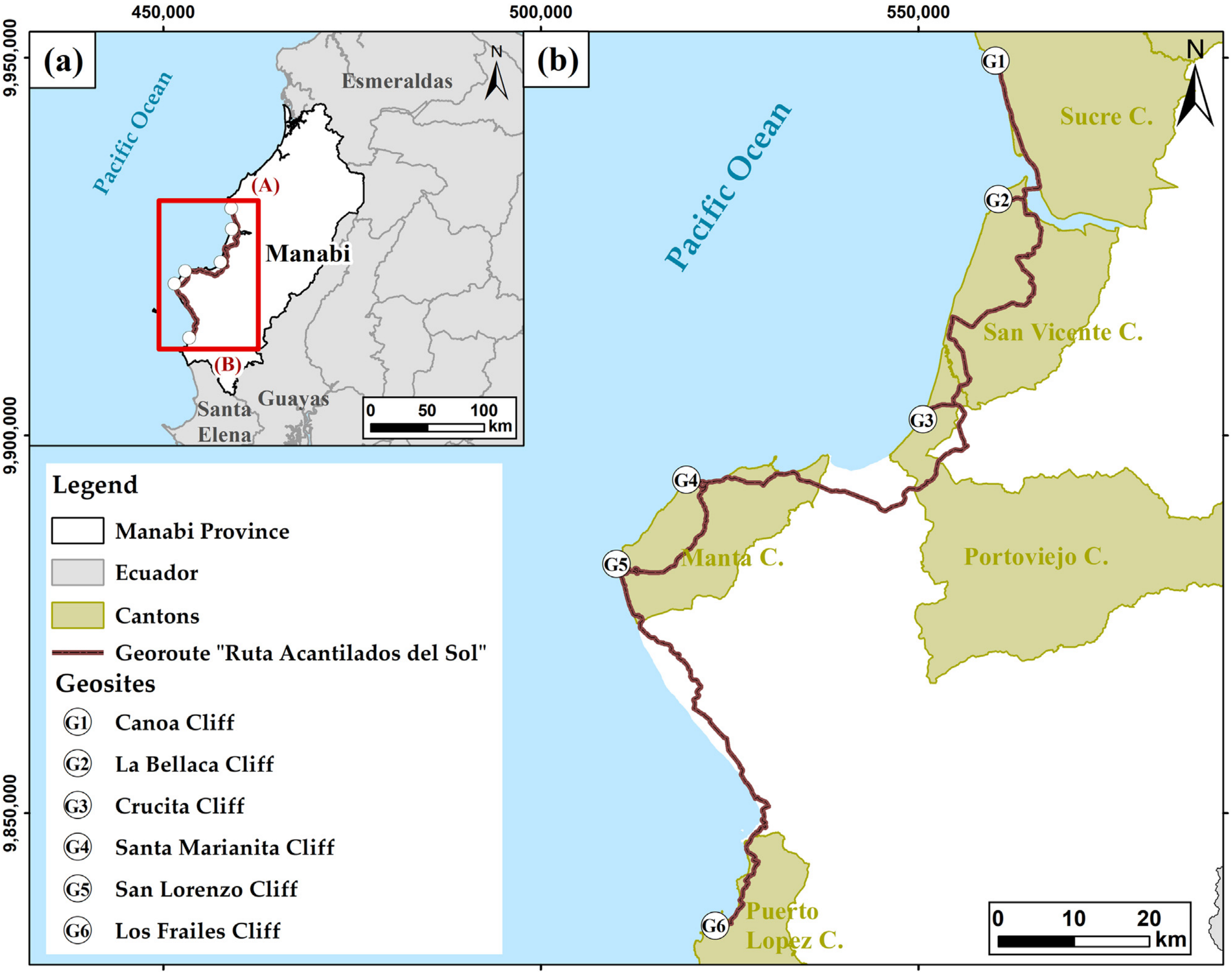

Fig. 6. Georoute “Ruta Acantilados del Sol”. (a) Georoute location considering accesses: (A) north access from Esmeraldas and (B) south access from Guayas or Santa Elena; (b) georoute showing geosites points, from north to south: G1 (Canoa Cliff in Sucre Canton), G2 (La Bellaca Cliff in San Vicente Canton), G3 (Crucita Cliff in Portoviejo Canton), G4 (Santa Marianita Cliff in Manta Canton), G5 (San Lorenzo Cliff in Manta Canton), and G6 (Los Frailes Cliff in Puerto Lopez Canton).

3.3.2. “Ruta Acantilados del Sol” georoute proposal

As an additional result of the assessments and analysis of the cliff sites, the main strategy proposed for promoting geoheritage and leveraging the geotourism potential of the province to stimulate economic development is the creation of a georoute with geomorphological interest. The georoute, named “Ruta Acantilados del Sol” spans 245 km from north to south, crossing the cantons of San Vicente, Sucre, Portoviejo, Manta, and Puerto Lopez in the province of Manabí, connecting the six evaluated sites.

For a comprehensive interpretation and effective promotion of geoheritage, the authors suggest considering several aspects:

(a) *Identification of actors and strategic allies*: The creation of the georoute would involve municipal representatives, tourist offices, and community inhabitants as key actors and partners. These actors would benefit from employment opportunities generated by promoting geological resources to the public.

(b) *Route approach*: The georoute offers two possible access points, one from the north and the other from the south of Manabí Province (Fig. 6(a)). Access A (north) starts from Esmeraldas province, with stops established in the following order: G1 (Canoa Cliff); G2 (La Bellaca Cliff); G3 (Crucita Cliff); G4 (Santa Marianita Cliff); G5 (San Lorenzo Cliff) and G6 (Los Frailes Cliff). These stops will allow visitors to observe the coastal erosive landforms forming the remarkable landscape. Access B (south) can begin from the provinces of Guayas or Santa Elena, with the route following the reverse order of Access A, starting with G6 and ending with G1 (Fig. 6(b)). The georoute covers a distance of 245 km, with a travel duration of approximately six hours, making it suitable for a one- or two-day vehicle trip.

(c) *Identification of resources*: The “Ruta Acantilados del Sol” georoute provides vehicle access, lodging infrastructure near the sites, opportunities to enjoy local gastronomy (seafood), purchase handmade products, and engage in various tourist and recreational activities.

(d) *Place adaptation*: To implement the georoute, it is necessary to adapt each site with tourist trails, safety indicators and entrance infrastructure that includes parking, rest and recreation areas (Fig. S1(a)). Moreover, the implementation should include signage with pictograms (Fig. S1(b)), tourist information panels (about site location, nearby attractions, flora and fauna) (Fig. S1(c)) and scientific information about the location (geological and natural hazard information panels) (Fig. S1(d)).

(e) *Promotion and dissemination*: To attract visitors to the georoute, it is essential to train local personnel to promote and provide information about each site. Additionally, hiring trained personnel can further encourage the appreciation of the geological heritage through brochures, social networks, and web pages. The dissemination material should showcase the most important characteristics, tourist and scientific information, and a map indicating the georoute location. These materials can be distributed through various media channels, such as tourist offices, travel agencies, television, websites, and social networks, to reach both national and international tourists.

4. Discussion

The findings of this study facilitated a semiquantitative assessment of the six sites of interest, considering their potential and relevance to promote geotourism in this region, which is characterised by a marine-coastal zone adorned with spectacular cliffs. The evaluation utilized qualitative methods to identify and address degradation issues due to natural and anthropic threats, formulating mitigation strategies under the Geotourism-Geoconservation-Geoeducation (3 G) system approach.

4.1. Geotouristic potential of selected sites

The evaluation through the IELIG-2018 Method revealed outstanding ratings for each site of interest, with values falling into the “high” category, emphasizing the chosen sites’ relevance and potential as geosites. The sites display diverse features of geomorphological, stratigraphic, tectonic, and sedimentological interest, complemented by cultural, aesthetic, and tourist values that enhance the attractiveness of geotourism development. It should be noted that the dynamic geomorphology prevailing in this region is associated with endogenous (e.g., seismic activity) and exogenous (e.g., marine erosion) geodynamic processes, which swiftly shape coastal landforms and change the local geomorphological configuration, causing natural degradation of the relief, as evidenced by landscape elements such as landslides. Such effects form the foundation for conservation proposals as they arouse the curiosity of both locals and visitors, particularly regarding the visible remnants left by events originating within the Earth’s surface, such as the 16A earthquake.

The Manabí coast lies in a zone of high seismic acceleration (NEC, 2014) where the effects of the earthquakes induce macroscopic geomorphological changes, offering a unique opportunity to observe the before and after states in the area altered by the impact of earthquakes of great magnitude. This presents a chance to witness phenomena such as stratiform uplifts and landslides in the beach-cliff sectors. From a conservation perspective, multiple criteria can be applied to protect and preserve these sites, while leveraging the active coastal dynamics related to seismic phenomena as a geoeducation tool.

The inclusion of these sites in the country’s existing geoheritage inventories fosters the visibility of regions previously overlooked (Berrezueta et al., 2021). This work also aligns with previous efforts where geological tourism proposals along the Ecuadorian coast were developed through community initiatives with academic contributions (Vera et al., 2019; Herrera-Franco et al., 2020).

Ruban et al. (2022) noted that regions rich in geoheritage often experience considerable tourism. Similar evaluations indicate that existing tourist infrastructure positively influences the assessment of geosites (Tomić et al., 2020), usually linked to the functional and tourist values of beach sectors (Braholli and Menkshi, 2021), whose significance is enhanced by the protection provided by nature reserves (Navarrete et al., 2022; Singtuen et al., 2022), as observed at Los Frailes Cliff. On the other hand, community tourism offers viable opportunities to foster the development of small communities (Ateş and Ateş, 2019).

4.2. Risks and hazards perception

Prosser et al. (2018) emphasise the importance of identifying potential threats and susceptibility of geosites. These cliffs are particularly vulnerable to degradation from natural threats, with varying levels of susceptibility and risk of degradation, ranging from medium (Santa Marianita, San Lorenzo, and Los Frailes Cliffs) to high (Canoa, La Bellaca, and Crucita Cliffs). Given the high scientific, educational, and tourist value of each site, their fragility remains a constant concern. Thus, tourism promotion in the area should address these threats through measures that cover potential risk events (Migoń and Pijet-Migoń, 2019).

In general, coastal cliffs undergo constant changes in their physical characteristics owing to different events (e.g., marine, fluvial and gravitational processes) (Flor-Blanco et al., 2022). In this study, coastal erosion was the primary cause of natural geomorphological changes at the sites. Canoa, La Bellaca, and Crucita cliffs are the most vulnerable because of their composition of soft sedimentary rocks (Rangel-Buitrago et al., 2020), requiring the installation of mitigation infrastructure (e.g., ripraps or breakwaters) to physically protect the cliffs (Schoonees et al., 2019).

Earthquakes represent another natural hazard that can induce instability in cliff slopes, trigger mass movements, and shape landforms (Chunga et al., 2019; Cruz deHowittz et al., 2006). Against high-magnitude earthquakes (such as the 16A earthquake), seismic and geotechnical risk studies can be used to establish security measures for geotourism in the area (Solórzano et al., 2022). Moreover, presenting geotourism hazards can raise visitor awareness and increase the public knowledge regarding disasters (Iqbal et al., 2023).

4.3. Proposed geotourism, geoeducation and geoconservation strategies

According to the SWOT analysis, the sites’ strength lies in their valuable geological and geomorphological resources, with high potential for the development of geotourism. However, their weaknesses are associated with the lack of a comprehensive protection plan that ensures the preservation of their physical integrity against natural and man-made threats while promoting sustainable geotourism management over time. To address these findings, tourism promotion strategies aim to integrate geotourism, geoeducation, and geoconservation resources and raise awareness amongst all stakeholders.

From a geotourism perspective, the proposal of the “Ruta Acantilados del Sol” georoute enables harnessing the geological and geomorphological potential of the study area for tourism, allowing visitors to enjoy the immersive in situ experience offered by panoramic landscapes (Kubalíková et al., 2022; Migoń and Pijet-Migoń, 2017), as reported by Mikhailenko and Ruban (2019) in the Western Caucasus (Russia). This approach also contributes to socioeconomic development (Duarte et al., 2020), promotes the cultural roots of the inhabitants and raises awareness of the importance of geoheritage (AbdelMaksoud et al., 2021). This aligns with current trends at the national and international levels that integrate geoconservation concepts (e.g., “Ruta Escondida” (Ecuador) (Carrión-Mero et al., 2020), “Estrada Real” (Brazil) (De Oliveira Bicalho and Teixeira, 2010), and “Geological Itinerary Through the Southern Apennine Thrust Belt” (Italy) (Bentivenga et al., 2017)).

Geoeducation can encompass information about natural processes, such as coastal erosion and the recent seismic effects of the 16A earthquake, highlighting coastal gravity processes (landslides) on the cliffs of Canoa, La Bellaca, and Crucita, and stratiform uplifts of sedimentary rocks (abrasion platforms) that became visible after the earthquake in places like Crucita Cliff. These aspects serve as educational and dissemination material on geomorphological changes after large earthquakes, but also as a resource to sensitise the population about the associated risks, as demonstrated by Henriques (2023) for the 1755 Earthquake in Lisbon (Portugal). Such geoscientific content can be explained through the creation of geoeducational models and diverse materials that encourage interaction and enhance visitors’ understanding of geoprocesses, as in Khon Kaen National Geopark (Thailand) (Singtuen et al., 2022).

Finally, in a broader sense, the results and strategies outlined in this work can be applied through the collective participation of academia, civil society, businesses, and government entities to guide the area towards sustainable development.

5. Conclusions

This study employed quantitative and semiqualitative approaches to evaluate the geotourism potential of six coastal cliffs on Ecuador's central coast. The group of sites features expansive beaches and cliffs stretching hundreds of meters, boasting valuable geological and geomorphological assets complemented by spectacular coastal landscapes, which also reveal unusual elements like stumps and abrasion platforms. Amongst all the sites, San Lorenzo Cliff stood out due to its substantial geoscientific content, characterised by a diverse range of geomorphological features and its regional geological significance (Cretaceous Basalts from Piñon Fm.), making it ideal for didactic purposes. Additionally, the presence of existing infrastructure, such as trails, indicates current tourist use that can be further enriched through the incorporation of geotourism.

This research shed light on the vulnerability of sites to both natural (e.g., coastal erosion, gravitational processes, earthquakes) and human-induced causes, and the need for geoconservation measures. A transversal plan is suggested, engaging stakeholders in actions and resource allocation to facilitate ongoing monitoring for preservation purposes. In addition, the georoute "Ruta Acantilados del Sol" could play a significant role in promoting the elements and processes that have shaped the coastline over time. The route's focus on coastal dynamics and coseismic effects can serve as a foundation for engaging in geoeducation activities and raising awareness of the local population and visitors. Moreover, the georoute could provide exceptional experiences regarding the region's natural splendour while implementing adequate planning to minimise possible adverse effects, thereby fostering the socioeconomic improvement of historically marginalised communities. This study serves as a valuable guide for recognising and analysing areas of geological importance in erosive coastal settings. The study could be enhanced using a second geosite assessment method to contrast evaluation parameters and improve the interpretation. Finally, this work empowers local governments to establish policies and strategies for using and preserving the existing geological heritage. At the community level, it promotes citizen participation in the sustainable management of natural resources through tourism and geoconservation.

Ethical statement

Ethical approval was not required for this study since human participants were ensured following local legislation and institutional requirements. All proceeds of this research were carried out following the Helsinki Declaration principles of human subject investigation. Participation in the focal group discussions was anonymous and voluntary, assuring consent of prospective respondents before participation. Data accumulated for this research was treated confidentially.

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Declaration of Competing Interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.geosus.2023.08.003.

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