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Geosites and Geotourism in the Local Development of Communities of the Andes Mountains. A Case Study

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Abstract: The inventory and assessment of a geosite in a territory provides a sound basis for the protection and use of its geological heritage. This article aims to evaluate the most relevant geosites in the province of Chimborazo (Ecuador), applying the Spanish Inventory of Sites of Geological Interest (IELIG, in Spanish) method, and proposing alternatives for geotourism development in the studied area. The methodological process was based on: (i) the inventory and preliminary selection of geosites; (ii) a semi-quantitative geosite assessment and proposal of travel itineraries for geotourism; and (iii) the application of the strengths, weaknesses, opportunities, and threats (SWOT) matrix to establish geotourism development strategies within a framework of sustainability. The global assessment of scientific, tourist, and academic interests demonstrates that 25% of the 20 evaluated geosites have very high interest and 75% have high interest. The top three geosites with the highest degrees of interest are the Chimborazo Volcano, known as 'Earth's Closest Point to the Sun', the Pallatanga geological fault, and the geosite named Comunidad Cacha. The SWOT analysis reveals that travel itineraries that combine cultural heritage elements and geosites could offer a real alternative for the region's sustainable development through geotourism.

Keywords: geosites; geoheritage; geoconservation; geotourism; Chimborazo Volcano

1. Introduction

The term geodiversity was first introduced in the early nineties. According to Gray [1], geodiversity is the variability of Earth's surface materials, landforms, and physical processes (abiotic elements). Materials are the rocks, soil, or the water; mountains, glaciers, and lakes are examples of landforms; and soil formation, coastal erosion, and sediment transport could be mentioned as processes. A definition of geodiversity, at a local scale, was suggested as a synthesis of the landscape that includes geological, hydrogeological, geomorphological, and climatic elements and processes [2]. The Law of Natural Heritage and Biodiversity (BOE Law 42/2007) of Spain [3], defines it as "The variety of geological elements, including rocks, minerals, fossils, soils, landforms, formations and geological units and landscapes that are the product and record of the evolution of the Earth". Geodiversity must be regarded as part of the natural heritage of the territory, which shapes the evolution of the planet and favors the development of life [4–6].

When the constituent elements of geodiversity have a high scientific value, they are known as geological heritage or geoheritage [7,8]. Geoheritage is inherent to natural heritage. It includes forms, elements, and structures originated by geological process and has a crucial role in understanding Earth's history [8,9].

Social perception of geodiversity and geological heritage has changed over time. Today, it is considered a right, a need, and a duty to protect the environment through the safeguard of geosites [10]. A geosite is a site where one or more geographically well-defined elements of the geodiversity are present and it has a singular tourist, cultural, or scientific value [2]. According to Prosser [10], geosites are sites with a high scientific value, assessed quantitatively and qualitatively through an inventory, assessment, and selection process to develop a management and threat prevention plan. Movable geological heritage also exists; it refers to vulnerable elements of earth sciences exposed to natural degradation or human action that can—or must—be protected ex situ. Their inclusion into a museum collection often means the only chance for the preservation of these invaluable inanimate natural monuments [11,12]. Geosites are sites with geological and geomorphological interest that are part of geological heritage and promote its conservation. It is important to note that, in recent years, there has been an increase in the number of UNESCO geoparks, reaching 161 in 2020 [13]. This circumstance has initiated many geosite characterization studies and the development of assessment methods [9]. According to [14], the basic study and the securing of geosites must follow a careful study that leads to their evaluation, while respecting their original features, in order to inform the development of sustainable tourism.

For the characterization of geosites—inventory, diagnosis, promotion, and management projects of geological resources have been carried out in several countries [15–18]. The Spanish Inventory of Places of Geological Interest (IELIG, acronym in Spanish) [19], as referenced by Serrano and González [20], Brilha [2], and Medina [5], is one of the methods widely used in geosite characterization [21–25]. The existing procedures are improving and evolving to provide a global evaluation of the geological heritage, considering tourist, scientific, and academic criteria. The geological routes (georoutes) are itineraries that aim to the geological heritage's value through the connection of different geosites. Examples of these georoutes can be found in Spain, such as the "la pizarrilla" geotrails, in Jaén [26]; the geotrails in the Yanhuitlán Geopark, in the Mixteca Alta-Oaxaca (Mexico) [27], and the geological itinerary of Sasso di Castalda in Italy [28].

Characterization procedures are based on the quantification of visual and susceptible aspects and the use of statistical data analysis to evaluate geological characteristics of geosites [17]. The IELIG method is the base methodology recommended by the ASGMI (Ibero–American Association of Geological and Mining Surveys) for assessing sites of geological interest in Ibero-America [29]. In Ecuador, it is the most commonly used assessment method (e.g., [30–34]). In general terms, the IELIG method [19] builds upon the work of experts who define the instrumental values of geosites (scientific, educational, and recreational tourism potential), together with susceptibility to degradation and protection priorities.

Geotourism has been conceptualized as the union of three components: forms, processes, and tourism [35,36]. Forms include existing landscapes with their characteristics and components. Processes include tectonic activity, weathering, deposition, etc. Tourism refers to the human dimension reflected in tourist activities and the appreciation of geology and geomorphology, among others [37,38]. The United Nations Educational, Scientific and Cultural Organization (UNESCO) mentions that geotourism implies traveling through a territory where the tourists explicitly understand that the landscape they observe contains unique forms modeled by dynamic processes that have left visible traces [39,40].

Geotourism cannot be reduced to 'geological tourism', but rather it is a broader concept, where the focus of attention is the geosite, the geological phenomena, the tourist use of the landscape potential, and the culture and customs of the local population [41,42]. It is essential to remember that the geotourism sector dynamics are prone to be influenced by impacts and crises deriving from environmental, climatic, and social factors [7,43–46].

The target region of this study is the province of Chimborazo (Ecuador). This province has remarkable cultural, natural, intangible, and geological characteristics with the potential to be officially recognized as elements of natural or cultural heritage [47,48]. The main economic activities in the area are agriculture, livestock breeding, mining, and handicrafts [49,50]. Tourist activity is also noteworthy, although, despite the singularities of the natural features and the efforts of regional and local authorities, geotourism does not reach its full potential [51,52]. The main reason for this could be the absence of a strategic plan that should include the inventory, characterization, and promotion of the territory's geological characteristics. One of the objectives of this study is to assess whether the socio-economic development of the territory could be stimulated by the inclusion of geosites in the tourist offer to complement traditional tourism.

The aim of this work is to evaluate the most notable geosites in the province of Chimborazo (Ecuador) by applying the semi-quantitative method of the IELIG and an analysis of strengths, weaknesses, opportunities, and threats (SWOT). We also wished to propose itineraries for the development of geotourism in the region. To reach our goals, we compiled and analyzed available information, and then employed international methods for the assessment of geosites located in the study area. This work is meant to lay the foundation for more detailed future works.

2. Geographical and Geological Setting

2.1. Geographical Setting

The Chimborazo province is in the south-central part of Ecuador, in the Inter-Andean region or Sierra (Figure 1). Its capital, Riobamba, is located 210 km southwest of the city of Quito (Ecuador). Its extension is of 6499.72 km^2, and it has a population of 458,581 inhabitants, 59.20% of which reside in rural areas [53]. From north to south, the province is crossed by the Western and Eastern Cordilleras and the Inter-Andean valley (a tectonic depression) between them [54]. The area is in the extreme southwest of the main volcanic arc of Ecuador [55], where the Chimborazo volcano rises. This is the highest volcano in the Northern Volcanic Zone of the Andes (6263 m above sea level) [56,57], and it is known as the farthest point from the center of the earth (6384 km), two kilometers farther than the Everest with its 6382 km [58,59]. There are also other volcanic centers that belong to the volcanic domain of the Inter-Andean valley, although most of them are extinct (e.g., centers of Igualata, Llimpi-Huisla) [60].

2.2. Geological Setting

Regionally, Ecuador is divided into tectonostratigraphic zones that extend parallel to the Northern Andes mountain range. From west to east, these are: (1) the oceanic terranes of the coastal region and the Late-Cretaceous Western Cordillera [61–64]. (2) the Chingual-Cosanga-Pallatanga-Puná (CCPP) dynamic fault system [65], which is also the eastern tectonic limit of the "North Andean Sliver" and is related to the oblique subduction of the Nazca plate. It formed a 20 to 30 km wide and 300 km long structural depression [60] known as the Inter-Andean valley, includes a dozen older andesitic volcanic centers [65], and deposits from the Miocene to the Holocene [60,63,66]. Finally, (3) the Eastern or Real Cordillera, separated from the Inter-Andean Valley by the Peltetec Fault, which is the continuation of the Romeral Fault of Colombia. This fault lies on a sequence of basal rocks from the Paleozoic to the Cretaceous of the South American Plate [67].

The study area (Figure 2a,b) comprises the southern termination of the Ecuadorian arc, where it is possible to identify volcanic centers from the late Pliocene to the Quaternary, including three of the four types of volcanism [60]. The volcanic front of the Western

Cordillera includes andesitic to dacitic composite stratovolcanoes, such as the El Chimborazo volcano [68]. The volcanic center of the Eastern Cordillera is mainly composed of andesitic stratovolcanoes, such as El Altar, a volcano that has not been studied in detail so far [66]. Moreover, the andesitic volcanic centers of the Inter-Andean valley, such as the Calpi and Licto slag cones, located in the Riobamba basin, are the result of the lower inclination of the subduction zone caused by the subduction of the Carnegie Ridge [60], and their period of activity is unknown [66].

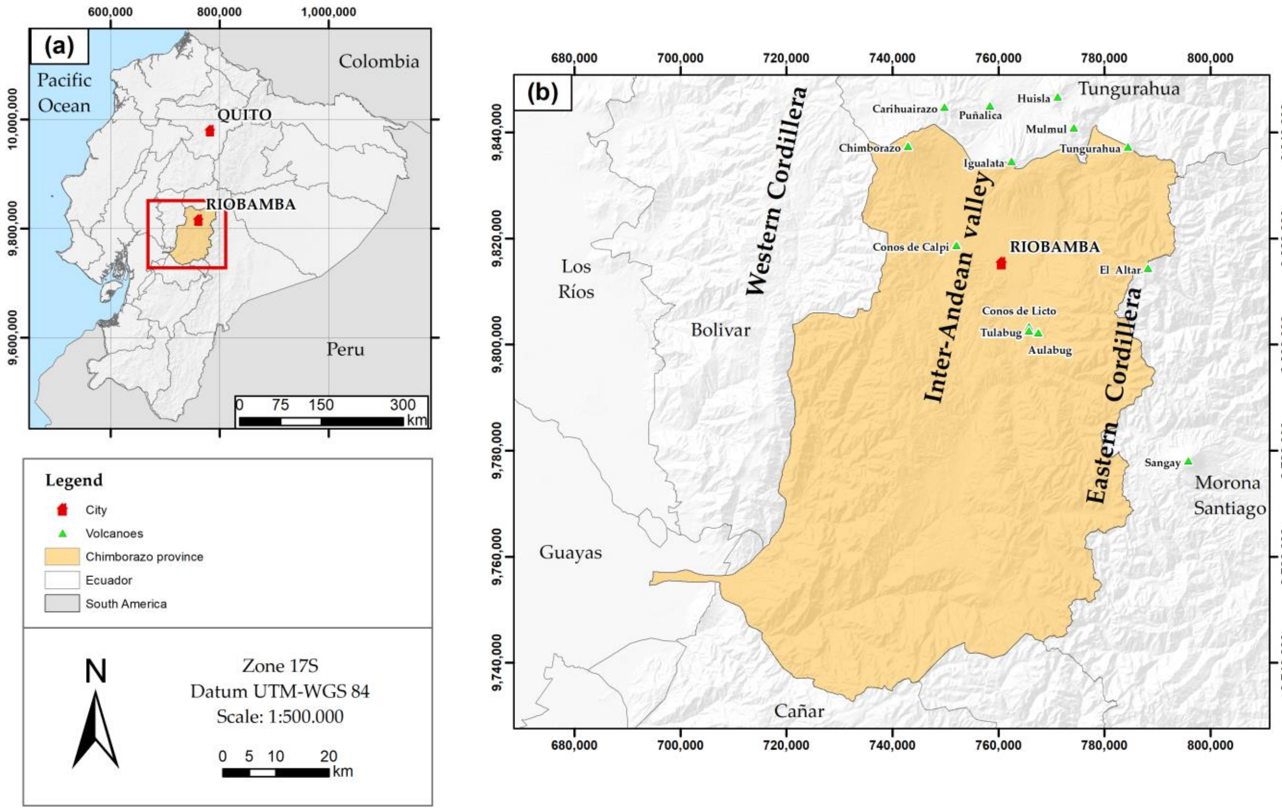

Figure 1. Location of Chimborazo province: (**a**) regional location of the study area within the NW zone of the South American margin; (**b**) local setting of Chimborazo province showing the main volcanoes.

From the lithological point of view, in the Chimborazo province, geological units of sedimentary, igneous, and metamorphic rocks emerge, ranging from the Triassic to alluvial deposits of the Quaternary (Figure 2b). These geological formations are affected by the sector's structural dynamics associated with the locally known Pallatanga Fault (Figure 2a), a NNE–SSW strike-slip fault that crosses the central part of the study area. This fault is believed to have caused the 1797 Riobamba earthquake [69].

The oldest lithologies are exposed along the western margin of the Eastern Cordillera, which marks the eastern border of the province (Figure 2a,b). They are composed of S-type granitoids of the Tres Lagunas unit [71], followed by Jurassic rocks, such as the metalavas and green schists of the Alao-Paute unit, metagrauvacas, and metavolcanites of the Maguazo unit. The Peltetec ophiolite and the Guasuntos Jurassic Unit are also discontinuously exposed, separated by the Peltetec Fault [71,72]. The Peltetec ophiolite was interpreted as an oceanic lithospheric section generated in a suprasubduction environment [71].

The Cretaceous units are in the western part of the area, composed of basalts and volcano-sediments of the oceanic plateau grouped in the Pallatanga unit and quartz-bearing turbidites of the Yunguilla formation [73]. The Paleocene–Eocene geology is represented by the andesites and volcanoclasts of the Macuchi formation and the Angamarca Group, which includes black and grey turbidites of the Apagua Formation of the late Eocene. In the south of the province, pyroclastic rocks and andesitic to rhyolitic lavas of the Saraguro outcrop are located. Moreover, in the central part, Miocene volcanoclastic deposits of the Zumbagua, and Mio-Pliocene pyroclastic deposits of the Tarqui and Pisayambo volcanics can be found. Other features are areas covered by glacial deposits, reworked pyroclasts (cangahua, distal facies (Figure 2b)), primary hot gas-rich pyroclastic flows (tephra, pyroclastic flows, ignimbrites), lahars and avalanches of the Quaternary [57,70], and intrusive rock outcrops.

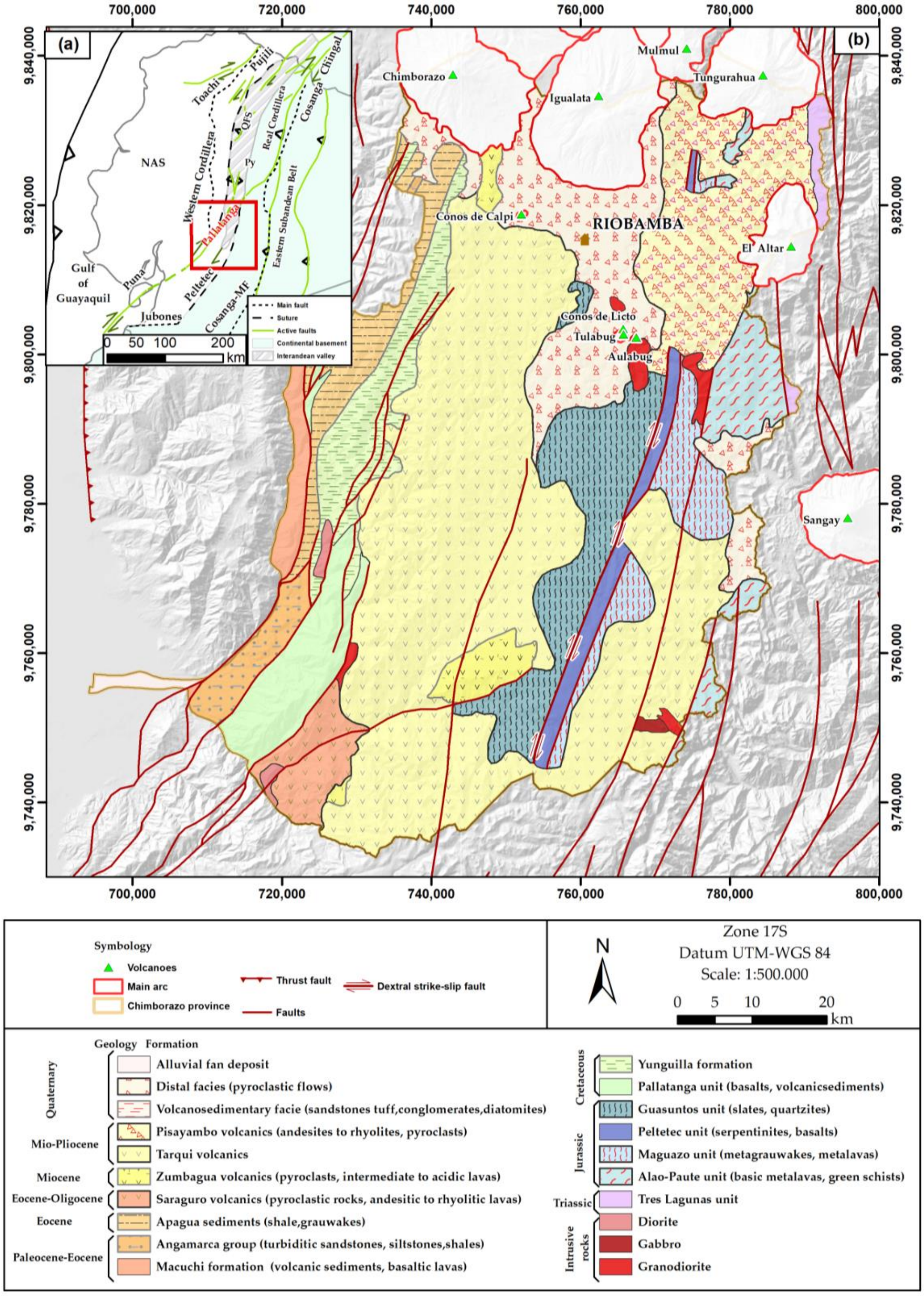

Figure 2. Geological map of the province of Chimborazo [70]: (**a**) tectonic map of Ecuador based on [65], showing major fault segments, active faults and delimitation of the continental basement. Abbreviations: NAS: North Andean Sliver; Py: Pisayambo zone, QFS: Quito active Fault System; (**b**) regional geology map of the Chimborazo province showing the main structures [70].

3. Materials and Methods

In this article, the IELIG method was applied to identify and select sites of geological interest (SGI) or geosites. Additionally, we used a SWOT analysis to evaluate the relationship between the geosites and the community. The proposed evaluation process was based on the guidelines, classification and assessment of a previous study by García-Cortés [19]. The IELIG does not only identify geosite targets of the inventory and their geological environment, but it also provides a diagnosis to design geoconservation measures. The study was structured into three stages (Figure 3): (i) phase I consisted of compilation of information, inventory, and preliminary selection of potential geosites; (ii) in phase II, the IELIG method was applied for the assessment of the selected geosites; and finally, (iii) phase III involved the strengths, weaknesses, opportunities, and threats (SWOT) analysis of the geosites regarding their contribution to the geotourism development of the region.

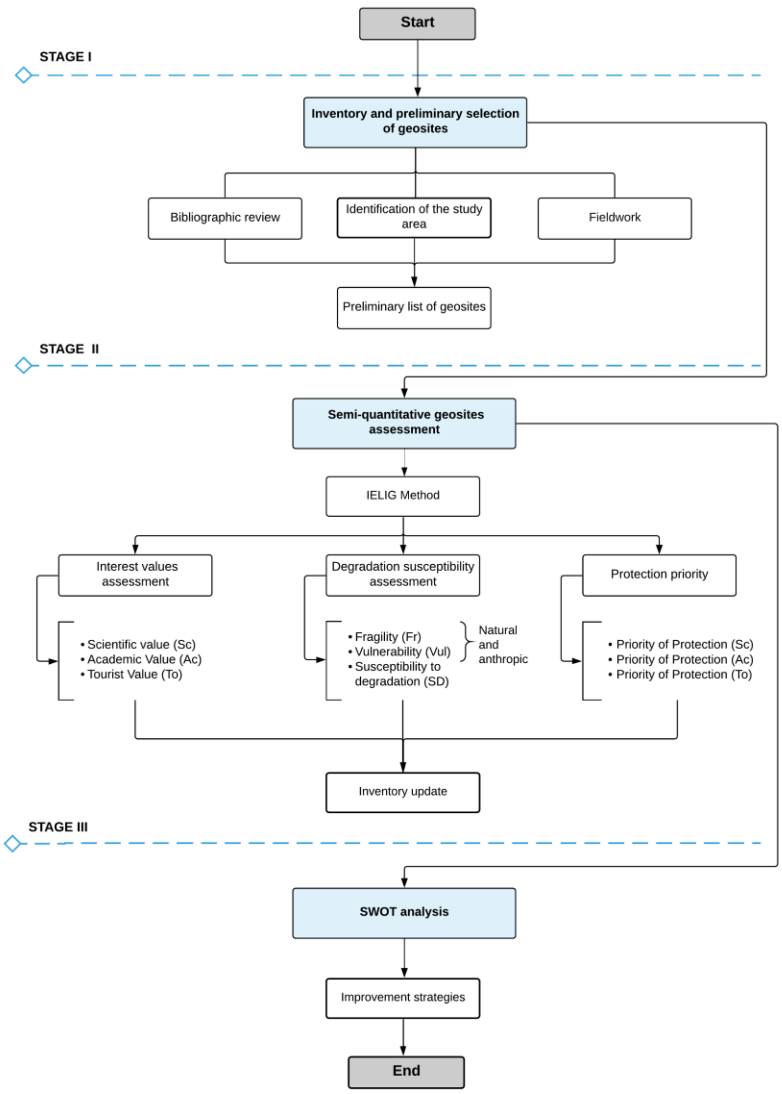

Figure 3. Outline of the applied methodology.

3.1. Inventory and Preliminary Selection of Geosites

In the first phase, we compiled information about the geosites from various sources, such as scientific articles, theses, thematic cartography, and other studies developed in the area. We also reviewed and correlated some points of the project framework 'Registry of geological and mining heritage and its impact on the defense and preservation of geodiversity in Ecuador' [74]. The aim of this phase was to obtain an overview of the geographical, social, and geological characteristics of the territory for the preliminary selection of potential geosites.

3.2. Semi-Quantitative Geosite Assessment

The IELIG method [19] was applied for the semi-quantitative assessment of the list of sites obtained in the preliminary phase (3.1). This procedure, unlike others, considers protection priority (Pp), which is an essential indicator of priorities in conservation actions. Table 1 shows the parameters and weights established by the IELIG to assess the scientific (Sc.), academic (Ac.) and touristic (To.) value of each site. A score of 0 to 4 is assigned to each parameter by experts.

Table 1. Established parameters to assess scientific (Sc.), academic (Ac.), and touristic (To.) interests based on [19]. Interest value rank (0, 1, 2, 3, or 4). Weight (constant values in %). Interpretation: maximum (400), very high (267–400), high (134–266), medium (50–134), low (<50).

Value / Parameters	Interest of the Geosites					
	Scientific (Sc.)		Academic (Ac.)		Touristic (To.)	
	Value	Weight	Value	Weight	Value	Weight
Representativeness	0 to 4	30	0 to 4	5	0 to 4	0
Standard or reference site		10		5		0
Knowledge of the site		15		0		0
State of conservation		10		5		0
Conditions of observation		10		5		5
Scarcity, rarity		15		5		0
Geological diversity		10		10		0
Educational values		0		20		0
Logistics infrastructure		0		15		5
Population density		0		5		5
Possibilities for public outreach (accessibility)		0		15		10
Size of site		0		0		15
Association with other natural elements		0		5		5
Beauty		0		5		20
Informative value		0		0		15
Possibility of recreational and leisure activities		0		0		5
Proximity to other places of interest		0		0		5
Socio-economic environment		0		0		10
Total (weight)		100		100		100
Total	Sc. = value × weight		Ac. = value × weight		To. = value × weight	

According to the values obtained for each geosite (i.e., scientific, academic, and tourist interest) considered in the study area (Table 1), the aim is to analyze to what extent their protection is a priority. Equation (1) is used to calculate the degradation susceptibility (DS), based on parameters, such as fragility and vulnerability due to anthropic threats, and assigned weights [19], shown in Table 2.

$$\mathrm{DS} = \frac{\mathrm{Fr.} \times \mathrm{Vul.}}{400}, \tag{1}$$

Table 2. Parameters of degradation susceptibility (DS) and weighs of each parameter. Interpretation of DS: maximum (400), very high (400–200), high (199–68), medium (67–13), low (<13).

Parameter	Fragility (Fr.)	
	Value	**Weight**
Geosite size	0 to 4	40
Vulnerability to looting		30
Natural hazards		30
Total (weight)		**100**
Total (Fr.)	**Fr. = value × weight**	
Parameter	**Vulnerability (Vul.)**	
	Value	**Weight**
Proximity to infrastructures	0 to 4	20
Mining exploitation interest		15
Protected area designation		15
Indirect protection		15
Accessibility		15
Ownership status		10
Population density		5
Proximity to recreational areas		5
Total (weight)		100
Total (Vul.)	Vul. = value × weight	

From the degradation susceptibility (DS), Equations (2)–(4) were used to obtain the values of protection priority (Pp) in its different domains: scientific Pp (Sc.), academic Pp (Ac.), and tourist or recreational Pp (To.). The global protection priority Pp (Equation (5)) generates a comprehensive value about the state of the geosite; it can be used to update the inventory of geosites, and to focus on those places that need restoration or application of appropriate conservation measures. The different sub-parameters to assign each type of value (0 to 4) are shown in detail in a study about the Spanish Inventory of Places of Geological Interest (IELIG) in its 2013 version [19].

$$\text{Pp (Sc.)} = (\text{ISc.})^2 \times \text{DS} \times (1/400^2), \quad (2)$$

$$\text{Pp (Ac.)} = (\text{IAc.})^2 \times \text{DS} \times (1/400^2), \quad (3)$$

$$\text{Pp (To.)} = (\text{ITo.})^2 \times \text{DS} \times (1/400^2), \quad (4)$$

$$\text{Pp} = \left(\frac{\text{ISc.} + \text{IAc.} + \text{ITo.}}{3} \right)^2 \times \text{DS} \times (1/400^2), \quad (5)$$

3.3. SWOT Analysis

In phase III, we analyzed the strengths, weaknesses, opportunities, and threats (SWOT) [75] of the assessed geosites. The analysis was developed with the participation of members of the academy and researchers. The aim of the SWOT analysis was to determine the area's potential in a more ambitious future project and to propose initiatives for the efficient and effective use of the geosites and their environment. Finally, as a product of this third phase, specific alternatives for optimizing geotourism were defined. The interpretation of the analysis described in previous sections provided the basis for these alternatives.

4. Results

4.1. Geosite Inventory and Description

Based on the collected information, 20 geosites were selected for detailed analyses. The selected sites have unique geological features determined by a specific geological description. In Figure 4 and Table 3, the selected sites and their primary geological interest type are shown. Figure 5 highlights the outstanding geological features of four of the identified geosites.

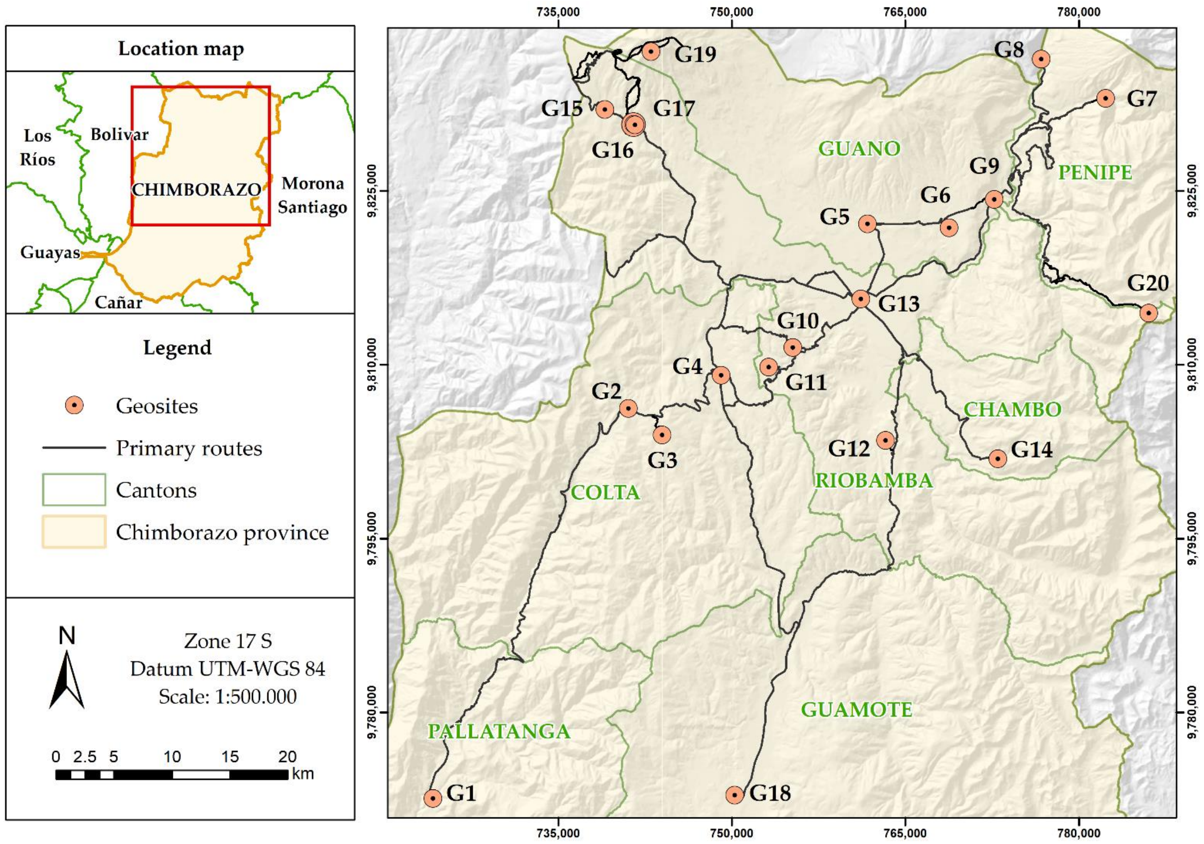

Figure 4. Location map of sites of geological interest. Falla Pallatanga (G1); Páramo Guacona (G2); Páramo de Navag (G3); Laguna de Colta (G4); Mirador de Guano (G5); Pozo Chingazo (G6); Cascada de Tambo (G7); Lahar Tungurahua (G8); Columnas de basalto de Guano (G9); Comunidad Cacha (G10); Laguna Comunidad Quero (G11); Huellas Megaterios de Riobamba (G12); Loma de Quito (G13); Termas Guayllabamba (G14); Cantera faldas Chimborazo (G15); Capas Volcánicas de Chimborazo (G16); Cascada La Chorrera (G17); Dunas Palmira (G18); Volcán Chimborazo (G19); Volcán El Altar (G20).

Table 3. List of potential geosites in the study area, typological and classification.

No.	Geosites	Type of Geological Interest
G1	Falla Pallatanga (geologic fault)	Structural
G2	Páramo Guacona (moorland)	Geomorphological
G3	Páramo de Navag (moorland)	Geomorphological
G4	Laguna de Colta (lagoon)	Geomorphological
G5	Mirador de Guano (viewpoint)	Geomorphological
G6	Pozo Chingazo (water well)	Hydrogeological
G7	Cascada de Tambo (waterfall)	Geomorphological
G8	Lahar Tungurahua (lahar)	Geomorphological
G9	Columnas de basalto de Guano (basalt columns)	Volcanic
G10	Comunidad Cacha (landscape-museum)	Geomorphological

Table 3. *Cont.*

No.	Geosites	Type of Geological Interest
G11	Laguna Comunidad Quero (lagoon)	Geomorphological
G12	Huellas de Mastodontes de Riobamba (mastodon footprints)	Paleontological
G13	Loma de Quito (hill)	Geomorphological
G14	Termas Guayllabamba (hot springs)	Hydrogeological
G15	Cantera faldas Chimborazo (mine)	Mining
G16	Capas Volcánicas de Chimborazo (Tephra fallout deposit)	Volcanic
G17	Cascada La Chorrera (waterfall)	Geomorphological
G18	Dunas Palmira (dunes-desert)	Geomorphological
G19	Volcán Chimborazo (volcano)	Volcanic
G20	Volcán El Altar (volcano)	Volcanic

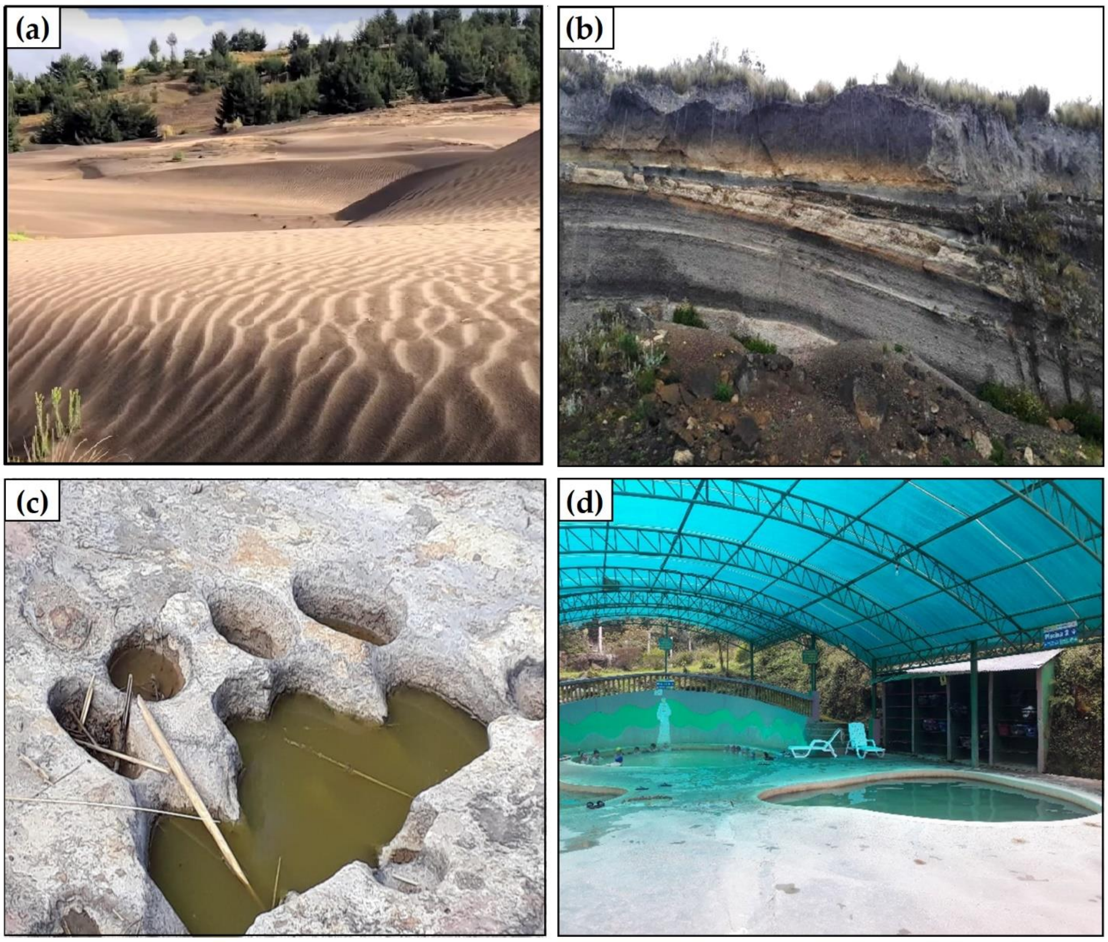

Figure 5. Examples of geosites: (**a**) Dunas Palmira (G18 in Table 3); (**b**) Capas Volcánicas de Chimborazo (G16 in Table 3); (**c**) Huellas de Mastodontes de Riobamba (G12 in Table 3); (**d**) Termas Guayllabamba (G14 in Table 3).

4.2. Geosite Assessment

4.2.1. Assessment of Scientific, Academic, and Tourist Interest

Table 4 presents the global results obtained from the average values of Sc., Ac., and To. interest types (Av = (Sc. + Ac. + To.)/3) regarding the 20 sites assessed by the IELIG method. The Chimborazo volcano has the highest and the Pozo Chingazo site the lowest average interest value (373.33/400 and 180.00/400, respectively, Table 4). In summary, 25% of the geosites have very high interest and 75% high interest.

Table 4. Assessment geosites in terms of scientific (Sc.), academic (Ac.), touristic (To.), and average (Av.) interest, susceptibility to degradation (DS), vulnerability due to anthropic threats (Vul.), and scientific (Pp (Sc.)), academic (Pp (Ac.)), touristic (Pp (To.)), and global (Pp) protection priority.

No.	Geosites	Sc.	Ac.	To.	Av.	DS	Pp (Sc.)	Pp (Ac.)	Pp (To.)	Pp
G1	Falla Pallatanga (geologic fault)	360	305	280	315.00	23.25	18.83	13.52	11.39	14.42
G2	Páramo Guacona (moorland)	265	310	255	276.67	22.50	9.88	13.51	9.14	10.76
G3	Páramo de Navag (moorland)	220	205	245	223.33	22.50	6.81	5.91	8.44	7.01
G4	Laguna de Colta (lagoon)	255	260	330	281.67	12.00	4.88	5.07	8.17	5.95
G5	Mirador de Guano (viewpoint)	195	225	260	226.67	43.75	10.40	13.84	18.48	14.05
G6	Pozo Chingazo (water well)	215	185	140	180.00	52.50	15.17	11.23	6.43	10.63
G7	Cascada de Tambo (waterfall)	215	210	205	210.00	66.50	19.21	18.33	17.47	18.33
G8	Lahar Tungurahua (lahar)	335	225	195	251.67	43.88	30.77	13.88	10.43	17.37
G9	Columnas de basalto de Guano (basalt columns)	250	235	190	225.00	43.75	17.09	15.10	9.87	13.84
G10	Comunidad Cacha (landscape-museum)	350	305	270	308.33	40.63	31.10	23.62	18.51	24.14
G11	Laguna Comunidad Quero (lagoon)	185	175	195	185.00	52.25	11.18	10.00	12.42	11.18
G12	Huellas Megaterios de Riobamba (megaterios footprints)	290	190	260	246.67	29.25	15.37	6.60	12.36	11.12
G13	Loma de Quito (hill)	195	225	165	195.00	44.00	10.46	13.92	7.49	10.46
G14	Termas Guayllabamba (hot springs)	200	215	275	230.00	63.38	15.84	18.31	29.95	20.95
G15	Cantera faldas Chimborazo (mine)	285	230	230	248.33	97.38	49.43	32.19	32.19	37.53
G16	Capas Volcánicas de Chimborazo (Tephra fallout deposit)	220	205	275	233.33	126.50	38.27	33.23	59.79	43.05
G17	Cascada La Chorrera (waterfall)	195	175	190	186.67	24.50	5.82	4.69	5.53	5.34
G18	Dunas Palmira (dunes-desert)	205	240	345	263.33	24.75	6.50	8.91	18.41	10.73
G19	Volcán Chimborazo (volcano)	380	370	370	373.33	15.75	14.21	13.48	13.48	13.72
G20	Volcán El Altar (volcano)	255	210	315	260.00	19.50	7.92	5.37	12.09	8.24

Six geosites, 30% of the total, reached the ‘very high’ range of scientific interest (Sc.). The Chimborazo Volcano (Figure 6a), known as the farthest point from the center of the earth (6384 km) [58,59], or ‘Earth’s Closest Point to the Sun’ [76], reached the highest score, 380. This significance of this geosite is increased by the facts that it is the highest mountain in Ecuador and hosts a large wildlife reserve [57,77]. Of the fourteen remaining geosites (70% of the total), the Páramo Guacona (Figure 6b) must be mentioned in the ‘high’ range (Figure 6b) with 265 points. Its importance is due to the springs that emanate in this moorland. It is located between the Llin and Navag moors. Currently, water harvesting, and channeling projects are being designed in the area. From the geosite, it is possible to appreciate the ‘V’ shape of the hydrographic systems, indicative of active in-depth erosion and significant vertical uplifts.

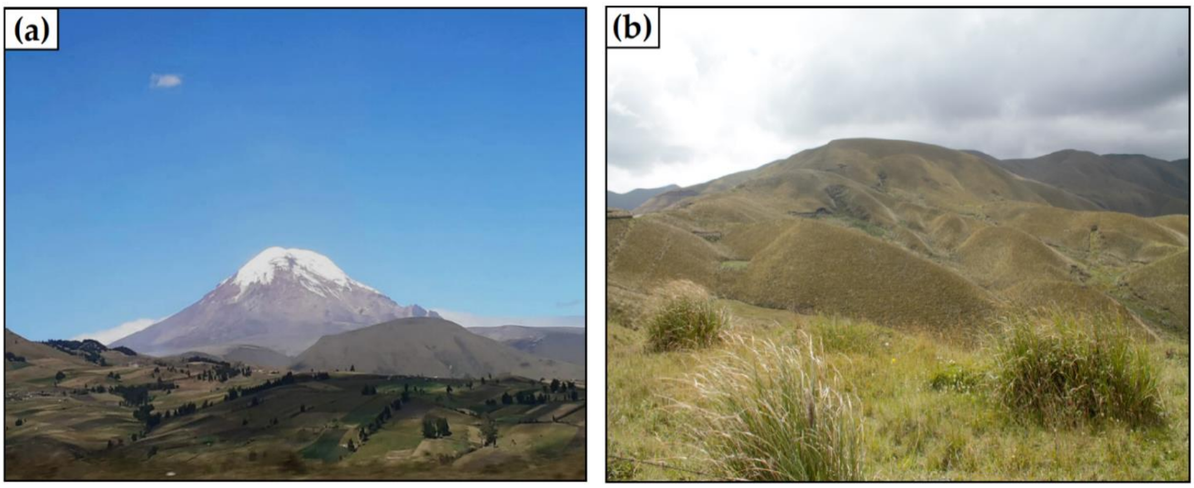

Figure 6. Examples of geosites of great scientific interest: (**a**) Volcán Chimborazo (G19 in Table 3); (**b**) Páramo Guacona (G2 in Table 3).

Regarding academic interest (Ac), four geosites (20%) have a 'very high' interest: the Chimborazo Volcano (370), the Páramo Guacoma (310), the Falla Pallatanga (Figure 7a), and the Cacha Community (Figure 7b) (with 305 points both). The Pallatanga Fault is a regional strike-slip fault that caused the 1797 Riobamba earthquake [69]. It provoked an approximately 956 kilometer long [78] longitudinal breach cutting through five provinces of Ecuador. The Cacha Community comprises rustic huts and circular museums as part of the Pucaratambo tourist center [79]. This geosite has added value due to its tremendous cultural potential, as it is the cradle of the influential Puruhá people. The remaining sixteen sites (80%) reached the 'high' range of interest, which proves that most geosites have great relevance in this area. The Laguna de Colta geosite reached the highest score, 260 points, in this category (Figure S1).

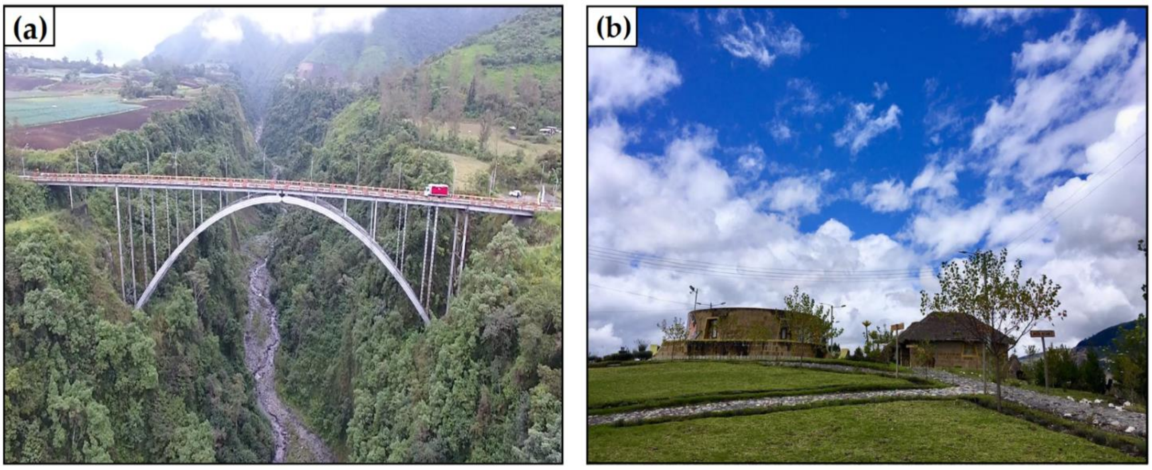

Figure 7. Examples of geosites of great academic interest: (**a**) Falla Pallatanga (G1 in Table 3); (**b**) Comunidad Cacha (G10 in Table 3).

The tourist interest (To.) assessment revealed that eight sites (40% of the total) are within the 'very high' range, again with the Chimborazo Volcano (Figure 6b) in the first position (370 points). The remaining twelve sites (60% of the 20 selected sites) are within the 'high' range. The highest score in this category was obtained by the Mirador de Guano geosite and the Riobamba Megaterios Footprints (see Figure 5c) (260 points, both). The Mirador de Guano is situated on a rock formation of volcanic origin named Colina Lluishig. From this viewpoint, it is possible to observe the Chimborazo volcano, El Altar volcano, Tungurahua Volcano, and Guano city (Figure 8a). On the way up to the viewpoint, there are monoliths carved in the middle of the 20th century. The most outstanding ones are the fish, the vessel, and the face of the Inca (Figure 8b).

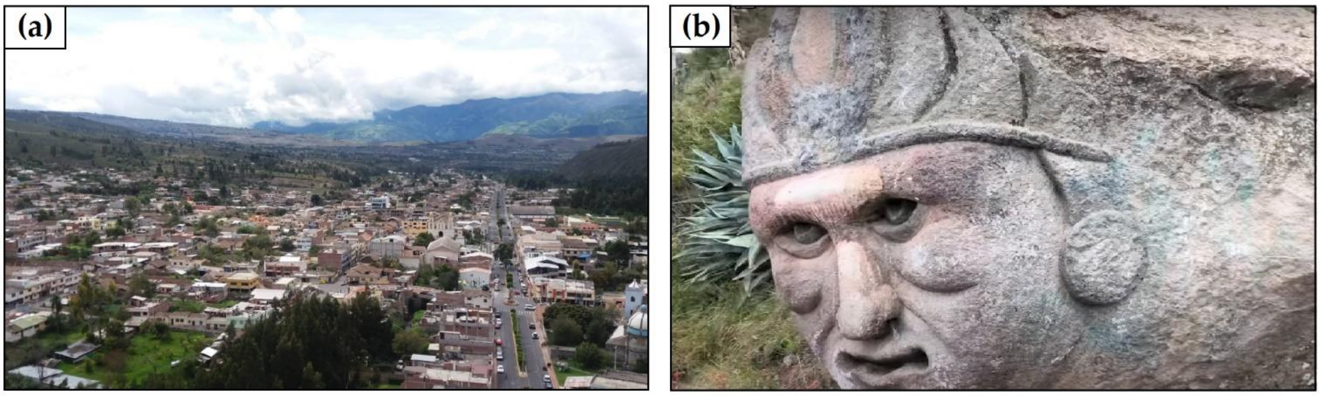

Figure 8. Examples of views from geosite The Mirador de Guanos (G5 in Table 3). (**a**) Panoramic view of the Guano city; (**b**) face of chief Toca monolith (warrior of the Puruhá culture).

The global assessments of the scientific, tourist, and academic interests are reflected in Figure 9, merging the results of the 20 geosites.

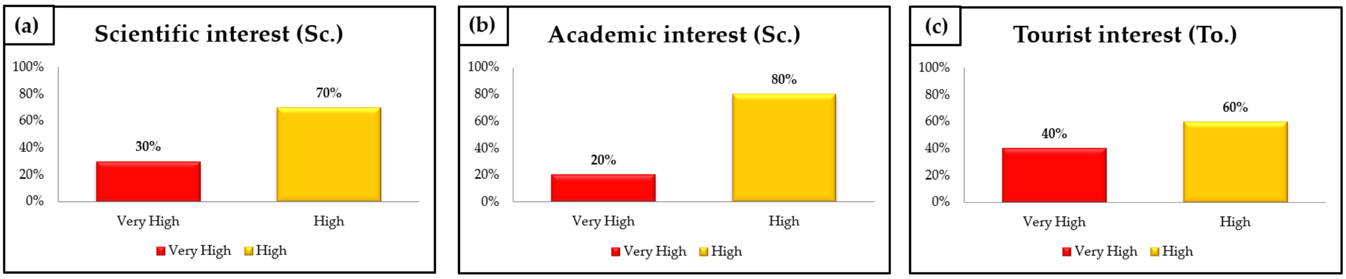

Figure 9. Tabulation of interests of the geosites as: (**a**) scientific; (**b**) academic; and (**c**) touristic.

4.2.2. Degradation Susceptibility

After the assessment of interest values, the susceptibility to degradation was evaluated and classified into 'high', 'medium' and 'low' categories (Figure 10). Two geosites (10%), the Capas Volcánicas de Chimborazo (126.50), and the Cantera faldas Chimborazo (97.375) fall into the 'high' category. These sites are vulnerable due to their easy access and lack of indirect protection. Moreover, 17 geosites (85%) are within the 'medium' range. The clearest example of this group is the Cascada de Tambo, which obtained 66.50 points. In the 'low' range, there is only one geosite (Laguna de Colta, 12) (5% of the total).

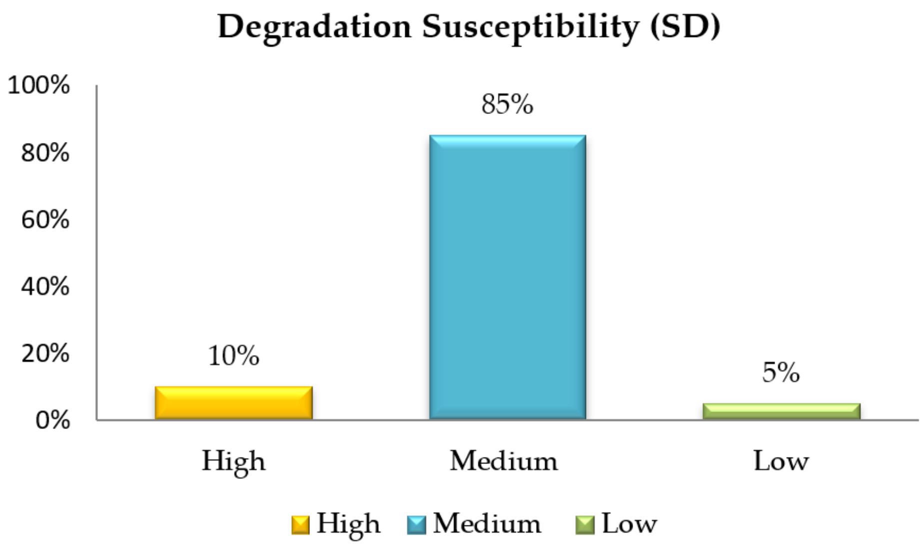

Figure 10. Values of the degradation susceptibility (DS) analysis.

4.2.3. Global Protection Priority

With the obtained degradation susceptibility (DS) values, the global protection priority was calculated (Table 4). Moreover, 30% of the 20 geosites have a 'high' protection priority level, which indicates the need for urgent or short-term protection measures. The top three sites in this category are Capas Volcánicas de Chimborazo (43.05), Cantera faldas Chimborazo (37.53), and Cacha Community (24.14). The remaining 14 geosites have a 'medium' Pp level and require protection measures in the medium- or long-term (Figure 11).

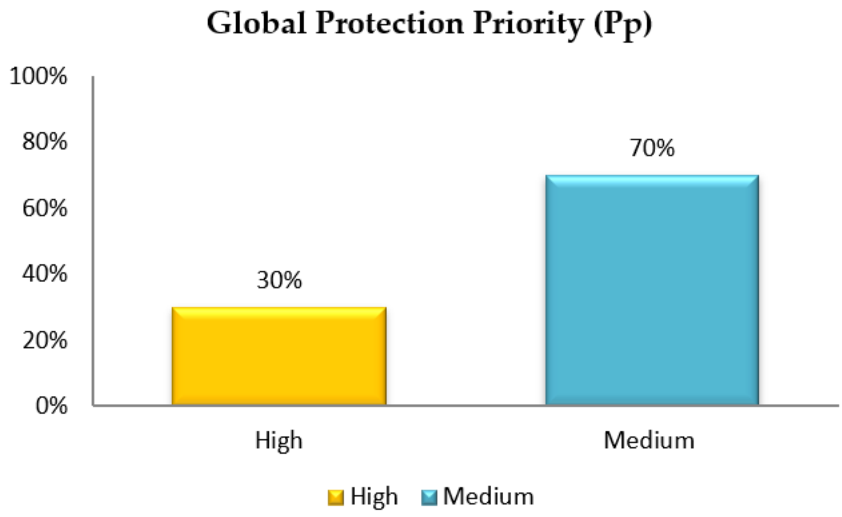

Figure 11. Values of global Protection Priority (Pp).

4.3. SWOT Analysis

Table 5 shows a matrix with internal and external criteria. At the intersection of each row and column, strategies were designed to improve geosite conservation and protection.

4.4. Proposed Itineraries Including Geosites

Based on the described data, the study proposes two travel itineraries as primary strategies for the promotion of geotourism development. Besides the geosites of this study, we also considered other outstanding cultural and tourist sites in the Chimborazo province. Itinerary # 01, named 'Geo-riqueza en Chimborazo', includes geosites of distinguished geological value and the most remarkable cultural sites of the area. Itinerary # 02, named 'Geoturismo-Chimborazo', includes geosites and tourist sites. The itineraries meet the following criteria:

- Tourists can access each selected geosite in their own vehicle.
- There exists an infrastructure with accommodation and restaurants within short distances.
- Tourist and recreational activities are offered.

The itinerary 'Geo-riqueza en Chimborazo' has a high level of difficulty (requires good physical condition) and takes approximately three days to complete (Figure 12). For this itinerary, three possible accesses are proposed that allow visiting the geosites and connected cultural attractions and biodiversity features. Access (A) (Guayaquil-Riobamba road) is an example of a tourist route that begins with a visit to the Pallatanga canton, followed by the Colta canton and Riobamba, to end with the Guano canton where the Chimborazo volcano is the most impressive geosite of this route. Access (B) (Baños-Penipe road) starts from the Riobamba canton, goes on towards the coast, passing through Colta and Pallatanga; on the way, it is possible to appreciate geo-forms, such as El Altar Volcano, Carihuairazo Volcano, and Chimborazo Volcano (Figure S2). Access (C) (Arenal-San Juan road) starts from the Chimborazo Volcano (Figure S2c) and goes towards the Pallatanga fault. In this itinerary, sites such as the Balvanera Church, Guano Museum, and Monastery Ruins are included, which also have geology-related aspects. For example, the Balvanera Church was built with local basalt blocks (Figure S3).

The 'Geoturismo-Chimborazo' itinerary is of low difficulty level and takes one day. Two possible accesses are proposed. Access (A) begins from the Falla de Pallatanga and proceeds to the Riobamba canton. Access (B) starts from Riobamba and ends at the Falla Pallatanga (Figure 13).

Table 5. SWOT analysis of the study area. The matrix combines internal features (i.e., strengths and weaknesses) identified by the letters (S) and (W) and external features (i.e., opportunities and threats) identified by letters (O) to (T).

Internal Environment / **External Environment**	**Strengths (S)**	**Weaknesses (W)**
	S_1. Variety of attractions, such as waterfalls, rock formations, paleontological fragments. S_2. Easy access. S_3. Unique and relevant landscape beauty. S_4. Valuable geological heritage.	W_1. Limited promotion and brochures about geosites and geotourism. W_2. Lack of knowledge and disinterest of the population. W_3. Lack of design of routes or circuits with geological information to visit the attractions. W_4. Some attractions are not covered by geosite protection and conservation.
Opportunities (O)	**Strategies: S + O**	**Strategies: W + O**
O_1. Boost the economy of the province. O_2. Creation of routes. O_3. Diverse and flexible tourist alternatives. O_4. Geotourism as a state policy.	$S_1.O_2$. Develop plans focused on promoting attractions through geological routes for tourists. $S_{4.}O_4$. Promote active national cooperation through initiatives that lead to better conservation of natural, cultural, and intangible heritage.	$W_1.O_1$. Generate geotourism promotion projects that serve as an alternative to improve the population's economic conditions and seek to promote integrated tourism. $W_4.O_{4.}$ Pursue scientific studies and research on intervention methods that allow the country to face the dangers that threaten its heritage.
Threats (T)	**Strategies: S + T**	**Strategies: W + T**
T_1. Lack of private economic resources that facilitate the implementation of programs and projects associated with geological tourism. T_2. Environmental degradation. T_3. High-quality demand in tourism services to confront the COVID-19.	$S_1.T_{2.}$ Promote the development of conservation and protection plans for geosites with the community's support to prevent deterioration. $S_3.T_1$. Promote both national and international recognition of assets through cooperation with government entities.	$W_{2.}T_3$. Involve experts in preservation and conservation issues to develop initiatives that prevent deterioration and improve the quality of tourism at geosites. $W_3.T_1$. Use marketing tools appropriately to keep the destination's spirit alive and thereby achieve its development in the tourism market.

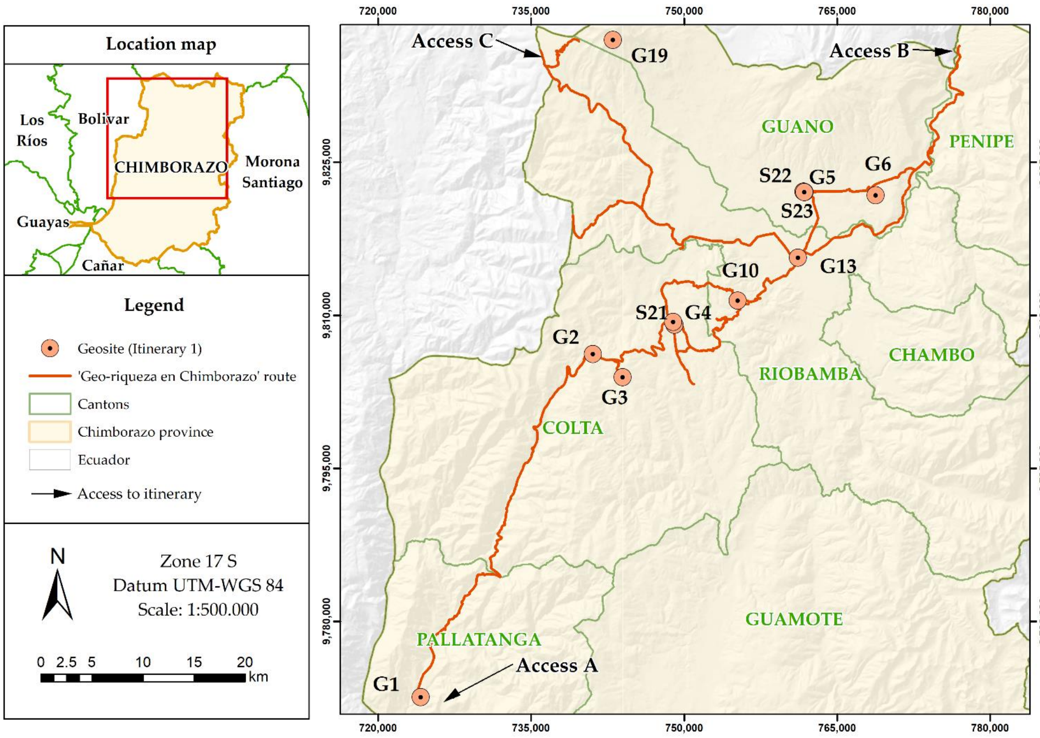

Figure 12. Suggested Itinerary, "Geo-riqueza en Chimborazo", consists of the 12 sites: Falla Pallatanga (G1), Páramo Guacona (G2), Páramo de Navag (G3), Laguna de Colta (G4), Iglesia Balvanera (S21), Comunidad Cacha (G10), Loma de Quito (G13), Mirador Guano (G5), Pozo Chingazo (G6), Museo Guano (S22), Ruinas Monasterio de Asunción (S23), Volcán Chimborazo (G19).

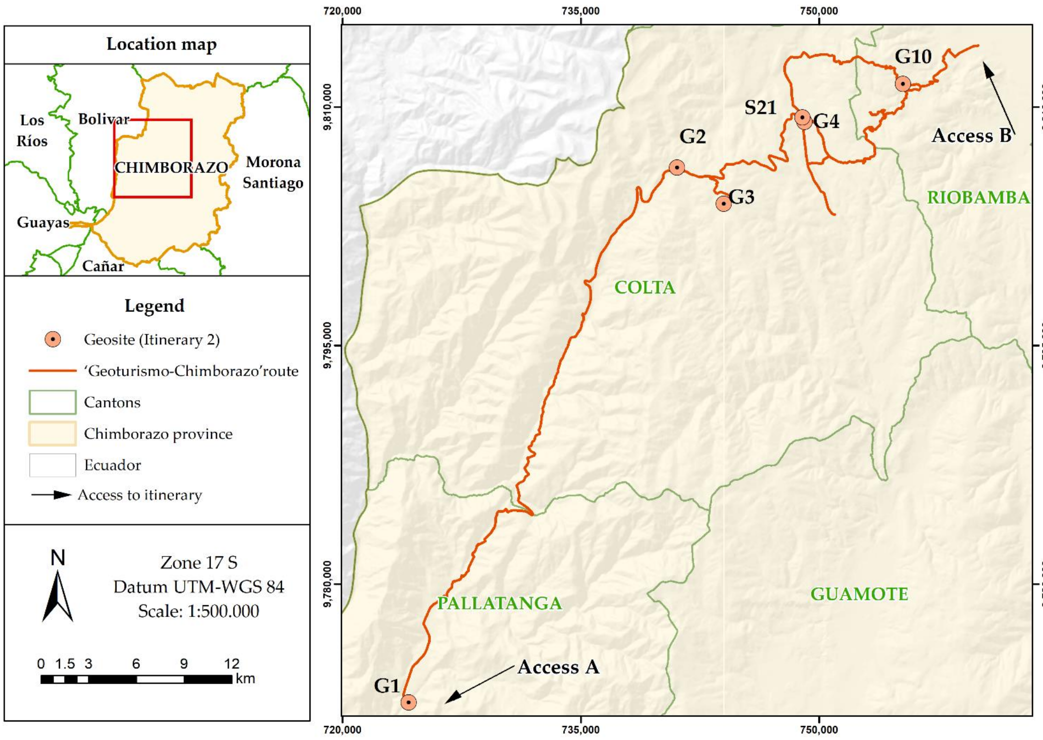

Figure 13. Suggested itinerary 'Geoturismo-Chimborazo' consists of 6 sites: Falla Pallatanga (G1), Páramo Guacona (G2), Páramo de Navag (G3), Laguna de Colta (G4), Iglesia Balvanera (S21), Comunidad Cacha (G10).

5. Interpretation of Results and Discussion

Chimborazo province has geosites of great geological relevance that portray the dynamics of the Andean tectonics. Some examples are the Pallatanga geological fault that has been active for at least 600 ka [66], the volcanoes linked to the oblique convergence of the Nazca plate, to the lower inclination of the subduction zone resulting from the Carnegie Ridge [60], or those located to the south of the prolongation of the Grijalva fracture zone (e.g., El Altar) [80–82]. Globally, these geological characteristics are reflected in the selection of geosites. The sites were evaluated by the IELIG method [19], which proved that they can provide a basis for the development of geotourism in the area. Geosites can promote social development of territories with outstanding geological heritage [30,83].

In general, the existing volcanic geoheritage includes elements that are significant tourist attractions [84]. The diversity of these elements in the province of Chimborazo offers the opportunity to promote volcanology-related geo-education, awareness of geological hazards, as well as understanding the resilience of communities that have experienced the effects of volcanic activity. For example, the characteristic asymmetric shape of the Chimborazo Volcano (it has three peaks Whymper, Politécnica, and Nicolás Martínez) is a testimony of the great collapse of the Late Pleistocene and of the different stages of volcanic eruptions [57]. This collapse produced a debris avalanche, the deposits of which are home to more than 130,000 people today [56]. This geosite is a suitable example to demonstrate the magnitude of volcanic phenomena.

According to the average value of scientific, academic, and tourist interests, 25% of geosites have 'very high' interest and 75% have 'high' interest. In the assessment of scientific interest, the highest weight of the seven parameters considered by the IELIG methodology belongs to representativeness (30%). Seven out of the 20 studied geosites received the maximum score (point: 4) to this parameter, which is proof that they faithfully record the geological characteristics of the territory. One of the most important geosites is the Chimborazo volcano, the highest peak of the Northern Andes [57]. It has been the object of study, mainly in the fields of glacial retreat and volcanic activity, by several eminent geoscientists, such as Humboldt, a German explorer, the father of modern biogeography, who made early descriptions of Chimborazo [85], and influenced other scientists, such as Darwin and Whymper. Numerous scientific articles have been published about this geosite (e.g., [56,57,67,86–88]), and the Chimborazo volcano has the maximum value in scientific interest (Table 4).

In academic assessment, the parameter of educational values receives the highest weight (20%) of the 12 parameters. Regarding educational values, the geosites score between 2 and 4 points, which suggests that teaching materials are already in use or that the site has a potential at some level of the educational system (schools, colleges, universities). Sites such as the Chimborazo volcano, Pallatanga fault, or Paramo Guacona stand out. The landscape is characterized by high Andean moorlands (paramos). Geosites like the Páramo Guacona also have secondary values related to hydrogeology, the environment, or biodiversity, in addition to their evident geomorphological interest. Thus, they provide opportunities to develop educational initiatives related to geological heritage or environmental protection and conservation.

Beauty carries the highest weight (20%) among the 11 parameters of touristic assessment. Pozo Chingazo obtained the lowest score (1 point) to this parameter. The top three geosites regarding touristic interest are Volcán Chimborazo, Dunas Palmira, and Laguna de Colta, all of which are popular tourist destinations that also offer alternative activities, such as hiking, biking, and climbing (Volcán Chimborazo); camping, ecotourism, and photography (Dunas Palmira); or boating, kayaking, birdwatching, cycling, hiking, religious tourism, archaeological tourism, and camping (Laguna de Colta). Additionally, these geosites have good access roads and are associated with natural and cultural heritage elements. One example of this is the Chimborazo volcano where a wildlife reserve is home to endemic species, such as the critically endangered condor or Andean members of the camelid family (vicuñas, llamas, alpacas) besides other wild animals and plants. This site also hosts cultural activities, like the 'Hieleros del Chimborazo' route, which honors the millennium-old tradition of ice mining for culinary purposes, an activity in decline due to the retreat of the glacier.

Most geosites reached high scores in terms of scientific, educational, and tourist interests. Regarding degradation susceptibility and protection priority, however, the geosite with the highest score is the Capas Volcánicas de Chimborazo (G16) (Figure 4, Table 3). This geosite, which presents erosional unconformities and interlayered glacial deposits (Last Glacial Maximum) [57], has been an object of study by the local and international geoscientific community, mostly due to its ease of access, as it is adjacent to the main road (Arenal–San Juan). This condition also makes it exposed to anthropic activities, which increases its vulnerability. The least susceptible geosite is the Laguna de Colta (G4) (Figure S1, Table 3), a site of considerable dimensions, as its length exceeds 2.5 km, and it has an area of approximately 2 km^2. The low susceptibility value suggests that this site is more resistant to anthropic actions probably due to the adequate plans for environmental management and ecotourism implemented here.

The geotourism envisioned for the analyzed geosites would combine landscape, entertainment, adventure, and gastronomy. Applying the biosecurity protocols demanded by the present situation (i.e., the COVID-19 pandemic), these plans could be put into action immediately and directly benefit local people. However, the geosites in the study area have one common threat: climate change. This problem has already caused alterations in one of the emblematic geosites of the area; between 1986 and 2013, the ice cover of the Chimborazo volcano decreased by 21% [86]. The effect of climate change on geosites is one of the ten priority areas of UNESCO's Global Geopark program [89]. The loss of the last Chimborazo glacier, widely known because of the famous case of the last Chimborazo ice maker [87], is one of the cultural consequences of climate change. This example provides an opportunity to raise awareness in visitors and the surrounding community.

From the methodological point of view, semi-quantitative evaluation of geosites [2,19] is a useful approach to establish the bases of future geotourism perspectives in a given territory. One of its advantages is the identification of weak points in the analyzed interests, warranting objectivity in the study. For the obtained results to be more accurate, it is recommended to use a combination of several methods/methodologies [90]. However, the IELIG method [19], a reference method in Ibero-America according to the ASGMI (Ibero-American Association of Geological and Mining Studies), was the only methodology applied here, and it yielded satisfactory results [29].

The IELIG method can be used in a wide range of areas, not only for protected wildlands. It can be applied to biological corridors, cantons, and other cases where geological diversity can be considered a resource, as proven by geological interest point assessment studies in Ecuador [30–34] and in other countries [23,25]. The IELIG method has a special feature within its vulnerability indicators. Unlike other procedures, such as the Brilha method [2], the IELIG establishes a parameter named 'Mining exploitation interest' for the assessment of a factor that presents a threat to geological heritage. This parameter distinguishes sites of mining–metallogenic interest, geological formations that are products or are close to mining operations, sites of mineralogical interest, and sites of mining interest due to their excellent exposure.

The SWOT analysis is a useful tool that complements geosite assessment and seeks to examine the geotourism potential of each geosite. It provides essential information about the applicability and viability of geotourism development. It also prioritizes the necessity to relate all the potential of the area including biodiversity, geodiversity, and culture [4,91,92]. The SWOT analysis has become a basic method to comprehensively examine unstable situations in sustainable development and has been applied in various studies related to geoparks [93–97].

The SWOT analysis contributed to the development of proposals, such as geotourism promotion projects and travel itineraries [30]. It also highlighted the need for provincial, cantonal, and parochial authorities to collaborate with academics and businesses to advance the sustainable development of geosites. Finally, it resulted in the proposal of itineraries providing specific information about the routes (e.g., duration, visit sites, difficulty), their interests (e.g., scientific, academic, and tourist interests of the geosites), and impact (e.g., compatibility with current activities). The itineraries were based on the results of the described geosite assessment and on successful examples of geotourism development initiatives (e.g., [98–100]). They might have a substantial influence on the opportunities of rural sectors.

6. Conclusions

According to the results of the IELIG method applied in this study, 25% of the assessed geosites have 'very high' and 75% have 'high' average interest values taking into account their scientific, academic and tourist interests. The Chimborazo Volcano, known as 'Earth's Closest Point to the Sun', obtained the highest score in the assessment. The DS values demonstrate that those geosites that are located close to infrastructures, such as main roads, or that lack any indirect protection, have high vulnerability values due to anthropic threats. Some geosites require immediate intervention. Moreover, 30% of the 20 geosites reaches a 'high' protection priority level, while the rest falls into the 'medium' protection priority category. Urgent protection measures should be implemented in the first group, but the rest of the sites meet the necessary conditions for geotourism development, such as accessibility and connectivity, other associated recreational activities, tourism facilities and services, and state of conservation. The IELIG method makes it possible to consider environmental-territorial characteristics in the assessment; therefore, it would be equally suitable for the evaluation of other areas in the region. Further studies, however, must be specifically adapted to the methodology of the central administration of the country.

The SWOT analysis shows that one of the greatest strengths of the selected geosites is their outstanding heritage value and their historical and cultural connections, through which they could offer excellent opportunities to foster geotourism and to boost the economy of Chimborazo province and the country. A key strategy involves geotourism promotion projects based on travel itineraries (such as those suggested in this article named 'Geo-riquezas en Chimborazo' and 'Geoturismo-Chimborazo') so that tourists can discover the geosites, their landscape, their culture, and enjoy a unique experience of knowledge, protection, and sustainable development. The two described travel itineraries are practical and feasible proposals that could become real alternatives to stimulate the development of the region while protecting the environment.

In general, the geotourism proposed here (itineraries) represents a sustainable enterprise that is compatible with the current socioeconomic activities (e.g., agriculture, livestock breeding, industry, trading, apiculture, and mining) of the area. Furthermore, these actions can contribute to the improvement of the quality of life of local people.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13094624/s1, Figure S1: One of the most visited geosites in the province of Chimborazo (a) "Colta" lagoon front landscape; (b) side landscape. Figure S2: three main geoforms of the Chimborazo province (a) Volcán Altar; (b) Volcán Carihuairazo; (c) Volcán Chimborazo; Figure S3: Representative geosite of the Chimborazo province (a) lateral part of the "Iglesia Balvanera"; (b) relic of the church; (c) front and striking part of the church.

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