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Assessment of Geomorphosites for Geotourism in the Northern Part of the "Ruta Escondida" (Quito, Ecuador)

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Abstract: The relevant geomorphological characteristics of territory represent an essential part of its natural heritage. They are also an asset to be exploited for stimulating socio-economic development. The "Ruta Escondida" in Ecuador constitutes a historical place full of culture and landscapes that have been shaped over time by geological and geomorphological processes. Among the geomorphological features of the study area, volcanic cones, hilltops, terraces, foothills and glacial valleys stand out. The aims of this work were: (1) to characterize 18 places of geomorphological interest, located in the northern part of the Ruta Escondida and (2) to propose alternatives (geotourism) to contribute to the local development of the area. The applied methodology included: (1) the compilation of geomorphological elements; (2) the assessment of geomorphosites using the Inventario Español de Lugares de Interés Geológico (IELIG) method and (3) a strengths–opportunities–weaknesses–threats analysis of the contribution and influence of geomorphosites in the development of the study area. With this work, it was possible to determine that all the analyzed geomorphological sites have a high and very high interest. The strengths, weaknesses, opportunities, and threats (SWOT) analysis revealed that the geomorphosites could provide significant added value to the development of geotourism on the route, complementing the already known cultural and historical attractions.

Keywords: geomorphological heritage; Ruta Escondida; geomorphosite; geotourism

1. Introduction

Geodiversity, as a concept analogous to biodiversity, was introduced in the early 1990s [1–4]. In recent years, this term became of everyday use in inventory studies, valuation and conservation of geological heritage [5–8]. According to Gray [9], geodiversity can be defined as "the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes) and soil features". It also refers to the assemblage of these features, their relationships, properties, interpretations, and systems. Geodiversity can also be considered as the basis of the increasing biological diversity existing in a territory [10,11]. Elements of geodiversity depend on and are directly exposed to human activities, with the consequent danger of their degradation. Thus, geodiversity assessment actions of recent years have been aiming to accumulate data that allow estimating its evolution. The assessment of geodiversity is carried out through both qualitative [9,12–15] and quantitative [10,16–24] assessment methods. These procedures make it possible to propose conservation plans (e.g., geoparks), to identify areas of interest (e.g., geological heritage) and to regulate their sustainable use (e.g., geotourism) [8,25,26].

According to Brilha [15], geological heritage is defined as geodiversity elements that have a unique scientific value. Geoheritage includes landforms, geomorphological, mining and glacial features [27]. The geomorphological heritage is part of the natural heritage of territorial and landscape relevance [28]. Figure 1 explains and correlates geodiversity and related concepts in a simplified framework [15].

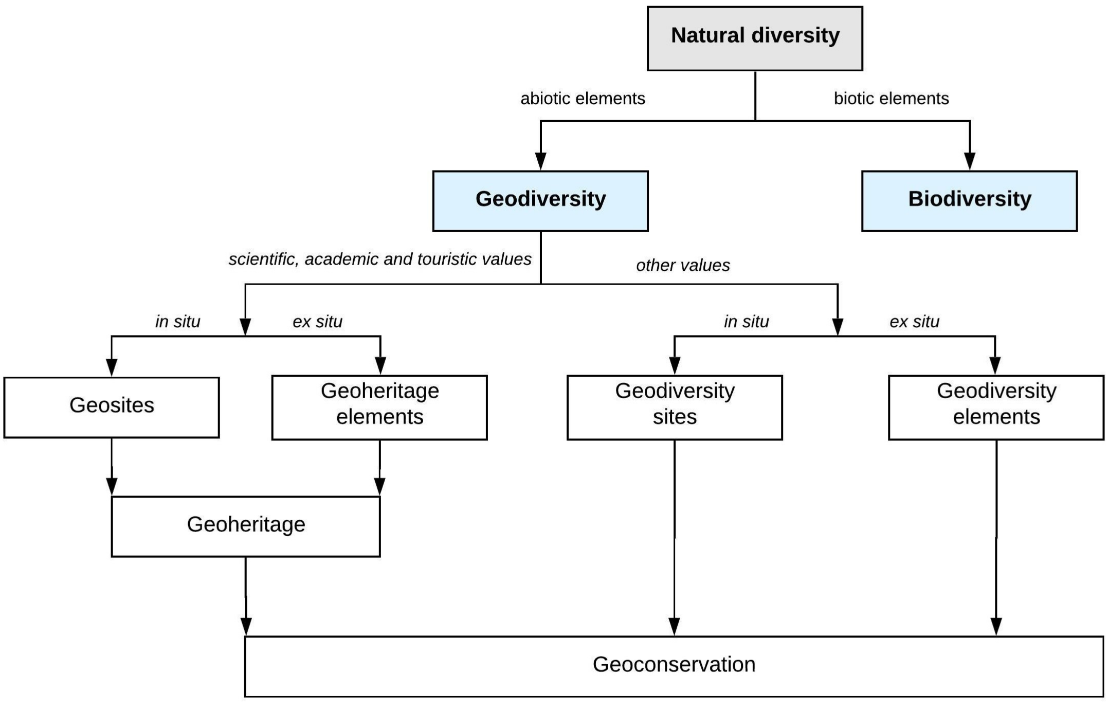

Figure 1. Conceptual framework of geodiversity, geological heritage and geoconservation. Modified from [15].

Different methods have been established that allow the assessment of geomorphological heritage. These methods also enable the promotion of geomorphosites and their protection against the effect of anthropic activity [29]. Geomorphological heritage is a territorial resource that forms part of the geological heritage of a territory, therefore, its study supports sustainable development. It also has significant value regarding the landscape [30].

Geosites are sites with geological and geomorphological interest that determine geological heritage and promote its conservation. These places are mainly located in rural areas, outdoors, although they are also found in urban environments [31]. Geomorphosites are places with a specific relief or geomorphological resource, considered as vestiges of dynamic processes in the history of the Earth, to which landscape, scientific, cultural and socio-economic value can be attributed, and are useful for the community [32–35]. Geosites are considered unique elements or vast, vulnerable panoramas that must be protected by a legal framework [36], focused on conservation, education and sustainable development [37].

According to Reynard and Paniza [36], geomorphosites are particularly susceptible to the lack of protection measures, and four types of actions can be taken to reduce their vulnerability: (1) to improve assessment methods that allow the objective selection of sites of high interest; (2) to enhance public awareness of the geomorphological value of the territory through education; (3) to promote management structures, such as geoparks; (4) to improve the legal basis for protection, which can be enforced either through property rights or using a public policy [36].

The conservation of geosites must be based on their audit, assessment and the definition of the need for specific actions [38]. More globally, geoconservation focuses on the management of geological components of scientific, touristic and cultural importance within a responsible social context [39,40]. Adequate management helps to protect the geological heritage adequately [41]. Furthermore, scientific understanding by the community is essential to implement conservation strategies [42].

Geotourism is a form of natural tourism that focuses explicitly on geology and landscape. It promotes tourism to geosites and the conservation of geodiversity and an understanding of earth sciences through appreciation and learning [43]. This is achieved through independent visits to geological features, use of geo-trails and viewpoints, guided tours, geo-activities and patronage of geosite visitor centers [44]. Geotourism is an activity that focuses on the proper organization and management of geosites and on the generation of environmental, community and economic benefits [44].

The study region is the northern part of the Ruta Escondida, located on the north of the province of Pichincha (Ecuador). It is situated in an area with an outstanding geomorphological character. The geomorphological features of the territory are derived mainly from volcanic activity (e.g., lahars, lava flows, volcanic craters, columnar disjunction) and, also, from processes related to glaciation (e.g., cirques, moraines, glacial valleys). All of these features are typical results of the geological and geomorphological evolutions of the Ecuadorian Andes [45], which is a country with a rich and recognized geodiversity [46].

Despite the singularities of the landforms and the efforts of regional and local authorities, the geotourism impact of these places is limited. The main reason could be the absence of a strategic plan that includes the inventory, characterization and promotion of the morphological peculiarities of the territory.

The main aims of this study are (1) to characterize the geomorphological places of interest in the area through a semi-quantitative assessment by the Inventario Español de Lugares de Interés Geológico (IELIG) method and (2) to apply a strengths, weaknesses, opportunities, and threats (SWOT) matrix analysis that allows defining the influence of the inclusion of geomorphosites as a resource of the Ruta Escondida. Based on the characterization and assessment, strategies are proposed to facilitate the implementation of geotouristic activities as a basis for local development.

2. Geographical and Geological Setting

The study area is located within the Ruta Escondida, in the province of Pichincha, in the north of Ecuador (Figure 2a). The zone is bordered by the Imbabura province to the north, by Quito city to the south and west, and by Pedro Moncayo city to the east [47] (Figure 2b). The Ruta Escondida consists of five parishes: Atahualpa, Chavezpamba, Perucho, Puéllaro and San José de Minas that belong to the Quito canton (Figure 2b) and occupies an area of approximately 467 km^2 [48]. The altitude of the site is between 1537 and 3500 meters above sea level and temperature ranges between 16 and 30 °C [49,50]. This work covers the Atahualpa and San Jose de Minas parishes (Figure 2) explicitly.

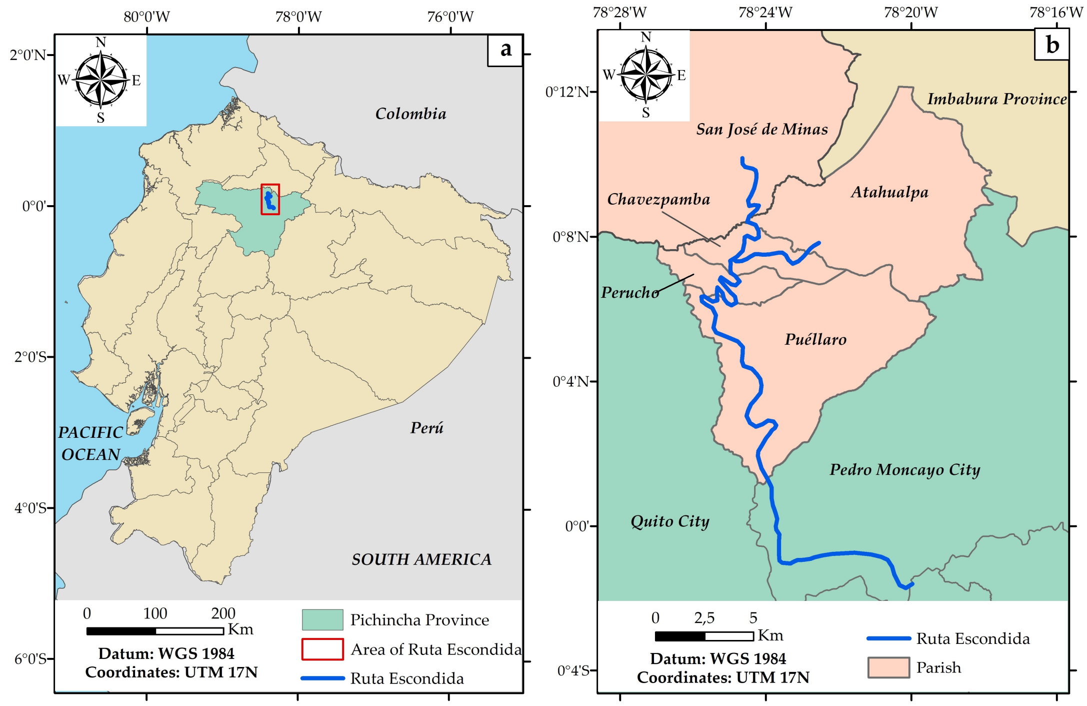

Figure 2. Location of the study area (**a**) general context; (**b**) local context.

At a regional level, the Ecuadorian Andes is part of a volcanic arc generated by the subduction that occurs between the Nazca plate and the continental lithosphere of South America in Miocene. In general, three main groups are distinguished in the Ecuadorian Andes: (i) frontal arc (western Cordillera), (ii) main arc (eastern Cordillera) and (iii) back arc (Oriente) [51,52]. Approximately 50 volcanoes, located in an area of an approximate length of 300 km from N–S and a width of 100–120 km from E–W, constitute the volcanic arc in front of Carnegie Ridge [53].

The volcanic complex consisting of the Mojanda and Fuya Fuya volcanoes is located 50 km NNE of Quito, in the Interandean valley (depression between the eastern and western Cordilleras that originates from the Miocene). The distance between the volcanoes is 3 km [54]. The formation of the Mojanda volcano began approximately 0.6 Ma ago and ended 0.18–0.20 Ma [55] or 0.165 Ma [56] ago. The formation of the Fuya Fuya volcano occurred less than 0.5 Ma ago, and continued until the Maximum Glaciation [57], and even until the Holocene [58].

Mojanda consists of two cones (Lower Mojanda and Upper Mojanda), located southwest of Cushnirumi Peak (the oldest dissected volcano). The Lower Mojanda is a basal cone of 16 × 18 km, in which an ancient caldera (Caldera 1) of 5 km wide is evidenced, which separates this structure from Upper Mojanda. Lower Mojanda consists mainly of andesitic lavas with a high content of silica and two-pyroxene andesites (Unit M-I-1). Lava flows of amphibole-bearing dacite (Unit M-I-2) can also be found [53,58] (Figure 3).

Upper Mojanda began to form with basaltic to high-silica andesite lava flows (M-II-1), followed by pyroclastic flows of basaltic andesite (ash-and-slag flows, M-II-2) and andesite block-and-ash flows (Unit M-II-3). After the phase of volcanic activity, the slopes were covered by a stratified sequence of breccias of approximately 300 m thickness, with a basaltic andesite composition, interlayered with lavas and fallout deposits (Unit M-II-4). Finally, the slopes of Mojanda are covered by a sequence of ash and lapilli layers (Unit M-II-5), which underlie a Pifo ash-fall layer, product of the partial destruction of the cone and the formation of the caldera (Caldera 2) [53,58] (Figure 3).

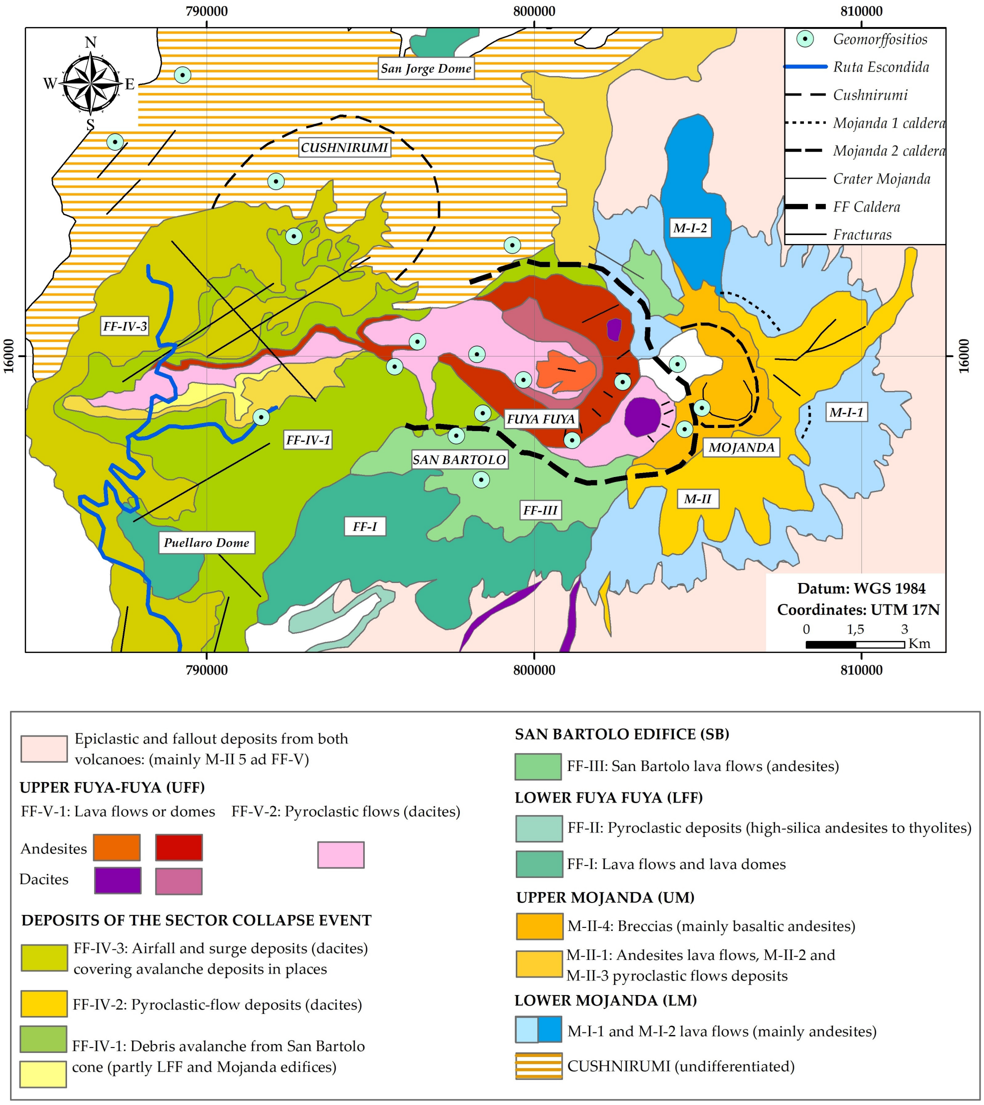

Figure 3. Geological map of the Mojanda–Fuya Fuya volcanic complex. Based on [53].

Fuya Fuya consists of three volcanic cones: Lower Fuya Fuya, San Bartolo and Upper Fuya Fuya. The Lower Fuya Fuya is constituted of high-silica andesitic to dacitic domes, with high silica content and coarse lavas (FF-I Unit). Based on petrologic data, two eroded eccentric domes—the Puellaro and San Jorge–are associated with the FF-I unit. Ash deposits and blocks are found to the SSW of the volcano; these form the FF-II unit [53,58] (Figure 3).

The San Bartolo cone is the second construction phase of the volcano and is composed of andesitic lavas (FF-III Unit). A major collapse in the sector caused a debris avalanche (FF-IV-1 Unit) from the San Bartolo cone, which flowed westward reaching a depth of approximately 100 m. The debris avalanche was accompanied by dacitic ash flows with pumice blocks (FF-IV-2 Unit), which expanded to the west, with a thickness of 50 m. Finally, the collapse of the San Bartolo cone ended with the emission of a sequence of pumice-lapilli fall layers interspersed with pyroclastic deposits (FF-IV-3 Unit), with thicknesses of approximately 20 m [53,58] (Figure 3).

Upper Fuya Fuya consists of two series of thick, glacially eroded, lavas and domes (FF-V-1 Unit). The lava series consists of hornblende dacite, while the domes contain andesite and dacite. Then, block-and-ash flows and pyroclastic flows were directed towards the west and south, while numerous fall deposits were deposited in the upper part of the volcanic complex (FF-V-2). Finally, three central lavas and the Colangal and Panecillo domes represent the last extrusions of the Fuya Fuya (FF-V-3).

In these lavas and domes, no glacial erosion is evidenced, based on which Holocene age was established for their formation [53,58] (Figure 3).

In Ecuador, according to Clapperton [59] and Schubert and Clapperton [60], the limit of glaciation is 3000 to 3600 m. The moraines have been dated between 33,000 and 43,000 BP, associated with the last ice age. However, volcanic activity makes observations on glacial deposits difficult [61]. Some geoforms present in the study area are considered products of the mini-glaciation or "little ice age", which occurred in the 14th and 19th centuries [62–64], the same one that could have shaped the terrain on the volcanic formations.

3. Materials and Methods

The procedure described in the present study comprised three phases: (i) compilation of the geomorphological element register, (ii) assessment of geomorphosites and (iii) preparation of the SWOT analysis matrix (Figure 4).

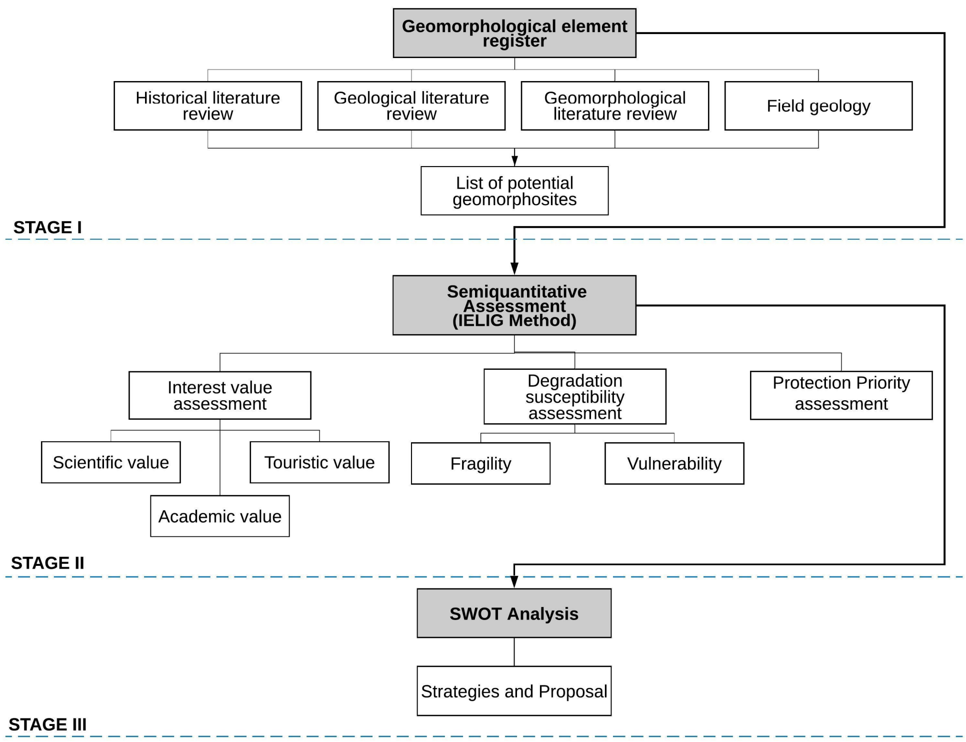

Figure 4. The general methodology of the study.

3.1. Geomorphological Element Register

In this first phase, existing information was reviewed and processed. Specifically, we compiled thematic cartography and preliminary studies developed in the area [48–50,65,66], together with the existing geological data, to select a potential site list to be considered as geomorphosites. In addition, base thematic mapping (geographic and geological) was carried out for the selected geomorphosite candidates.

3.2. Geomorphosite Assessment

This phase focused on the assessment of the scientific, didactic and tourist interest of the geomorphosites, through the application of the IELIG methodology (acronym in Spanish for "Inventario Español de Lugares de Interés Geológico") [14]. This method identifies sites of geological interest based on the assessment of a wide range of parameters, giving criteria scores between 0 and 4, where 0 is the lowest, and four is the highest [14]. These parameters are grouped into four sections: (i) values of interest (scientific (Sc), academic (Ac) and tourist or recreational (To)) (Table 1), (ii) fragility (Fr), (iii) vulnerability (Vul) and (iv) protection priority (Pp). Pp is determined from the degradation susceptibility (DS) calculation based on Fr and Vul produced by external threats (Table 2). This parameter complements the total interest values [14]. According to García et al. [14], the value of Pp on the different axes (i.e., scientific Pp (Sc), academic Pp (Ac) and tourist Pp (To)) is obtained by multiplying the square of the value of their interest with the area susceptibility degree (DS) and divided by 400^2 to keep the same scale. Finally, the global priority Pp value is based on the average of the scores of interest multiplied by the degree of susceptibility (DS) and by $(1/(400)^2)$ as detailed in Table 3.

Table 1. Criteria and indicators used for the quantitative assessment of geosites using the IELIG methodology (acronym in Spanish for "Inventario Español de Lugares de Interés Geológico"). Weight (constant values in %) for the value of interest: scientific (Sc), academic (Ac) and Tourist (To). Interpretation: maximum (400), very high (267–400), high (134–266), medium (50–134), low (<50) [14].

Geosite Assessment Model (IELIG)				
Parameters / Indicators	Values	Weight		
		Sc	Ac	To
Representativeness	0–4	30	5	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 situation		0	0	10
Total		100	100	100

Table 2. Susceptibility assessment of the geosites and mining sites. Fragility (Fr), vulnerability (Vul), degradation susceptibility (DS) [14].

	Susceptibility	
Parameter/Characteristics	**Fr**	
	Value	**Weight**
Geosite size	0–4	40
Vulnerability to looting		30
Natural hazards		30
Total Value		100
Parameter/Characteristics	**Vul**	
	Value	**Weight**
Proximity to infrastructures	0–4	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 Value		100
	DS	
DS: (Fr × Vul)/400	(>400) Maximum (400–200) Very high (199–68) High (67–13) Medium (<13) Low	

Table 3. Protection priority (Pp) assessment of geosites and mining sites, based on the priority of protection of the scientific value Pp (Sc), academic Pp (Ac) and tourist Pp (To) [14].

PROTECTION	
$\text{Pp (Sc)} = (\text{ISc})^2) \times \text{DS} \times (1/400^2)$ Ec. 1 $\text{Pp (Ac)} = (\text{IAc})^2 \times \text{DS} \times (1/400^2)$ Ec. 2 $\text{Pp (To)} = (\text{ITo})^2 \times \text{SD} \times (1/400^2)$ Ec. 3	
$\text{Pp} = (\frac{\text{ISc} + \text{IAc} + \text{ITo}}{3})^2 \times \text{DS} \times (1/(400)^2)$ Ec. 4	(>400) Maximum (400–113) Very high (113–17) High (16–1) Medium (0) Low

3.3. SWOT Analysis Matrix and Proposal for Geotourism

A strengths, weaknesses, opportunities, and threats (SWOT) analysis [67] was conducted taking into account the list of assessed sites of geological interest. This analysis made it possible to determine the potential that geomorphosites present for the development of geotourism. The analysis was carried out with the participation of members of the academy, the public sector, and the private sector, all of them with interest and knowledge of the topic. The aim was to define strategies that optimize geotourism in the Ruta Escondida.

4. Results

4.1. Geomorphological Element Register

Based on the information collected from 36 places of geomorphological interest [65], the north of the Ruta Escondida was decided upon as the target area. Specifically, 18 sites with great geomorphological interest were studied (Figure 5). The selected geomorphosites have unique geomorphological characteristics that were determined from a general description. Two of the evaluated sites (15 and 16) are located outside the province of Pichincha. Table 4 shows the selected places and a brief description of their main characteristics. In Figure 6, six of the identified geomorphosites are presented outlining their outstanding morphological features. This register is the starting point of the evaluation of scientific, academic and tourist potential.

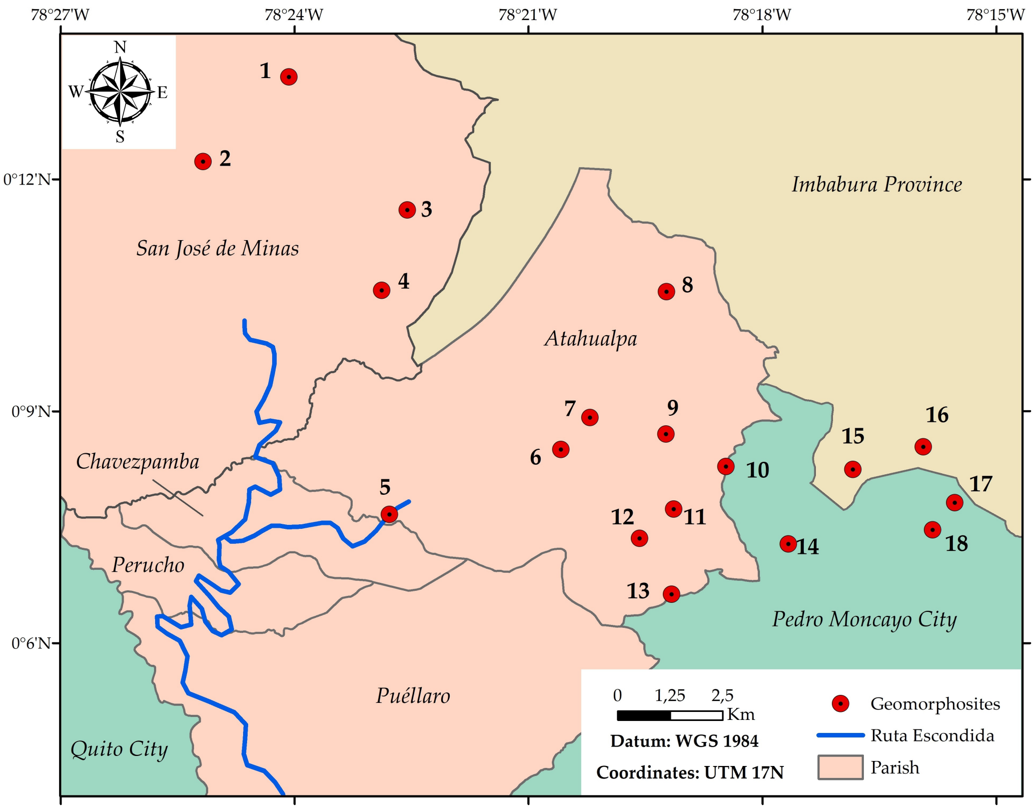

Figure 5. Location of potential geomorphosites: (1) Cimas San José de Minas (peaks), (2) Relieves de Chavezpamba y San José de Minas (mountainous relief), (3) Relieve de San José de Minas (volcanic relief), (4) Piedemonte San José de Minas (foothills), (5) Valle Atahualpa (valley), (6) Coluviones de Atahualpa (colluviums), (7) Domo Atahualpa (dome), (8) Cima de Atahualpa (peak), (9) Terrazas de Atahualpa (hanging terraces), (10) Domo El Panecillo (dome), (11) Pendiente Fuya Fuya (spreading slope), (12) Flujos de Atahualpa (lahar flows), (13) Relieve de Atahualpa (volcanic relief), (14) Valle de San Bartolo–Fuya Fuya (glacial valley), (15) Montículos Fuya Fuya (moraines), (16) Laguna de Mojanda (lagoon), (17) Macizo Mojanda (rock massif) y (18) Flujos Mojanda (flows).

Table 4. List of potential geomorphosites in the study area, typological classification and general characteristics.

N°	Geomorphosite	Type	Main Characteristics
1	Cimas de San José de Minas	Sharp peaks	These geomorphosites have slopes between 70 and 100%, located in the Atahualpa and San José de Minas sectors.
2	Relieves de Chavezpamba y San José de Minas	Mountainous relief	Most of the area presents geoforms with sharp and rounded peaks, slopes between the range 12–25% in the sectors of Puéllaro and Perucho and 70–100% in Atahualpa and San José de Minas.
3	Relieve de San José de Minas	Volcanic relief	Reliefs, product of the volcanism of the area, are found on the slopes of Mojanda and Fuya Fuya.
4	Piedemonte San José de Minas	Foothills	Plain located next to the volcanic Cushnirumi, consisting of colluvial alluvial material and deposits of the Fuya Fuya.
5	Valle Atahualpa	Valley	Valley of sand, gravel and blocks of variable composition, located in the Atahualpa and San José de Minas sectors.
6	Coluviones de Atahualpa	Colluvium	Geoforms of sand with blocks of one meter in diameter are found throughout the study area.
7	Domo Atahualpa	Volcanic dome	Small dome located in the Atahualpa forest, composed of lava with a high content of silica.
8	Cima de Atahualpa	Peaks	Peaks in the Atahualpa sector with slopes between 60 and 80% and some similarity to those of San José de Minas.
9	Terrazas de Atahualpa	Hanging terrace	Morphological unit of tectonic origin, with slopes between 2 and 12%, constituted of andesitic tuffs, covered with deposits from the Fuya Fuya.
10	Domo El Panecillo	Volcanic dome	Dome constituted of andesitic and dacitic lava flows, on its southwest side evidence of the collapse can be seen.
11	Pendiente Fuya Fuya	Volcanic spreading slope	A steep slope of tectonic origin, through which avalanche flows descended from the Fuya Fuya volcano.
12	Flujos de Atahualpa	Lahar flow	Pyroclasts from the Fuya Fuya volcano are found throughout the route, except in Perucho parish.
13	Relieve de Atahualpa	Volcanic relief	Volcanic reliefs similar to those present in San José de Minas. In the lower part they present rounded shapes, as a product of erosion.
14	Valle de San Bartolo–Fuya Fuya	Glacial valley	U-shaped valley consists of Mojanda glacial deposits. The valley is constituted of the San Bartolo cone and the Fuya Fuya domes.
15	Montículos Fuya Fuya	Glacial moraines	Small rounded hill, constituted of heterogeneous and sub-rounded material, as a product of the advance of the ice, which is located next to the Laguna Mojanda.
16	Laguna de Mojanda	Lagoon	The lagoon is in the caldera of the Mojanda volcano, on top of basaltic andesites and sediments interspersed with volcanic ash.
17	Macizo Mojanda	Rock massif	Rocky massif constituted of andesitic lavas from the Mojanda volcanic complex.
18	Flujos Mojanda	Flows	Flows situated under the rocky massifs, in areas with intense erosion.

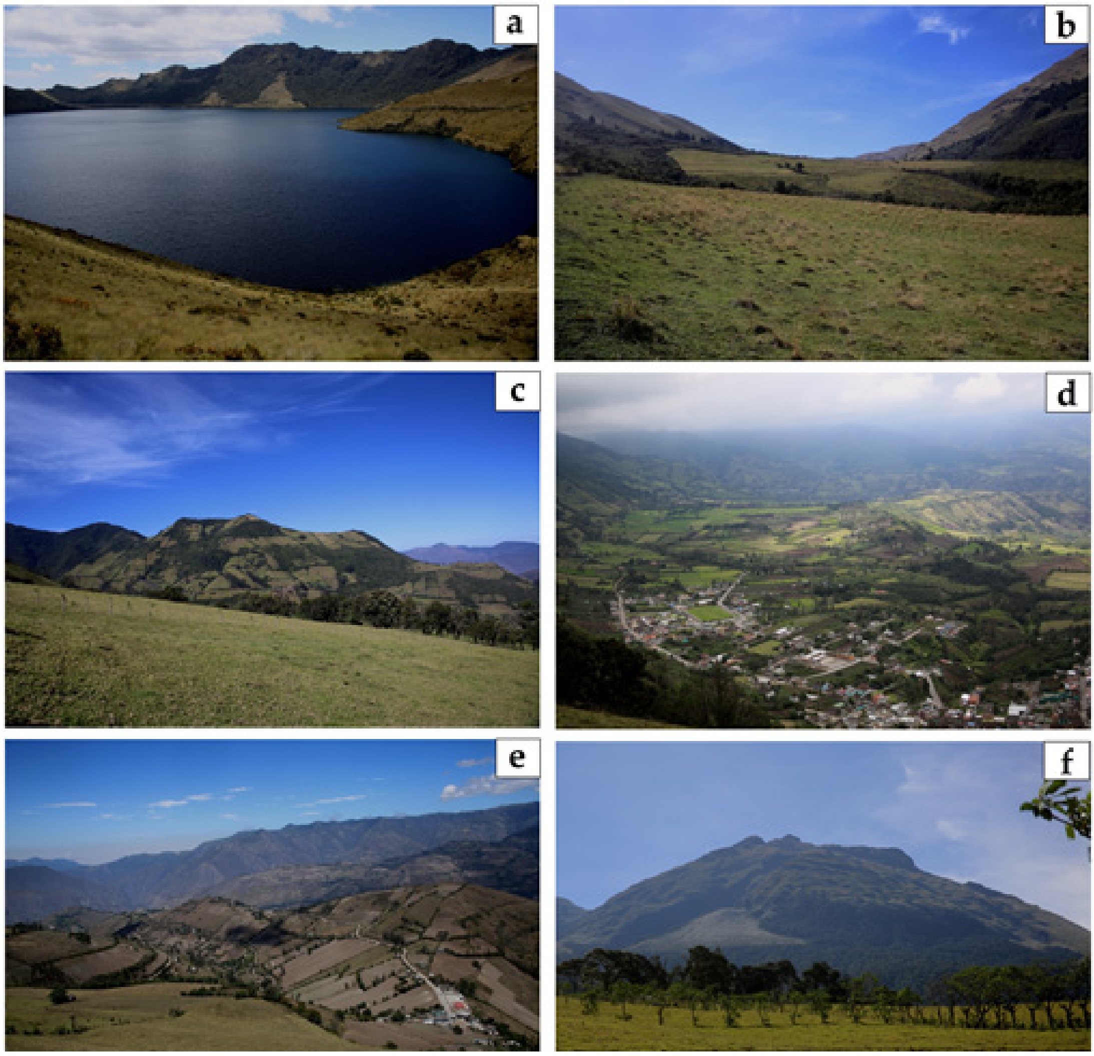

Figure 6. Examples of geomorphosites in the study area: (**a**) Laguna de Mojanda, (**b**) Valle de San Bartolo–Fuya Fuya, (**c**) Cima de Atahualpa, (**d**) Piedemonte San José de Minas, (**e**) Cimas de San José de Minas, (**f**) Domo Atahualpa [65].

4.2. Geomorphosite Assessment

The global results obtained from the average values of the interest types (Sc, Ac and To) of the 18 points evaluated by the IELIG method are presented in Table 5. The average interest (Sc + Ac + To/3) calculated for each one of the geomorphosites shows that the maximum value (267/400, Table 5) corresponds to the Mojanda lagoon (Figure 6a) and the Panecillo dome. The minimum value (97/400, Table 5) corresponds to Atahualpa ancient colluviums. In general, 5.56% of geomorphosites have very high interest, 33% high interest and 61.11% medium interest (Figure 7).

Table 5. Scores of the scientific (Sc), didactic (Ac) and tourist (To) interests of the geomorphosites.

N°	Geomorphosite	Interests			Average Interest (AI)
		Sc	Ac	To	
1	Cimas de San José de Minas	145	115	135	132
2	Relieves de Chavezpamba y San José de Minas	100	95	135	110
3	Relieve de San José de Minas	110	115	160	128
4	Piedemonte San José de Minas	75	110	150	112
5	Valle Atahualpa	240	160	125	175
6	Coluviones de Atahualpa	120	65	105	97
7	Domo Atahualpa	135	105	170	137
8	Cima de Atahualpa	130	130	145	135
9	Terrazas de Atahualpa	90	80	140	103
10	Domo El Panecillo	240	175	190	267
11	Pendiente Fuya Fuya	120	115	160	132
12	Flujos de Atahualpa	110	80	105	130
13	Relieve de Atahualpa	115	110	112	113
14	Valle de San Bartolo—Fuya Fuya	130	110	150	130
15	Montículos Fuya Fuya	105	85	120	103
16	Laguna de Mojanda	325	250	225	267
17	Macizo Mojanda	225	145	195	188
18	Flujos Mojanda	175	160	190	175

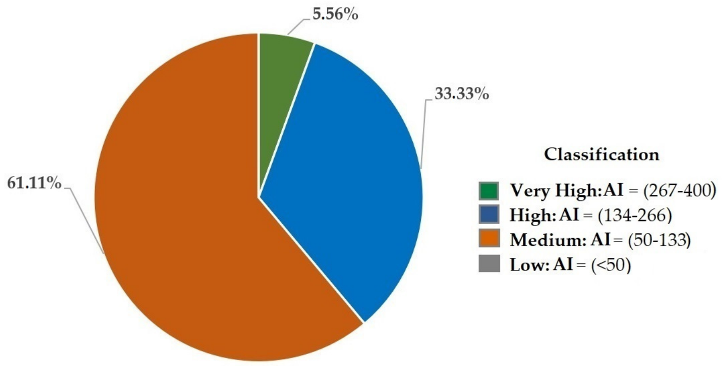

Figure 7. Classification of the results obtained from the AI of the geomorphosites.

The obtained susceptibility results of the 18 sites, based on their fragility and vulnerability, are presented in Table 6. The results reflect that 72.22% of the sites have low susceptibility to degradation with a minimum value of 0/400. The remaining 27.78% have medium susceptibility with maximum values of 36.25/400 (Table 6 and Figure 8).

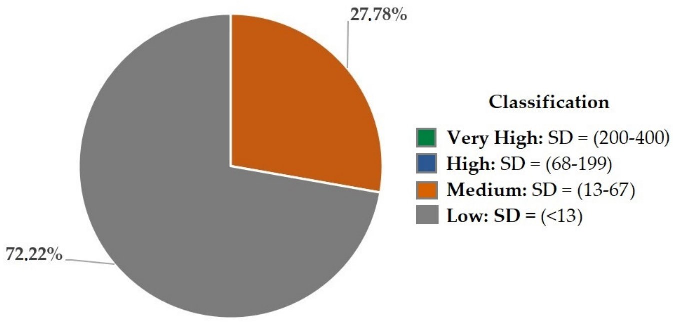

Figure 8. Classification of the obtained results of susceptibility to degradation (SD) of the geomorphosites.

Table 6. Assessment results of the susceptibility to degradation (SD), fragility (F) and vulnerability (Vul.) due to anthropic threats.

N°	Geomorphosite	Susceptibility		
		F	Vul	SD
1	Cimas de San José de Minas	0	25	0
2	Relieves de Chavezpamba y San José de Minas	30	80	6
3	Relieve de San José de Minas	110	100	27.50
4	Piedemonte San José de Minas	100	145	36.25
5	Valle Atahualpa	70	140	24.50
6	Coluviones de Atahualpa	100	100	25
7	Domo Atahualpa	0	25	0
8	Cima de Atahualpa	0	25	0
9	Terrazas de Atahualpa	0	70	0
10	Domo El Panecillo	0	115	0
11	Pendiente Fuya Fuya	0	80	0
12	Flujos de Atahualpa	80	160	32
13	Relieve de Atahualpa	40	80	8
14	Valle de San Bartolo—Fuya Fuya	0	55	0
15	Montículos Fuya Fuya	80	25	5
16	Laguna de Mojanda	0	70	0
17	Macizo Mojanda	0	55	0
18	Flujos Mojanda	0	85	0

According to the results of the degree of interest and susceptibility to degradation, 72% of the sites have a low protection priority value (0–0.64/400), while the remaining 28% present medium PP (1.46–4.69/400) (Table 7 and Figure 9).

Table 7. Results of the protection priority (PP) assessment.

N°	Geomorphosite	Protection Priority			
		PP (Sc)	PP (Ac)	PP (To)	PP
1	Cimas de San José de Minas	0	0	0	0
2	Relieves de Chavezpamba y San José de Minas	0.38	0.34	0.68	0.45
3	Relieve de San José de Minas	2.08	2.27	4.40	2.83
4	Piedemonte San José de Minas	1.27	2.74	5.1	2.83
5	Valle Atahualpa	8.82	3.92	2.39	4.69
6	Coluviones de Atahualpa	2.25	0.66	1.72	1.46
7	Domo Atahualpa	0	0	0	0
8	Cima de Atahualpa	0	0	0	0
9	Terrazas de Atahualpa	0	0	0	0
10	Domo El Panecillo	0	0	0	0
11	Pendiente Fuya Fuya	0	0	0	0
12	Flujos de Atahualpa	2.42	1.28	2.21	1.93
13	Relieve de Atahualpa	0.66	0.61	0.66	0.64
14	Valle de San Bartolo–Fuya Fuya	0	0	0	0
15	Montículos Fuya Fuya	0.34	0.23	0.45	0.33
16	Laguna de Mojanda	0	0	0	0
17	Macizo Mojanda	0	0	0	0
18	Flujos Mojanda	0	0	0	0

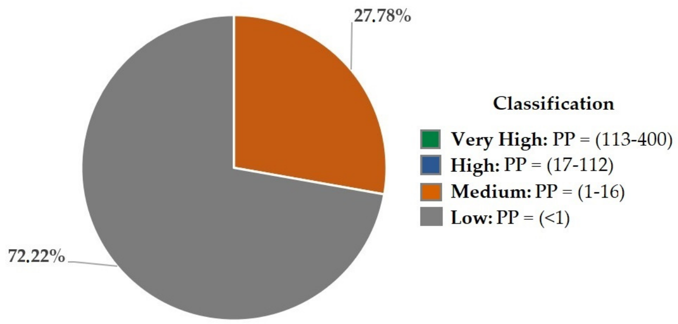

Figure 9. Classification of the results obtained from the protection priority (PP) assessment of the geomorphosites.

4.3. SWOT Analysis Matrix

The SWOT analysis of the geomorphosites made it possible to identify the main strengths, opportunities, weaknesses and threats in the study area, in order to generate strategies by combining internal (strengths and weaknesses) and external (opportunities and threats) characteristics, as summarized in Table 8.

Table 8. Strengths, weaknesses, opportunities, and threats (SWOT) matrix analysis of geomorphosites in the Ruta Escondida. The SWOT combining internal environment (strengths and weaknesses) identified by numbers 1 to 7 and the external environment (opportunities and threats) identified by letters (a) to (e).

External Environment / **Internal Environment**	Strengths	Weaknesses
	1. Large number of geomorphosites. 2. Existence of scientific research on the Ruta Escondida (geological, archaeological and paleoecological). 3. Presence of natural and cultural landscape. 4. Variety of climatic levels. 5. Some erosive processes (natural erosion) reveal geological structures for observation, increasing educational and research interest. 6. Proximity to populated areas and the capital of the country. 7. Second-order road infrastructure in good condition.	1. Geomorphosite assessment scarcity. 2. Geoforms exposed to erosion (anthropic). 3. Lack of knowledge of natural potential. 4. Low development of geotourism in the country. 5. Lack of geomorphosite conservation. 6. Third-order roads with low maintenance.
Opportunities	**Strategies: Strengths + Opportunities**	**Strategies: Weaknesses + Opportunities**
a. Geomorphosite promotion to increase the local economy. b. Conservation of culture and traditions. c. Creation of training programs in the area. d. Interest of the provincial, municipal and parochial government to enhance natural and cultural resources. e. Academic research interest in the area.	1-a. Promote geomorphosites that illustrate the importance of the natural environment of the region. 2-e. Strengthen links between rural communities and academia for future research in different scientific areas. 3-d. Promote natural resources by each parish government to publicize geological resources. 5-c. Build awareness in the community about geomorphosites and their importance in the geotourism sector. 6-d. Access to places in good condition, which favors geotourism development.	1-a. Assess geological elements in the scientific, educational and tourist fields for their promotion to the community. 2-c. Train local community about protection measures that geomorphosites need due to anthropic activity. 3-c. Provide training on the preservation and importance of the resources that nature offers. 4-c. Promote geotourism development nationwide through documentaries. 6-d. Monitor access roads to geomorphosites to ensure geotourism.
Threats	**Strategies: Strengths-Threats**	**Strategies: Weaknesses-Threats**
a. Global economic crisis and health emergency, which will prevent the allocation of resources for further research and tourism promotion. b. Aggressive climate changes. c. Low financing in projects of scientific interest.	2-c. Scientific development of research institutions through funding from public and private organizations. 3-b. Implementation of protection measures for geological and cultural heritage.	1-c. Implementation of programs that cultivate funds aimed at the assessment of the geological elements. 3-a. Documentaries about geological resources.

4.4. Proposed Itinerary to Visit Geomorphosites

Based on the described data, we propose the development of a specific itinerary of the geomorphosites in the Ruta Escondida called "Rocks & Water in Ruta Escondida" (Figure 10).

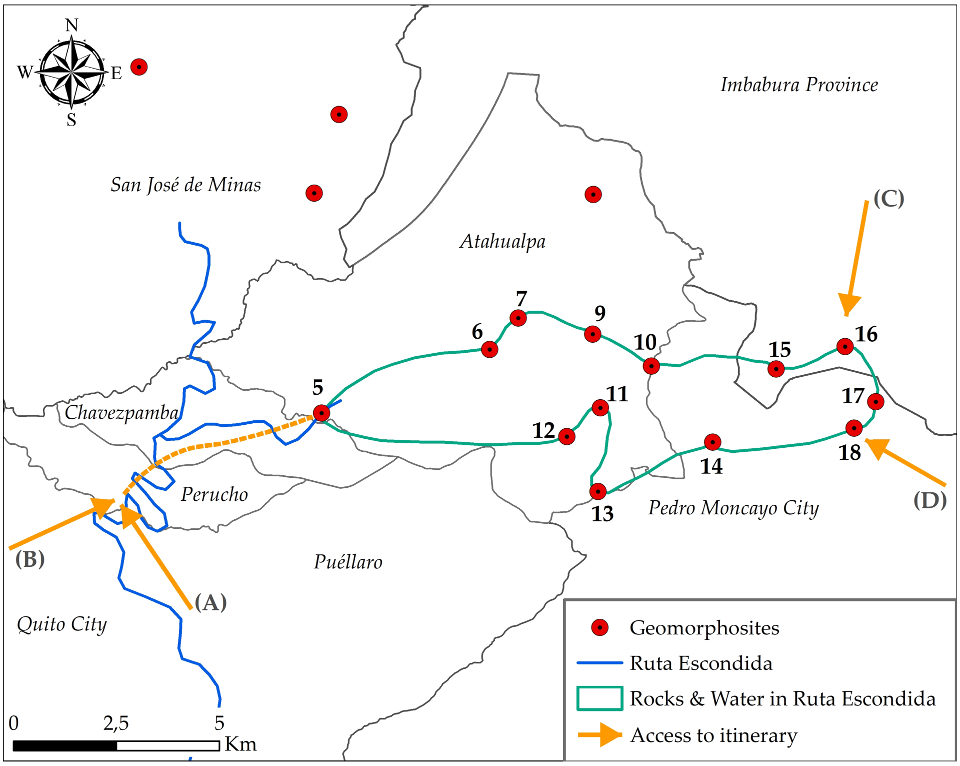

Figure 10. Suggested itinerary "Rocks & Water in Ruta Escondida", selecting several geomorphosites. Geomorphosites: (5) Valle Atahualpa (valley), (6) Coluviones antiguos de Atahualpa (colluvium), (7) Domo Atahualpa (volcanic dome), (9) Terrazas de Atahualpa (hanging terrace), (10) Domo El Panecillo (Volcanic dome), (11) Pendiente Fuya Fuya (volcanic spreading slope), (12) Flujos de Atahualpa (lahar flow), (13) Relieve de Atahualpa (volcanic relief), (14) Valle de San Bartolo–Fuya Fuya (glacial valley), (15) Montículos Fuya Fuya (glacial moraines), (16) Laguna de Mojanda (lagoon), (17) Macizo Mojanda (rock massif) y (18) Flujos Mojanda (Mojanda flows). Access to the itinerary: (**A**) access from Quito city, (**B**) access from Puéllaro parish, (**C**) access from Imbabura UNESCO (United Nations Educational, Scientific and Cultural Organization) Global Geopark, (**D**) access from Pedro Moncayo city.

The proposed itinerary is one example among several potential alternatives considering the sites inventoried in this study. The route matches the following criteria: (i) accessibility to every selected geomorphosite with a motor vehicle/walking; (ii) pleasant and attractive tour with reasonably short distances between sites of interest. Four possible accesses are proposed to the route (Figure 9) that allow visiting the geomorphosites and also integrate cultural attractions and biodiversity features.

Access A is an example of a touristic tour. The tour begins with a visit to Quito city, then continues to the Perucho parish, followed by the Chavezpamba parish, to end with the Atahualpa parish and part of Pedro Moncayo city. Through these places, the tourist can visit different geomorphosites, including specific sites with natural or cultural wealth (Table 9).

Table 9. List of touristic places with natural and cultural wealth.

N°	Site	Type	Main Characteristics
1	Río Cubí	Natural wealth	Waterfalls, rich vegetation and several species of birds.
2	Museo de Perucho: Arqueología e Historia	Cultural wealth	Museum of the Ruta Escondida pre-Columbian history.
3	Iglesia de Perucho	Cultural wealth	Wooden structure, built in 1700, with a sober style and austerity touch.
4	Cerro Itagua	Natural wealth	Natural viewpoint to observe the Chacezpamba parish, the Fuya Fuya hill and the Mojanda forest.
5	Iglesia Parroquial de Chavezpamba	Cultural wealth	Brick, clay and wood structure, built in 1950.
6	Aguas termales de Atahualpa	Natural wealth	Thermal water spa, rivers and vegetation.
7	Camposanto de Atahualpa	Cultural wealth	Site with cypress trees molded to different shapes, such as bears and birds.
8	Iglesia Parroquial de Atahualpa	Cultural wealth	Church built in 1923 with community collaboration. Contains a legendary rock with the image of the Virgen del Quinche.
9	Bosque protector Mojanda	Natural wealth	A forest of approximately 1200 hectares, with several species of native Andean flora, of which two areas have been declared protective forest.

The circuit can be completed in one or two days, with the possibility of visiting other sites nearby. A general assessment of the proposed route from the average values of every suggested site is presented in Table 10. The results reveal the significance of this geotourism route and its potential contribution to the regional tourism offer. A complete visit to all the inventoried geomorphosites would take approximately four days.

Table 10. Interest, Fr., Vul., DS, and Pp assessment in the context of the proposed route (Figure 10).

Itinerary	Interest				Susceptibility			Protection Priority			
	Sc	Ac	To	AI	Vul	Fr	DS	Sc	Ac	To	Pp
"Rocks & Water in Ruta Escondida"	163.8	113.8	152.8	143.5 (High)	81.5	28.5	5.80 (Low)	1.1	0.5	0.6	0.7 (Low)

5. Interpretation of Results and Discussion

The Ruta Escondida, located in a singular volcanic complex, holds unique geomorphological landscapes with geotouristic potential. This potential is reflected in the assessment of 18 geomorphosites (Table 4), according to the IELIG method [14]. The obtained results show that 5.56% of sites present a very high average interest (AI) value, highlighting the Laguna del Mojanda, which, due to its geological nature, is the most outstanding geomorphosite in the area (Table 5 and Figure 6). The "knowledge of the site" parameter is the one that generally obtains the lowest score due to the lack of geomorphosite studies that could promote their potential at national and international level.

The SD results of the sites are classified in the low to medium categories (Table 6 and Figure 7), which translates into low to medium PP values (Table 7 and Figure 8). This is due to the large extension of the sites, thanks to which the threat of anthropic activity is limited despite the relative proximity to communities. This also means that minimal protection measures are required.

One of the advantages of applying the method to a set of geomorphosites is the identification of weak points in the academic, scientific, tourist and SD aspects. The applied methodology allowed a detailed analysis of the studied geomorphosites. According to Štrba et al. [68,69], the application of several methods generates different results, rendering it essential to assess the sites of interest by a combination of various methodologies to obtain a more complete assessment. To improve the results obtained, the authors recommend the inclusion of one or more geomorphosite assessment methodologies (e.g., [18,34,70–75]). In this work, only one assessment method (IELIG) was used, because it is the base methodology recommended by the ASGMI (Ibero–American Association of Geological and Mining Surveys) for assessing geological interest sites [76]. Moreover, this methodology has already been employed in the other points assessment of geological interest in Ecuador (e.g., [8,26,77–82]). In general, the work carried out in the study area regarding the inventory, valuation, promotion, protection and use of geosites is similar to the approach adopted in other countries (e.g., [71,83–90]).

The semi-quantitative assessment of the geomorphosites formed the basis for the SWOT matrix analysis. Through this analysis the potential of sites of geomorphological interest of the Ruta Escondida was determined, as an alternative for the geotourism development in the area. In addition, guidelines or action strategies have been established in order to broaden the tourism attraction of the route through the adaptation of geomorphosites that highlight the importance and geological beauty of the area and its relationship with the biodiversity and culture. For better use of the sites in tourist activities, the specific typology (sizes) of the geomorphosites could be considered. However, in this first study, they were all grouped as a complex typology.

According to Kubalíková [91], the SWOT analysis is a qualitative assessment tool that integrates the knowledge of experts with the perception of the local population, and which provides meaningful information for authorities interested in new development alternatives. This analysis has already been used in the qualitative evaluation of places of geological interest in different zones [71,91–95].

Based on the inventory and assessment of the geomorphosites present in the study area and the SWOT analysis, a series of initiatives are proposed with the aim of facilitating the implementation of geotourism activities as a basis for local development. These proposals could be summarized as follows:

1. To correlate the inventories of this work with others obtained in nearby areas, such as the one by Ayala [50], and try to unify assessment criteria [14].
2. To promote the development of local biological, geological, archaeological and paleontological research. This initiative will allow us to recognize the scientific importance of the area at a national and international level, as well as its direct link with tourism and education.
3. To promote geomorphosites as a geotourism alternative that allows the sustainable development of the area. For this, the provincial, cantonal and parochial authorities need to work with academic and business support, on the creation and adaptation of sites as tourist destinations.
4. To strengthen the quality of services offered to the visitor, through the conditioning of the road infrastructure and facilities that ensure access to each geomorphosite. Additionally, to offer routes that allow visiting various geomorphosites with general and particular information (difficulty, distance, type of access).
5. To reinforce territorial development plans through the implementation of regulation that ensure the conservation of geomorphosites.
6. To determine the rate of erosion caused by the new activities (geotourism) and to propose initiatives that minimize the impact.
7. To implement other tourist activities (trail travel, cycling, sale of handicrafts, typical food and culture) at the geomorphosites to broaden the touristic offer of the Ruta Escondida.

6. Conclusions

From the methodological point of view, the performed assessment fosters the scientific dissemination of the geological potential of the Ruta Escondida as an alternative for economic development and as one of the essential geotourism destinations of the country.

The obtained results reveal that the northern part of the route is characterized by considerable scientific, educational and tourist interest, reflected by the average AI values that range between 97 and 267 (medium to very high interest). The SD and PP values also guarantee that it is feasible to add the studied area to the so-called Ruta Escondida, offering more and more varied alternatives for tourists through the integration of geological, biological, and cultural wealth. The semi-quantitative assessment by the IELIG method and the SWOT matrix analysis carried out in the north of the Ruta Escondida reflect a high potential as an alternative in geotourism development (e.g., suggested itinerary "Rocks & Water in Ruta Escondida" proposed in this article). The researchers recommend enhancing the assessed sites through (i) development of scientific research, (ii) reformulation of territorial development plans that ensure the protection of the area, and (iii) improvement of site conditions and complementary activities for tourists. These actions would contribute to the improvement of the quality of life of the people in the area.

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