

# GIS-Based Geodiversity Assessment and Geosite Representativeness for Geoconservation Planning in the Ruta del Oro Geopark Project, Ecuador

María Jaya-Montalvo<sup>1,2,3,\*</sup>, Camila Holguin-Ortega<sup>2</sup>, Edgar Berrezueta<sup>4</sup>,  
Jairo Dueñas-Tovar<sup>2,3,6</sup>, Paul Carrión-Mero<sup>2,3</sup> and Fernando Morante-Carballo<sup>2,5,6</sup>

<sup>1</sup>Facultad de Ingeniería en Mecánica y Ciencias de la Producción, Escuela Superior Politécnica del Litoral, ESPOL, Campus Gustavo Galindo, Km. 30.5 Vía Perimetral, Guayaquil, 090902, Ecuador

<sup>2</sup>Centro de Investigación y Proyectos Aplicados a las Ciencias de la Tierra, Escuela Superior Politécnica del Litoral, ESPOL, Campus Gustavo Galindo, Km. 30.5 Vía Perimetral, Guayaquil, 090902, Ecuador

<sup>3</sup>Facultad de Ingeniería en Ciencias de la Tierra, Escuela Superior Politécnica del Litoral, ESPOL, Campus Gustavo Galindo, Km. 30.5 Vía Perimetral, Guayaquil, 090902, Ecuador

<sup>4</sup>Department of Resources for Ecological Transition, Geological and Mining Institute of Spain (IGME, CSIC), Oviedo 33005, Spain

<sup>5</sup>Facultad de Ciencias Naturales y Matemáticas, Escuela Superior Politécnica del Litoral, ESPOL, Campus Gustavo Galindo, Km. 30.5 Vía Perimetral, Guayaquil, 090902, Ecuador

<sup>6</sup>Geo-recursos y Aplicaciones, Escuela Superior Politécnica del Litoral, ESPOL, Campus Gustavo Galindo, Km. 30.5 Vía Perimetral, Guayaquil, 090902, Ecuador

## Abstract

Geodiversity encompasses the variety of geological, geomorphological, pedological, and mineral elements of a territory, and its assessment is fundamental for developing geoconservation and geotourism strategies. Geographic Information Systems (GIS) allow for the integration of these components and the identification of areas with heritage relevance for geotourism planning. Despite the importance of the geological and mining heritage of the Ruta del Oro Geopark Project (southwest Ecuador), its geodiversity has not yet been quantified or spatially related to the inventory of Sites of Geological Interest (SGI). This study aimed to evaluate the spatial distribution of the geopark project's geodiversity by comparing it with the inventory and available assessments of Sites of Geological Interest (SGI), to identify spatial overlaps, gaps in representation, and priority areas for management. The methodology was developed in three phases: i) collection and processing of geoinformation for the study area; ii) calculation of the geodiversity sub-indices (geological, geomorphological, pedological, and mineral); and iii) integration of the geodiversity index and comparative analysis with the inventory of geological sites. The high and very high categories cover 30.13% of the study area, the moderate category 30.39%, and the low and very low categories 39.48%. The Piñas canton has approximately 50% of its surface area in the high and very high categories. Of the 37 inventoried sites, 24.32% are in areas of high and very high geodiversity, while 75.68% are distributed among the remaining categories. Integrating the geodiversity index with the inventory of geological sites within a Geographic Information System environment allows for the identification of priority areas and supports the management of geological heritage. It is recommended to expand the inventory in areas of high and very high geodiversity that are underrepresented and to evaluate the heritage value of the geological sites located in the very low to moderate categories.

## Keywords

Spatial analysis, Geoconservation, Geoheritage, Geminins heritage, Rural communities

## 1. Introduction

According to Gray [1], geodiversity encompasses the variety of geological and geomorphological features that make up terrestrial landscapes and form the basis upon which human activities and ecosystems

ICAIFW 2026: Workshops at the 9th International Conference on Applied Informatics 2026, October 13–17, 2026, Orlando, United States

\*Corresponding author.

✉ mjava@espol.edu.ec (M. Jaya-Montalvo); camiholg@espol.edu.ec (C. Holguin-Ortega); e.berrezueta@igme.es (E. Berrezueta); kenjduen@espol.edu.ec (J. Dueñas-Tovar); pccarri@espol.edu.ec (P. Carrión-Mero); fmorante@espol.edu.ec (F. Morante-Carballo)

ORCID 0000-0002-6804-6377 (M. Jaya-Montalvo); 0009-0003-4775-095X (C. Holguin-Ortega); 0000-0002-2667-7461 (E. Berrezueta); 0000-0002-3232-4611 (J. Dueñas-Tovar); 0000-0002-9747-7547 (P. Carrión-Mero); 0000-0003-0374-0306 (F. Morante-Carballo)



© 2026 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

develop. However, these components possess intrinsic value and are of scientific, educational, cultural, and economic significance [2]. The identification and assessment of geodiversity have become essential aspects of the design and implementation of strategies for the protection and utilisation of geological resources, promoting scientific outreach and sustainable development [3, 4].

Methodologies for assessing geodiversity are classified into qualitative, quantitative, and mixed approaches; recent literature favors quantitative methods based on Geographic Information Systems (GIS) due to their greater reproducibility [5]. Specifically, quantitative methods calculate the geodiversity index using parameters and indicators, typically through digital mapping in GIS environments. Among these approaches, the methodology proposed by Pereira [6] is widely applied and has become popular within grid-based GIS approaches [7]. This methodology quantifies the abiotic elements within each cell of a grid, and these are then totalled to obtain the final Geodiversity Index [8].

In geopark projects, the grid-based GIS index is used because it enables areas with the greatest abiotic richness within a large territory to be located, compared and prioritised [9]. In several geoparks, the areas with the highest index scores coincide with Sites of Geological Interest (SGI), existing tourist infrastructure or geopark initiatives [8, 10]. However, in some cases, Sites of Geological Interest are located in areas with a low or medium geodiversity index [11].

In Ecuador, methods have been developed to map geodiversity on a national scale and analyze its relationship with protected areas and geopark projects. These studies have highlighted the overlap between areas of high geodiversity and territories with potential for conservation and geotourism [8]. However, whilst national analyses are suitable for identifying general trends, they have limitations when it comes to guiding management decisions at the local level [12]. This situation is particularly relevant for the Ruta del Oro Geopark project, whose area encompasses geological, geomorphological and mining features with scientific, cultural, educational and tourist potential [12]. Despite the existence of a preliminary inventory of Sites of Geological Interest, there is yet no integrated spatial assessment to determine which sectors harbor the greatest abiotic diversity, to what extent the inventoried Sites of Geological Interest represent this diversity, and where priority areas for geoconservation might be located.

In this context, the following question arises: How does the geodiversity of the Ruta del Oro project vary spatially at a local scale, and how does this relate to the distribution of Sites of Geological Interest, mining heritage and geotourism potential? This research aims to assess the geodiversity of the Ruta del Oro Geopark project and to compare it with the distribution and evaluation of Sites of Geological Interest, with a view to identifying spatial overlaps, gaps in representation, and priority areas for management.

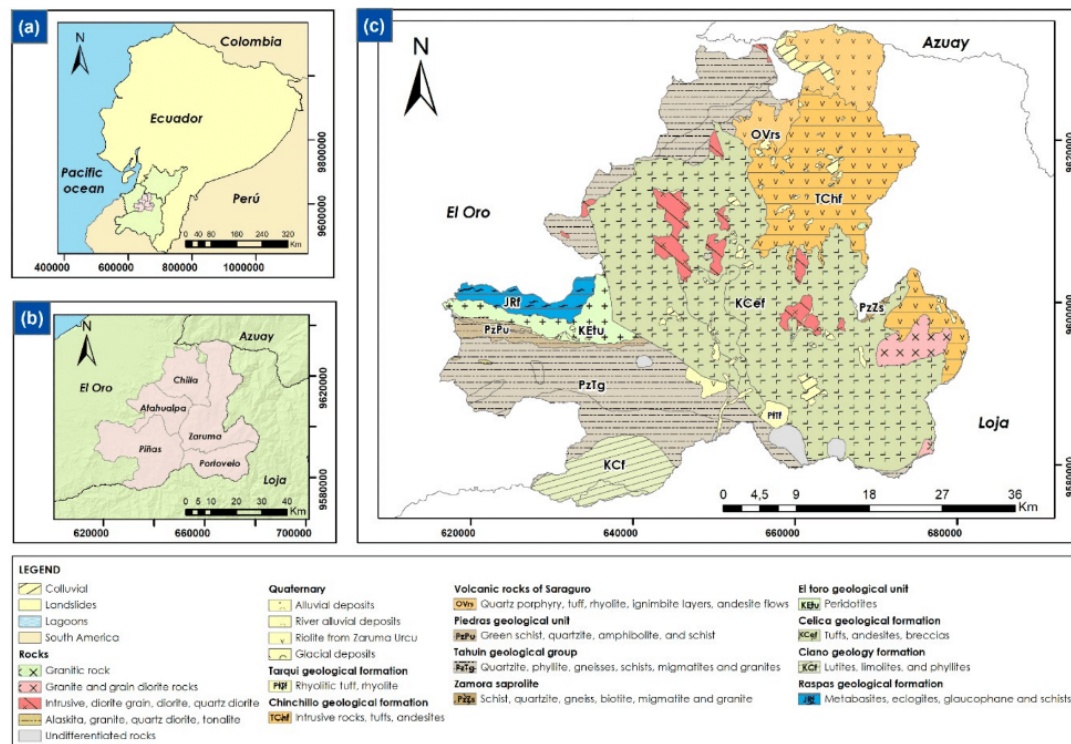
## **2. Materials and methods**

### **2.1. Geographic and geologic context**

The Ruta del Oro Geopark Project is situated in the province of El Oro (southwest Ecuador); it covers an area of approximately 2,000 km<sup>2</sup> and encompasses the cantons of Chilla, Atahualpa, Piñas, Zaruma and Portovelo [12] (Figure 1 a-b). The territory is biogeographically influenced by the arid areas of the coastal zone and humid areas of the western foothills of the Andes. [13]. The study area is part of a complex geological setting dominated by metamorphic and igneous rocks, with Quaternary deposits (Figure 1c). The main geological units include the El Oro Metamorphic Complex, the Tahuín Group, the volcanic sequences belonging to the Saraguro Group, and granitic and granodioritic intrusions associated with various magmatic events; it also contains Quaternary alluvial, colluvial, and fluvial deposits [14].

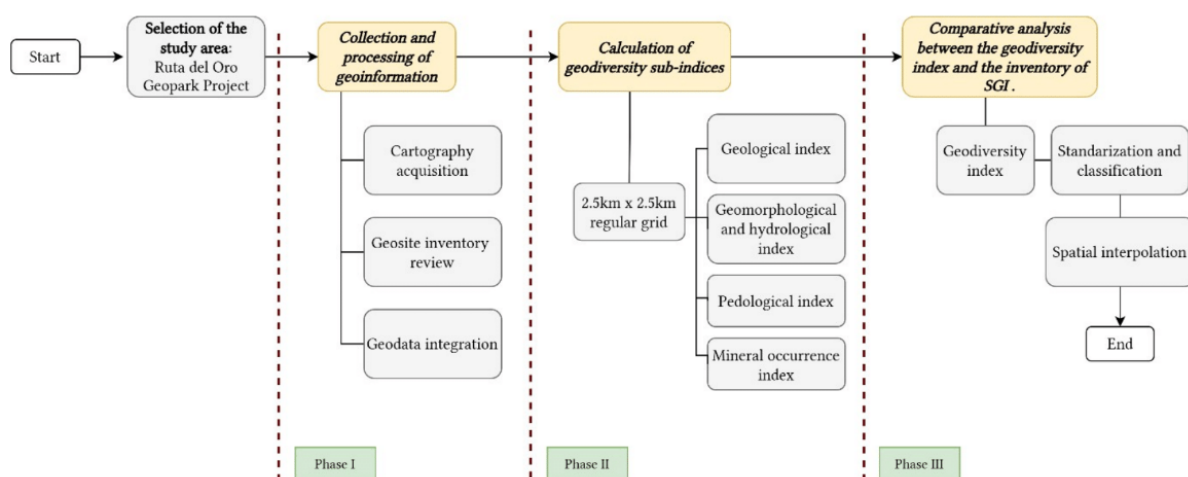
### **2.2. Methodology**

The study applied the methodology proposed by Pereira et al. [6] for the quantitative assessment of geodiversity, with adaptations to the scale and availability of information in the study area. This



**Figure 1:** Study area of the Ruta del Oro Geopark Project: (a) location in Ecuador, (b) delimitation of the geopark, and (c) geological setting.

approach allows the richness of abiotic elements present in each unit of a regular grid to be estimated based on raster or vector data within a GIS environment. The methodological approach was organised into three phases (Figure 2): i) collection and processing of geoinformation from the study area, ii) calculation of geodiversity sub-indices, and iii) comparative analysis between the geodiversity index and the inventory of Sites of Geological Interest.



**Figure 2:** Flowchart of the methodology applied to assess geodiversity in the Ruta del Oro Geopark Project.

### 2.2.1. Phase I: collection and processing of geoinformation

In Phase I, thematic maps covering geology, geomorphology, mineral occurrences, and soils were compiled for the Ruta del Oro Geopark project, including their reference system, scale, and resolution

(Table 1). Subsequently, the layers were projected onto the World Geodetic System (WGS) 1984, Zone 17s, and processed using QGIS (version 4.2.0). In addition, the inventory of Sites of Geological Interest from the research project ‘Proposal for the Ruta del Oro Geopark and its impact on territorial development’ (CIPAT-02-2018) was reviewed, as was the scientific literature relating to the geoheritage of the study area. For each site, its name, location, type, primary and secondary geological interests, description and documentary sources were systematised. A check was also carried out to determine whether the site had undergone a prior quantitative assessment, analysing the methodology applied, the criteria considered and the scores assigned to its scientific, educational and tourist values, as well as to its risk of degradation, where this information was available. Once the inventory had been cleaned up and standardised, the coordinates of the Sites of Geological Interest were imported into QGIS to generate a vector point layer.

**Table 1**

Geospatial data used in the calculation of geodiversity.

| Contents                      | Data                                                                                                                                                                | Scale       | Classification of features in the GIS | Source |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|---------------------------------------|--------|
| <b>Geological index</b>       | Hydrogeology (lithology, formations)                                                                                                                                | 1:250.000   | Polygons                              | [15]   |
| <b>Geomorphological index</b> | Geomorphology (land-forms)                                                                                                                                          | 1:25.000    | Polygons                              |        |
|                               | Rivers of South America                                                                                                                                             | 1:1'000.000 | Lines                                 | [16]   |
|                               | Lakes and Lagoons of Ecuador (National Scale). Open-access maps from the Military Geographic Institute (IGM). Version 4.0                                           | 1:1'000.000 | Polygons                              | [17]   |
| <b>Mineral index</b>          | Non-metallic                                                                                                                                                        | 1:1'000.000 | Points                                | [18]   |
|                               | Metallic minerals                                                                                                                                                   | 1:1'000.000 | Points                                | [19]   |
|                               | Mining concessions                                                                                                                                                  | 1:5.000     | Polygons                              | [20]   |
| <b>Pedological index</b>      | Geopedological Unit. Edition published by the Ministry of Agriculture and Livestock (MAG)—General Coordination Office for National Agricultural Information (CGINA) | 1:25.000    | Polygons                              | [15]   |

### 2.2.2. Phase II: Calculation of geodiversity sub-indices

The quantitative assessment methodology proposed by Pereira et al. [6] was adapted in this phase to align with the territorial scale and the availability of geoinformation within the boundaries of the geopark project. Using the layers processed in Phase I, four sub-indices were calculated: lithological, geomorphological, pedological, and mineral occurrence. Each sub-index was obtained by counting the different units or elements present in each analysis cell (morphological unit (UMO) and order of the hydrographic network for geomorphology; soil taxonomic order for pedology; geological age for the geological index; and type of mineral material for the mineral occurrence index).

To standardise the spatial unit of analysis, a regular grid of square cells was generated using the Create Grid tool in QGIS. The size of each cell was determined in accordance with the spatial resolution criteria proposed by Hengl [21], based on the total surface area of the study area and the target number

of spatial units. Consequently, a resolution of  $2.5 \times 2.5$  km (equivalent to  $6.25$  km<sup>2</sup> per spatial unit) was adopted. This resolution enabled the thematic layers to be integrated into a common unit, whilst maintaining a sufficient level of detail to represent spatial variations within the study area.

### 2.2.3. Phase III: Spatial distribution of geodiversity

In this phase, the influence of the Sites of Geological Interest (SGI) inventory component on the spatial distribution of geodiversity was assessed. Initially, the number of SGI occurrences in each cell of the selected grid was calculated. The sites were assigned to spatial units using a spatial join in QGIS (version 4.2.0).

Subsequently, the geodiversity index was generated by integrating the lithological, geomorphological, pedological, and mineral occurrence indices. Before integration, the partial indices were standardised to a common scale (1) as defined by Carrión-Mero et al. [8], to ensure comparable contributions and prevent differences between their numerical ranges from influencing the final result.

$$Norm\ value = \frac{V_{obs} \times 5}{V_{Max}}, \quad (1)$$

The results for each sub-index were reclassified independently using Jenks' [22] natural break method. The lithological, geomorphological, pedological, and mineral occurrence indices were classified into five categories: very low, low, medium, high, and very high. Subsequently, the number of SGIs that coincided with the geodiversity categories was quantified. Finally, the values assigned to the cells were interpolated using the v.surf.rst tool to generate continuous surfaces and facilitate the visualisation of geodiversity within the Ruta del Oro Geopark project.

## 3. Results and discussion

### 3.1. Spatial distribution of geodiversity components

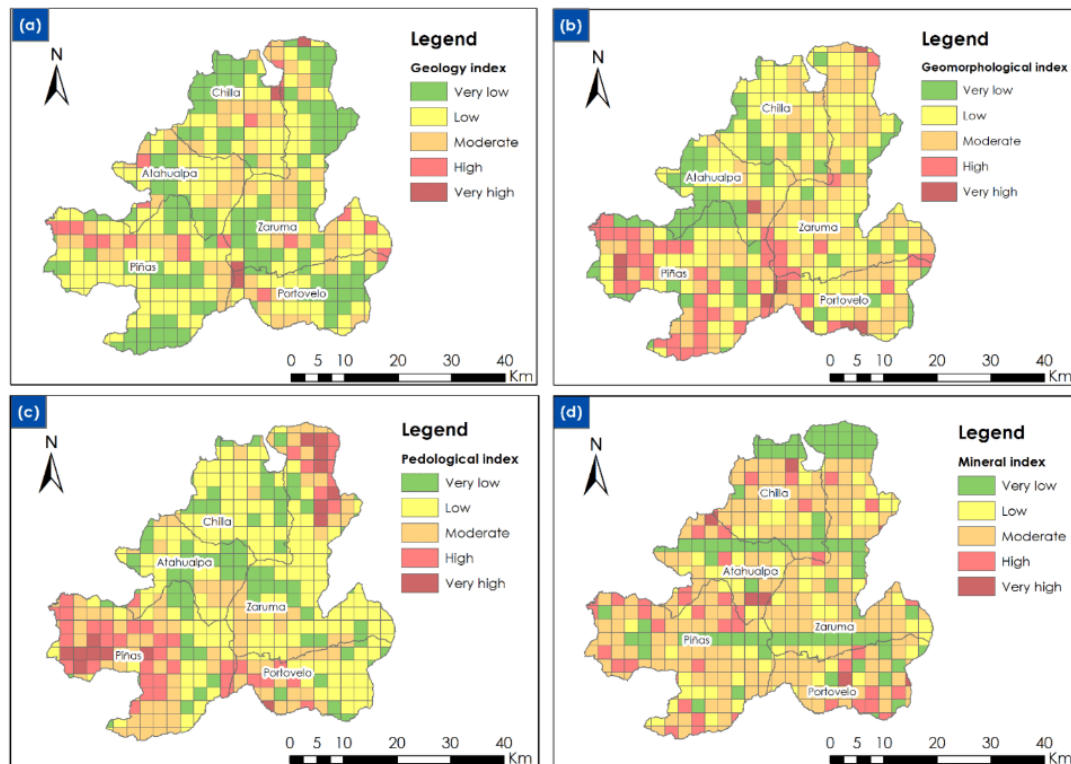
Figure 3 shows the four indices calculated using the grid-based approach in GIS. The geological sub-index shows a predominance of low and moderate categories, with higher concentrations of diversity in the Piñas and Atahualpa sectors and on the boundary between Zaruma and Portovelo (Figure 3a). This pattern is associated with contact between geological units of different ages and origins, notably in the south: the El Oro metamorphic complex, the Tahuín Group, the Célica Formation, and the volcanic sequences of the Saraguro Group, the coexistence of which increases geological diversity within each cell [23]. Low to very low values indicate a lower variety of geological units per cell.

The geomorphological sub-index (landforms and hydrography) shows the highest categories concentrated in the canton of Piñas and in the centre of the Zaruma-Portovelo mining district (Figure 3b), while moderate and low categories predominate further north. These variations reflect the coexistence of different morphological units and hydrographic features within the grid cells, such as mountainous terrain, hilly terrain (ranging from low to very high), river valleys, ancient colluvial-alluvial deposits, and low terraces [24].

The soil sub-index shows a more heterogeneous pattern, with high and very high concentrations in Piñas, as well as isolated patches to the north of Zaruma and to the west of Portovelo. The high and very high categories are associated with areas where different soil orders coexist, mainly inceptisols, andisols, and miscellaneous soils, thereby increasing soil diversity (Figure 3c). The low categories are distributed in the central sectors towards the north, due to the presence of entisols and inceptisols. This index is also related to the geomorphological index, as the latter is likewise influenced by slope, drainage, moisture, and weathering in soil differentiation [25, 26].

The mineral occurrence sub-index showed a predominance of moderate to very high values across the entire Ruta del Oro Geopark Project area, with maximum values distributed unevenly across the five cantons (Figure 3d). This distribution is consistent with the regional nature of the district, whose mineralisation is not confined to the towns of Zaruma and Portovelo but extends through tectonically

controlled veins and structures. This mineralisation is part of the Au-Ag-Cu vein hydrothermal system associated with volcanic sequences and intrusive bodies [27]. The distribution shows a partial correspondence with the Machala metallogenic belt, which extends for approximately 75 km in a NW–SE direction (source: IIGE [28]) and the Zaruma–Portovelo district [29].



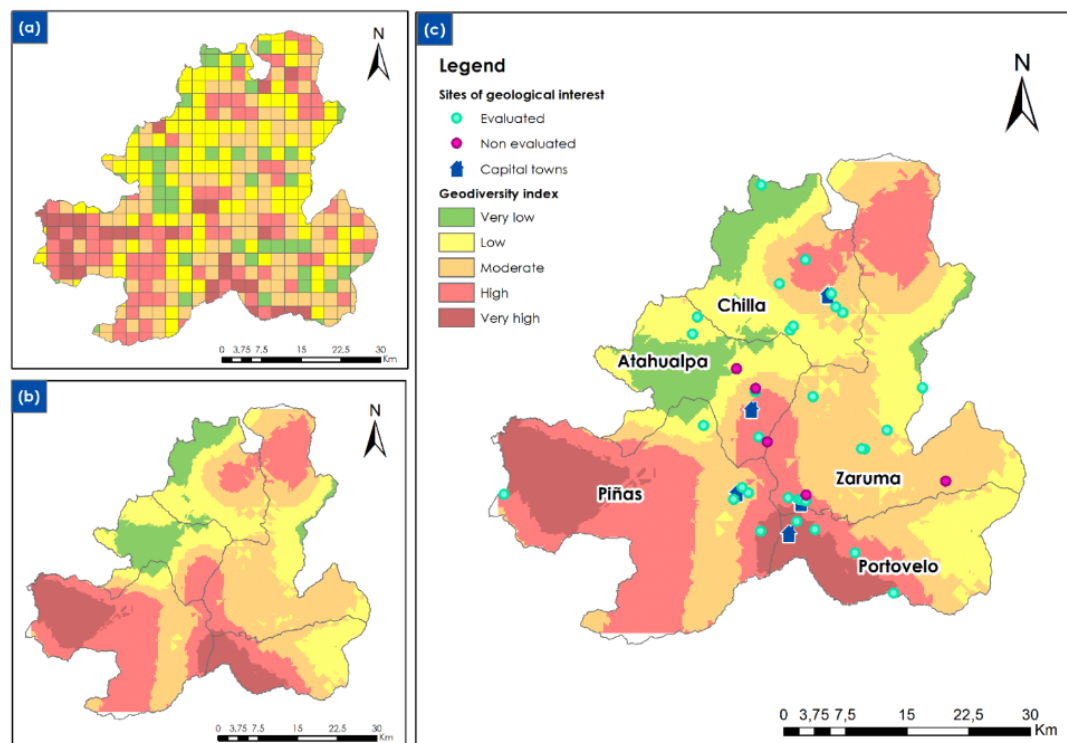
**Figure 3:** Spatial distribution of geodiversity sub-indices: (a) geological index, (b) geomorphological index, (c) pedological index and (d) mineral index.

### 3.2. Integrated geodiversity index and SGI

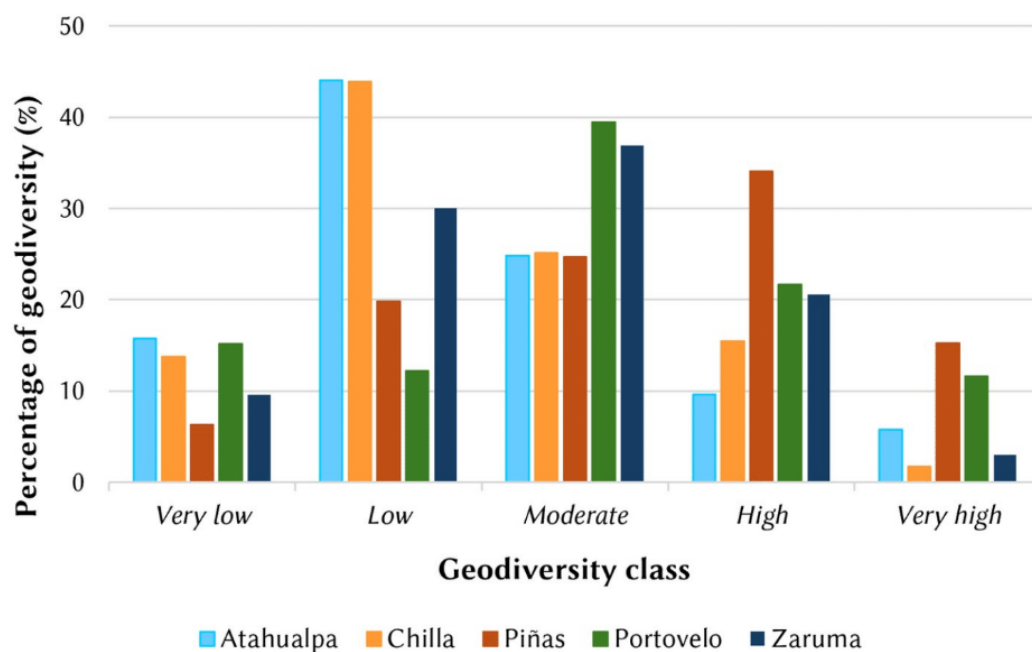
The integrated geodiversity index showed marked spatial variability across the entire project area of the Ruta del Oro Geopark (Figure 4). The ‘high’ and ‘very high’ categories covered 30.13% of the study area; the ‘moderate’ category accounted for 30.39%; and the ‘low’ and ‘very low’ categories comprised 39.48% (Figure 4). The largest area of geodiversity was identified in the western and south-western sectors around Piñas (Figure 4c).

Comparison of geodiversity levels and the IELIG method for selected Sites of Geological Interest. The distribution of geodiversity classes showed clear differences between the five cantons:

- Atahualpa and Chilla are dominated by the ‘low’ class, which accounts for approximately 44% of each canton. In both, the moderate class accounts for approximately 25%, while the high and very high classes have a limited presence. Chilla has the lowest proportion of geodiversity in the ‘Very high’ category.
- Piñas has the highest proportion of its territory in the high and very high classes. Taken together, these two categories account for approximately 50% of the canton, confirming that Piñas constitutes the project’s main territorial hub of high geodiversity.
- Portovelo is dominated by the moderate class, at around 40%, followed by the high and very high classes, which together account for around a third of its area.
- Zaruma also shows a predominance of the moderate class, at around 37%, followed by the low class, at approximately 30%. Although Zaruma possesses a widely recognised mining geopatrimony [30], the proportion of its territory classified as very high geodiversity is small.



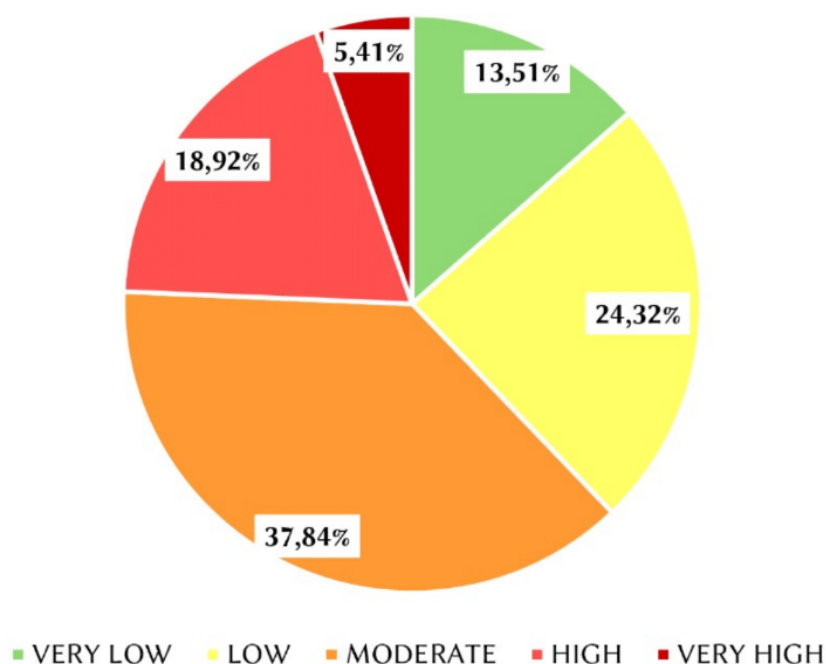
**Figure 4:** Spatial representation of the geodiversity index: (a) geodiversity index obtained from Fishnet, (b) geodiversity surface interpolated using the v.surf.rst tool, and (c) final geodiversity map of the study area showing the distribution of Sites of Geological Interest (SGI).



**Figure 5:** Percentage of geodiversity applied to the cantons in the Ruta del Oro Geopark Project, excluding the GSIs.

Sites of Geological Interest were distributed across the five geodiversity classes (Figure 6). The highest proportion of Sites of Geological Interest was found in areas of moderate geodiversity (37.84%), followed by those of low (24.32 %), high (18.92%), very low (13.51%), and very high (5.41%) geodiversity. In total, 24.33% (9 SGI) of the 37 sites surveyed were in areas of high or very high geodiversity, while 37.83% (14

SIG) were in areas of low or very low geodiversity.



**Figure 6:** Percentage distribution of Sites of Geological Interest (SGI) within the Ruta del Oro Geopark project.

These results indicate a partial spatial correlation between the geodiversity index and the inventory of Sites of Geological Interest. Although the majority of sites were in areas of moderate to very high geodiversity (62.16%), a substantial proportion were in areas of low diversity. This distribution is supported by assessments of Sites of Geological Interest conducted under the Ruta del Oro Geopark Project using the IELIG methodology [31], which show that several sites located in areas of low geodiversity possess high heritage value. This suggests that the heritage value of a site of geological interest depends not only on the quantity or variety of abiotic elements present in the grid cell but also on individually assessed attributes, such as representativeness, integrity, and scientific, educational, and tourism potential. These attributes complement the information provided by the geodiversity index in identifying priority areas for geoconservation (Table 2).

The contrasting patterns of geodiversity distribution at the cantonal level reinforce the distinction between geodiversity hotspots and established geological heritage concentrations. Piñas exhibited the highest proportion of high and very high geodiversity, whereas the best-documented geological and mining heritage is concentrated in Zaruma and Portovelo. This suggests that the existing SGI inventory reflects both the intrinsic geological importance of the Zaruma-Portovelo mining district and the historical concentration of research and inventory efforts in the area. Conversely, the high geodiversity recorded in Piñas may indicate the presence of underrepresented geological, geomorphological, or mineral features that require more extensive field research in the areas identified in this study.

Although the proposed geodiversity index offers a regional view of the spatial distribution of abiotic diversity, several limitations should be considered. The existing SGI inventory may be spatially biased toward the historically and scientifically well-documented Zaruma-Portovelo mining district. Therefore, areas of high geodiversity with few inventoried sites, particularly west of Piñas, should be considered potential gaps in the inventory. Future research should evaluate the sensitivity of the geodiversity index to different grid sizes, classification procedures and interpolation parameters. Field studies should prioritise areas of high and very high geodiversity with limited representation in the existing SGI inventory, particularly in the west and southwest of Piñas and the central corridor between Piñas, Atahualpa, and Zaruma. These studies should verify the presence, integrity, and potential value of the area's geological, geomorphological, and mining features.

**Table 2**

Comparison of geodiversity levels and IELIG assessment for selected SGI.

| Canton    | Sites of Geological Interest (SGI)   | Geodiversity level | Assessment using the IELIG method |
|-----------|--------------------------------------|--------------------|-----------------------------------|
| Atahualpa | San Juan de cerro azul waterfall     | Low                | High                              |
|           | Daucay waterfall                     | Moderate           | High                              |
| Chilla    | Chillacocha lagoon                   | Low                | High                              |
|           | Ashigsho hot springs                 | Moderate           | High                              |
| Piñas     | La Florida waterfall                 | High               | High                              |
| Portovelo | ‘Magner-Turner’ mineralogical museum | Very high          | Very high                         |
|           | Arcoiris waterfall                   | High               | High                              |
| Zaruma    | "El sexmo" touristic mine            | High               | Very high                         |
|           | Zaruma-Urcu hill                     | High               | High                              |
|           | "El calvario" hill                   | High               | High                              |
|           | Arcos' hill                          | Low                | High                              |

## 4. Conclusion

The study revealed a 24.32% spatial correlation between areas of high to very high geodiversity and part of the inventory of Sites of Geological Interest. In comparison, the remaining 75.68% was distributed across areas of moderate to very low geodiversity. Taken together, these results indicate that the geodiversity index is a valuable tool for territorial planning within the Ruta del Oro Geopark Project, as it allows for the identification of priority areas for geoconservation, guides future research, and provides spatial criteria for managing geological heritage.

Based on the geodiversity map obtained, research and management actions for geological heritage should focus on:

- Prioritise expanding the inventory in the Piñas canton, where areas of high and very high geodiversity are identified with a limited representation of SGI, suggesting an incomplete inventory in these sectors.
- Strengthen the evaluation, conservation, and enhancement of the geological heritage of the Zaruma-Portovelo district, where the coincidence between areas of high geodiversity and a greater concentration of SGI constitutes a solid basis for generating geoconservation strategies within the geopark project.

This study has the following limitations regarding its methodological approach:

- Mining concessions were used as an approximation for calculating the mineral sub-index, given the limited availability of data on metallic and non-metallic resources in the region.
- The geodiversity index depends on the scale and resolution of the mapping used; therefore, some smaller geological features may not be represented in this analysis.

Finally, this study demonstrates that integrating the geodiversity index with the geological features inventory (SGI) provides a valuable tool for geoheritage management. The methodology employed offers a foundation for guiding geoconservation and land-use planning efforts, and its reproducibility facilitates its application in other territories to enhance and conserve geological heritage.

## Acknowledgements

The authors gratefully acknowledge the support of the Escuela Superior Politécnica del Litoral (ESPOL) through the research project "Propuesta de Geoparque Ruta del Oro y su incidencia en el desarrollo territorial" (code CIPAT-02-2018).

## Declaration on Generative AI

The authors have not employed any Generative AI tools.

## References

- [1] M. Gray, *Geodiversity: valuing and conserving abiotic nature*, John Wiley & Sons, 2013.
- [2] J. E. Gordon, R. Crofts, E. Díaz-Martínez, K. S. Woo, Enhancing the role of geoconservation in protected area management and nature conservation, *Geoheritage* 10 (2018) 191–203.
- [3] J. Brilha, Inventory and quantitative assessment of geosites and geodiversity sites: a review, *Geoheritage* 8 (2016) 119–134.
- [4] R. Dowling, D. Newsome, *Handbook of geotourism*, Edward Elgar Publishing, 2018.
- [5] Z. Zwoliński, A. Najwer, M. Giardino, Methods for assessing geodiversity, in: *Geoheritage*, Elsevier, 2025, pp. 31–71.
- [6] D. I. Pereira, P. Pereira, J. Brilha, L. Santos, Geodiversity assessment of paran  state (brazil): an innovative approach, *Environmental management* 52 (2013) 541–552.
- [7] C. Lopes, Z. Teixeira, D. I. Pereira, P. Pereira, Identifying optimal cell size for geodiversity quantitative assessment with richness, diversity and evenness indices, *Resources* 12 (2023) 65.
- [8] P. Carri n-Mero, J. Duenas-Tovar, M. Jaya-Montalvo, E. Berrezueta, N. Jim nez-Orellana, Geodiversity assessment to regional scale: Ecuador as a case study, *Environmental Science & Policy* 136 (2022) 167–186.
- [9] M. P l, G. Albert, From geodiversity assessment to geosite analysis–a gis-aided workflow from the bakony–balaton unesco global geopark, hungary, 2023.
- [10] D. G. Harbowo, L. P. Siringoringo, et al., Locating geodiversity hotspots through grid-based spatial indexing: Lombok island, indonesia, *Journal of Geoscience, Engineering, Environment, and Technology* 10 (2025) 215–223.
- [11] T. Mici  Ponjiger, T. Luki , Đ. A. Vasiljevi , T. A. Hose, B. Basarin, S. B. Markovi , M. M. Milanovi , A. Valjarevi , M. D. Vuji i , U. Stankov, et al., Quantitative geodiversity assessment of the fru ka gora mt.(north serbia) by using the geodiversity index, *Geoheritage* 13 (2021) 61.
- [12] P. Carrion-Mero, L. Soto-Navarrete, B. Apolo-Masache, J. Mata-Perell , G. Herrera-Franco, J. Briones-Bitar, Environmental assessment and tourism carrying capacity in geosites of the ruta del oro geopark project, *Geoheritage* 17 (2025) 37.
- [13] C. Garz n Santomaro, M. Vega-Y nez, J. Ja n, M. Y nez-Mu oz, *El oro megadiverso del p ramo al manglar*, 2019.
- [14] E. R. Berrezueta Alvarado, M. J. Dom nguez Cuesta, P. Carri n, T. Berrezueta, G. Herrero, et al., Propuesta metodol gica para el aprovechamiento del patrimonio geol gico minero de la zona zaruma-portovelo (ecuador), *Trabajos de Geolog a*, 26 (2006).
- [15] MAG, CGINA, Geoportal del agro ecuatoriano, 2026. URL: <http://geoportal.agricultura.gob.ec/>.
- [16] B. Lehner, G. Grill, Global river hydrography and network routing: baseline data and new approaches to study the world’s large river systems, *Hydrological Processes* 27 (2013) 2171–2186.
- [17] IGM, Cartografia de libre acceso (escala nacional) – geoportal ecuador, 2026. URL: <https://www.geoportaligm.gob.ec/portal/index.php/descargas/cartografia-de-libre-acceso/registro/>.
- [18] INIGEMM, Mapa de ocurrencias de minerales no met licos, 2011, escala 1:1.000.000, 2011. URL: [https://drive.google.com/file/d/1htTEX0\\_tYWIKIRamP4vc7GvCqnHWhQux/view](https://drive.google.com/file/d/1htTEX0_tYWIKIRamP4vc7GvCqnHWhQux/view).

- [19] INIGEMM, Mapa de indicios de minerales metálicos de la república del ecuador, 2009, escala 1 1'000.000, 2011. URL: [https://drive.google.com/file/d/1htTEX0\\_tYWIKIRamP4vc7GvCqnHWhQux/view](https://drive.google.com/file/d/1htTEX0_tYWIKIRamP4vc7GvCqnHWhQux/view).
- [20] A. de Regulación y Control Minero, Geoportal de catastro minero: Límites territoriales internos, conali 2020, 2026.
- [21] T. Hengl, Finding the right pixel size, *Computers & geosciences* 32 (2006) 1283–1298.
- [22] G. F. Jenks, The data model concept in statistical mapping, *International yearbook of cartography* 7 (1967) 186–190.
- [23] N. Suhr, Y. Rojas-Agramonte, D. M. Chew, A. J. Pinto, D. Villagomez-Diaz, T. Toulkeridis, R. Mertz-Kraus, Detrital-zircon geochronology and provenance of the el oro metamorphic complex, ecuador: Geodynamic implications for the evolution of the western gondwana margin, *Journal of South American Earth Sciences* 90 (2019) 520–539.
- [24] A. Winckell, *Relieve y geomorfología del ecuador*, 1982.
- [25] D. A. L. Isminio, C. E. G. R. Schaefer, E. F. do Amaral, D. do Vale Lopes, M. R. Francelino, E. O. Senra, Soil-landform interplays from the highlands of the eastern andes cordillera to the lowlands of the peruvian amazon, *Catena* 244 (2024) 108248.
- [26] N. Bernhard, L.-M. Moskwa, K. Schmidt, R. A. Oeser, F. Aburto, M. Y. Bader, K. Baumann, F. Von Blanckenburg, J. Boy, L. van den Brink, et al., Pedogenic and microbial interrelations to regional climate and local topography: New insights from a climate gradient (arid to humid) along the coastal cordillera of chile, *Catena* 170 (2018) 335–355.
- [27] E. Berrezueta, B. Ordóñez-Casado, W. Bonilla, R. Banda, R. Castroviejo, P. Carrión, S. Puglla, Ore petrography using optical image analysis: application to zaruma-portovelo deposit (ecuador), *Geosciences* 6 (2016) 30.
- [28] A. Egüez, A. Albán, E. Gallardo, M. Reinoso, W. Lomas, S. Toainga, et al., Mapa metalogenético de la república del ecuador 1: 1000000, Ministerio de Energia y Recursos Naturales No Renovables. doi 10 (2019).
- [29] P. Schütte, M. Chiaradia, F. Barra, D. Villagómez, B. Beate, Metallogenic features of miocene porphyry cu and porphyry-related mineral deposits in ecuador revealed by re-os, 40ar/39ar, and u-pb geochronology, *Mineralium Deposita* 47 (2012) 383–410.
- [30] P. Carrión-Mero, O. Loo-Oporto, H. Andrade-Ríos, G. Herrera-Franco, F. Morante-Carballo, M. Jaya-Montalvo, M. Aguilar-Aguilar, K. Torres-Peña, E. Berrezueta, Quantitative and qualitative assessment of the “el sexmo” tourist gold mine (zaruma, ecuador) as a geosite and mining site, *Resources* 9 (2020) 28.
- [31] G. M. Herrera Narváez, M. J. Domínguez Cuesta, et al., Propuesta geoparque ruta del oro basada en especificaciones unesco: aspectos geológicos provincia de el Oro-Ecuador, Ph.D. thesis, ESPOL. FICT, 2022.