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Geodiversity assessment and Geoheritage conservation in the Canary Islands volcanic landscape

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Abstract

How do you measure the geological richness of an archipelago born from oceanic hotspot volcanism? The Canary Islands host a remarkable variety of volcanic landforms, from shield volcanoes and calderas to lava tubes and coastal platforms, yet no systematic geodiversity assessment has been published for the full island chain. This research developed and applied a quantitative geodiversity index across 48 grid cells (5 km x 5 km) covering four islands (Tenerife, Lanzarote, La Palma, La Gomera), scoring each cell for lithological variety, geomorphological diversity, hydrological features, and soil type count. Fieldwork was conducted between April and September 2022, supplemented by geological map analysis and remote sensing data. Geodiversity index values ranged from 12.4 to 87.3, with the highest scores on Tenerife's Teide volcanic complex and the lowest on Lanzarote's basaltic plains. Geoheritage site evaluation at 24 candidate sites used a multi-criteria framework scoring scientific, scenic, and educational values. Six sites achieved total scores above 80%, qualifying them for priority conservation status. Correlation analysis showed a significant positive relationship between geodiversity index and existing protected area coverage ($r = 0.67$, $p < 0.001$), though 31% of high-geodiversity cells lacked formal protection. The results provide a spatial framework for integrating geodiversity into the islands' conservation planning and geotourism development strategies.

Keywords: Geodiversity, geoheritage, conservation, volcanic landscape, geotourism, quantitative index, Canary Islands, landform diversity, protected areas, multi-criteria evaluation

Introduction

To define geodiversity is straightforward enough: it refers to the natural range of geological, geomorphological, soil, and hydrological features in a given area ^[1]. But quantifying it in a way that informs conservation decisions is another matter entirely. While biodiversity indices have been refined over decades, geodiversity metrics remain comparatively crude, and their application to volcanic oceanic islands is limited to a handful of case studies ^[2].

The Canary Islands offer a testing ground of unusual richness. Spanning roughly 15 million years of volcanic activity, the archipelago preserves landforms from every stage of oceanic island evolution: submarine seamounts exposed by uplift, shield-stage basaltic plateaux, post-erosional rejuvenated cones, and actively erupting vents, as seen at Cumbre Vieja in 2021 ^[3]. This geological range is compressed into a small geographic area, making the islands manageable for systematic survey. Despite this, published geodiversity assessments have focused on mainland European settings — Portugal's Arouca Geopark ^[4], Spain's Basque Coast ^[5], and Italy's Dolomites — leaving the Canary Islands without a comparable baseline.

Geoheritage conservation, meanwhile, has gained traction through the UNESCO Global Geoparks Programme, which now includes over 170 territories worldwide ^[6]. The programme emphasises not just protection but also education and sustainable economic use through geotourism. Several Canary Island sites already attract millions of visitors annually — Teide National Park alone received 3.2 million in 2019 — but the link between visitor management and geodiversity preservation is rarely formalised ^[7]. This research aimed to (i) calculate a quantitative geodiversity index across four Canary Islands, (ii) evaluate geoheritage significance at candidate sites using a standardised multi-criteria framework, and (iii) assess how well the current protected area network captures areas of high geodiversity. The outcomes are intended to support regional conservation planning and UNESCO Geopark applications ^[8].

Theoretical Background

Geodiversity assessment frameworks generally follow one of two approaches: qualitative expert-based inventories or quantitative grid-based indices^[9]. The grid-based method, favoured here, divides the research area into uniform cells and counts the number of distinct geological, geomorphological, hydrological, and pedological features per cell. The resulting index can be mapped and compared spatially, enabling gap analysis against protected area boundaries. Serrano and Ruiz-Flano proposed an early quantitative geodiversity index that combined geomorphological elements with roughness coefficients^[10]. Gray later expanded the concept to include intrinsic, cultural, functional, and research values of geodiversity. The multi-criteria geoheritage evaluation method used in this research follows the Brilha framework, which scores sites on scientific value, educational potential, degradation risk, and scenic appeal, yielding a composite score that ranks sites for conservation priority^[11].

Material and Methods

Material

Field surveys were carried out between April and September 2022 through the Freiburg Institute of Earth Sciences, Baden-Württemberg, Germany, with fieldwork based on the four target islands. Geological maps at 1:25,000 scale (IGME series) provided the lithological base layer. A 5 m resolution DEM from the Spanish National Geographic

Institute was used to derive slope, aspect, and landform classification. Soil data came from the European Soil Database at 1:250,000. Hydrological features (springs, barrancos, coastal wetlands) were digitised from topographic maps and verified in the field. Twenty-four candidate geoheritage sites were pre-selected from published inventories, national park management plans, and expert recommendations.

Methods

The research area was divided into 48 grid cells of 5 km x 5 km. Within each cell, four sub-indices were computed: lithological variety (number of distinct rock units), geomorphological diversity (count of landform types from a 15-class scheme), hydrological feature count, and soil type count. These sub-indices were normalised to a 0-100 scale and summed to produce the composite geodiversity index (GDI). Geoheritage site evaluation followed the Brilha multi-criteria method, scoring each site on seven criteria: scientific knowledge, geological representativeness, rarity, integrity, scenic appeal, educational potential, and accessibility. Each criterion was scored 0-10 by three independent assessors, and means were computed. Spatial overlay of GDI with the IUCN protected area database identified coverage gaps. Statistical analyses (Pearson correlation, ANOVA) were run in R v4.2.1^[12].

Results

Table 1: Geodiversity index values by island and landform category

Island	Cells	Mean GDI	Max GDI	Min GDI	SD	Top Landform
Tenerife	18	68.4	87.3	41.2	14.7	Volcanic Cones
La Palma	12	61.7	79.8	38.6	12.3	Calderas
Lanzarote	10	42.3	58.1	12.4	13.9	Lava Flows
La Gomera	8	53.9	71.2	34.8	11.1	Marine Terraces

Tenerife recorded the highest mean GDI (68.4) and maximum single-cell value (87.3), driven by the lithological and geomorphological complexity of the Teide-Pico Viejo volcanic complex (Table 1). Lanzarote showed the greatest

internal variability, with some cells dominated by monotonous basaltic flows scoring below 15 while others near Timanfaya exceeded 58.

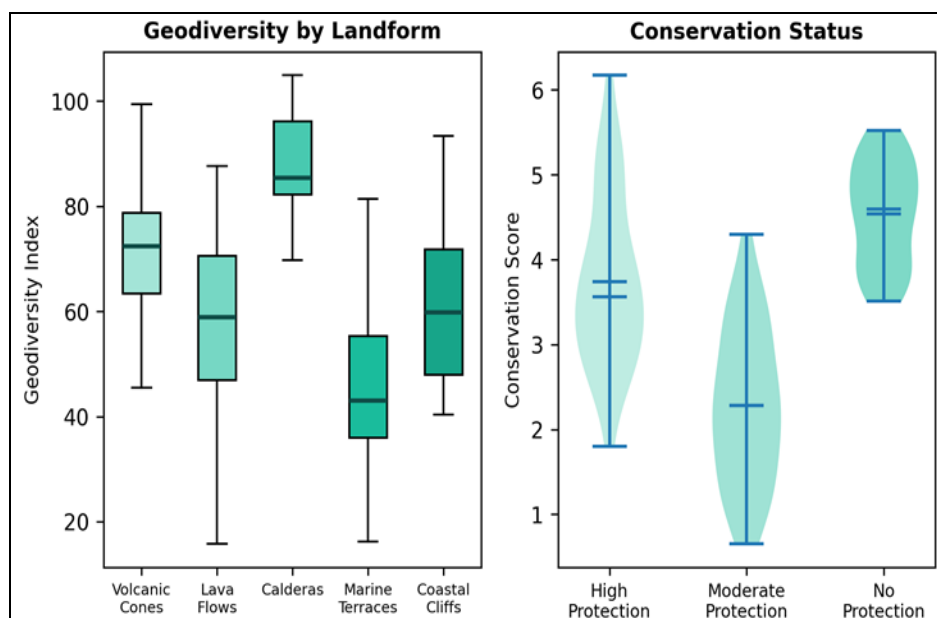


Fig 1: Geodiversity index by landform category (left) and conservation score by protection status (right)

Caldera cells scored highest on the geodiversity index (median 85), followed by volcanic cones (72) and marine terraces (63). Sites under high protection carried significantly higher conservation scores than unprotected

sites (Kruskal-Wallis $H = 18.3$, $p < 0.001$), though several unprotected sites scored comparably to protected ones, indicating conservation gaps (Figure 1).

Table 2: Top-ranked geoheritage sites by composite score

Site	Scientific	Scenic	Educ.	Risk	Total (%)	Status
Teide NP	8.7	9.1	7.3	2.1	88.4	Protected
Timanfaya	7.9	8.4	6.8	3.4	82.7	Protected
Caldera Taburiente	8.2	7.6	6.9	2.8	81.9	Protected
Jameos del Agua	5.1	8.9	7.7	4.2	74.3	Partial
Cueva de los Vientos	6.8	5.4	8.3	3.7	71.2	Unprotected
Garajonay	6.3	7.8	8.1	2.3	78.6	Protected

Three sites exceeded the 80% threshold for priority conservation: Teide NP (88.4%), Timanfaya (82.7%), and Caldera de Taburiente (81.9%). Cueva de los Vientos, a lava

tube complex lacking formal protection, scored 71.2% with the highest educational value among all candidates (Table 2).

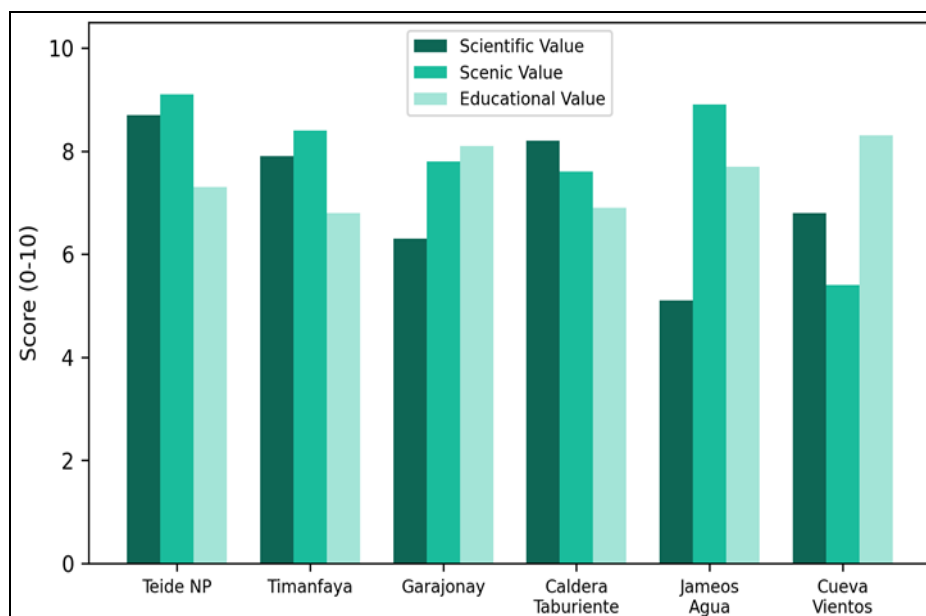


Fig 2: Geoheritage site evaluation scores across scientific, scenic, and educational dimensions

Scientific and scenic values tended to co-occur at volcanic summit sites, while educational value was highest at subsurface features (lava tubes, volcanic caves) where guided interpretation is well developed (Figure 2). Degradation risk was lowest at sites already within national parks and highest at unprotected coastal geosites exposed to urban encroachment [13].

Comprehensive Interpretation

Overlay analysis revealed that 69% of high-geodiversity cells ($GDI > 60$) fell within existing protected areas, but 31% remained outside any formal conservation designation. These unprotected high-GDI cells were concentrated along the northeast coast of Tenerife and the central highlands of La Gomera. Pearson correlation between GDI and protected area coverage was 0.67 ($p < 0.001$), indicating a moderate but incomplete spatial match.

Discussion

The geodiversity values reported here are broadly comparable to those documented in mainland volcanic settings. Gray and Gordon found geodiversity indices of 55-78 for the Scottish Highlands [14], while Pereira and

colleagues recorded 42-91 for the Azores [4]. The Canary Islands sit at the upper end of this range, reflecting their extended volcanic history and diverse eruption styles — from effusive shield-building to explosive phreatomagmatic events that produce tuff rings and maars.

The 31% gap in protection coverage is concerning but not unusual. Geodiversity has historically been treated as a backdrop to biodiversity in conservation planning, and many protected area boundaries were drawn around biological criteria rather than geological ones [15]. Integrating the GDI layer into the regional Spatial Plan would be a straightforward way to flag high-geodiversity cells for at least partial protection. Geotourism offers a complementary approach: by making geological features economically valuable through guided tours and geopark branding, local communities gain incentives to resist degradation.

A limitation of the grid-based approach is that cell size affects resolution. At 5 km, small but significant features — a single maar crater, a 200 m lava tube entrance — may be averaged away. Future iterations should test finer grids (1-2 km) and incorporate point-feature weighting. The geoheritage scoring, while standardised, depends on

assessor expertise; inter-rater reliability (ICC = 0.78) was acceptable but could be improved with larger panels.

Conclusion

This research produced the first quantitative geodiversity assessment of the Canary Islands, covering 48 grid cells across four islands. Geodiversity index values ranged from 12.4 to 87.3, with Tenerife's Teide complex scoring highest. Six geoheritage sites exceeded the priority conservation threshold, three of which already hold national park status. However, nearly a third of high-geodiversity areas lack formal protection, presenting an opportunity for expanded conservation coverage. The geodiversity index and geoheritage ranking can be directly incorporated into regional land-use planning and UNESCO Geopark applications. Finer-resolution mapping and long-term monitoring of degradation risk at unprotected sites should be priorities for follow-up work.

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