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Process-Based Geoheritage Assessment Reveals Geological Controls on Volcanic and Basement Landscapes in Plateau State, Nigeria

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Abstract

Plateau State, a highland state in north-central Nigeria, hosts one of the most diverse assemblages of volcanic and basement-controlled landforms in West Africa, including monogenetic cones, maars, ring complexes, granitic uplands, waterfalls, springs, crater lakes, and post-mining terrains. Yet these features are only weakly integrated into a formal geoheritage framework. This study presents the first process-based and spatially explicit assessment of geosites in the state by combining field mapping, digital elevation model-derived terrain analysis, and community knowledge. Eighteen representative geosites, selected to cover the principal volcanic, basement, and hydrological landform types of Plateau State, were evaluated to find how lithology, structure, and topography influence their distribution and geoheritage significance. Geosite clustering corresponds strongly to lithological boundaries, volcanic centers, fault-guided drainage, and major relief contrasts. A standardized assessment framework further

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reveals high intrinsic geological value but uneven accessibility, documentation, visitor management, and tourism infrastructure across the region. Wase Rock, Shere Hills, and Butura Rocks are the highest-ranking sites, while several scientifically important volcanic and hydrological geosites are still underdeveloped or vulnerable in management terms. The study shows how linking geological processes to geoheritage assessment can guide conservation priorities and sustainable geotourism development, while also strengthening the representation of African landscapes in global geoheritage discourse.

Keywords: Geoheritage, Volcanic landscapes, Geosite assessment, Plateau State Nigeria

Introduction

Plateau State, an elevated administrative region in north-central Nigeria, preserves a remarkable record of magmatism, tectonic uplift, deep weathering, hydrological evolution, and long-term human interaction with the landscape. Its geoheritage includes monogenetic cones, maars, trachytic plugs, granitic ring complexes, crater lakes, waterfalls, inselbergs, and post-mining terrains, which together document geological events spanning Precambrian basement assembly to Cenozoic intraplate volcanism (Ogezi et al. 2010; Lar et al. 2014; Goki et al. 2016). These landforms have clear scientific, educational, and cultural significance (Omosanya et al. 2025a). Yet, despite their importance, they are unevenly documented within the emerging geoheritage literature of Nigeria.

This limited documentation reflects a broader continental pattern. Over the past decade, African geoheritage research has grown rapidly, with inventories, geotourism assessments, and conservation studies from Libya, Egypt, Morocco, Angola, South Africa, São Tomé, and other parts of the continent (AbdelMaksoud et al. 2021, 2022; Jacobs et al. 2024; Baadi and Németh 2023; Jacobs et al. 2024; Elkaichi et al. 2025; Omosanya et al. 2025a). However, this work is uneven in geographical coverage, and many studies are site-specific or descriptive rather than process oriented. Although Plateau State has long been recognized for its volcanic landforms, abandoned tin-mining terrains, and scenic rock masses (Ogezi et al. 2010; Goki et al. 2016; Ebikemefa 2020), few studies have systematically linked these features to lithology, structural inheritance, topography, and hydrology within a standardized geoheritage framework. This

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omission is particularly significant in post-mining landscapes, where conservation, hazard, and water-management concerns converge (Omosanya and Ridwan 2025).

Recent geoheritage research emphasizes process-based interpretation, spatial analysis, and community engagement as essential foundations for sustainable geotourism and geoconservation (Dowling and Newsome 2018; Henriques and Neto 2023; Chingombe 2024). Plateau State provides an especially strong setting for such an approach because its volcanic centers, granite uplands, hydrological features, and mining-impacted terrains occur within a single region and can therefore be understood as parts of an interconnected geological landscape (Figs. 1, 2). This study therefore develops a process-based geoheritage framework for Plateau State by integrating geological mapping, digital elevation model analysis, field verification, and community-based inquiry. Specifically, we aim to: (a) determine how lithological, structural, and geomorphic factors control the distribution of key geosites; (b) evaluate their scientific, educational, cultural, and geotourism value using an established rubric; and (c) identify priority sites and landscape clusters for conservation, interpretation, and sustainable geotourism development.

Methods: Geosites

This study combines geospatial analysis, field observations, and community-derived knowledge to evaluate how geology, topography, and cultural perceptions shape the distribution and significance of geosites in Plateau State, Nigeria (Figs. 1–5). The assessment covers the three main geological domains of the state: (1) Precambrian basement rocks (migmatites, gneisses, and granites); (2) Younger Granite ring complexes and associated felsic intrusions; and (3) Cenozoic volcanic fields composed of cones, maars, lava-capped plateaus, plugs, and basaltic lava flows (Figs. 2, 4). The 18 geosites were selected because they met at least two of the following criteria: (i) prior recognition in published literature or government inventories; (ii) clear geomorphic expression in topographic data or satellite imagery; (iii) field verifiability; and (iv) local cultural or educational importance. This design allowed the inventory to capture the principal volcanic, basement, hydrological, and mining-related landform types present in Plateau State rather than only the most accessible tourist sites.

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Geological mapping used 1:100,000 and 1:250,000 sheets from the Nigerian Geological Survey Agency (NGSA; https://ngsa.gov.ng/), accessed through institutional request and therefore not fully open access. Terrain analysis used the public 30-m Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) distributed through USGS EarthExplorer (https://earthexplorer.usgs.gov/). Hillshade, elevation, slope, curvature, and terrain ruggedness index (TRI) layers were generated in QGIS v3.36.3. These products were chosen because they resolve complementary geomorphic attributes: hillshade enhances lineaments and crater rims, elevation surfaces quantify relative relief, slope and curvature discriminate scarps from basin floors, and TRI captures roughness linked to volcanic edifices, granite inselbergs, and site accessibility. High-resolution Google Earth Pro imagery (https://earth.google.com/) was used as a supplementary, publicly accessible visual layer to refine cone outlines, drainage traces, road access, and land cover patterns.

Consequently, geosite locations were compiled from published records, NGSA maps and archives, field reconnaissance with a Garmin eTrex 32x (typical horizontal accuracy ±3 m), and community referrals. During the fieldwork in January 2025, lithology, structures, photographs (Figs. 6–17), and geomorphological sketches at 13 accessible sites were documented. During the same campaign, semi-structured interviews and small-group discussions were held in communities near Pidong Crater Lake, Wase Rock, Shere Hills, Mafara Waterfall, Mazah, and Butura Rocks to record local names, perceived hazards, land-use constraints, and cultural meanings. For the spatial analysis, mapped geosites were overlain on geological maps and DEM-derived layers to test their association with lithological contacts, ring structures, fault/lineament corridors, volcanic centers, and topographic highs. Hydrological controls were examined using sink-filling and hydrologically corrected DEM analysis derived from the SRTM DEM to identify structurally guided channels, closed depressions, and spring-emergence zones relevant to waterfalls, crater lakes, and perennial springs.

Methods: Geotourism Assessment

Geoheritage and geotourism assessment followed the criterion-referenced rubric of (Dmytrowski and Kicinska 2011), as later operationalized by (Krawiec et al. 2022), but adapted to Plateau State conditions (Fig. 3). The rubric uses five basic domains: intrinsic value (I), positioning value

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(II), cultural value (III), scope of information (IV), and tourist development (V). Following Krawiec et al. (2022), intrinsic value integrates significance, visibility, state of preservation, size, aesthetic quality, uniqueness, and thematic diversity; positioning evaluates distance from roads and tourism nodes as well as the difficulty of visiting the site; cultural value captures links with history, belief, mining heritage, or local folklore; information value records the availability and reliability of published and online material; and tourist development evaluates management, signage, and visitor facilities. Because road access in Plateau State is highly uneven and often seasonally constrained, positioning (II) was kept analytically separate from educational value so that scientific importance would not be artificially reduced by infrastructural deficits.

In our adaptation, the maximum scores were I = 21, II = 11, III = 2, IV = 6, and V = 7, giving Educational Value (EV) = I + III + IV and Geotourist Attractiveness (GA) = EV + V. Geological significance within the intrinsic domain was judged from how clearly a site represents regional geological processes, its rarity in Plateau State, and the quality of observable features. Information value was split between peer-reviewed or archival sources and publicly accessible digital information. Tourist-development scores recorded legal or customary access, signage, visitor paths, parking or rest areas, and evidence of active management. Because no site occupied the full range of possible values, the results are discussed primarily as continuous comparative scores rather than collapsed into arbitrary classes.

Field verification was essential for assessing access conditions, slope gradients, vegetation cover, and physical barriers. Four trained geoscientists independently completed one scoring sheet per accessible site (13 sites × 4 assessments = 52 initial score sheets). Discrepancies were then discussed against field photographs, GPS records, and written notes, and a fifth evaluator acted only when consensus could not be reached. The final EV and GA values were linked to site coordinates for comparative mapping and radar-plot visualization (Fig. 18). Permissions were obtained for privately owned and sacred locations, and “cultural sensitivity” in this study refers to access restrictions, ritual significance, taboo areas, or community expectations concerning photography and visitor behavior. These constraints were recorded because they affect both site management and the feasibility of future geotourism development.

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Results

Geological and Terrain Controls on Landscape Organization

Plateau State shows a close correspondence between bedrock architecture and surface morphology (Figs 2, 4, 5). The landscape includes Precambrian basement rocks, Younger Granite ring complexes and associated felsic intrusions, Cretaceous–Paleogene sedimentary units, and extensive Cenozoic volcanic fields (Burke 2001; Lar et al. 2014; Dada et al. 2024). Hillshade, slope, and TRI models show that major landforms are concentrated along lithological contacts, circular intrusive margins, and linear fracture corridors. Two morphotectonic domains are especially prominent. The Kerang volcanic field has six small-volume monogenetic volcanoes sensu Németh and Kereszturi (2015), including scoria cones, cratered cones, and maar-like depressions, with summit elevations of ~1,250–1,400 m and slopes commonly exceeding 20–30° (Table 2; Figs. 4, 5). Their NW–SE arrangement parallels mapped basement fractures, consistent with structurally guided magma ascent. By contrast, the Tuwak–Tazak Ring Complex forms a broad, domed massif with concentric ridges and radial drainage, morphology typical of an exhumed Younger Granite ring complex rather than discrete cone volcanism (Figs. 1, 2, 4, 5, 9; Dada et al. 2024). South of the main Kerang cluster, smaller vents and cratered mounds define a subparallel trend that is compatible with the same fracture-controlled vent system, although this relationship requires higher-resolution structural mapping to confirm.

Description of Geosite Types

Columnar-Jointed Basalts and Lava Flows

Well-preserved columnar-jointed basalts were documented at Gahweng (9.52066° N, 8.70971° E), Mafara Waterfall (10.07736° N, 8.72691° E), and Surra Volcano (9.04000° N, 9.85972° E) (Figs. 6, 7; Table 1). These sites preserve cooling-contraction structures characteristic of basaltic lava flows, where polygonal fractures evolve during progressive inward cooling (Aydin and DeGraff 1988; DeGraff and Aydin 1993). At Gahweng, the exposed surface forms a laterally continuous polygonal pavement dominated by hexagonal and subordinate pentagonal columns. Vertical faces expose prisms locally exceeding 1 m in height, with near-regular spacing and fracture intersections approaching 120°, showing systematic crack propagation during cooling. Mafara displays shorter, thinner, and more variably curved columns developed in a waterfall escarpment. Here, column continuity is commonly interrupted by subhorizontal and radial

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fractures, and exposed column lengths are largely decimeter scale, suggesting stronger post-emplacement disintegration. At Surra, thick lava units preserve tall, upright columns with sharp margins, while talus aprons at the base contain detached polygonal blocks that retain original joint geometry. Across the three sites, variation occurs mainly in column height, continuity, curvature, and degree of weathering rather than in the underlying jointing mechanism. Together, these exposures provide clear evidence for thermally driven jointing in basaltic lava flows and show how subsequent weathering and slope processes modify columnar architecture after emplacement.

Hills, Inselbergs, and Granite Weathering Sites

Shere Hills (9.92314° N, 9.05944° E), Butura Rocks (9.35186° N, 8.87189° E), and Kambar Emurwi / "Seven Doors" (9.29244° N, 9.01056° E) record deep weathering and fracture-controlled erosion within the Precambrian basement complex (Figs. 8, 9). In the DEM derivatives, these sites coincide with zones of high local relief, sharp slope breaks, and short linear valleys that follow dominant NE–SW and NW–SE structural trends. At Shere Hills, elevations reach ~1,739 m a.s.l. (Table 1), making the site the highest topographic expression in the dataset. The landscape includes elongated granite ridges, rounded inselbergs, perched boulders, and closed depressions. Slope and curvature maps show that the lake basin occupies a topographic hollow bounded by linear ridge segments, consistent with structural guidance. Field observations confirm pervasive joint sets, exfoliation surfaces, and smooth dome-like granite morphologies generated by spheroidal weathering. Butura Rocks present a different expression of the same basement weathering system: large granitic blocks form overhangs, crevices, and cavity networks around fracture intersections. The outcrops expose foliation, joints, and sheeting fractures within porphyritic granite and migmatitic enclaves, showing how rock fabric controls block detachment and shelter formation. At Kambar Emurwi, interconnected cavities known locally as the "Seven Doors" occupy widened fractures within jointed granite, and the dimensions and orientation of the openings correspond closely with the dominant structural grain observed in the field.

Distinctive Structural and Erosional Landforms

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Bina–Mushere Rocks (9.07040° N, 8.95467° E), Riyom Rocks (9.60443° N, 8.80503° E), Luham Rock (9.05820° N, 9.56565° E), Kwi Conical Hill (9.61694° N, 8.850277° E), Pankshin Hill (9.317198° N, 9.443192° E), and the Tuwak–Tazak Ring Complex (9.28512° N, 9.46345° E) represent a second group of landforms in which differential erosion, structural inheritance, and long-term weathering are particularly clear (Fig. 10). Bina–Mushere and Riyom show rugged basement topography composed of short ridges, stepped slopes, and structurally guided drainage developed on granitoids and migmatite–gneiss assemblages. The DEM reveals aligned valleys and repeated break-of-slope zones that mirror the regional foliation and joint grain, signifying that inherited Pan-African fabrics still influence modern erosion. The Tuwak–Tazak Ring Complex contrasts with these basement highs by preserving a circular to arcuate footprint expressed as concentric ridges, radial drainage, and a broad central high, consistent with erosional dissection of a Younger Granite ring complex (Dada et al. 2024).

Kwi Conical Hill and Luham Rock illustrate more isolated residual forms. Kwi is a steep, near-symmetrical conical hill with radial gullies and a small resistant cap, morphology compatible with denudation of a resistant volcanic or intrusive core. Luham Rock is a classic inselberg with smooth dome-like flanks and exfoliation sheets produced by prolonged unloading and spheroidal weathering. Pankshin Hill shows a more compound morphology with twin summits separated by a shallow saddle, indicating differential erosion across a structurally heterogeneous bedrock mass. These landforms are distinctive not because they are subjectively “exceptional”, but because they clearly express specific erosional responses to lithology, jointing, and long-term tropical weathering.

Volcanic Landforms

Wase Rock (9.07639° N, 9.95833° E) is a prominent trachytic plug or volcanic neck that rises abruptly above the surrounding plains in southeastern Plateau State (Figs. 11–13). Field observations show steep cliffs, well-developed joints, spire-like projections, and sharp lithological contacts between the resistant trachytic core and surrounding country rocks. Its isolated form and the absence of any preserved outer cone at the surface are consistent with deep erosion of a former volcanic edifice, comparable to exhumed vent remnants described in monogenetic volcanic fields elsewhere (Németh 2003; Németh and Kereszturi 2015). Beyond

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Wase Rock, the Jos Plateau preserves a broad spectrum of volcanic landforms, including scoria (cinder) cones, cratered cones, maars, lava-capped plateaus, shield-like lava cones, dome-like mounds, and volcanic ridges (Figs. 5, 12, 13; Table 2). In the Kerang field, Kerang I and II rise to ~1,374 and 1,337 m a.s.l., respectively, and display steep outer slopes of about 25–30°, while Dal I is better described as a maar-diatreme depression and Dal II as an eroded scoria cone or tuff-ring remnant (Table 2). Around Pidong, circular to elliptical depressions with steep inner walls and flat floors are consistent with maar morphology. By contrast, Kwakwi and Amshel are broad, lower-relief volcanic edifices better described as shield-like lava cones or lava-dome/shield hybrids than as simple "cones". This diversity of forms shows that Plateau State volcanism was not restricted to one volcano type but involved multiple eruption styles and variable magma-water interaction, in line with the spectrum expected in monogenetic volcanic provinces (Németh and Kereszturi 2015).

Springs, Lakes, and Volcanic-Structural Hydrology

Pidong Lake (9.28766° N, 9.20260° E) and Mazah Spring (9.95788° N, 8.94333° E) show how volcanic topography and basement fracture permeability control local hydrology (Fig. 14). Pidong occupies a closed depression within the Kerang volcanic field and is surrounded by low cones and crater rims that act as local drainage divides. DEM-based flow routing shows convergence of surface runoff into the basin, while field observations indicate that the depression also receives subsurface recharge along fractured volcanic and granitic margins. The surrounding landforms are well preserved morphologically, but the present dataset does not allow precise age assignment; thus, the site is interpreted primarily as a structurally confined volcanic basin rather than evidence of recent eruption. Mazah Spring emerges from a narrow fracture-controlled zone in granitic gneiss, where joints intersect and a small shear zone channel groundwater to the surface (Figs. 1, 4, 5). The spring therefore provides a direct example of structurally focused discharge in basement terrain. Overall, all the sites in this category show that hydrological geoheritage in Plateau State is controlled not only by climate and relief, but by the interaction of volcanic depressions, lithological contrasts, and fracture permeability.

Structurally Controlled Waterfalls

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Kurra Falls (9.45007° N, 8.71581° E), Assop Falls (9.51730° N, 8.62240° E), and Mafara Waterfall (10.07736° N, 8.72691° E) document contrasting modes of waterfall formation related to basement structure, bedrock resistance, and columnar-jointed volcanic rocks (Figs. 15–17). In the hydrological maps, all three occur at marked breaks in slope along mapped river channels (Fig. 15). Kurra Falls occupies a narrow bedrock gorge cut into crystalline rocks, and the waterfall lip follows a linear fracture-controlled corridor visible in both the channel planform and gorge walls. Assop Falls is broader and multi-tiered, extending laterally across gently inclined bedrock benches; its morphology reflects distributed flow over irregular rock steps rather than a single vertical fall. Mafara differs from both sites because the cascade is segmented by vertical to subvertical basalt columns. Water descends along joint planes and column boundaries, creating a staircase of short drops and plunge pools. The angular basalt blocks at the foot of the falls preserve the original joint geometry, confirming that rock mass structure directly controls channel form and retreat style.

Geoheritage Scoring and Comparative Site Evaluation

Using the adapted Dmytrowski–Kicińska/Krawiec rubric described above 13 of the 18 inventoried geosites were quantitatively assessed; five sites were excluded from scoring because road access, terrain, or land-use constraints prevented consistent field evaluation. The results, summarized in Table 3 and Figure 18, show clear variation in geotourist attractiveness across the assessed sites. Wase Rock recorded the highest geotourist attractiveness (GA = 36), reflecting a combination of high intrinsic value (I = 21), strong documentation (IV = 6), cultural associations (III = 2), and relatively developed visitor infrastructure (V = 7). Shere Hills ranked second (GA = 33), supported by high intrinsic value (I = 20), good accessibility (II = 9), and the strongest combined educational profile after Wase. Butura Rocks followed with GA = 29, showing that strong scenic quality, road access, and site usability can partly compensate for lower cultural or information scores. Assop Falls and Kerang Volcanoes each reached GA = 28, whereas lower-scoring sites such as Mafara Waterfall Columnar Basalts (GA = 21) and Mazah Spring (GA = 24) were penalized mainly by weak documentation, lack of interpretive materials, and limited site facilities rather than by low scientific merit.

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Overall, these scores reveal three broad patterns. First, intrinsic geological value is still consistently high across much of the inventory, with many sites scoring between 17 and 21 in that domain. Second, the final rankings are strongly shaped by external factors, especially accessibility, site marking, and the availability of documentation. Third, scientific importance does not automatically translate into visitor readiness. This is true as several of the most informative geosites remain poorly prepared for tourism and public engagement. This distinction is significant for management, as it highlights sites that require conservation measures, interpretation, and basic infrastructure before active promotion. Additionally, when combined with the spatial analysis, the value assessment offers a more integrated picture of geoheritage quality across Plateau State. Relating the scored geosites to communication networks, geological zones, and morphotectonic domains shows that the strongest geotourism opportunities tend to occur where high geological value coincides with reasonable accessibility. At the same time, several scientifically important sites are still peripheral or logistically constrained. This spatial mismatch has direct planning implications, highlighting the need to prioritize infrastructure, interpretation, and legal protection in areas where geoheritage significance is high but tourism readiness remains low.

Educational Value (EV) and Geotourist Attractiveness (GA)

The thirteen scored geosites also show clear differences in educational value (EV = I + III + IV) and geotourist attractiveness (GA = EV + V) (Table 3; Figure 18). Under this Plateau State adaptation, EV isolates scientific, cultural, and interpretive potential, while GA adds visitor-development capacity. EV ranges from 16 to 29. Wase Rock records the highest EV (29), followed by Shere Hills (28). Bina–Mushere Rocks, Kerang Volcanoes, Pidong Lake, and the Tuwak–Tazak Ring Complex each score 23, indicating solid educational potential even where visitor infrastructure is still limited. Mafara Waterfall Columnar Basalts yields the lowest EV (16), largely because interpretation and documentation are weak despite the quality of the geological exposure. GA ranges from 21 to 36. Again, Wase Rock leads (36), followed by Shere Hills (33) and Butura Rocks (29). Assop Falls reaches a relatively high GA (28) because its accessibility and facilities elevate its tourism appeal above sites with comparable scientific scores. In contrast, the Tuwak–Tazak Ring Complex has EV = 23 but GA = 25, showing that a geologically important site can remain underdeveloped from a visitor perspective. The combined

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EV–GA comparison therefore helps distinguish sites that are already tourism-ready from those that are currently more valuable for research, geoeducation, and future investment.

Discussion

Geological and Geomorphic Controls on Volcanic Landscapes and Geoheritage in Plateau State, Nigeria

The distribution of geosites across Plateau State reflects a coherent geological framework controlled by lithology, inherited structures, volcanic emplacement, and long-term erosion (Figs. 1, 2, 4, 5). Volcanic cones, columnar basalts, ring complexes, waterfalls, and springs are not randomly scattered. They cluster along mapped lithological boundaries, fracture corridors, and topographic gradients. In the Kerang and Tuwak–Tazak sectors, cone alignments, crater depressions, radial drainage, and relief contrasts collectively show that basement structures guided magma ascent and later influenced erosion and runoff organization. Comparable first-order structural control has been described in other African intraplate volcanic provinces, including the Cameroon Volcanic Line and the Hoggar (Fitton 1987; Burke 2001; Liégeois et al. 2005).

Moreover, the terrain morphology further reinforces these controls. Closed depressions and low-gradient volcanic basins concentrate runoff and favor lake development, while fractured basement slopes and lithological breaks localize spring emergence and waterfalls. In Plateau State, this is expressed by the crater-basin setting of Pidong Lake, the fracture-controlled discharge at Mazah Spring, and the break-of-slope positions of Kurra, Assop, and Mafara Falls (Figs. 14–17). Human pressure is most visible around accessible sites such as Wase Rock and parts of the Kerang field, where farms, footpaths, roadside development, and visitor traffic encroach on the immediate geomorphic setting. These observations show that management must protect not only iconic outcrops but also the surrounding fracture zones, drainage paths, and volcanic slopes that make them scientifically meaningful.

Key Geological Processes Shaping Geoheritage in the Jos Plateau

The geoheritage of the Jos Plateau reflects the interaction of three long-lived geological processes: Precambrian basement evolution, Cenozoic intraplate volcanism, and prolonged

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tropical weathering. These processes jointly produced the diverse volcanic, structural, and geomorphic features observed across Plateau State (Figs. 1–17). The structural framework of the region is inherited largely from Pan-African tectonism, during which granitoids, migmatites, and gneisses were emplaced and deformed along major fracture and shear systems (Goodenough et al. 2014; Dada et al. 2024). These ancient structures continue to influence landscape development by guiding erosion, drainage patterns, and magma ascent. The alignment of volcanic cones, ring complexes, and linear valleys across the plateau reflects repeated reactivation of these basement fabrics (Figs. 1, 2, 15). Cenozoic intraplate volcanism is the second key process when volcanic cones, maars, lava plateaus, and intrusive plugs formed as magma exploited pre-existing fractures within the basement. Similar structural control on volcanism has been documented elsewhere in Africa, including along the Cameroon Volcanic Line and in the Hoggar region (Burke 2001; Fitton 1987). The contrast between steep monogenetic cones and broad ring complexes in Plateau State is not merely morphological, but genetically significant. It indicates that the region records both shallow, short-duration volcanic eruptions and deeper, more complex intrusive magmatic systems (Walker 1989; Németh and Kereszturi 2015; Omosanya et al. 2020). While the cones testify to rapid surface construction by relatively simple eruptive episodes, the ring complexes point to prolonged magmatic evolution, structural emplacement, and deep crustal interaction (Thouret 1999; Acocella 2021).

Differential erosion has then acted as a secondary control, enhancing the topographic expression of resistant intrusive complexes while changing or partially degrading the more fragile volcanic cones. Additionally, long-term tropical weathering has further shaped the landscape. Chemical weathering, exfoliation, and spheroidal breakdown of granitic rocks have produced inselbergs, tors, and rock cavities, while differential erosion along joints and lithological boundaries has preserved resistant volcanic and intrusive cores (Figs. 8, 9). Hydrological features such as springs, crater lakes, and waterfalls are closely tied to fracture permeability and lithological contrasts. Recognizing these processes is essential for geoheritage interpretation, as the value of the Jos Plateau lies not only in scenic landforms, but in their ability to record deep-time tectonic inheritance, magmatic evolution, and surface processes.

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Management and Policy Implications for Geoheritage Conservation and Geotourism Development

The findings have practical implications for how geoheritage is managed in Plateau State. Most importantly, the results argue against piecemeal protection of isolated tourist spots. Because the sites are rooted within larger volcanic, structural, and hydrological systems, effective management must run at landscape scale. This conclusion is supported by the mapped association of geosites with lineament corridors, volcanic clusters, drainage networks, and lithological boundaries (Figs. 1, 2, 5, 15). A key implication is the need to protect geosites in context (Omosanya et al. 2025b; Omosanya and Ridwan 2025). Wase Rock depends scientifically on its interpretation as an exhumed trachytic plug; the Kerang sites are meaningful as a field of related vents rather than as disconnected cones; and hydrological sites such as Pidong and Mazah are best understood as products of basin geometry and fracture permeability. Protecting only the visible main feature while ignoring adjacent lava surfaces, spring recharge zones, or structurally controlled drainage would therefore reduce the scientific integrity of the site. The scoring results further show that high geological value does not automatically translate into high geotourism readiness. Mafara columnar basalts and Mazah Spring, for example, are scientifically informative but remain weakly supported by access, signage, safety provisions, and interpretation.

At a broader scale, the clustering of volcanic, basement, hydrological, and mining-related sites creates a realistic basis for linked geotrails rather than an immediate standalone UNESCO Global Geopark proposal. A phased approach would be more feasible: (a) formal inventory and legal recognition of priority sites; (b) community co-designed interpretation, signage, and low-impact visitor infrastructure; and (c) integration of these nodes into regional educational routes connecting volcanoes, ring complexes, crater lakes, waterfalls, and mining heritage. Discussions during fieldwork indicated local interest in site visibility and livelihood opportunities, especially near Wase, Shere, and Mafara, but also highlighted concerns about land ownership, sacred access rules, and uneven road quality. These realities suggest that community-backed geotrails and state-level protection are more immediate priorities than geopark nomination, although they could form the groundwork for future geopark-scale initiatives.

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Comparison with Previous Work

Earlier studies laid important foundations for recognizing the geoheritage potential of Plateau State, but much of this work remained largely descriptive rather than analytical. Ogezi et al. (2010) listed notable sites such as Riyom Rock, Pidong Lake, and the Gahweng basalts and emphasized their scenic and tourism appeal, yet without explicitly linking these features to the geological processes responsible for their formation. Goki et al. (2016) highlighted abandoned tin-mining areas and their geotourism value but did not place those anthropogenic terrains within a broader structural and geomorphic framework. Ebikemefa (2020) addressed cassiterite-bearing zones and artisanal mining from a socio-economic perspective, again with limited attention to the process-based controls on geosite distribution. Through the integration of DEM analysis, structural interpretation, hydrology, and field verification, the present study moves beyond inventory to explain why specific geosites occur where they do and why some remain more resilient, accessible, or vulnerable than others.

Constraints and Limitations

This study has a few limitations that must be acknowledged. First, precise age constraints are unavailable for many volcanic features across Plateau State, preventing a detailed chronological reconstruction. Second, morphostructural interpretation relies chiefly on 30-m DEM data, so subtle scarps or small faults may remain unresolved. Third, only 13 of the 18 inventoried geosites (72.2%) could be quantitatively scored; the remaining five sites (27.8%) were excluded because of poor roads, rugged terrain, seasonal access, or land-use restrictions preventing consistent field assessment. These constraints do not invalidate the regional patterns reported here, but they do mean that finer-scale structural mapping, geochronology, geophysics, and repeat site visits are needed to refine the model. Despite these constraints, the integrated framework applied here shows strong potential for advancing geoheritage research in understudied regions. The combination of geological mapping, terrain analysis, hydrological observations, and field-based site assessment provides a practical and transferable approach for linking Earth processes to geoheritage value, even where data availability and access are limited. This is particularly relevant for large parts of Nigeria and other African regions where logistical challenges often restrict field-based evaluation.

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Conclusion

This study shows that the geoheritage of Plateau State is organized by geological process rather than isolated scenery. By integrating geological mapping, DEM analysis, field observations, and community knowledge, the study provides the first spatially explicit framework for linking geosite distribution in Plateau State to lithological boundaries, structural fabrics, volcanic centres, and hydrological controls. We identify Wase Rock, Shere Hills, and Butura Rocks as the best-developed flagship sites, but several scientifically important locations, especially columnar basalts, springs, and volcanic basins, remain under-documented and under-managed. Plateau State therefore constitutes a major volcanic and basement-controlled landscape in West Africa with clear potential for geoeducation, geotourism, and conservation. Future work should prioritize geochronology, geochemistry, structural mapping, and community-based interpretation so that these landscapes can be protected as connected geological systems rather than isolated attractions.

Author Contributions

KOL: Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Statistical Analysis, Interpretation of Results, Figure creation and editing, Writing – Review & Editing. BI: Fieldwork Coordination, Resources, Data Acquisition, Writing. GOM: Validation, Writing – Review & Editing, Quality Assurance. Project Administration. SHO: Validation, Review & Editing, Quality Assurance. OA: Visualization, Review & Editing, Quality Assurance. All authors reviewed the manuscript.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest associated with this study.

Ethics statement

Where local stakeholder engagement occurred (e.g., structured interviews and informal consultations with community members, park staff, and local authorities to document site accessibility, land use, cultural associations, and perceived threats), participation was entirely voluntary. Informed consent was obtained from all individuals who participated in stakeholder

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interviews, consultations, or discussions during fieldwork. Participation was voluntary, and participants were informed of the purpose of the research and their right to withdraw at any time

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

AbdelMaksoud KM, Abdulsamad EO, Muftah AM, Aly MF 2022. Geomorphosite inventory of Apollonia and Cyrene in northeast Libya: involvement in geotourism promotion. Geoheritage. 14:114. https://doi.org/10.1007/s12371-022-00747-z

AbdelMaksoud KM, Baghdadi MI, Ruban DA 2021. Caves as geoheritage resource in remote desert areas: A preliminary evaluation of Djara Cave in the Western Desert of Egypt. Geologos 27:105–113. https://doi.org/10.2478/logos-2021-0011

Acocella V 2021. Volcano-Tectonic Processes, Advances in Volcanology. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-030-65968-4

Aydin A, DeGraff JM 1988. Evolution of polygonal fracture patterns in lava flows. Science. 239:471–476. https://doi.org/10.1126/science.239.4839.471

Baadi K, Németh K 2023. Volcanic landscape of the Middle Atlas: A representative heritage of Moroccan geological history, in: Baadi, K. (Ed.), Geoheritage of the Middle Atlas (Morocco. Springer, Cham, pp. 195–218. https://doi.org/10.1007/978-3-031-27073-4_13

Burke K 2001. Origin of the Cameroon line of volcano-capped swells. Journal of Geology. 109:349–362. https://doi.org/10.1086/319977

Chingombe W 2024. A framework for evaluating geotrails for education and geotourism. African Journal of Hospitality, Tourism and Leisure. 13:66–75. https://doi.org/10.46222/ajhtl.19770720.483

Dada SS, Olobaniyi SB, Omosanya KO 2024. Geology and Natural Resources of Nigeria 1st ed. CRC Press, Boca Raton. https://doi.org/10.1201/9781003454908

DeGraff JM, Aydin A 1993. Effect of thermal regime on growth increment and spacing of contraction joints in basaltic lava. Journal of Geophysical Research. 98:6411–6430. https://doi.org/10.1029/92JB01709

DOI: https://doi.org/10.57647/gcr.2026.0901.02

Dmytrowski P, Kicinska A 2011. Waloryzacja geoturystyczna obiektów przyrody nieożywionej i jej znaczenie w perspektywie rozwoju geoparków. Problemy Ekologii Krajobrazu 29.

Dowling RK, Newsome D (Eds.) 2018. Handbook of Geotourism. Edward Elgar Publishing, Cheltenham Northampton.

Ebikemefa J 2020. Artisanal cassiterite mining and geotourism potentials on the Jos Plateau, Nigeria. Journal of Environmental Earth Science. 10:44–52.

Elkaichi A, Errami E, El Hamidy M 2025. African trends in research promoting geoheritage, geoconservation, geotourism, and geoparks: state of the art and future challenges. Episodes. 48:315–327. https://doi.org/10.18814/epiiugs/2025/025010

Fitton JG 1987. The Cameroon line, West Africa: a comparison between oceanic and continental alkaline volcanism. Geological Society, London, Special Publications. 30:273–291. https://doi.org/10.1144/GSL.SP.1987.030.01.13

Goki NG, Dibal HM, Lar UA 2016. Preliminary assessment of the post-mining geotourism potential of the Plateau tin fields, Nigeria. Acta Geoturistica. 7:21–30.

Goodenough KM, Lusty PAJ, Roberts NMW, Key RM, Garba A 2014. Post-collisional pan-African granitoids and rare metal pegmatites in western Nigeria: Age, petrogenesis, and the ‘pegmatite conundrum.’ Lithos. 200–201: 22–34. https://doi.org/10.1016/j.lithos.2014.04.006

Henriques MH, Neto K 2023. A geo-itinerary to foster sustainable tourism in West African islands: storytelling the evolution of the ancient Cameroon Volcanic Line coral reefs. Sustainability. 15:16863. https://doi.org/10.3390/su152416863

Jacobs LL, Schröder S, Sousa N, Dixon R, Fiordalisi E, Maréchal A, Mateus O, Nsungani PC, Polcyn MJ, Pereira GDCR, Rochelle-Bates N, Schulp, AS, Scotese CR, Sharp I, Silvano CG, Swart R, Vineyard DP 2024. The Atlantic jigsaw puzzle and the geoheritage of Angola. Geological Society, London, Special Publications. 543:395–408. https://doi.org/10.1144/SP543-2022-301

Krawiec A, Wysocki W, Jamorska I, Belzyt S 2022. Geoturist evaluation of geosites in the Tuchola Forest Biosphere Reserve (N Poland). Resources. 11:13. https://doi.org/10.3390/resources11020013

DOI: https://doi.org/10.57647/gcr.2026.0901.02

Lar UA, Tsalha MS, Bart HW 2014. Preliminary 40Ar/39Ar geochronology of the Kassa volcanic field on the Jos Plateau, Nigeria. Continental Journal of Earth Sciences. 9:16–29.

Liégeois J-P, Benhallou A, Azzouni-Sekkal A, Yahiaoui R, Bonin B 2005. The Hoggar swell and volcanism: Reactivation of the Precambrian Tuareg shield during Alpine convergence and West African Cenozoic volcanism, in: Plates, Plumes and Paradigms. Geological Society of America (pp. 379-400). https://doi.org/10.1130/0-8137-2388-4.379

Németh K 2003. Calculation of long-term erosion in Central Otago, New Zealand, based on erosional remnants of maar/tuff rings. Zeitschrift für Geomorphologie. 47:29–49. https://doi.org/10.1127/zfg/47/2003/29

Németh K, Kereszturi G 2015. Monogenetic volcanism: personal views and discussion. International Journal of Earth Sciences. 104:2131–2146. https://doi.org/10.1007/s00531-015-1243-6

Neto K, Henriques MH 2022. Geoconservation in Africa: State of the art and future challenges. Gondwana Research. 110:107–113. https://doi.org/10.1016/j.gr.2022.05.022

Ogezi AEO, Lar AU, Akpa TC 2010. Geological and geotourism potentials of some sites in Plateau State, Nigeria. Earth Science Research Journal. 14:99–114.

Omosanya KO, Maia AR, Eruteya OE 2020. Seismic, morphologic and scale variabilities of subsurface pipes and vent complexes in a magma-rich margin. Bulletin of Volcanology. 82:40. https://doi.org/10.1007/s00445-020-01379-3

Omosanya KOL, Bunyaminu I, Mosuro GO, Oluwatosin SH 2025a. Sacred landscapes and indigenous geoconservation in Nigeria: integrating traditional knowledge for sustainable geoheritage. Episodes 0001;0. https://doi.org/10.18814/epiiugs/2025/025045

Omosanya KOL, Oludipe V, Oseni R, Mosuro GO, Saka Omosanya H, Isah B, Sheriff S 2025b. Balancing Extraction and Conservation: Policy Instruments for Geoheritage Protection in Mineral-Rich Nigeria. SSRN. https://doi.org/10.2139/ssrn.5283197

Omosanya KOL, Ridwan O 2025. Global strategies for protecting geoheritage sites from mining with lessons for Nigeria and Africa. Discover Geoscience. 3:218. https://doi.org/10.1007/s44288-025-00332-1

Thouret J-C 1999. Volcanic geomorphology—an overview. Earth-Science Reviews. 47:95–131.

DOI: https://doi.org/10.57647/gcr.2026.0901.02

Walker GPL 1989. Gravitational (density) controls on volcanism, magma chambers and intrusions. Australian Journal of Earth Sciences. 36:149–165. https://doi.org/10.1080/08120098908729479

Table 1. List of selected geosites in North-Central Plateau State, Nigeria, showing their geographical coordinates, regional location, and classification by feature type.

#	Geosite	Latitude (N)	Longitude (E)	Geology	TRI	Elev
1	Assop Falls	9.517299	8.622403	Paleogene Igneous	13.15295	736
2	Bina-Mushere Rocks	9.0704	8.95467	Precambrian	27.01851	790
3	Butura Rocks	9.351859	8.87189	Precambrian	25.65151	1425
4	Gahweng Columnar Basalts	9.52066	8.70971	Precambrian	1.0000	1060
5	Riyom Rocks	9.604433	8.80503	Precambrian	4.3589	1294
6	Kurra Falls	9.45007	8.71581	Cretaceous	6.78233	1141
7	Mafara Waterfall	10.07736	8.7269097	Cretaceous	6.16441	1101
8	Mazah Spring	9.95788	8.94333	Paleogene Igneous	35.42598	1135
9	Pidong Lake	9.28766	9.2026	Cretaceous	5.83095	1314

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10	Shere Hills	9.92314	9.05944	Lower Cretaceous	10.90871	1739
11	Wase Trachytic plug	9.07639	9.95833	Paleogene Igneous	49.76947	306
12	Kerang Volcanoes	9.35095	9.192861	Precambrian	26.81417	1337
13	Tuwak-Tazak Ring Complex	9.28512	9.46345	Paleogene Igneous	9.38083	1300
14	Surra Volcano	9.04	9.85972	Holocene	29.20616	305
15	Kambar Emurwi	9.292444	9.010556	Precambrian	11.87434	1326
16	Luham Rock	9.058201	9.565646	Precambrian	25.74879	818
17	Kwi Conical Hill	9.616944	8.850277	Precambrian	12.68858	1314
18	Pankshin Hill top	9.317198	9.443192	Precambrian	20.02498	1354

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Table 2. Geospatial and Geomorphological Characteristics of Selected Volcanoes in Plateau State, Nigeria. Slope and Elevation were derived from SRTM data.

#	Latitude	Longitude	Volcanoes	Type	Morphology	Slopes & Preservation	Geology	Elev	TRI
1	9.85608	8.73275	Miango volcano Fort I & II	Cone	Cone with crater breach	Breached scoria cone	Paleogene Igneous	1272	18.57417
2	9.85	8.73861	Miango volcano II	Cone	Broad	Eroded maar–tuff ring	Paleogene Igneous	1228	15.74802
3	9.617861	8.827801	Riyom I	Volcanic Plateau	Cone with broad flat summit (lava-capped)	Steep lower slopes (~25–30°)	Paleogene Igneous	1283	22.51666
4	9.627006	8.821137	Riyom II	Volcanic Plateau	Large	Scoria/stratiform cone (lava-capped)	Paleogene Igneous	1288	17
5	9.577705	8.645793	Kwakwi	Cone	Broad	Shield-like lava cone (eroded)	Paleogene Igneous	1081	12.04159
6	9.403643	9.175805	Amshel (Wushik-Lakas)	Cone	Dome-like	Lava dome / shield hybrid	Paleogene Igneous	1216	12

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7	9.35095	9.192861	Kerang II	Cinder Cone	Small	Scoria (cinder) cone	Paleogene Igneous	1337	26.81417
8	9.342246	9.190731	Kerang I	Cone	Large cone with breached rim and nested craters	Steep outer slopes (~25–30°)	Paleogene Igneous	1374	19.41649
9	9.329931	9.199378	Dal II	Cone	Low-relief	Eroded scoria cone / tuff ring	Paleogene Igneous	1345	17.32051
10	9.320619	9.201271	Dal I	Cone	Broad	Maar-diatreme	Paleogene Igneous	1342	18.3303
11	9.291622	9.203045	Pidong	Crater	Deep crater infilled with water	Rim slopes ~18–25°	Paleogene Igneous	1307	5
12	9.28306	9.28056	Jiblik	Cone	Elongated volcanic ridge	Compound scoria–lava flow complex	Paleogene Igneous	1038	5.56776
13	9.22925	9.27443	Timjahas (Kagu)	Cone	Steep-sided	Scoria cone	Paleogene Igneous	923	6.245
14	9.18716	9.26394	Ampang (Katul)	Cone	Broad cone with wide	Moderate slopes (~20–25°)	Precambrian	921	11.09054

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					summit crater				
15	9.04	9.85972	Surra	Cone	Cone with basaltic core; lava infill	Outer flanks ~25–30°	Holocene	305	29.20616
16	9.18176	8.79972	Passakai Field	Dome	Landscape of many small cones	Cones with slopes ~15–22°	Miocene	1274	16.76305

Table 3. Multi-Criteria Assessment of Geosites in Plateau State, Nigeria. Assessment of selected geosites based on intrinsic, positional, cultural, and educational values, as well as tourist development and geotourist attractiveness. Educational value (EV) is calculated as the sum of intrinsic value (I), cultural value (III), and information availability (IV), while Geotourist Attractiveness (GA) is the sum of EV and tourist development score (V).

Geosite#	I	II	III	IV	V	VII	VIII
Assessment Criteria	Intrinsic value of the site	The positioning value of the site	The cultural value of the site	Scope of information on the site and its availability	Tourist development of the site	Educational value (EV = I + III + IV)	Geotourist attractiveness (GA = EV + V)
Gahweng Columnar Basalts	17	7	1	2	4	20	24
Mafara Waterfall Columnar Basalts	14	8	0	2	5	16	21
Shere Hills	20	9	2	6	5	28	33
Butura Rocks	19	9	1	2	7	22	29
Bina-Mushere Rocks	21	9	0	2	2	23	25
Pidong Lake	17	7	1	5	4	23	27
Mazah Spring	15	8	0	4	5	19	24

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Wase Trachytic plug	21	8	2	6	7	29	36
Kerang Volcanoes	17	7	1	5	5	23	28
Tuwak-Tazak Ring Complex	21	9	0	2	2	23	25
Kurra Falls	17	7	1	2	4	20	24
Assop Falls	17	11	0	5	6	22	28
Mafara Waterfall	15	6	2	2	5	19	24
Min	14	6	0	2	2	16	21
Max	21	11	2	6	7	29	36
Mean	17.77	8.08	0.85	3.46	4.69	22.08	26.77

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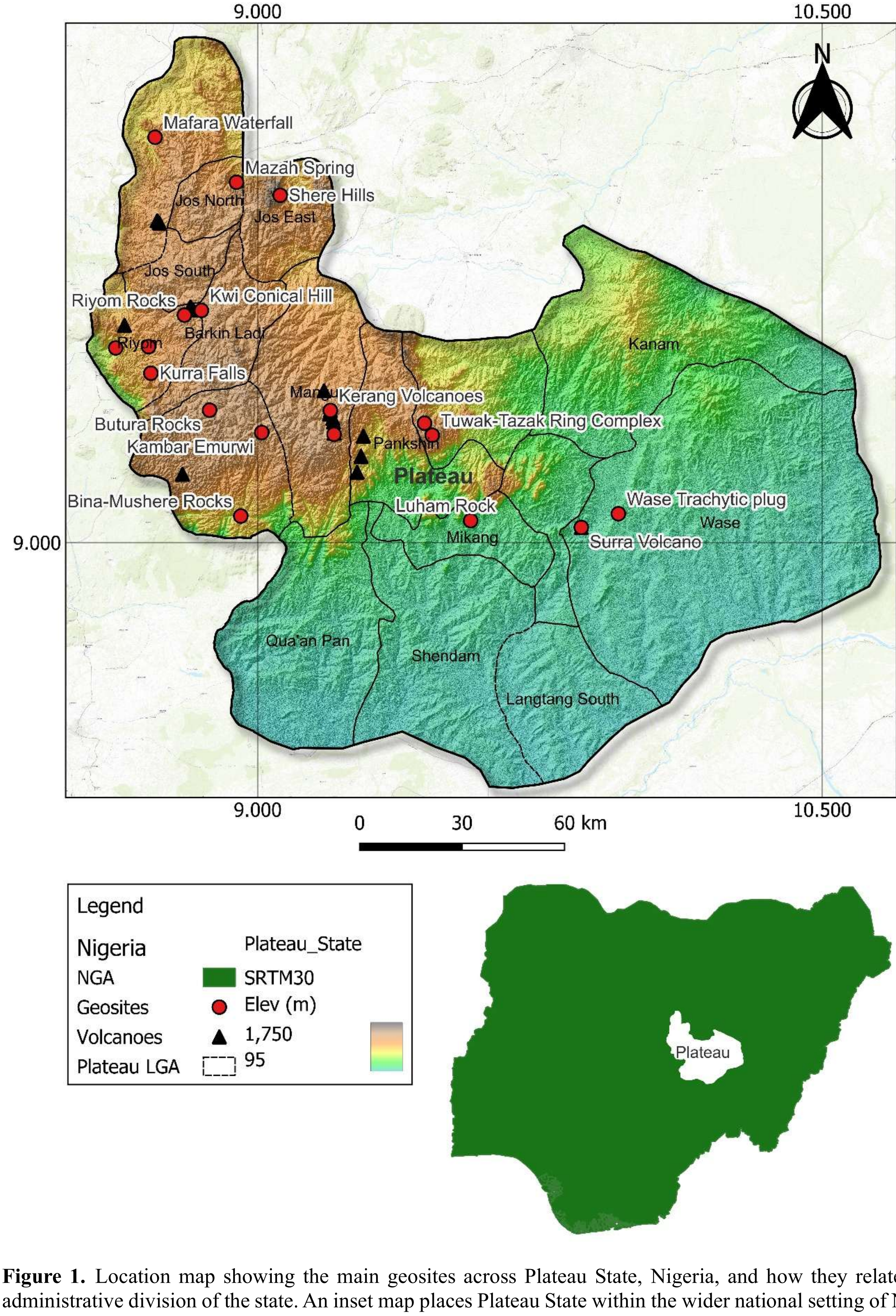

Figure 1. Location map showing the main geosites across Plateau State, Nigeria, and how they relate to the administrative division of the state. An inset map places Plateau State within the wider national setting of Nigeria. Note: The map is based on a Digital Elevation Model (DEM) of Plateau State derived from SRTM30 data and displayed with hillshade to enhance terrain detail. Elevation ranges from about 95 to 1,750 meters, with contour intervals of 100 and 250 meters. *Map projection: WGS 84 / UTM Zone 32N-EPSG:32632*

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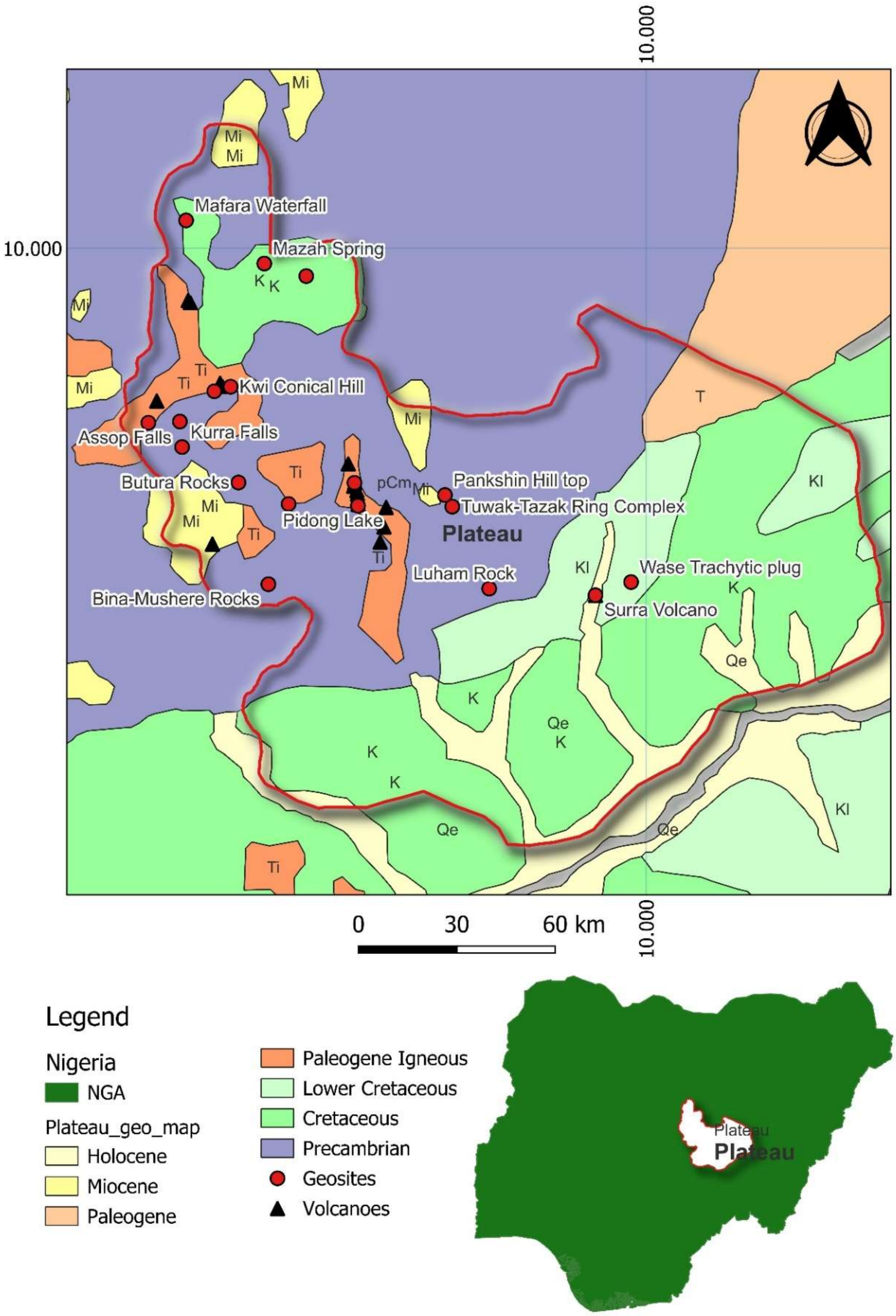

Figure 2. Geological map of Plateau State, Nigeria, showing the distribution of major lithological units and their relationship with significant geosites. The mapped formations include Precambrian basement rocks, Cretaceous sediments, Paleogene igneous intrusions, Miocene to Holocene deposits, and associated volcanic complexes. The geological map is draped with hillshade for enhanced terrain visualization. Prominent geoheritage sites such as Shere Hills, Wase Trachytic Plug, Kerang Volcanoes, and Surra Volcano are highlighted, showing the interplay between geological evolution and geomorphological expression. The inset shows the location of Plateau State within Nigeria. *Map projection: WGS 84 / UTM Zone 32N-EPSG:32632*

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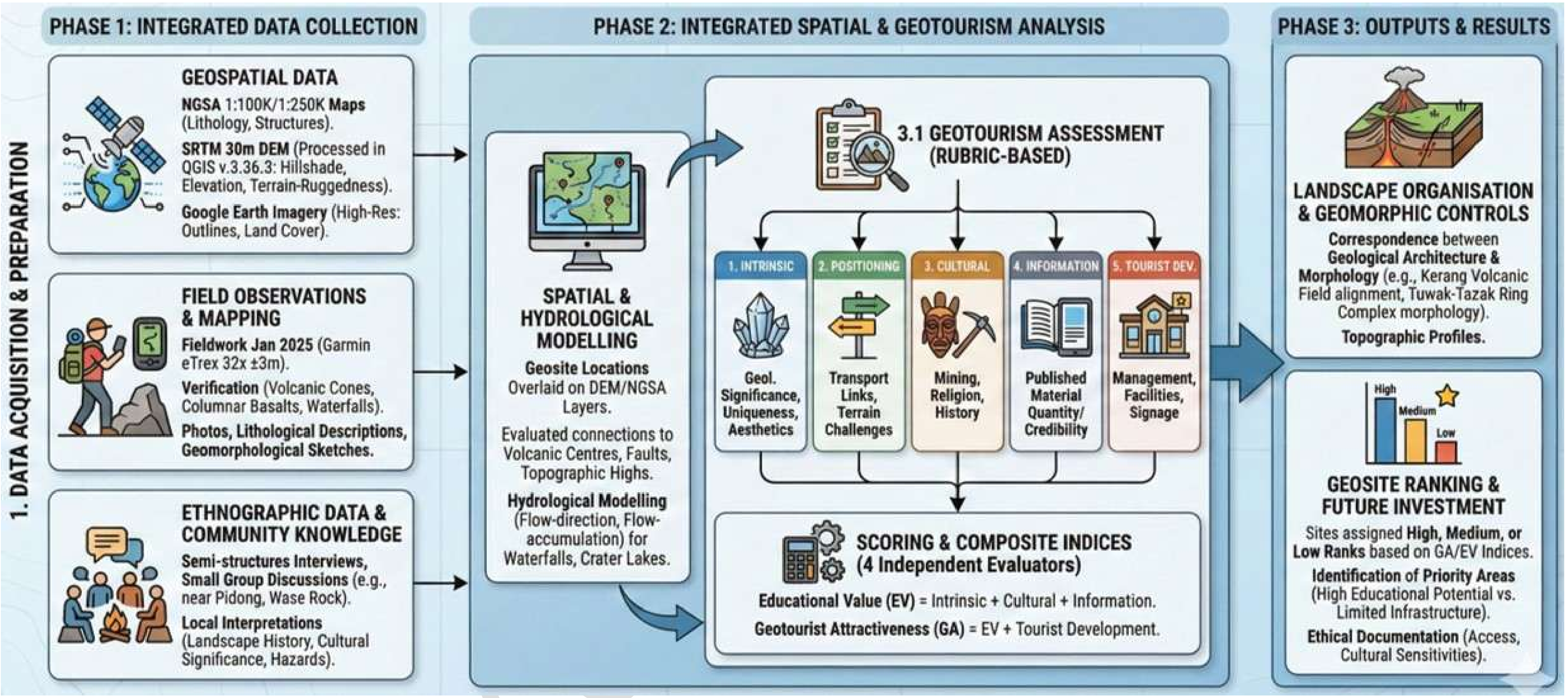

Figure 3: Integrated research framework for geosite evaluation in Plateau State, Nigeria. The diagram summarises a three-phase approach that combines geological, topographic, and cultural perspectives. Phase 1 outlines integrated data collection, including geospatial datasets, field mapping, and community-based ethnographic knowledge. Phase 2 presents spatial, hydrological, and geotourism analyses, where geosites are assessed using a rubric that captures intrinsic geological value, accessibility, cultural significance, information quality, and tourism development potential. Phase 3 highlights the key outputs, linking landscape organisation and geomorphic controls to geosite ranking, educational value, geotourism attractiveness, and future investment priorities. **Ethical note**: *This figure was generated using Gemini AI and subsequently reviewed, refined, and validated by the authors to ensure scientific accuracy and contextual relevance.*

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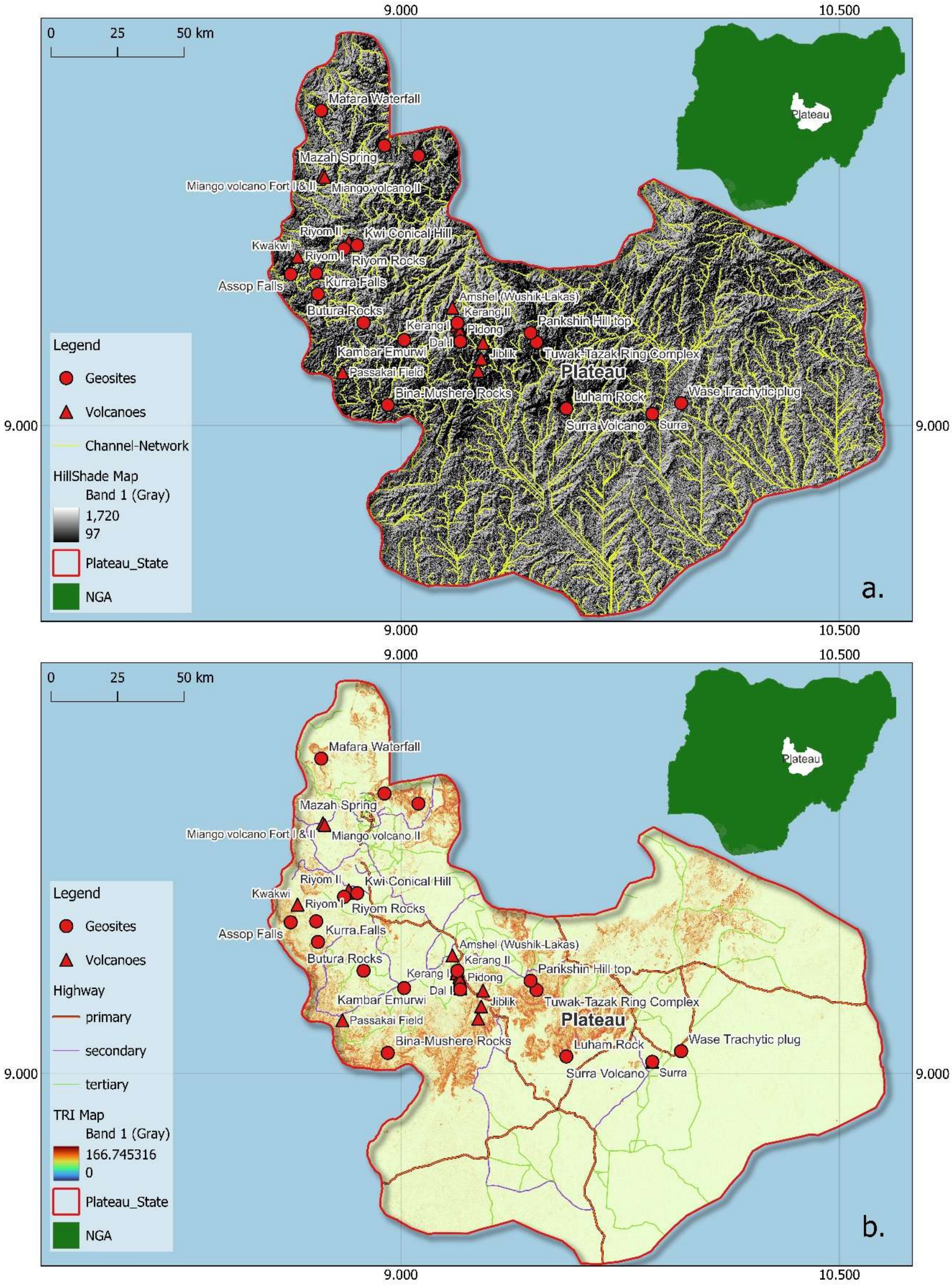

Figure 4: Spatial distribution of mapped geosites and volcanic features in Plateau State, Nigeria. (a) Hillshade map showing the location of identified geosites (red circles) and volcanoes (red triangles) superimposed on the drainage/channel network (yellow lines) within the Plateau State boundary (red outline). (b) Terrain Ruggedness Index (TRI) map showing the same geosites and volcanoes in relation to the road network, classified into primary, secondary, and tertiary roads. The inset map indicates the location of Plateau State within Nigeria. *Map projection: WGS 84 / UTM Zone 32N-EPSG:32632*

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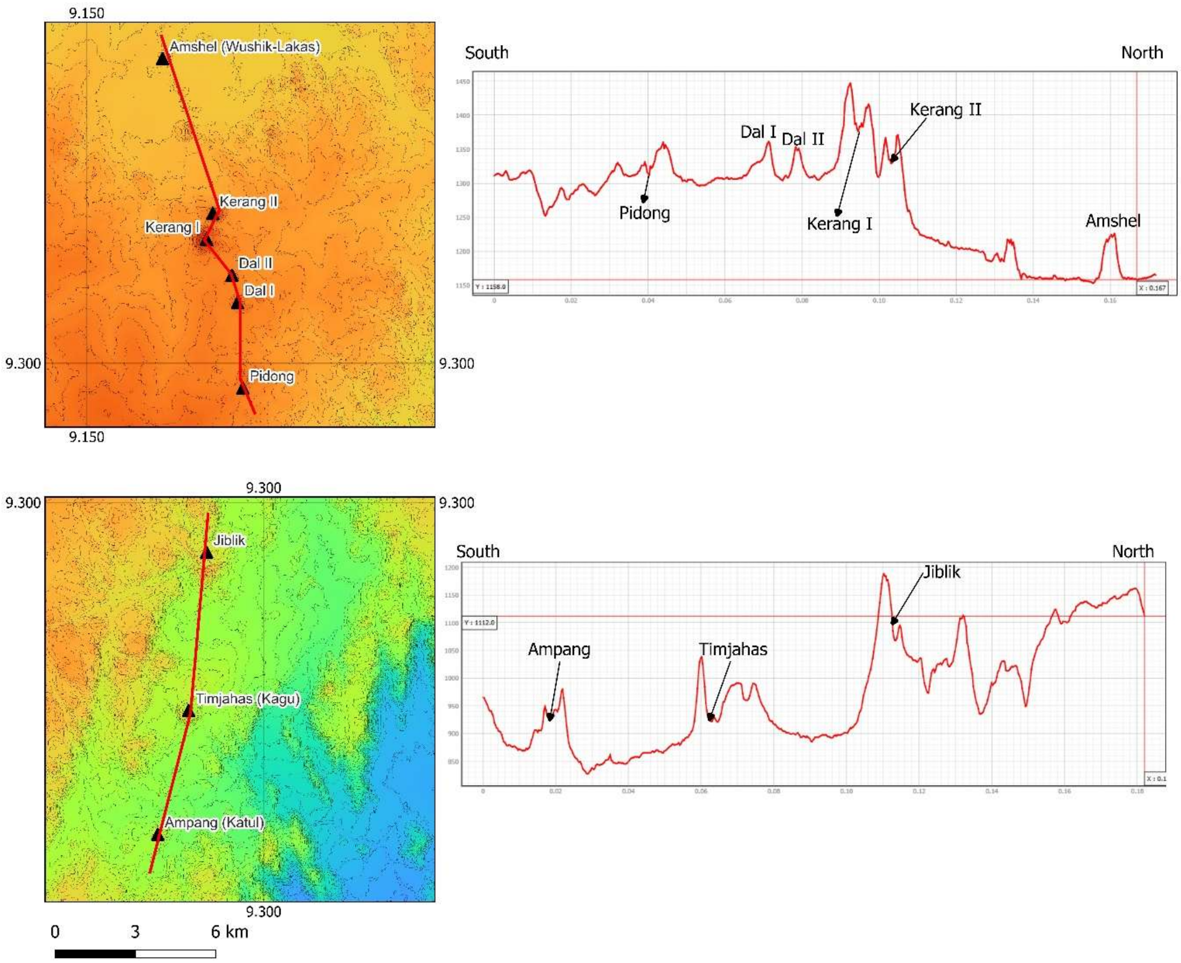

Figure 5: Topography and elevation profiles of two volcanic fields along south–north transects. The SRTM30 maps show shaded relief with the profile lines marked in red, while the plots on the right show how elevation changes along each transect. The upper transect crosses the Amshel, Kerang I and II, Dal I and II, and Pidong volcanoes, capturing clear summit peaks and uneven flanks that reflect differences in volcano size, shape, and erosion. The lower transect intersects the Ampang, Timjahas (Kagu), and Jiblik volcanoes, where steep rises and intervening lows highlight contrasting volcanic forms and underlying structural influences. These maps show the range of volcanic morphologies in the area and provide a straightforward view of how the volcanoes are organised across the landscape. *Map projection: WGS 84 / UTM Zone 32N-EPSG:32632*

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Figure 6. Field photographs showing spectacular exposures of columnar basalts in Plateau State, Nigeria. (a–c) Well-preserved columnar joints at Gahweng, showing polygonal patterns, vertical prisms, and close-packed cooling structures formed by contraction during basaltic lava solidification. (d–e) Extensive columnar basalt ridges from Mafara Waterfall, displaying laterally continuous jointed surfaces with clear hexagonal geometries and gentle undulating topography. Hammer and field geologists provide scale. These outcrops represent outstanding volcanic geoheritage sites, signifying the tectono-magmatic history of the Plateau region

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Figure 7. Geological features of Surra Volcano, Plateau State, Nigeria. (a) Satellite image showing the well-preserved volcanic cone with a prominent summit depression. (b–d) Field photographs of columnar basalts at the volcano's flanks, showing prismatic jointing formed by cooling contraction of basaltic lava. The exposures display both upright and collapsed columns, highlighting structural disintegration due to prolonged weathering and erosion.

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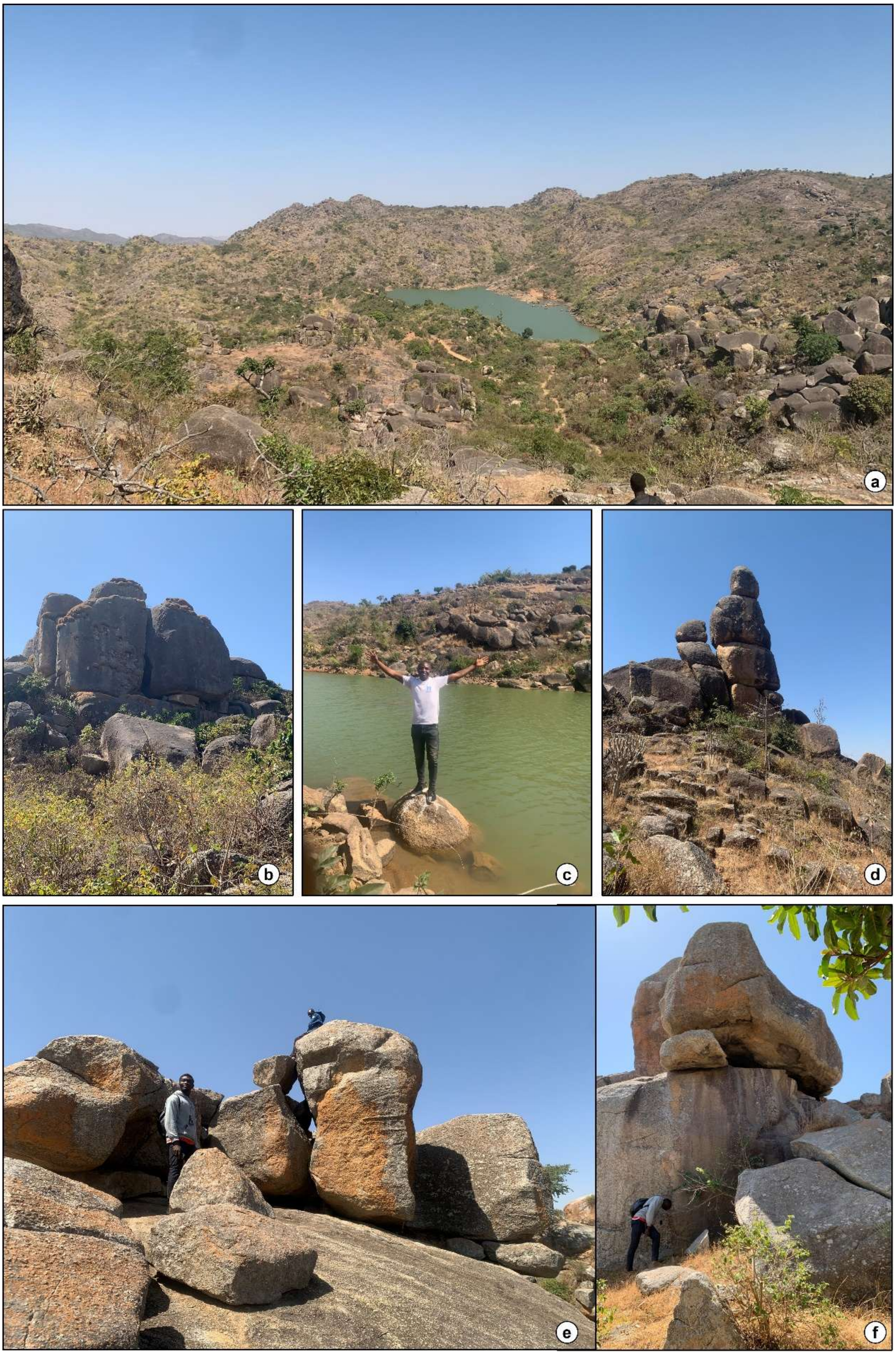

Figure 8.. Field photographs showcasing prominent lithological sites in Plateau State, Nigeria. (a–d) Shere Hills, showing rugged granite inselbergs, boulder-strewn landscapes, and freshwater lakes placed within the highland terrain, highlighting the geomorphological evolution of the region. (e–f) Butura, showing massive granite boulders, rock shelters, and cave-like features formed by prolonged weathering and erosion, offering insights into geomorphic processes and human interactions with the landscape.

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Figure 9. Field photographs of remarkable geoheritage features at Kambar Emurwi (Seven Doors), Plateau State, Nigeria. (a) Large granite boulders forming natural caves and rock shelters, locally known as the “Seven Doors,” representing geomorphological evolution through prolonged weathering and structural disintegration. (b) Exposed granitoid with distinct mineral banding and deformation textures, highlighting the complex tectono-metamorphic history of the region. (c) A unique rock surface showing deep, rounded depressions interpreted as erosional or weathering features of geomorphic and cultural significance.

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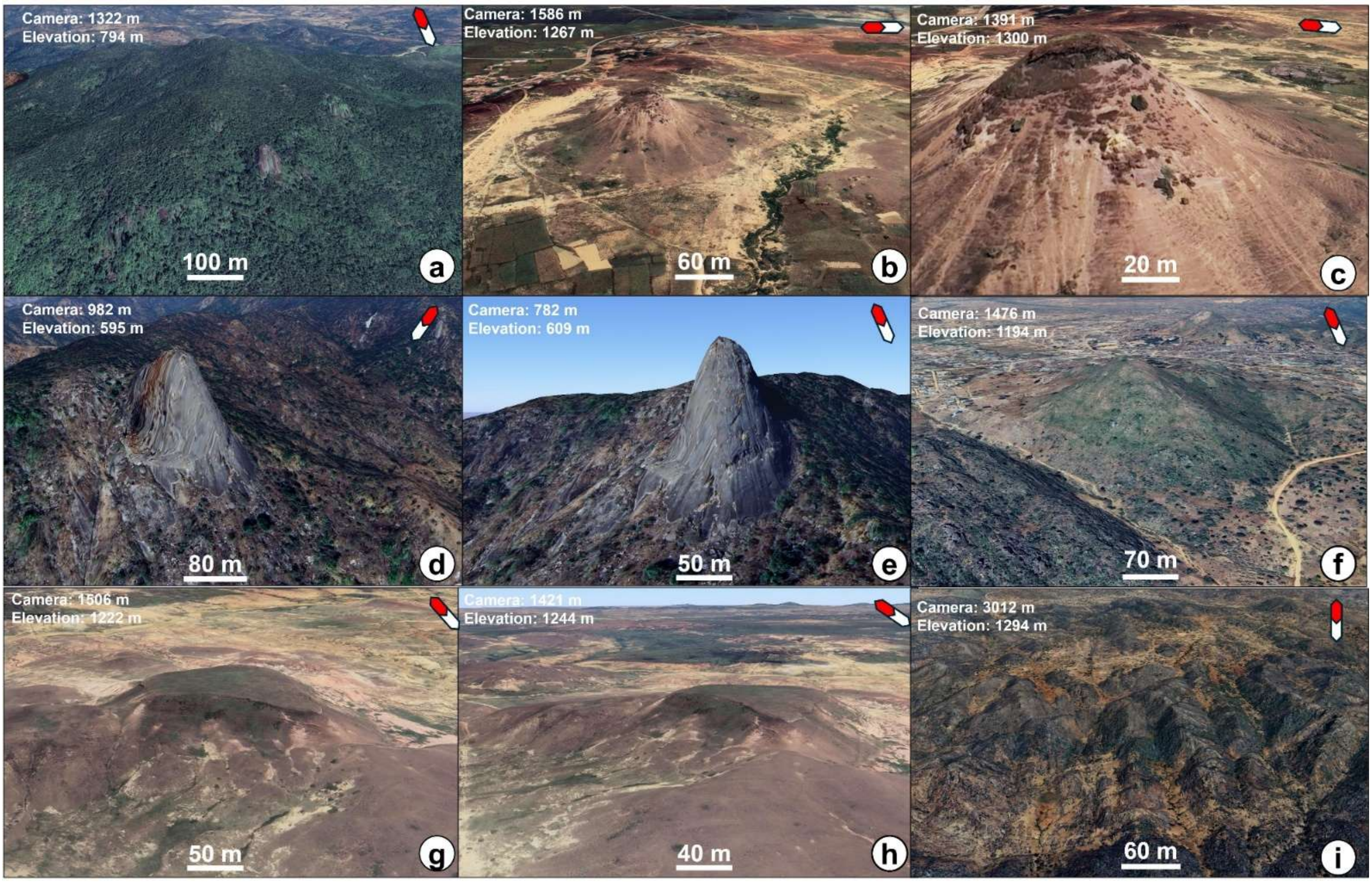

Figure 10: Representative volcanic landforms and related geomorphological features viewed in oblique perspective. Panels (a–i) show a range of volcanic edifices and erosional remnants, captured from different viewing heights and angles. These include well-preserved volcanic cones with clear summit forms, steep-sided plugs and necks, subdued lava domes, and degraded volcanic hills shaped by erosion and surface processes. Scale bars highlight differences in size and relief, while variations in slope, surface texture, and vegetation cover reflect contrasting eruption styles, material strength, and post-eruptive modification. Together, the images provide a visual overview of the diversity of volcanic morphologies across the landscape and illustrate how volcanic structures evolve through time under climatic and tectonic influences.

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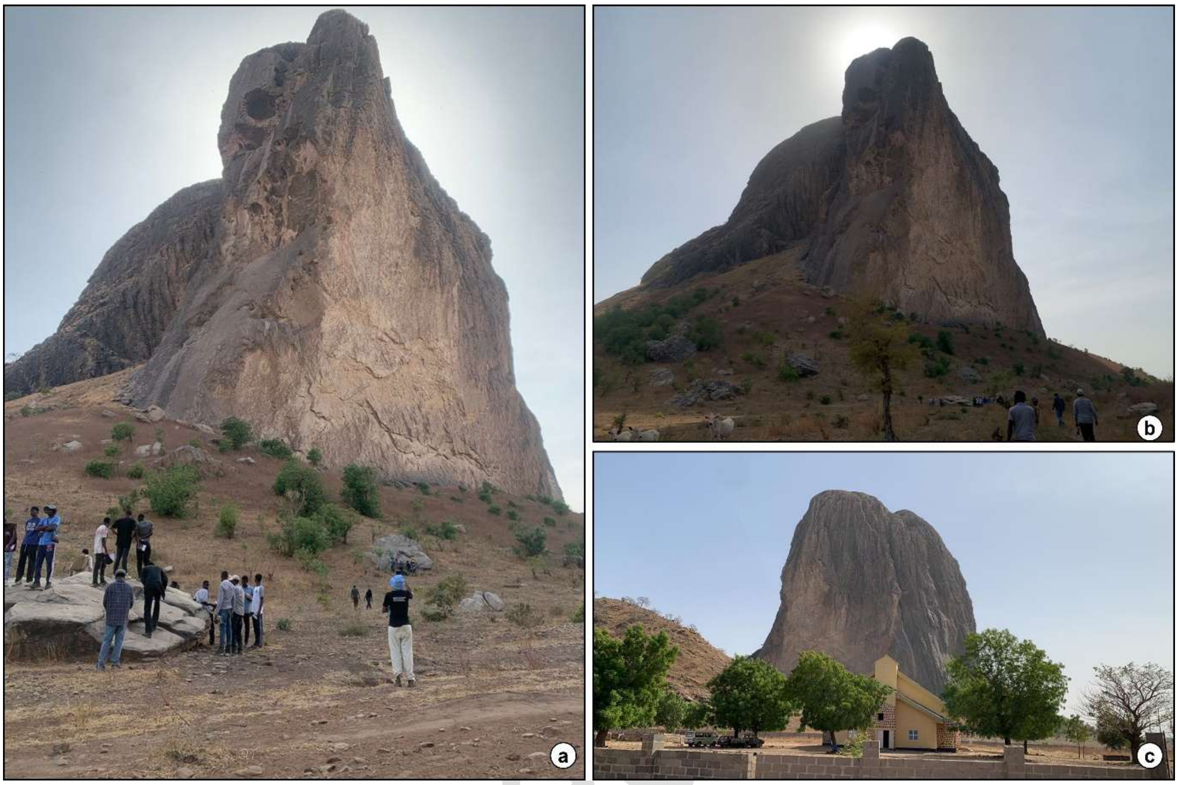

Figure 11. Field photographs of Wase Rock, Plateau State, Nigeria, a prominent volcanic plug rising steeply above the surrounding plains. (a–b) Panoramic views of the massive trachytic intrusion, showing its near-vertical cliffs and isolated geomorphic expression, which make it one of Nigeria's most iconic landforms. (c) Distant perspective showing the imposing height of the plug relative to nearby human settlements and vegetation. Wase Rock represents the deeply eroded remnant of a volcanic system, providing valuable insights into magmatic emplacement processes. It is of great geological, ecological, cultural, and geotourism significance, and a prime candidate for geoheritage conservation.

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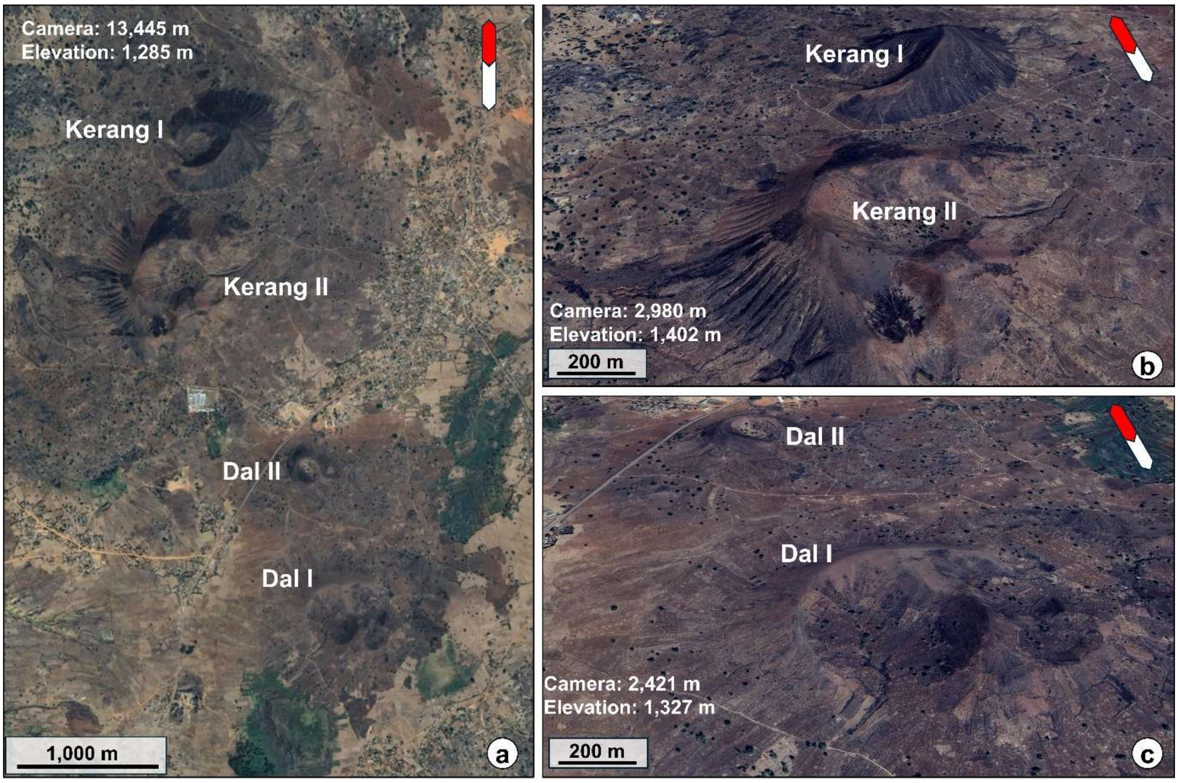

Figure 12. Satellite imagery of the Kerang volcanic field, Plateau State, Nigeria, highlighting distinct volcanic cones and geomorphic features. (a) Orthophoto view showing four major volcanic edifices (Kerang I,II, Dal I and II) distributed across the landscape, with surrounding settlements visible. (b) Oblique perspective of cones Kerang I and II, showing their steep flanks, breached craters, and associated radial erosion gullies. (c) Oblique perspective of Dal I and II, displaying subdued morphologies and crater depressions, indicative of varying eruption styles and erosional histories. Scale bars and elevation data provide spatial context.

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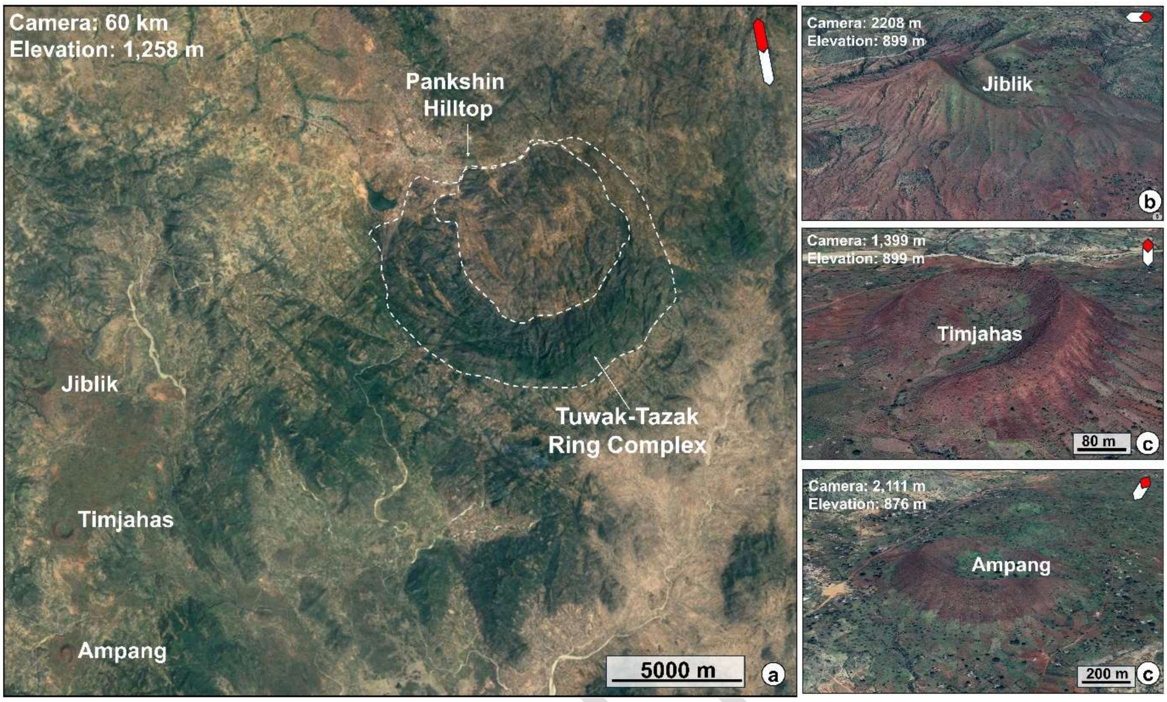

Figure 13. Satellite imagery of the Kerang volcanic field and Tuwak-Tazak Ring Complex, Plateau State, Nigeria. (a) Regional view showing volcanic cones Jiblik, Timjahas (Kagu) and Ampang (Katul) in proximity to the large Tuwak-Tazak Ring Complex, outlined in white dashed lines. Oblique perspective of cone (b) Jiblik, compound scoria-lava flow complex (c) Timjahas (Kagu), characterized by a prominent crater, steep flanks, and radial erosional gullies. (d) Ampang (Katul), exhibiting a wide summit depression and well-preserved cone morphology surrounded by agricultural fields and settlements.

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Figure 14. Field photographs of key hydro-volcanic and geothermal features in study area. (a–c) Pidong Crater and Lake, showing a maar-type volcanic depression now hosting a freshwater lake surrounded by rugged highlands and weathered volcanic rocks, highlighting volcanic-hydrological interactions. (d–e) Mazah hot spring discharging into Precambrian basement rocks, with flowing thermal waters cascading over jointed granite exposures, displaying mineral precipitates and biological activity. These features jointly show the interplay of volcanism, groundwater circulation, and tectonics in shaping the unique landscape of the study area.

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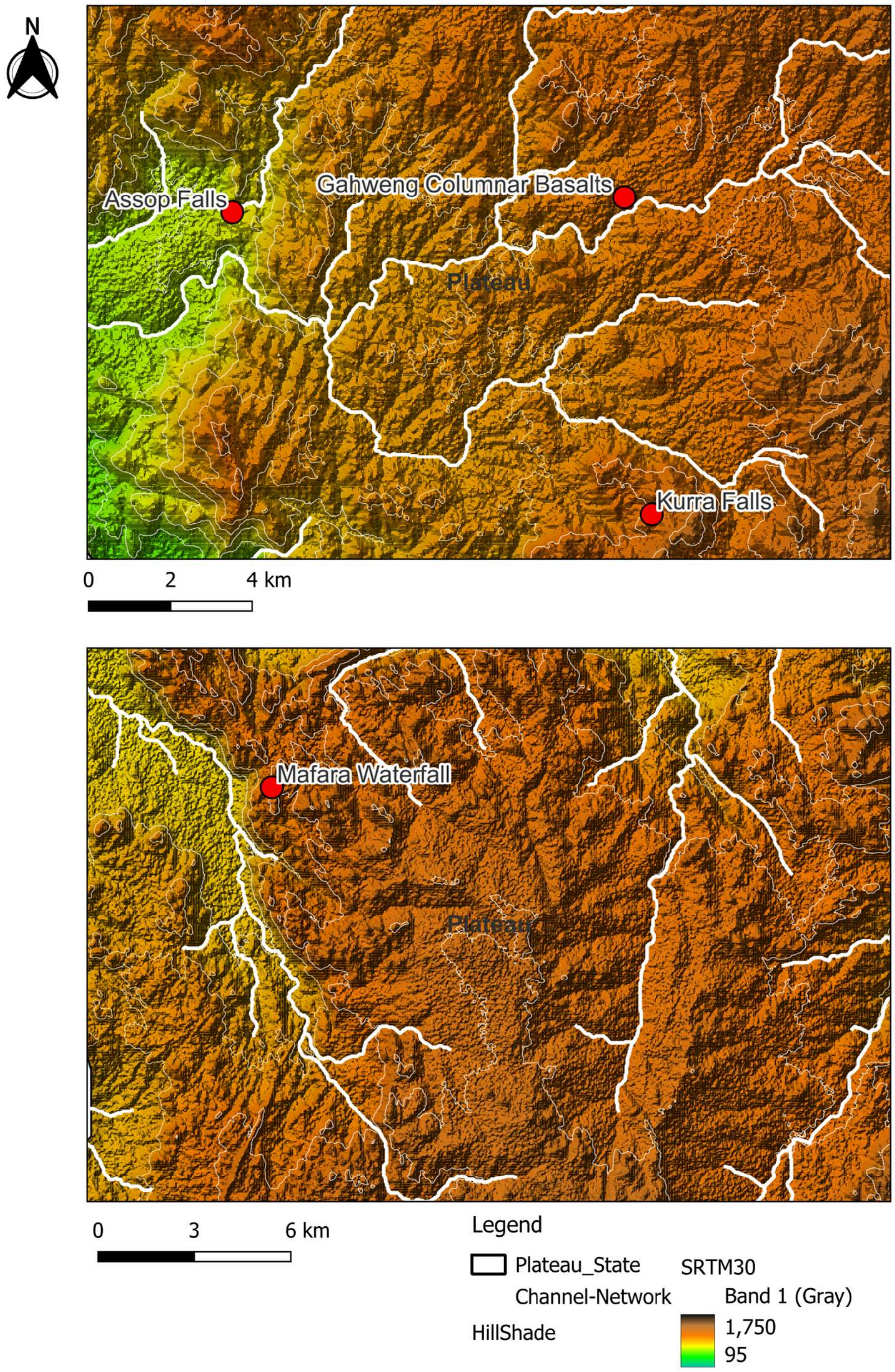

Figure 15. (a) and (b) Digital Elevation Model (DEM) of Plateau State, Nigeria, derived from SRTM30 data overlain by stream channel network and topographic contours to showcase the spatial distribution of major rivers, tributaries, and drainage networks in relation to key geoheritage sites. The map highlights the relative positions of the labelled waterfalls, including Assop, Kura, and Mafara, which are directly associated with major surface water systems draining the Plateau highlands. These waterfalls mark zones of abrupt elevation change along river channels, reflecting structural and lithological controls on fluvial incision. The integration of hydrological features with the locations of waterfall provides insights into landscape evolution, water resource dynamics, and the geoheritage value of hydrological and geomorphic systems of the study area.

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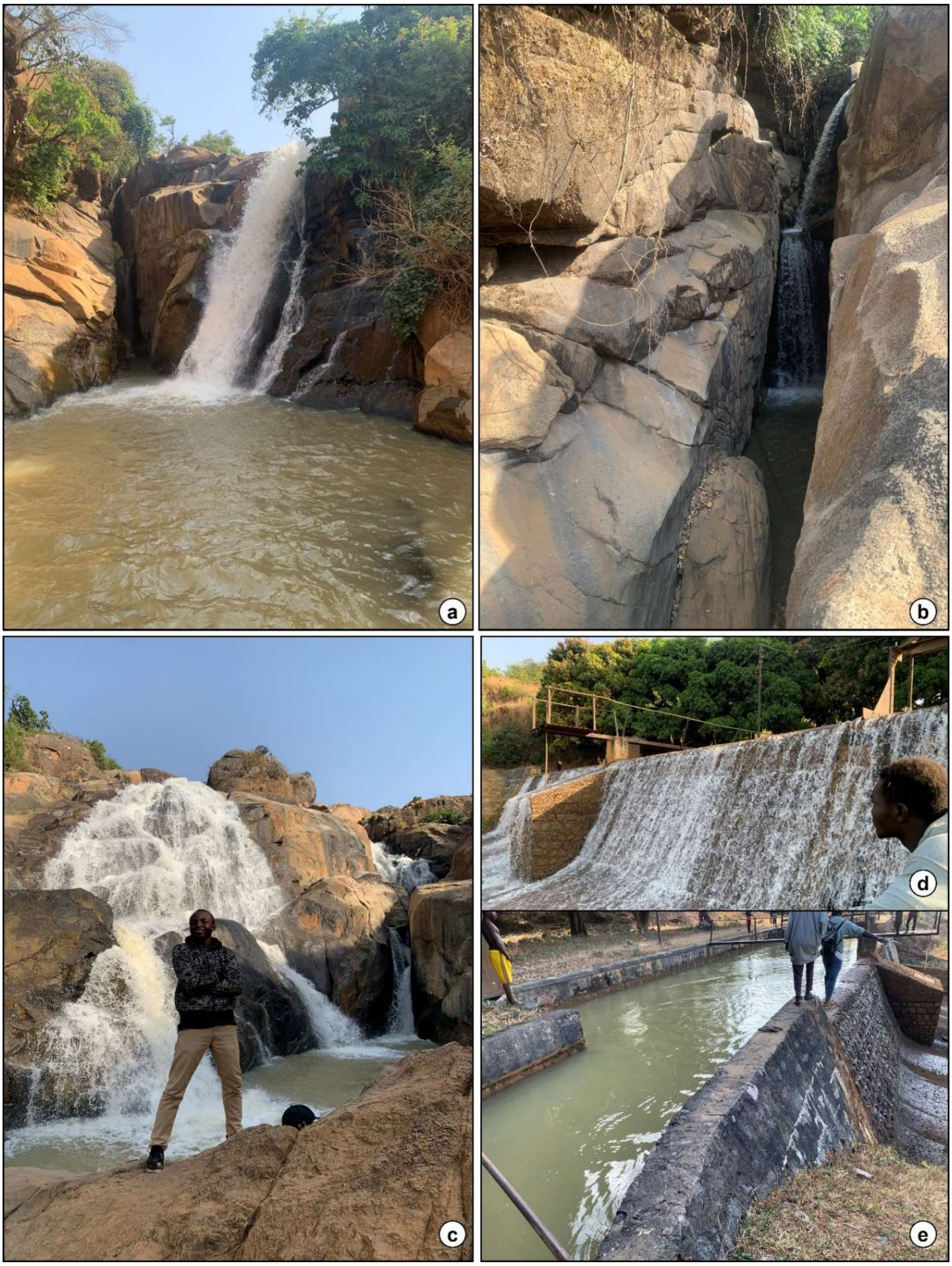

Figure 16. Waterfalls and associated hydrological features of Plateau State, Nigeria. (a–b) Kurra Waterfall, displaying cascades over jointed Precambrian basement rocks, with narrow channels and plunge pools highlighting structural control on fluvial incision. (c–e) Assop Falls, a multi-tiered cascade system draining the Jos Plateau, where water flows over steep bedrock surfaces into downstream channels. Engineered spillways and diversion structures (d–e) demonstrate the integration of natural hydrology with human water management.

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Figure 17. Mafara Waterfalls, Plateau State, Nigeria, showing the interplay between fluvial processes and volcanic geology. (a–c) Cascading water over well-developed columnar basalts, highlighting prismatic jointing formed during cooling and contraction of basaltic lava flows. The stepped waterfall morphology reflects structural control by the basalt columns. (d) Close view of the falls with vertical jointed columns exposed, demonstrating their geomorphic and aesthetic significance. (e) Community interaction at the waterfall, emphasizing its socio-cultural and ecological importance. Mafara represents a striking example of volcanic geomorphology and hydro-geomorphic evolution, with high geoheritage, geotourism, and educational potential within the Nigerian Plateau landscape. It is a unique geosite that fulfils the UNESCO criteria for characterisation as a Global Geopark.

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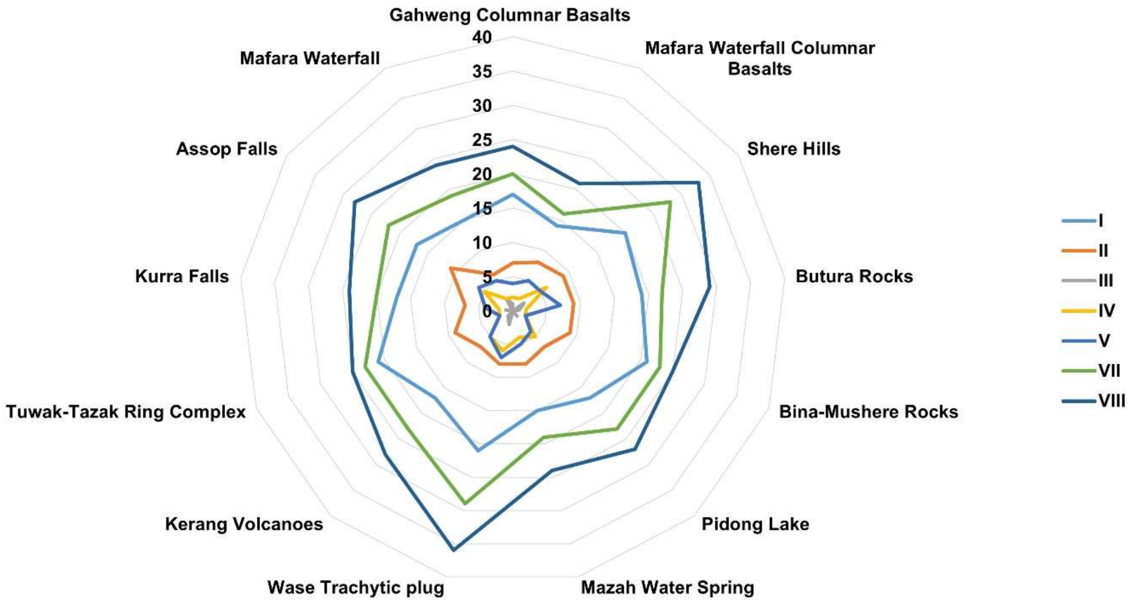

Figure 18. Radar plot showing comparative geoheritage significance scores of 13 major geosites in Plateau State, Nigeria, including waterfalls (Assop, Kurra, Mafara), volcanic landforms (Kerang Volcanoes, Wase Trachytic Plug, Tuwak-Tazak Ring Complex), rock formations (Butura Rocks, Bina-Mushere Rocks, Shere Hills), and hydrological features (Pidong Lake, Mazah Water Spring). The eight evaluation criteria (I–VIII) include scientific, educational, aesthetic, recreational, cultural, conservation, accessibility, and tourism values. Gahweng Columnar Basalts, Wase Trachytic Plug, and Shere Hills consistently record higher multi-criteria scores, signifying their prominence as priority geoheritage sites. This assessment supports strategic planning for conservation and sustainable geotourism development across Plateau State.

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