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Geoheritage Vulnerability Assessment for Conservation-Oriented Tourism Planning in the Outer Himalaya: A Case Study of Udhampur District in Jammu and Kashmir, India

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ABSTRACT

The Himalayan region possesses immense tourism potential and hosts several world-class destinations; however, its geoheritage landscapes are increasingly threatened by unregulated tourism development and associated infrastructure expansion. This research assesses the vulnerability of geoheritage in Udhampur district, Jammu and Kashmir, using a geospatial method to analyse how topography and lithology affect tourism stability. Digital Elevation Model (DEM) data were used to derive slope and elevation metrics, while lithological information was sourced from the Geological Survey of India. Vulnerability maps were created by categorising key physical variables into low, moderate, and high-risk levels. A buffer analysis within a 5 km radius around three major tourist sites: Patnitop, Pancheri, and Mantalai was conducted to evaluate the impact of tourism pressure. Results show that areas with steep slopes and weak Shiwalik formations, especially near Mantalai, are highly vulnerable and unsuitable for extensive tourism infrastructure. Zones with moderate vulnerability need careful eco-tourism management, whereas relatively stable areas near Patnitop can support limited development with strict environmental measures. The study highlights the importance of vulnerability-based zoning, site-specific conservation strategies, and community involvement for sustainable preservation of geoheritage. These findings offer a spatial decision-support framework for incorporating geoheritage conservation into tourism planning in sensitive mountain regions.

Keywords: *Himalayas, Tourism Potential, Geoheritage, vulnerability, Geospatial and Conservation.*

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Introduction

Tourism in the Himalayan region is renowned worldwide for its exceptional natural landscapes, biodiversity, and cultural heritage [21, 1]. Jammu and Kashmir, situated in the western Himalayas, has significant tourism potential thanks to its snow-capped mountains, alpine meadows, glaciers, lakes, and religious and adventure tourism sites. The tourism sector plays a vital role in regional economic growth by creating jobs and enhancing infrastructure (40). Nevertheless, the rapid growth of tourism is increasingly damaging to fragile geoheritage sites. Visitor pressure, unregulated access, and infrastructure development are increasing threats to the sites' inherent values and physical integrity [5].

Geoheritage is an essential part of the world with geological and geomorphological origins [19]. Geoheritage represents the assemblage of geological, geomorphological, palaeontological, and landscape features that collectively document the Earth's evolutionary history and possess significant scientific, educational, cultural, and aesthetic value [27, 18 & 26]. They form a vital part of the world's natural heritage. It includes important sites, or geosites, as well as objects such as rocks, minerals, fossils, and landscapes that are crucial for understanding Earth's history [25, 27].

Moreover, the presence of geosites in a region can greatly enhance its tourism appeal and developmental prospects [35]. Because of their scientific, educational, and cultural importance, these sites and objects deserve protection. The growing worldwide focus on geoheritage and its preservation is evident in initiatives such as the UNESCO International Geoscience and Geoparks Programme's "Geological Heritage Sites" project, overseen by the International Union of Geological Sciences [15, 21]. Nevertheless, geodiversity is a vital component of nature, with much surface biodiversity relying on the subsoil and surface. It includes a broad array of processes, environments, and evolutionary histories that significantly bolster biodiversity's diversity and resilience. Consequently, it is important to consider geodiversity carefully to ensure effective conservation [12].

In recent decades, geoheritage has emerged as an important component of the discourse on sustainable development, particularly through its integration with geotourism, geoeducation, and landscape conservation. Geoheritage and geotourism have been increasingly recognised as mechanisms that can contribute to responsible tourism and community development when effectively managed [14]. However, geoheritage resources are inherently fragile and face multiple threats, including anthropogenic pressures such as unplanned

tourism infrastructure and large-scale construction, climate-induced hazards that accelerate erosion and destabilise landforms, and poor regulatory frameworks that fail to protect sensitive geological features [6, 24 & 11]. These vulnerabilities are especially pronounced in tectonically active and geomorphologically sensitive mountain regions, where complex topography and unstable substrates make geological sites highly susceptible to degradation. Effective conservation strategies for geoheritage, therefore, require coordinated planning, geospatial analysis, and integration of community and policy responses to ensure that tourism development does not compromise geological integrity and long-term sustainability [14, 37].

The Himalayan region of India exemplifies this paradox of high geoheritage value and high vulnerability. As one of the world's youngest and most dynamic mountain systems, the Himalaya hosts a wide spectrum of geological formations shaped by ongoing tectonic uplift, erosion, and mass-wasting processes [36]. The Udhampur district of Jammu & Kashmir (India), situated within the Outer and Lesser Himalayan zones, occupies a strategically important geological setting where the Shiwalik sedimentary formations, Palaeogene sequences, and older Palaeozoic to Precambrian litho-units are exposed across a rugged and dissected terrain. This geological diversity manifests in steep slopes, river valleys, structural discontinuities, and distinctive landforms that not only define the region's physiography but also contribute to its geoheritage significance. At the same time, the district lies within an area influenced by major Himalayan thrust systems, rendering it prone to landslides, erosion, and slope instability processes that are further exacerbated by road construction, tourism infrastructure, and increasing visitor pressure.

Tourism growth in the Indian Himalaya has emerged as a double-edged sword: while it provides economic opportunities and regional development, it also intensifies environmental stress and geoheritage degradation when not guided by conservation-oriented planning. Whereas the surge in tourism in the Indian Himalaya region has heightened the region's vulnerability to natural hazards such as landslides and flash floods [20]. Popular destinations such as Patnitop, along with emerging sites like Pancheri and Mantalai in Udhampur, attract visitors for their scenic landscapes, religious significance, and natural settings, yet these attractions are closely tied to underlying geological features that are sensitive to disturbance. Unregulated construction, vegetation removal, and slope modification can accelerate geomorphic instability, threatening both the integrity of geoheritage and human safety. This underscores the urgent need to move beyond qualitative descriptions of geoheritage value toward spatially explicit, quantitative assessments of vulnerability that can inform sustainable tourism and land-use policies.

The Himalayas, one of the youngest and most tectonically active mountain ranges, are also among the most susceptible to landslides. Their fragile geology, steep slopes, and heavy monsoon rains contribute to high instability [2]. Events like the 2013 Kedarnath disaster in Uttarakhand, where heavy rainfall caused landslides and flash floods, resulting in numerous fatalities, highlight the destructive power of these hazards [13]. In Himachal Pradesh, especially around Kullu–Manali, rainfall-triggered landslides are common, often causing road closures and infrastructure damage during the monsoon season [30].

Jammu and Kashmir face similar challenges. The Jammu–Srinagar National Highway (NH-44), which links the Kashmir Valley with the rest of India, often suffers disruptions due to rainfall-induced landslides, especially in the Ramban and Banihal areas [34]. Udhampur district, located in the outer Himalayas, is particularly at risk because of its steep terrain, fragile soils, and heavy monsoon rains. Frequent reports highlight slope failures that hinder traffic, damage farms, and threaten lives. For instance, the 2015 landslide in Udhampur blocked roads and stranded hundreds of vehicles, underscoring the ongoing threat to mobility and livelihoods [23, 16].

Recent studies emphasize that effective geoheritage conservation requires an integrated framework combining geospatial analysis, vulnerability assessment, governance mechanisms, and community participation [8, 38]. GIS-based approaches, in particular, offer powerful tools for analyzing terrain characteristics such as slope, elevation, and lithology, which are critical determinants of geoheritage sensitivity in mountainous environments. By identifying zones of differential vulnerability, such assessments support evidence-based zoning, infrastructure planning, and targeted conservation strategies. Moreover, linking geoheritage protection with geoeducation and community-led geotourism enhances local stewardship while promoting long-term socio-economic benefits, as demonstrated by geopark initiatives in other mountainous regions worldwide [39, 17]. Tourism can serve as a vital means of disseminating information about protected areas and increasing tourists' awareness of the environmental impacts of their actions [22, 10]. Effectively applying geotourism principles, promoting both geotourism and geoheritage, along with practicing geoconservation, can significantly support tourism growth while also protecting natural heritage [3]. The ideas of geodiversity and geotourism focus on the geological environment within the abiotic sphere, highlighting the significance of geological and geomorphological features. Sharples emphasized the importance of conserving geodiversity for future generations. In this context, geotourism is essential because it helps implement geoconservation and raise public awareness [31].

Geoparks in Hebei Province, China, contribute to regional sustainable development by integrating geoheritage protection with geotourism promotion. Geoheritage plays a key role in linking conservation with sustainable tourism, providing socio-economic benefits to the local people [39]. A geoheritage conservation strategy must be based on documentation, legal protection, awareness campaigns, and integration of geoeducation into tourism initiatives. We have recommended the creation of geoparks in the Himalaya to safeguard geological diversity while promoting responsible geotourism that benefits local communities [17].

This successful geoheritage conservation in tourism sites relies on an integrated management strategy that systematically tackles vulnerability. By pinpointing key vulnerability factors and linking them to specific managerial actions such as transparency, inclusion, and institutional governance, the suggested framework provides a practical way to mitigate conservation risks. Effectively managing vulnerability is vital for protecting geoheritage across physical, functional, and visual aspects, thereby promoting long-term sustainability in tourism destinations [7].

The vulnerability of geoheritage sites in Iran's tourism destinations is primarily due to tourism pressure, poor governance, limited stakeholder involvement, and insufficient planning.

These factors are key drivers of degradation. The text stresses that unmanaged vulnerability endangers the physical integrity and sustainability of geoheritage resources. It also underscores the importance of implementing integrated conservation and management strategies to promote sustainable tourism development [8]. Current methods for assessing geoheritage degradation risk are mostly localized and qualitative. There is increasing interest in quantitative evaluations, and climate change is identified as an underexplored but significant threat. This underscores the need for more robust and standardized frameworks for risk assessment to enhance geoheritage conservation [38]. The study, which assesses the geoheritage and geotourism potential of the Jhamarkotra area in India through GIS analysis and qualitative methods, highlights the area's geological and cultural significance but notes that low local awareness and socio-economic challenges impede sustainable growth, underscoring the need for integrated, eco-friendly management approaches [33]. The importance of geoeducation as a vital tool for conserving geoheritage within tourism destinations by increasing awareness, involving stakeholders, and encouraging responsible actions. Incorporating geoeducation into tourism planning facilitates informed decision-making and helps alleviate stress on sensitive geological sites, thereby supporting their long-term sustainability [9].

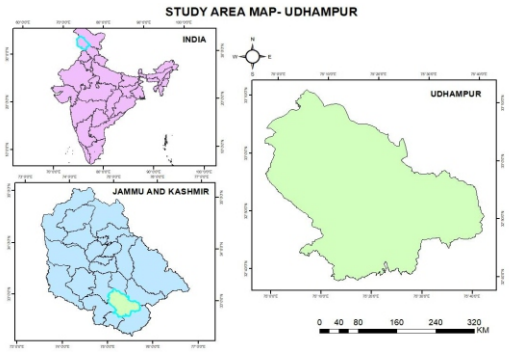
The growth of tourism must be balanced with the conservation efforts; a nuanced strategy is vital in this regard. It involves community participation, capacity building, empowerment, and education by providing skills, knowledge, training, incentives, and resources. Local people are the main stakeholders and can serve as proactive guardians in implementing environmental protection policies aimed at environmental conservation. By equipping themselves with conservation skills and training, they can effectively address environmental challenges [32]. After a comprehensive review of the literature, this study aims to assess the vulnerability of geoheritage landscapes to tourism pressure using geospatial techniques and to propose site-specific conservation and eco-tourism strategies for sustainable tourism planning.

Study area

Udhampur district, located in the southeastern part of the Jammu region of Jammu and Kashmir, constitutes one of the state's 20 administrative districts and covers an area of about 2,380 km^2 [Fig. 1]. Geographically, the district lies between latitudes 32°34′ N and 33°30′ N and longitudes 74°16′ E and 75°38′ E and forms an integral part of the Outer Himalayan (Shiwalik) zone, which is recognized for its geologically young formations and high environmental sensitivity. The district exhibits pronounced topographic variability, characterized by steep slopes, dissected hill ranges, and narrow valleys [Figs 5, 6]. Elevation increases markedly toward the north and northeast, where mountain ranges rise above 2,500 m [Fig. 5] and experience cool, temperate climates. In contrast, the southern part of the district is dominated by comparatively lower Shiwalik hills under a warm, humid subtropical climate. Forest ecosystems cover nearly 1,042 km^2 and display considerable diversity, ranging from tropical dry and evergreen formations at lower elevations to subtropical pine, Himalayan temperate, and sub-alpine forests at higher altitudes. The combination of complex terrain, fragile geological formations, and diverse ecosystems makes Udhampur particularly vulnerable to land degradation and environmental stress, especially as human intervention driven by tourism expansion increases. Owing to its diverse physical landscape, climate, cultural heritage, and vegetation, different locations in Udhampur support a variety of tourism types, including nature-based, cultural, pilgrimage, and eco-tourism. Against this backdrop, the present study concentrates on Patnitop, Panchari, and Mantalai, three well-established tourist destinations with geoheritage sites, to evaluate geoheritage vulnerability, as these areas have experienced notable tourism growth and associated developmental pressures in recent years [Fig. 2, 2a & Table 1].

Table 1: Showing the description of the selected major tourist sites in Udhampur District

S. No.	Tourist Site	Coordinates	Description
1	Mantalai.	33°00'15"N, 75°21'29"E	Mantalai is a revered and picturesque location surrounded by dense deodar forests. Its main attraction is a temple dedicated to Lord Shiva. The region features rugged, high-altitude terrain with steep slopes, especially in the southern and central areas of the buffer zone. The combination of steep gradients and fragile lithology renders the area ecologically vulnerable to erosion and landslides, a risk that has grown due to recent land-use and land-cover changes. The transformation of natural forests and vegetation into built-up areas for roads and tourism infrastructure has heightened pressure on land resources.
2	Panchari	33°05'17"N, 75°07'48"E	This picturesque hill resort is surrounded by lush, coniferous forests and features many natural attractions. It has significant tourism potential, offering activities like trekking, mountaineering, adventure sports, camping, paragliding, and pilgrimages. Key attractions include Kainth Gali, Dayari Jungle, and Shankri Devta Temple. Nevertheless, the central and southern regions, with their higher elevations and steeper slopes, are susceptible to soil erosion and minor slope failures, especially as tourism grows. The combination of rugged terrain and land use/cover changes in certain areas increases the risk of erosion and landslides.
3	Patnitop	33°05'11"N, 75°19'51"E	A famous hill resort situated on a scenic plateau in the Shiwalik Range of the Himalayas, surrounded by meadows and vibrant green pine forests. It stands out as the leading tourist spot in Udhampur, with upgraded lodging and recreational amenities, attracting visitors year-round. Nearby attractions include Skye View Gandola (Ropeway), Nathatop, Kud Market, Vasuki Naag Temple, a children's amusement park, and ziplining activities. The Patnitop area features gentler slopes and more gradual elevation changes than other areas, thanks to its stable, plateau-like terrain. However, despite this stability, Patnitop is threatened by rapid tourism expansion and dense settlement, which endanger agricultural land and natural vegetation.

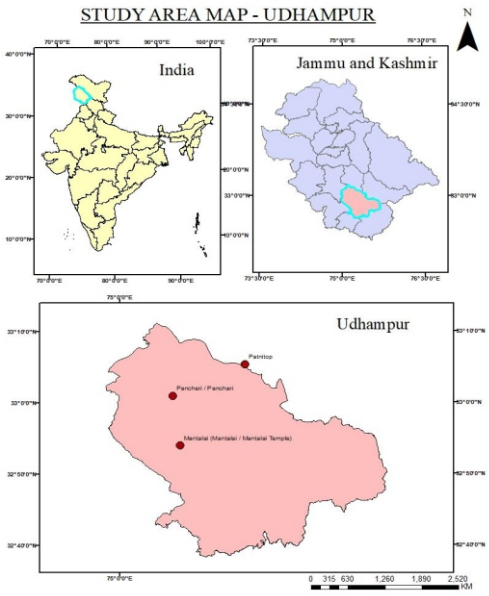


Source: *SOI (Survey of India) and Arc GIS*

Fig. 01: Map showing the location of Udhampur District (Jammu and Kashmir) in India

Methodology

Geoheritage vulnerability maps were developed using geospatial techniques to evaluate the influence of terrain characteristics and lithology on the stability of tourism areas in the Udhampur district. Lithological information was sourced from the Geological Survey of India (GSI), while Digital Elevation Model (DEM) data used to derive elevation and slope layers were obtained from the United States Geological Survey (USGS). Slope and elevation maps were generated from the DEM and classified into three categories: low, moderate, and high to represent variations in relief and terrain steepness. The lithological map was generalized to depict the dominant rock formations within each site. To define the spatial extent of the analysis, circular buffer zones were delineated around the three principal tourism destinations: Patnitop, Pancheri, and Mantalai. A focused spatial analysis was carried out using a 5 km buffer (10 km diameter) centred on the destination centres. These locations were selected due to rapid tourism growth over the past decade, accompanied by substantial infrastructure expansion, including enhanced road networks, increased accommodation facilities, and the development of recreational and entertainment amenities. The 5 km buffer was considered appropriate, as tourism-related activities are largely concentrated within the core zones of these destinations. All these layers (slope, elevation, and lithology) were overlaid in a GIS environment to identify zones of higher vulnerability. The final maps highlight how combinations of slope steepness and rock type can help understand the geological sensitivity of each site and support conservation-based tourism planning.

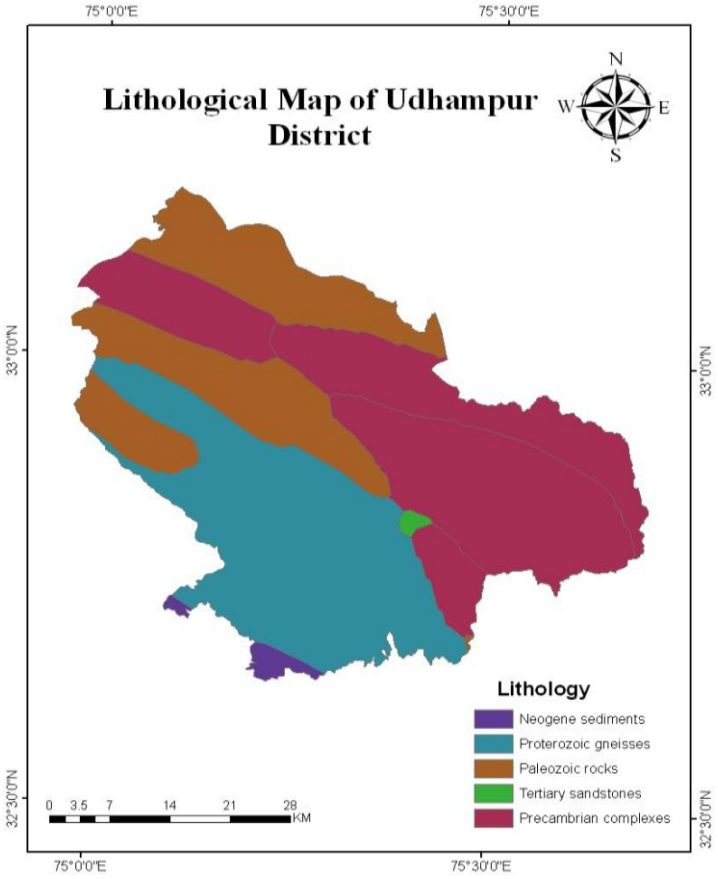


Source: *SOI (Survey of India) and Arc GIS*

Fig. 02: Map showing the location of Udhampur District with selected tourist sites for study

Figs. 2a Geoheritage sites at 1. Pancheri, 2. Mantalali and 3. Patnitop (Left to right)

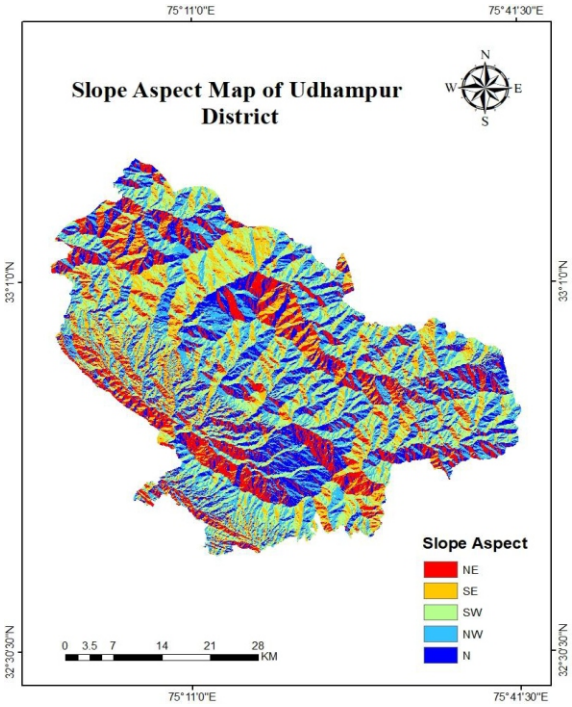
Results and Discussion



Source: *Geological Survey of India (GSI) & Arc GIS*

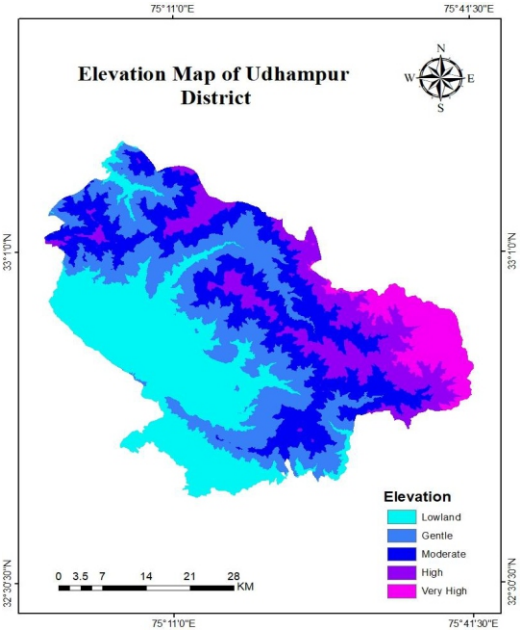
Fig. 03: shows the lithological map of Udhampur District

The lithological map of Udhampur District shows significant geological diversity typical of the Outer Himalaya [Fig. 3]. Precambrian complexes are prevalent in the central and eastern regions, forming relatively durable rock units. Proterozoic gneisses cover much of the southern and southwestern areas, showing moderate resistance but being vulnerable to weathering along structural planes. Paleozoic rocks appear as elongated belts in the northern sector, representing folded sedimentary layers with varying erosion resistance. Neogene sediments, primarily located at the southwestern edges, are composed of weak, unconsolidated materials highly prone to erosion and slope failure. The contrast between hard crystalline rocks and softer sedimentary formations significantly affects slope stability and geoheritage vulnerability, with Neogene and Paleozoic units being more susceptible, especially due to tourism-related disturbances.



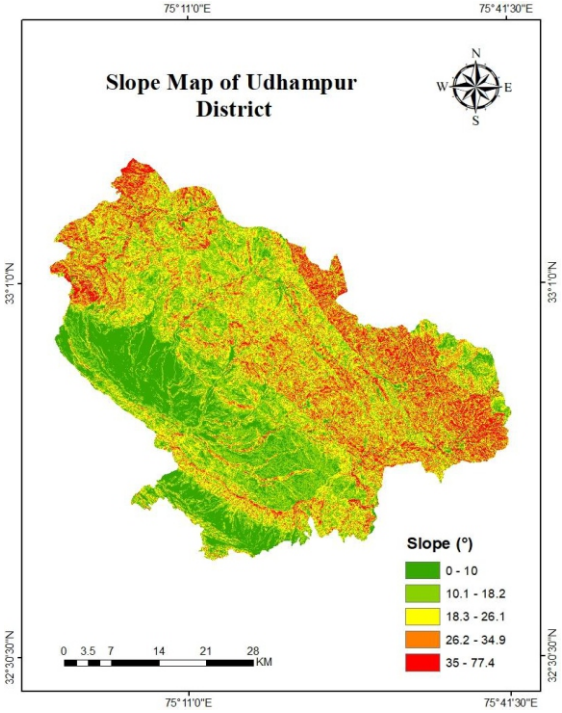
***Source:** Geological Survey of India (GSI) & Arc GIS*
Fig. 04: shows the slope aspect map of Udhampur District

The slope aspect map of Udhampur District shows a wide range of orientations typical of the dissected Himalayan terrain [Fig. 4]. Slopes facing north and northwest are common and tend to hold more moisture, making them more prone to weathering and instability. East- and southeast-facing slopes are often found along valley sides and are prone to active erosion, while south- and southwest-facing slopes receive more sunlight, accelerating surface degradation. This variability in aspect significantly influences microclimates, erosion processes, and geoheritage.



***Source:** United States Geological Survey (USGS) & Arc GIS*
Fig. 05 shows the elevation map of Udhampur District

The Udhampur District elevation map shows significant altitudinal variation typical of the Outer Himalayan region [Fig. 5]. Lowlands mainly lie in the southern and southwestern parts, where gentle terrain supports settlements, farming, and tourism infrastructure. Elevation rises gradually toward the centre, characterised by gentle to moderate slopes that act as transition zones between plains and mountain ranges. The northern and northeastern areas feature high to very high elevations, marked by rugged terrain with steep slopes and deep valleys. These zones are geomorphologically sensitive and more susceptible to erosion, landslides, and slope instability. The distinct altitudinal gradient affects land use, access, and tourism potential, with higher elevations being more vulnerable to geoheritage issues and needing stricter conservation and development measures.



***Source:** United States Geological Survey (USGS) & Arc GIS*
Fig. 06: shows the slope map of Udhampur District

The Udhampur District's slope map highlights significant terrain variability characteristic of the Outer Himalaya [Fig. 6]. Gentle slopes (0–10°), mostly in the southern and southwestern parts, offer stable ground suitable for settlements and limited tourism. Moderate slopes (10.1–26.1°) are prevalent in the central area and need careful oversight if tourism activities are to be developed. Widespread in the northern and eastern parts, steep to very steep slopes (>26.2°) are highly prone to landslides and erosion, increasing geoheritage risks. These zones are unsuitable for extensive tourism infrastructure and require strict conservation efforts.

1. Geoheritage Vulnerability of Mantalai

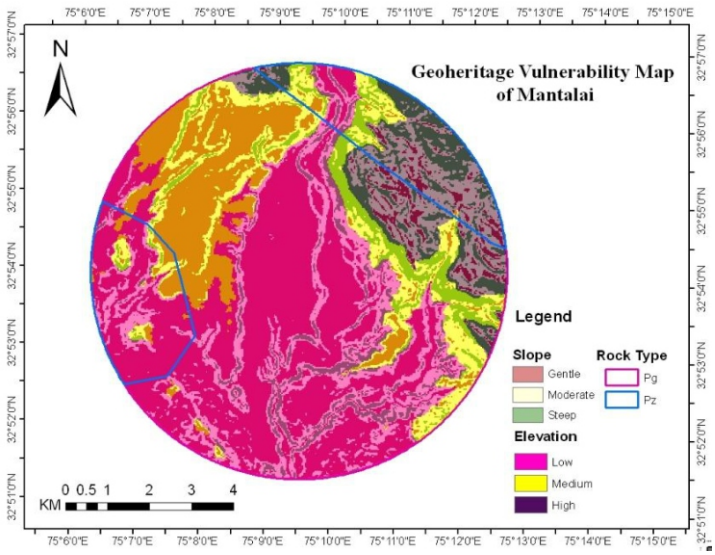


Fig. 07: shows the Geoheritage vulnerability of Mantali (within a buffer zone of 5 km)

The Mantalai geoheritage site is increasingly affected by tourism-related development, heightening pressure on its already delicate terrain. The presence of high-elevation areas and steep slopes in the southern and central parts of the buffer zone makes the landscape particularly vulnerable to land-use changes driven by expanding tourism [Fig. 7]. Slope analysis identifies areas where gradients exceed stability limits, increasing the risk of erosion, slope failure, and mass wasting. These dangers are worsened by modifications such as road widening, hill cutting, and the construction of tourism infrastructure, including parking lots, accommodations, and access trails. Lithological factors further increase this susceptibility. The dominance of Palaeogene (Pg) and Palaeozoic (Pz) rocks, mainly related to Shiwalik sedimentary formations, indicates relatively weak, unconsolidated, and heavily weathered materials. These litho-units are inherently prone to erosion and deformation under external stress. Tourism activities, particularly increased foot traffic, vehicle vibrations, excavation, and poor drainage, accelerate the deterioration of these formations. In many places, slope instability is directly linked to human interference rather than natural geomorphic processes. The combination of steep slopes, fragile lithology, and expanding tourism routes greatly increases the vulnerability of geoheritage at Mantalai. Unregulated tourism growth not only threatens the structural stability of geological features but also endangers visitor safety and the site's long-term sustainability. Seasonal tourist surges intensify pressure on slopes through temporary infrastructure, waste buildup, and vegetation removal, all of which reduce slope cohesion and increase surface runoff.

2. Geoheritage Vulnerability of Pancheri

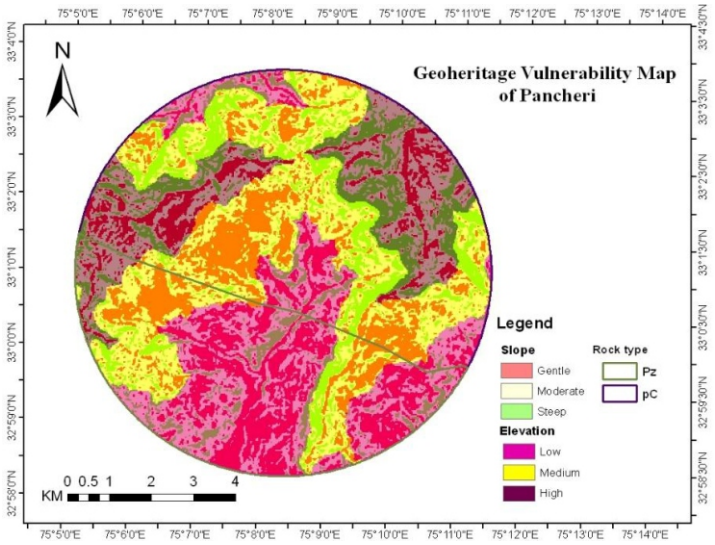


Fig. 08: shows the Geoheritage vulnerability of Pancheri (within a buffer zone of 5 km)

Pancheri features a somewhat rugged terrain, with alternating zones of medium and high elevation, creating a balanced topographic profile. Unlike Mantalai, the slope classes in Pancheri are more evenly spread out, with large areas composed of moderate slopes, indicating stable geomorphic conditions. This stability is reinforced by the lithological framework, consisting of two main rock units Palaeozoic (Pz) and Precambrian (pC) rocks generally linked to older, more compact, and structurally resilient sedimentary or metamorphic formations [Fig. 8]. These litho-units resist weathering and erosion better, reducing overall geoheritage vulnerability. Nonetheless, the central and southern parts of Pancheri show localized zones of higher elevation and steeper slopes that are more vulnerable to geomorphic disturbances. Soil erosion and minor slope failures are evident, especially where vegetation cover has been disturbed, and tourism-related activities are increasing. The construction of access roads, viewing points, trekking routes, and small accommodations can disturb slope stability, particularly when built near drainage channels or on unstable cut slopes. Although tourism is currently less intense than in Mantalai, future expansion in Pancheri presents risks to geoheritage if not properly managed. Increased visitor activity, trail widening, and unplanned infrastructure can speed up surface runoff and soil erosion, even in areas with stable lithology. Fragile rock surfaces in high-slope zones may gradually degrade, threatening the geological features that underpin the site's geoheritage value.

3. Geoheritage Vulnerability of Patnitop

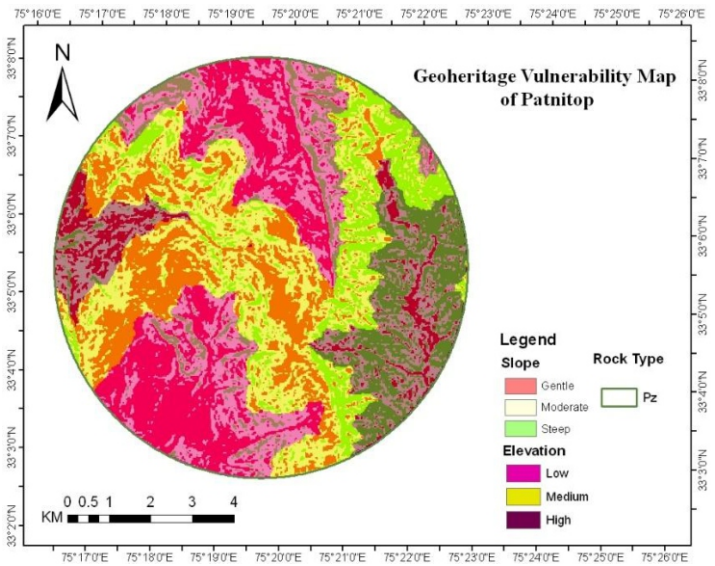


Fig. 09: shows the Geoheritage vulnerability of Patnitop (within a buffer zone of 5 km)

The Patnitop region features gentle slopes and a clear elevation gradient, reflecting its location on a relatively stable, plateau-like geomorphic surface. Unlike Mantalai and Pancheri, this area is mainly composed of a single lithological unit—Palaeozoic (Pz) rocks—indicating consistent geological makeup across the landscape [Fig. 9]. This uniformity, along with moderate relief, points to a naturally stable terrain with lower risk of slope-related hazards in undisturbed conditions. However, geoheritage vulnerability in Patnitop mainly stems from intense tourism activity and dense human settlements rather than geomorphic instability. As a top hill station, Patnitop has rapidly expanded, with hotels, roads, recreational facilities, and urban infrastructure, resulting in significant land-use changes, vegetation removal, and increased surface sealing. These factors disturb natural drainage and accelerate soil erosion. While the slope map shows mostly low to moderate gradients, steeper areas along the plateau's edges are potential zones of erosion and minor landslides, especially where slopes have been altered for construction or cleared for tourism infrastructure. Heavy foot traffic, vehicle movement, and informal trails further compact soil and degrade surfaces, gradually reducing slope stability.

Conservation Measures and Policy Relevance

Across all three sites, the overlay of slope, lithology, and elevation provides a comprehensive picture of how geoheritage vulnerability differs within Udhampur's Outer Himalayas. Mantalai represents a high-sensitivity geomorphic zone, Pancheri a moderate but mixed terrain, and Patnitop a human-induced vulnerability zone.

Together, these maps demonstrate how tourism-induced pressures intersect with geological fragility, a key concern for sustainable landscape management in the Himalayas. Based on these results, conservation priorities should be initiated.

The results of the geoheritage assessment highlight the need for a balanced approach between tourism development and geological conservation in Udhampur district. The study demonstrates that areas with steep slopes, fragile rock formations, and active geomorphic processes, such as in Pancheri and Mantalai, are more prone to erosion, slope failure, and degradation of geoheritage features. Therefore, these zones should be brought under strict tourism zoning regulations that carefully control construction and infrastructure development.

The vulnerable geoheritage sites in hilly regions of the Himalayas should shift from mass tourism to eco-tourism by restricting heavy construction, enforcing laws, sensitising locals, and implementing vulnerability zoning [4]. Moreover, the promotion of Eco-tourism should be accompanied by community participation, governance, and careful planning [28].

A geo-conservation-based zoning plan can be developed by categorizing the region into three levels.The geoheritage vulnerability zoning provides an effective framework for understanding and managing tourism-related pressures in the fragile Himalayan landscapes of Udhampur district. The delineation of high, moderate, and low vulnerability zones highlights how terrain steepness, lithological weakness, and geomorphological sensitivity strongly influence a tourism area's capacity to accommodate development. In particular, areas with steep slopes and weak Shiwalik formations, such as parts of Mantalai, exhibit high susceptibility to erosion and slope instability, underscoring the incompatibility of mass-tourism infrastructure with such environments. These results support earlier studies emphasizing that unregulated tourism development in geologically young mountain belts can accelerate land degradation and geoheritage loss. Moderate-vulnerability zones, including relatively stable plateaus and areas adjacent to major natural landmarks such as Pancheri, represent transitional spaces that require careful regulation of tourism development. The analysis suggests that while these areas are more resilient than high-vulnerability zones, they remain sensitive to surface disturbance and hydrological alteration. Consequently, low-density and eco-oriented tourism models appear more suitable than conventional infrastructure-intensive development. This finding aligns with broader geotourism research that highlights the importance of balancing accessibility with conservation in landscapes of intermediate stability. Low-vulnerability zones, such as the areas surrounding Patnitop town, are comparatively more suitable for essential tourism infrastructure due to gentler terrain and more stable lithological conditions.

However, the results indicate that even in these zones, unchecked expansion can indirectly affect adjacent vulnerable areas through increased traffic, waste generation, and altered drainage patterns. This reinforces the argument that vulnerability zoning should not be viewed as a binary restriction tool but rather as a dynamic planning mechanism that integrates environmental safeguards across all development intensities.

The study also highlights the importance of site-specific conservation strategies in mitigating geoheritage degradation. Measures such as slope stabilization through bio-engineering, restrictions on slope cutting, and regulation of road widening near geosites are particularly relevant in the Outer Himalayan context, where natural processes and human activities interact intensively. Furthermore, controlled visitor access and geo-interpretation were identified as essential tools for reducing physical damage while enhancing public understanding of geological values, thereby supporting both conservation and educational objectives.

The proposed concept of a Udhampur Geoheritage Park emerges from the findings as a practical mechanism for integrating vulnerability management, geoeducation, and community participation. By linking conservation goals with local livelihoods through geo-guiding and eco-tourism initiatives, such a model could reduce dependency on extractive or construction-based development while strengthening stewardship of geoheritage resources. This approach resonates with global geoheritage frameworks that emphasize participatory governance and education as key components of sustainable geotourism.

Overall, the discussion underscores that vulnerability-based spatial planning, when combined with targeted conservation measures and community engagement, can significantly enhance the sustainability of tourism in geologically sensitive Himalayan regions. The insights from Udhampur district contribute to the growing body of geoheritage research advocating a shift from mass tourism toward conservation-led, education-oriented tourism models in mountain environments.

Conclusion

Udhampur district, situated in the Outer Himalayas, has considerable tourism potential but is marked by fragile geoheritage conditions. The vulnerability of its geoheritage mainly results from interactions among terrain features, lithology, and the rapid increase in tourism. Geospatial analyses of lithology, slope, and elevation show significant spatial differences in vulnerability at three main tourist sites: Pancheri, Mantalai, and Patnitop. Mantalai, with its steep slopes and weak Shiwalik formations, is highly vulnerable and very sensitive to infrastructure projects, making large-scale tourism development unsuitable. Pancheri is a transitional area with moderate vulnerability, where unchecked tourism growth could cause localized geomorphic instability. Patnitop, although relatively stable and with consistent lithology, faces growing geoheritage stress mainly from dense settlements and tourism expansion, rather than from its natural terrain. The vulnerability maps created in this study offer a solid spatial basis for planning tourism that respects terrain sensitivity and conserves geoheritage.

By classifying areas into high-, moderate-, and low-vulnerability zones, decision-makers can identify regions that need strict protection, controlled development, or careful tourism management. High-vulnerability zones require strict construction controls and conservation efforts. Moderate zones can support eco-tourism with low impact under regulation, while relatively stable zones may host limited tourism infrastructure if eco-friendly designs and environmental safeguards are used. Besides spatial planning, the results emphasize the importance of integrating geoheritage conservation into regional tourism policies and development plans.

Site-specific management, community involvement, and awareness programs are vital to reducing human pressure on fragile geomorphic systems. Engaging local communities can improve the stewardship of geoheritage while supporting sustainable livelihoods. Overall, this research illustrates how geospatial tools can help balance tourism growth with geoheritage preservation. The methods and insights from this study can be applied to other Himalayan and mountainous regions facing similar issues, promoting more resilient, sustainable, and conservation-focused tourism development.

Author Contributions

All the authors contributed to the study. Rajan Bharti (First Author) contributed to the writing, conceptualisation, research methodology, design, data collection, analysis, and manuscript preparation. Dr Tek Chand Saini (Second Author) contributed to supervision, reviewing, formatting, and editing, overall guidance and academic supervision. All authors read and approved the final manuscript.

References

1. Badola, R., Hussain, S. A., Dobriyal, P., Manral, U., Barthwal, S., Rastogi, A., & Gill, A. K. (2018). Institutional arrangements for managing tourism in the Indian Himalayan protected areas. *Tourism Management, 66*, 1–12. https://doi.org/10.1016/j.tourman.2017.10.020.
2. Dahal, R. K., & Hasegawa, S. (2008). Representative rainfall thresholds for landslides in the Nepal Himalaya. *Geomorphology*, 100(3–4), 429–443. https://doi.org/10.1016/j.geomorph.2008.01.014.
3. Dowling, R. K. (2011). *Geotourism's global growth*. Geoheritage, 3(1), 1–13. https://doi.org/10.1007/s12371-010-0024-7
4. Dutta, P., Mandal, U. K., Paramanik, R., Subba, B., & Tamang, L. (2025). Geosensitivity assessment for the formulation of geoconservation strategies in the Darjeeling Hill region, India. *International Journal of Geoheritage and Parks, 2,* 319–333. https://doi.org/10.1016/j.ijgeop.2025.02.005.
5. Dutta, P., Mandal, U. K., Paramanik, R., Subba, B., & Tamang, L. (2025). Geosensitivity assessment for the formulation of geoconservation strategies in the Darjeeling Hill region, India. *International Journal of Geoheritage and Parks, 13*(2), 319–333. https://doi.org/10.1016/j.ijgeop.2025.02.005
6. Faccini, F.; Ferrando, A.; Coratza, P. Geoheritage Degradation Risk Assessment: Methodologies and Insights. *Sustainability 2024, 16*, 10336. https://doi.org/10.3390/ su162310336.
7. Ferdowsi S (2025), "Management of geoheritage conservation and vulnerability in tourism destinations". *Tourism Review*, Vol. 80 No. 2 pp. 601–623, doi: https://doi.org/10.1108/TR-03-2024-0189.

8. Ferdowsi, S. Vulnerability of Geoheritage in Tourism Destinations in Iran. *Geoheritage 17*, 124 (2025). https://doi.org/10.1007/s12371-025-01167-5.
9. Ferdowsi, S., Tavana, M., Heydari, R., & Štrba, Ľ. (2025). Geoeducation: The key to geoheritage conservation in tourism destinations. *International Geology Review, 67*, 1–23. https://doi.org/10.1080/00206814.2025.2466028.
10. GhulamRabbany, M., Afrin, S., Rahman, A., Islam, F., & Hoque, F. (2013). *Environmental effects of tourism*. American Journal of Environment, Energy and Power Research, 1, 117–130.
11. Gordon, J. E. (2023). *Climate change and geotourism: Impacts, challenges, and opportunities*. Tourism and Hospitality, 4(4), 514–538.
12. Gray, M. (2013). *Geodiversity: Valuing and conserving abiotic nature* (2nd ed.). John Wiley & Sons.
13. Gupta, R. P., & Sah, M. P. (2008). Impact of the 1998 and 2007 cloudbursts and flash floods in Uttarakhand, Himalaya. *Current Science, 94*(4), 484–491.
14. Gupta, V., Anand, S., Wei, D., Wang, G., & Tripathi, S. C. (2024). Exploring applied sustainable strategies through geoheritage and geotourism: A systematic literature review. *International Journal of Geoheritage and Parks, 12*(4), 660–677. https://doi.org/10.1016/j.ijgeop.2024.11.009
15. Hilario, A.; Asrat, A.; Van Wyk de Vries, B.; Mogk, D.; Lozano, G.; Zhang, J.; Brilha, J.; Vegas, J.; Lemon, K.; Carcavilla, L.; et al. (Eds.) *The First 100 IUGS Geological Heritage Sites*; International Union of Geological Sciences (IUGS): Zumaia, Spain, 2022; ISBN 1-79239-975-8.
16. India Today. (2015, August 8). *Amarnath Yatra suspended due to J-K highway landslide blockage*. https://www.indiatoday.in/india/jammu-and-kashmir/story/amarnath-yatra-suspended-due-j-k-highway-landslide-blockage-287153-2015-08-08.
17. Kothyari, G. C., Pant, P. D., Kotlia, B. S., Mehta, M., Joshi, H., Chauhan, D. S., Dumka, R. K., Luirei, K., et al. (2023). Geoheritage Sites in Kumaun Himalaya of Uttarakhand, India. *Geoheritage, 15*(3), 104. https://doi.org/10.1007/s12371-023-00834-9.
18. Li, Q. J., Ng, Y., & Wu, R. (2022). Strategies and problems in geotourism interpretation: A comprehensive literature review of an interdisciplinary Chinese to English translation. *International Journal of Geoheritage and Parks, 10*(1), 27–46. https://doi.org/10.1016/j.ijgeop.2022.02.001.
19. Li, W., Newsome, D., & Dowling, R. (2022). *Strategies and problems in geotourism interpretation. International Journal of Geoheritage and Parks, 10*(1), 27–46. https://doi.org/10.1016/j.ijgeop.2022.01.005.
20. Lorenz, D. F., & Dittmer, C. (2021). Disasters in the 'abode of gods' — vulnerabilities and tourism in the Indian Himalaya. *International Journal of Disaster Risk Reduction, 55*, 102054. https://doi.org/10.1016/j.ijdrr.2021.102054.
21. Lozano, G.; Carcavilla, L.; Finney, S.; Hilario, A.; Vegas, J.; Van Wyk de Vries, B.; Zhang, J. (Eds.) *The Second 100 IUGS Geological Heritage Sites*; International Union of Geological Sciences (IUGS): Zumaia, Spain, 2024; ISBN 979-8-218-45558-3
22. Muhanna, E. Sustainable Tourism Development and Environmental Management for Developing Countries. Problems and Perspectives. Probl. Perspect. Manag. 2006, 4, 14–30.
23. NDTV. (2015, March 17). *Thousands stranded in Jammu-Srinagar highway after landslides*. https://www.ndtv.com/india-news/thousands-stranded-in-jammu-srinagar-highway-after-landslides-747259.
24. Newsome, D., Dowling, R. K., & Leung, Y.-F. (2018). *Geotourism: A sustainable tourism focus*. In K. K. F. & others (Eds.), *Geotourism and Sustainability* (pp. 1–20). [See summaries of management implications in geoheritage contexts]
25. ProGEO. Conserving Our Shared Geoheritage–A Protocol on Geoconservation Principles, Sustainable Site Use, Management, Fieldwork, Fossil and Mineral Collecting; ProGEO: Uppsala, Sweden, 2011; p. 12.
26. Reynard, E. Geosite. In Encyclopedia of Geomorphology; Goudie, A., Ed.; Routledge: London, UK, 2004; p. 440, ISBN 978-0-415-86300-1
27. Reynard, E., & Brilha, J. (Eds.). (2018). *Geoheritage: Assessment, protection, and management*. Elsevier. https://doi.org/10.1016/B978-0-12-809531-7.00001-4.
28. Samal, R., & Dash, M. (2022). Ecotourism, biodiversity conservation and livelihoods: Understanding the convergence and divergence. *International Journal of Geoheritage and Parks, 11(6)*. https://doi.org/10.1016/j.ijgeop.2022.11.001.
29. Sati, V.P (2026). Tourism and livelihood sustainability in the Garhwal Himalaya. *Discover Sustainability* 7, 69. https://doi.org/10.1007/s43621-025-02433-w.
30. Sharma, R., Gupta, N., & Singh, A. (2022). Rainfall-induced landslides in Himalayan terrain: Soil, slope, and deforestation linkages. *Natural Hazards*, 112, 1229–1248.
31. Sharples, C. Concepts and Principles of Geoconservation; Tasmanian Parks & Wildlife Service: Hobart, Australia, 2002; p. 79.
32. Sianipar, I. M. J., Lee, C.-H., Wang, H.-J., Kim, D.-C., & Suryawan, I. W. K. (2025). Adaptive strategies and community engagement for sustainable conservation and tourism in Komodo National Park, Indonesia. *International Journal of Geoheritage and Parks*, 13(3), 335–349. https://doi.org/10.1016/j.ijgeop.2024.09.004.
33. Singh, B. V. R., Sen, A., Verma, L. M., Mishra, R., & Kumar, V. (2021). Assessment of potential and limitation of Jhamarkotra area: A perspective of geoheritage, geopark and geotourism. *International Journal of Geoheritage and Parks, 9*(2), 157–217. https://doi.org/10.1016/j.ijgeop.2021.04.001.
34. Singh, R., Bhat, S. A., & Mir, R. A. (2023). Rainfall extremes in Jammu and Kashmir: Emerging patterns and socio-economic implications. *Climate Risk Management*, 42, 100515.
35. Štrba Ľ, Kolačkovská J, Kudelas D, Kršák B, Sidor C. Geoheritage and Geotourism Contribution to Tourism Development in Protected Areas of Slovakia—Theoretical Considerations. *Sustainability*. 2020; 12(7):2979. https://doi.org/10.3390/su12072979.
36. Valdiya, K. S. (2016). *The making of India: Geodynamic evolution*. Springer. https://doi.org/10.1007/978-3-319-25029-8.
37. Valentini, L., Guerra, V., & Lazzari, M. (2022). *Enhancement of geoheritage and development of geotourism: Communication through art and landscape interpretation. Geosciences, 12*(7), 264. https://doi.org/10.3390/geosciences12070264
38. Vandelli, V., Selmi, L., Faccini, F., Ferrando, A., & Coratza, P. (2024). Geoheritage Degradation Risk Assessment: Methodologies and Insights. *Sustainability*, *16*(23), 10336. https://doi.org/10.3390/su162310336.
39. Wang, Y., Li, X., Han, Z., Han, J., Pang, X., Song, W., & Wang, Q. (2023). From Geoparks to Regional Sustainable Development: Geoheritage Protection and Geotourism Promotion of Geoparks in Hebei Province, China. *Geoheritage*, 15(1), 102. https://doi.org/10.1007/s12371-023-00984-4.
40. Wani, M. A. (2022). *Tourism in Kashmir: Development and economic impact. International Journal of Tourism and Hotel Management, 4*(1), 1–6. https://doi.org/10.22271/27069583.2022.v4.i1a.35.