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ARTICLE

Feasibility Studies and Analysis of Geopark in Kutch Region of Gujarat, India as the UNESCO Recognised World Geoheritage and Tourism Site

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ABSTRACT

Sites and landscapes of international geological significance are managed with a comprehensive approach of conservation, education, and sustainable development in UNESCO Global Geoparks, which comprise a single, cohesive geographic area. A growing number of people are adopting the bottom-up strategy, which involves local communities and combines sustainable development with conservation. The viability of creating a UNESCO-recognized geopark in Kutch is assessed in this study. This study examines the key geoheritage features of the Kutch region, explores the socio-economic prospects of a geopark through geotourism and community development, and evaluates its conformity with UNESCO's Global Geopark criteria on conservation, education, and sustainability. The study also evaluates the overall feasibility of the project,

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its economic, social, and environmental implications, and the adequacy of the requisite infrastructure.. Its geological, cultural, and historical significance, as well as socioeconomic and environmental factors, are the parameters considered for investigation. Despite multiple applications to UNESCO, the Gujarat region of Kutch, which is rich in geological, cultural, and historical elements, is not recognised as a World Heritage Site. In actuality, there are 195 geoparks in 48 nations worldwide as of 2023, however India does not have one. The findings of the study provide critical insights that can direct initiatives to establish India's first geopark and promote regional sustainability.

Keywords: UNESCO; Geoparks; Kutch Region; Geological Heritage; Feasibility Study; Conservation

1. Introduction

Geoheritage sites represent invaluable natural assets that preserve the Earth's geological history, offering insights into its evolutionary processes and serving as platforms for education, research, and tourism [1,2]. Recognizing the importance of safeguarding these significant landmarks, the UNESCO Global Geopark program was established to promote the protection and sustainable use of such sites while fostering socio-economic benefits for local communities [3]. In this context, the Kutch region of Gujarat, India, emerges as a potential candidate for geopark designation, owing to its diverse and well-preserved geological, paleontological, and geomorphological features [4].

The Kutch region is characterized by its unique topography, including the Kutch Fossil Park, Jurassic rock formations, and tectonic landforms shaped by the Indian Plate's active geological processes [5]. Its fossil-rich deposits, such as ammonites and dinosaur remains, are of global significance and have been studied extensively for their contribution to understanding Mesozoic stratigraphy and paleoenvironments [6]. In addition to its natural treasures, the region is rich in cultural and historical heritage, which offers immense potential for geotourism and educational initiatives [7]. However, despite its significant geoheritage value, the region faces challenges such as limited awareness, inadequate infrastructure, and environmental concerns, necessitating a systematic feasibility analysis to realize its potential as a UNESCO-recognized geopark.

This study builds upon existing research on geoheritage conservation [2,8] and geopark development to evaluate the feasibility of establishing a geopark in the Kutch region. It examines the region's geoheritage assets, stakeholder perspectives, and alignment with UNESCO criteria through a multidisciplinary approach that integrates geospatial analysis, field surveys, and socio-economic assessments. By addressing these aspects, this research contributes to the broader discourse on sustainable development through geoheritage conservation and offers a roadmap for future geopark initiatives in geologically significant regions.

This paper evaluates the feasibility of creating a geopark in Gujarat's Kutch region. There are 195 geoparks worldwide as of 2023, spread over 48 nations. Despite its diverse geological features and rich cultural heritage, India still needs its geopark. Even though India has nominated many geological locations for consideration as Global Geoparks to UNESCO, these submissions have been routinely rejected since the necessary legislation is lacking. This study assesses the viability of establishing a geopark in the Kutch region, considering its geological, cultural, and historical features and the socioeconomic and environmental aspects that may impact the decision to construct a geopark. The feasibility of establishing a geopark in the region, the accessibility of required infrastructure and resources, and the possible economic, social, and environmental effects of such an endeavour will all be covered by the study.

The present study is aimed to identify and document the significant geological, paleontological, and geomorphological features of the Kutch region, to study the potential socio-economic benefits of a geopark, including geotourism, local employment, and community development and to assess the compliance of the Kutch region with UNESCO's guidelines for Global Geoparks, including aspects of conservation, education, and sustainable development.

2. Review of Literature

A geopark is a geographic region with a rich geological legacy of international importance. Geoparks leverage this legacy to raise public awareness of significant societal

issues in light of our planet's constant change. In addition to working to create disaster mitigation plans among local communities, they raise awareness about natural dangers like earthquakes, tsunamis, and volcanic eruptions. In addition to implementing sustainable practices that encourage the use of renewable energy and responsible tourism, or geotourism, geoparks house records of historical climate changes and act as educators on present climate change. The Travel Industry Association of America and National Geographic Traveller Magazine popularised geotourism in 2002, emphasising sustainability. Numerous academics have made substantial contributions to the research of geoparks and geotourism.

According to Swarna et al.[9], Kutch may grow into a National Geopark due to the region's geological significance and the requirement for infrastructural development to support geotourism. The study highlights the importance of sustainable economic growth in the area while examining the financial and sociological advantages of such development. The uncommon geological legacy of the Kutch region is under threat from human activity, according to the scientists, and urgent action is required to preserve it. According to Patzak and Eder[10], a geopark is a protected area that has several geological heritage sites that are particularly significant, unique, or beautiful. These landforms represent the area's geological history, processes, and events.Sinclair[11] acknowledged that the tourism industry can create job opportunities in both the formal and informal sectors.

"Sustainable tourism" refers to the development of tourism that meets the needs of present travelers and host communities, all while safeguarding and enhancing opportunities for future generations, as outlined by the World Tourism Organization[12] in 1998. The organization places significant emphasis on the comprehensive management of resources to conserve biological diversity, essential ecological processes, cultural integrity, and life support systems. This approach aims to balance the demands for economic, social, and aesthetic considerations.

Geotourism is defined by Tourtellot[13] as a type of tourism that improves a location's geographic character, including its environment, culture, heritage, and people's quality of life. The author underlined the value of sustainable development and the necessity of preserving and promoting a destination's distinctive attributes. Geological Survey of India[14] in 2001 identified 26 national geological monuments that have the potential to become geoparks and thereby promote geotourism in India. According to Buckley[15], geotourism is not a novel concept but a means of blending development and sustainability with tourism market segmentation.

A geopark is a picturesque site with uncommon natural features, crucial geological heritage, aesthetic value, and a specified scale and scope that incorporates other natural and cultural attractions into a unique natural area[16]. In addition to being a destination for tourism and leisure, a geopark also acts as a significant protected area for geological heritage and as a centre for geoscientific research and public outreach. Fenell[17] argued that Geotourism, a subset of ecotourism, revolves around natural resources, offering an immersive and educational experience with nature. It is ethically managed to minimize impact, prioritizing local control, benefits, and scale. Typically unfolding in natural environments, geotourism is expected to contribute to the conservation or preservation of these areas.

Stokes et al.[18] emphasised that geotourism is an emerging niche market within sustainable tourism that revolves around preserving and enhancing the unique geographical character of a place. Dusar[19] suggested that applying the geopark concept to mountain karst regions in Vietnam is the best way to safeguard the unique karst landscape, promote sustainable development, and improve residents' living standards. Dowling and Newcome[20] defined it as sustainable tourism centred on engaging with the Earth's geological features to promote environmental and cultural comprehension, appreciation, and conservation, all while benefiting the local community. Dowling and Newsome[20] claimed that geotourism is part of the broader context of geographical tourism, encompassing geographical, socioeconomic, and cultural dimensions. Geotourism is a target of geoparks. Pralong[21] described it as a diverse form of tourism that educationally and entertainingly explores natural sites and landscapes featuring captivating earth-science elements.

Eder[22] stressed that Geoparks strive to incorporate the conservation of geological heritage into a sustainable regional economic and cultural development strategy. Hose[23] noted that although geotourism gained popularity in the 1990s, its roots can be traced back to the seventeenth century. Its resource base encompasses geosites, museums, library and archive collections, and artistic outputs. According to

Miller and Washington [24], geotourism upholds conservation ideals about a location's natural resources, culture, heritage, and customs while celebrating the feeling of place. It includes travel-related industries, including housing, dining, shopping, entertainment, and sightseeing, when they offer and encourage genuine experiences that are distinctive to the region and help the locals.

Boley [25] proposed a The Geotourism Survey Instrument (GSI) was employed to analyze the behavior of geotravelers in geotourism destinations, specifically in the Crown on the Continent region spanning Montana, USA, and Canada. The study concentrated on four assessed dimensions of geotourism: culture-heritage, environment, aesthetics, and the well-being of local communities. According to Dowling [26], geotourism enhances sustainability principles and emphasises the "sense of place" to highlight the uniqueness of a locale and benefit both visitors and residents.

The vital role that geoparks play in fostering the economic growth of nearby communities was covered by Farsani and Coelho [27]. Geoparks are a cutting-edge method of protecting geological and ecological heritages that also help to fuel the expansion of geotourism. Geoparks, especially in rural regions, generate new economic activity and job prospects through geotourism. This promotes the manufacture of regional goods and handicrafts related to geotourism and geoproducts. Hartling and Meier [28] emphasised the direct impact of geotourism on the revenue, income, and employment generated by tourism in the economic activities of geoparks. According to the Global Geopark Network, geoparks are defined as areas with clearly defined boundaries large enough to support local economic and cultural development, mainly through tourism.

According to Nowlan [29], The designation of a property as a geopark does not alter its legal status. The regulations about ownership and administration of the sites continue to be governed by federal, provincial, territorial, municipal, and First Nation laws. Despite the endorsement and coordination provided by UNESCO through the Global Geoparks Network (GGN), UNESCO does not possess any legal authority over geopark territory's local, regional, territorial, national, aboriginal, or private ownership or management. Furthermore, the GGN and UNESCO support has led to extended journeys to geoparks.

Mahadevan [30] reported that Varkala Beach, a unique sedimentary geo- morphological structure located on the flat Kerala coast in India, is on course to become the country's first national geopark under the Geological Survey of India's initiative to conserve geologically essential sites.

According to Jean-Marc et al. [31], geo-conservation is preserving geological heritage by identifying, managing, and protecting significant sites and landscapes with geological or geomorphological significance. Nature conservation and the teaching of earth science depend on the preservation of geological formations.

3. Study Area

Kutch district, officially spelled Kutch is a district of Gujarat state in western India, with its headquarters at Bhuj. The Kutch region, located in the northwestern part of Gujarat, India, is renowned for its diverse geological, ecological, and cultural attributes. Covering an area of approximately 45,652 square kilometers, it is the second-largest district in India. Bordered by the Arabian Sea to the south and the Great Rann of Kutch to the north, the region is characterized by its arid climate, distinct topography, and active tectonic settings. The study area lies between 22°41′N to 24°45′N latitude and 68°09′E to 71°54′E longitude, making it a unique geological province with features of international significance (**Figure 1**).

Geologically, Kutch is a part of the western margin of the Indian subcontinent and is known for its Jurassic and Cretaceous rock formations, fossil-rich deposits, and salt flats. Prominent geoheritage features include the Kutch Fossil Park, the Bhuj Formation, and the tectonically active Kutch Mainland Fault, which has been the epicenter of significant seismic activity, including the devastating Bhuj earthquake of 2001 [32]. These geological formations are crucial for understanding Earth's evolutionary history, particularly the Mesozoic Era, due to their rich repository of marine and terrestrial fossils. The region is also home to a variety of landscapes, including desert plains, hill ranges like the Kalo Dungar (Black Hill), coastal areas, and the saline marshlands of the Rann of Kutch. The interplay between these diverse environments has contributed to the region's unique biodiversity, supporting species such as the Indian wild ass, flamingos, and other endemic flora and fauna [33].

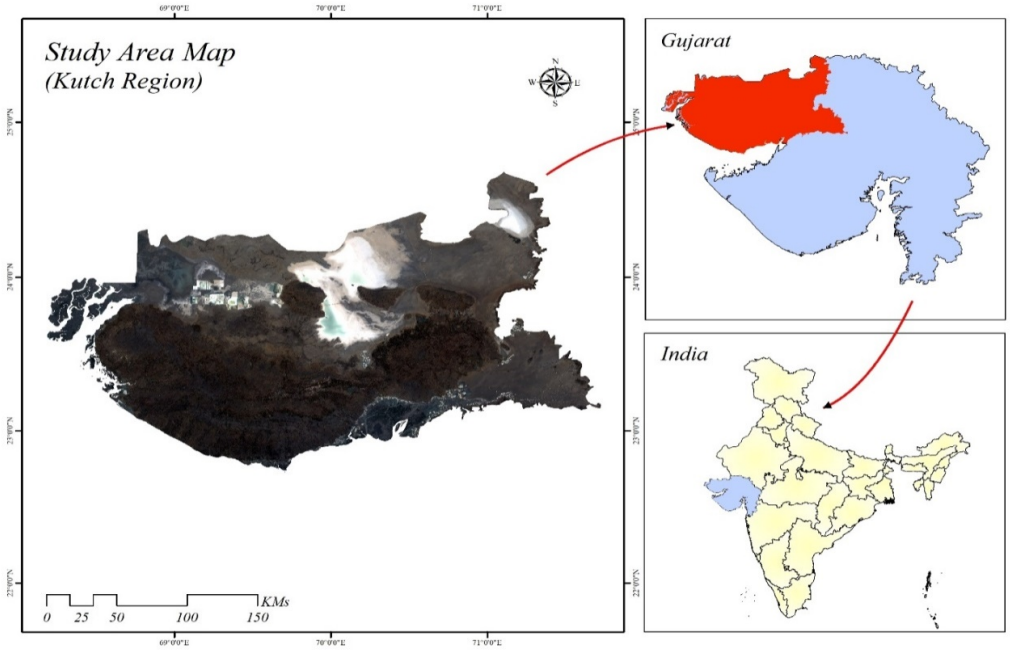

Figure 1. Study Area Map.

Source: Prepared by Authors.

4. Database and Methodology

A systematic approach was adopted to assess the feasibility of establishing a UNESCO Global Geopark in the Kutch region, integrating extensive fieldwork, stakeholder consultations, spatial analysis, and strategic planning. Field visits were conducted across key geoheritage sites, including the Kutch Fossil Park, Jurassic rock formations, and tectonic fault zones, where geological features were meticulously documented to highlight their scientific and aesthetic significance. In addition to field observations, interviews and focus group discussions were carried out with local communities, geologists, tourism officials, and conservationists to gain insights into the socio-economic and environmental implications of geopark development. High-resolution satellite imagery and topographic maps were analyzed to map geoheritage sites and evaluate their spatial relationships with existing infrastructure and human settlements.

Data collection involved multiple methodologies to ensure a comprehensive understanding of the region's potential as a geopark. Documentary research was conducted by reviewing books, academic journals, official reports, and online sources to gather information on geological formations, biodiversity, cultural heritage, and the current state of tourism infrastructure in Kutch. Field surveys were undertaken to document geological formations, assess land use, and identify prospective geosites through mapping, photography, and detailed site observations. Additionally, stakeholder interviews provided valuable insights into local perspectives, indigenous knowledge, and socio-economic considerations related to the geopark initiative.

A SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted to critically evaluate the region's strengths, limitations, opportunities, and potential risks. The analysis helped identify the unique geological attributes and rich cultural heritage that could be leveraged for geopark development while also recognizing challenges such as inadequate infrastructure and environmental concerns. Opportunities for sustainable tourism, educational outreach, and community development were explored, while potential threats like climate change impacts and resistance from local stakeholders were considered.

For data analysis, both quantitative and qualitative methods were employed. Statistical tools were used to assess data on tourist inflow, economic benefits, and environmental impact, ensuring an evidence-based approach to geopark feasibility. Qualitative analysis was conducted to interpret feedback from interviews and surveys, allowing for a deeper understanding of stakeholder perspectives and the cultural significance of the identified geosites.

Based on the findings, a strategic development plan was formulated, focusing on infrastructure enhancement, community engagement, and promotional initiatives. Infrastructure development proposals emphasized improving accessibility, visitor amenities, and conservation measures to support sustainable tourism. Community engagement strategies were designed to foster local employment, capacity-building programs, and the preservation of indigenous cultural practices[7]. Furthermore, marketing and educational initiatives were suggested to raise awareness about the geopark through outreach programs, guided tours, and digital promotions.

5. Result and Discussion

5.1. Geoheritage Value Assessment (GVA)

To prioritize geosites within the region, I developed a Geoheritage Value Assessment (GVA) index. Each site was evaluated based on four weighted criteria:

$$\text{GVA} = (\text{S} \times \text{Ws}) + (\text{E} \times \text{We}) + (\text{C} \times \text{Wc}) + (\text{A} \times \text{Wa})$$

Where:

- S: Scientific Value
- E: Educational Value
- C: Cultural Value
- A: Aesthetic Value
- W: Weight assigned (normalized to 1)

Sites Evaluated:

- Kutch Fossil Park (Bhuj)
- Naredi Ammonite Beds
- Kalo Dungar (Black Hill)
- Lakhpat Fault Zone

Scores (based on field surveys and expert consultation): S = 5, E = 4, C = 3, A = 4

Weights: Ws = 0.3, We = 0.25, Wc = 0.2, Wa = 0.25

$$\text{GVA} = (5 \times 0.3) + (4 \times 0.25) + (3 \times 0.2) + (4 \times 0.25) = 1.5 + 1.0 + 0.6 + 1.0 = 4.1/5$$

Sites scoring above 3.5 were marked as high-priority geosites for geopark inclusion.

5.2. Geospatial and NDVI Analysis

I employed remote sensing and GIS tools (QGIS, Landsat 8, Sentinel-2 imagery) to map vegetation cover, topographic variation, and human accessibility around geosites. In particular, I used NDVI to understand ecological vulnerability:

$$\text{NDVI} = (\text{NIR} + \text{RED})/(\text{NIR} - \text{RED})$$

Example – Kalo Dungar Slope (Scrub Zone):

- NIR = 0.64, RED = 0.22
- NDVI = (0.64 − 0.22) / (0.64 + 0.22) = 0.42 / 0.86 ≈ 0.488

This value indicates moderate vegetation, confirming my visual assessment of semi-arid scrubland. Buffer analysis (5 km radius) was applied around geosites to assess proximity to roads, settlements, and services

5.3. Cost-Benefit Analysis (CBA)

To evaluate economic feasibility, I performed a simplified cost-benefit analysis based on projected geotourism income and required infrastructure costs:

$$\text{Net Benefit(NB)} = \text{Total Benefits(TB)} - \text{Total Costs(TC)}$$

$$\text{BCR} = (\text{TC})/(\text{TB})$$

Example – Kutch Geopark:

TB = ₹2.5 crore (based on projected annual footfall of 60,000 tourists × ₹400 avg. spend)

TC = ₹1.2 crore (visitor centers, signage, eco-parking, salaries)

NB = ₹2.5 − ₹1.2 = ₹1.3 crore, BCR = 1.2 / 2.5 = 2.08

This positive BCR demonstrates a financially viable if managed sustainably.

5.4. Stakeholder Analysis using Likert Scale

I conducted semi-structured interviews and Likert-scale surveys with 60 participants from Dhordo, Bhujodi, Naredi, and Lakhpat, including:

- Local artisans

- Homestay owners
- Teachers
- Government officials

They were asked to rate statements like:

- *"Our village would benefit from a geopark."*
- *"We are aware of the fossil significance in this region."*

Ratings ranged from 1 (Strongly Disagree) to 5 (Strongly Agree).

Example – Awareness of Geoheritage (Naredi Village):

Responses: 5, 4, 4, 3, 4

$$\text{Mean Score} = 20/5 = 4.0$$

High awareness scores confirmed community willingness, though lower scores in Lakhpat (avg. 2.6) revealed areas needing awareness drives.

5.5. Visitor Carrying Capacity (VCC) Estimation

To prevent environmental degradation, I estimated carrying capacity for sensitive sites:

$$\text{VCC} = \text{A} \times \text{R} \times \text{V}/\text{T}$$

Where:

A = Area available (e.g., 2.5 sq. km for Naredi fossil zone)

R = Daily ecological recovery rate (assumed 0.8)

V = Visitor tolerance (estimated as 400/day)

T = Time frame (e.g., 30 days

$$\text{VCC} = 2.5 \times 0.8 \times 400/30 = 26.7 \text{visitors}/\text{day}$$

This metric was proposed for seasonal visitor regulation, especially during winter peaks.

The integration of field observations, participatory surveys, geospatial tools, and analytical models provided a multi-dimensional understanding of the region's readiness for geopark recognition. These methods not only evaluated the potential of individual sites but also helped propose a structured action plan for sustainable geotourism, community engagement, and geoheritage conservation. Final Integration involves Multi-Method Strength. Together, these methods offered a comprehensive and context-sensitive framework to assess the Kutch region's readiness for geopark recognition (**Table 1**).

Table 1. Each method provided a unique dimension of insight.

Method	Focus	Contribution
GVA	Geoheritage Prioritization	Scientific site ranking
NDVI	Ecological Health	Environmental baseline
CBA	Economic Viability	Funding justification
Surveys	Social Acceptability	Community alignment
VCC	Visitor Impact Control	Sustainability tool

A feasibility assessment was conducted to evaluate the economic, environmental, and social sustainability of the proposed geopark. A cost-benefit analysis was performed to assess the project's financial viability, ensuring long-term economic sustainability. Environmental impact assessments were carried out to identify potential ecological risks and propose mitigation measures. Lastly, the social acceptability of the project was evaluated by ensuring alignment with local values and securing community support. The overall evaluation included a detailed comparison of the region's characteristics with UNESCO Global Geopark criteria, identifying key gaps and formulating recommendations to bridge them. This multifaceted approach provided a holistic framework for assessing the feasibility of the Kutch region as a UNESCO-recognized geopark, paving the way for sustainable geoheritage conservation and tourism development (**Table 2**).

Table 2. SWOT Analysis: Feasibility of Kutch Geopark.

Strengths	Weaknesses
Rich Geological Heritage: Fossil-rich sites like the Kutch Fossil Park near Bhuj and ammonite beds in Naredi Village.	Limited Awareness: Many locals in areas like Ler and Jara are unaware of the significance of the geoheritage sites.
Unique Landforms: The Great Rann of Kutch (world's largest salt marsh) and the Kalo Dungar (Black Hill).	Infrastructure Challenges: Remote sites like Naredi lack basic tourism infrastructure such as roads and signage.

Table 2. *Cont.*

Strengths	**Weaknesses**
Proximity to Urban Centers: Bhuj serves as a hub, providing access to the region's key sites.	Environmental Concerns: Sites like the Great Rann of Kutch are ecologically sensitive and prone to degradation.
Cultural and Historical Heritage: Traditional crafts from villages like Bhujodi and the Kutchi Rabari Tribe culture.	Policy Gaps: Lack of dedicated geoheritage policies in India to support conservation and geopark designation.
Educational Potential: Sites like the Kutch Fossil Park are ideal for academic research and educational tourism.	Funding Issues: Insufficient investment for large-scale conservation and infrastructure development.
Opportunities	**Threats**
Global Recognition: Geopark designation could position Kutch alongside UNESCO sites like Marble Arch Caves Geopark (Ireland).	Environmental Degradation: Increased footfall in fragile areas like the Rann of Kutch may harm biodiversity.
Geotourism Potential: Fossil sites and formations could attract international visitors, boosting the local economy.	Over-tourism: Overcrowding in popular areas such as Kalo Dungar could damage the ecosystem.
Community Engagement: Local tribes like the Rabari and Ahir could be involved in sustainable tourism and craft promotion.	Climate Risks: The region's arid climate and frequent droughts may challenge sustainability efforts.
Academic Partnerships: Collaboration with institutions like the Gujarat Mineral Research Development Society (GMRDS).	Governance Challenges: Coordination between local, state, and national authorities remains weak.
Eco-friendly Tourism: Developing green infrastructure to reduce the environmental footprint.	Resistance from Locals: Lack of perceived benefits could lead to community resistance against the initiative.

Source: Prepared by Author.

5.6. Identified Geo-Sites in Kutch Region

The geosites display the geological legacy the Kutch region has amassed throughout its geological history. These geosites can draw in visitors and researchers interested in learning more about the region of Kutch's geological heritage. The following discusses the geosites found in the Kutch region (**Figure 2**).

Figure 2. Geosites in Kutch Region.

5.7. Key Fossil Discoveries

Significant fossil evidence, including dinosaur bones and footprints, has been discovered in the Balasinor Fossil Park, located near Raiyoli village in the Mahisagar district. This site is one of the most important dinosaur fossil locations in India, showcasing fossils from the Late Cretaceous period. Marine fossils, such as ammonites, have been found in abundance in areas like Naredi, Jara, and Ler in the Kutch district. These fossils are key indicators of the Mesozoic marine environments and provide insights into ancient biodiversity. The Jurassic sedimentary rocks of the Kutch Basin, particularly near Bhuj and Khatrol Hill, are rich in fossil assemblages, including bivalves, gastropods, and corals. These formations are of global significance for understanding the Jurassic period.The Kutch Fossil Park near Bhuj is internationally recognized for its Jurassic fossils, including marine ammonites and vertebrate remains. These fossils provide critical insights into the Mesozoic era and are studied globally for their paleontological significance [34]. The Kutch Mainland Fault (KMF) and associated seismic activity are important for understanding tectonic processes along the Indian Plate. The region's geology is often referenced in global studies of plate tectonics and seismicity [33]. The Great Rann of Kutch is a unique salt desert formed by marine transgressions and tectonic uplift, showcasing geomorphological processes of global relevance.

The Great Rann of Kutch is the most visited site due to its iconic White Desert and the popularity of the Rann Utsav. Cultural-geotourism destinations like Dhordo and Bhujodi draw substantial domestic and international visitors. Fossil sites like the Kutch Fossil Park and Naredi Ammonite Beds attract more niche audiences, such as researchers and educational tours. Sites like Kalo Dungar and Lakhpat Fort have moderate visitor numbers, which could be enhanced with better infrastructure and marketing. International tourism could be increased with targeted promotions, particularly for sites like Dholavira and fossil parks.

The first ichthyosaur fossil found in India was discovered in the Kutch (Kutch) region of Gujarat in 2016. This significant find, which is approximately 152 million years old, dates back to the Jurassic period and represents a marine reptile that lived during the age of dinosaurs. The ichthyosaur fossil was unearthed in the Lodai village of Kutch. This region is known for its rich fossil deposits and unique geological formations. The fossil measured around 5.5 meters in length and was remarkably well-preserved, making it one of the most complete ichthyosaur fossils ever found in the Indian subcontinent (**Figure 3**).

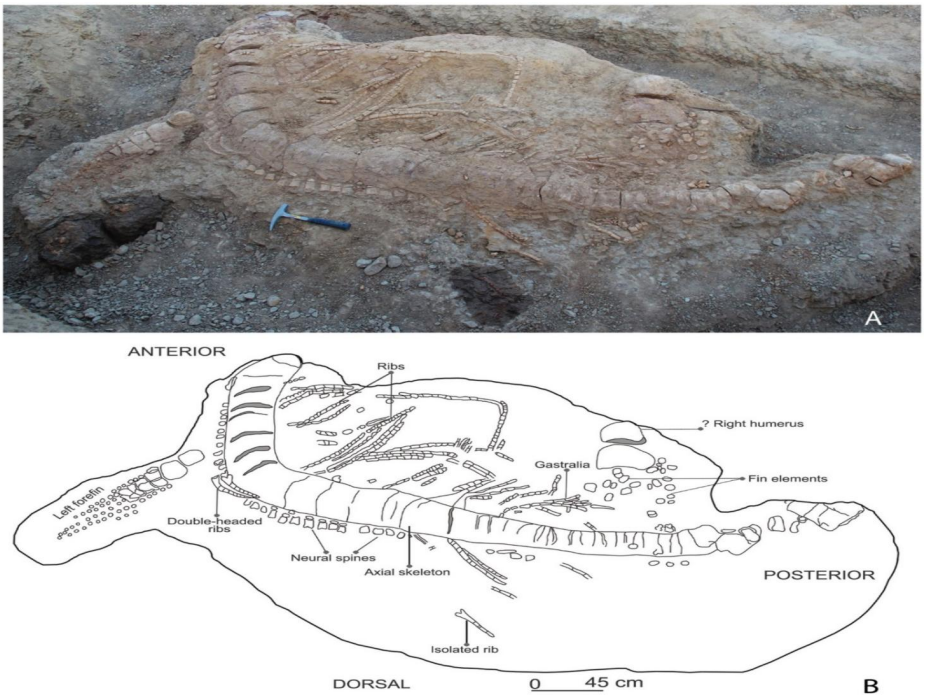

Figure 3. (**a**) Photograph of the Excavated Ichthyosaur Skeleton in Kotrol Formation near Lodai Village; (**b**) Sketch of Ichthyosaur. Source:Prasad et al. [35].

This discovery provided evidence of the interconnection of the marine ecosystems of India with other parts of the world during the Jurassic period. It also confirmed that the Kutch region was submerged under a shallow sea during this time, making it a hotspot for marine biodiversity. The find was made by an international team of paleontologists, led by Dr. G. V. R. Prasad [35] from the University of Delhi, in collaboration with researchers from India and abroad.

Kutch's Pleistocene deposits have yielded a treasure trove of large mammal fossils, including Stegodon, a massive elephant-like creature with four tusks, Sivatherium, a giraffe-like herbivore with bony horns, and giant hyenas. These fossils paint a picture of a savanna-like environment teeming with megafauna. Sabre-toothed cats, such as Smilodon, were formidable predators during the Pleistocene. Fossils of these iconic predators have been found in various parts of Kutch, shedding light on their ecology and interactions with other species (**Figure 4**).

(**a**)

(**b**) (**c**)

Figure 4. *Cont.*

(**d**)

Figure 4. (**a**) Skeleton of Stegodon; (**b**) Sivatherium, a giant Giraffe; (**c**) Skull of sabre-toothed Cat; (**d**) Fossilized Hominid Teeth.
Source: https://dinoanimals.com/animals/stegodon-one-of-the-largest-proboscideans/.

Kutch is renowned for its early human finds, with the discovery of stone tools and fossilised hominid teeth suggesting the presence of Homo erectus around 1.5 million years ago. This evidence pushes back the timeline of human occupation in the Indian subcontinent and sheds light on the early migration patterns of our ancestors (**Figure 4**).

Marine Invertebrates: Kutch, a mesmerising region in western India, isn't just renowned for its dinosaur and early human finds. Beneath the sands and within the rugged cliffs lie secrets whispered by countless marine invertebrates that thrived millions of years ago. Their fossilised shells, exoskeletons, and trace marks paint a vibrant picture of ancient underwater ecosystems, each fragment a piece of the puzzle reconstructing Kutch's prehistoric seas.

Kutch's shallow, warm seas teemed with life during Jurassic Period (201-145 million years ago). Ammonites, spiral-shelled cephalopods related to modern nautiluses, dominated the scene. Fossils of Ceratites (**Figure 5a**) and Harpoceras (**Figure5b**) reveal agile swimmers adapted to feed on plankton and smaller invertebrates.

(**a**) (**b**)

Figure 5. (**a**) Fossils of Ceratitis; (**b**) Fossils of Harpoceras.
Source: https://www.fossils-uk.com/new-in-c40/fossils.

The marine ecosystem experienced increased diversity during Cretaceous Period (145-66 million years ago). Bivalves such as oysters and clams flourished, leaving behind intricate shells that demonstrate adaptations to various types of seabeds . Sea urchins and crinoids, spiny echinoderms, fed on algae and filtered food particles, with their fossilised remains narrating stories of varied seafloor communities.

Marine life rebounded and adapted to changing environments following the Cretaceous mass extinction during Paleocene and Eocene Epochs (66–34 million years ago). Foraminifera, tiny single-celled organisms, became abundant, offering clues about past temperatures and ocean chemistry. Nummulites, large coin-shaped foraminifera, formed thick limestone deposits in some areas, their presence like shimmering coins scattered across the ancient seabed (**Figure 6**).

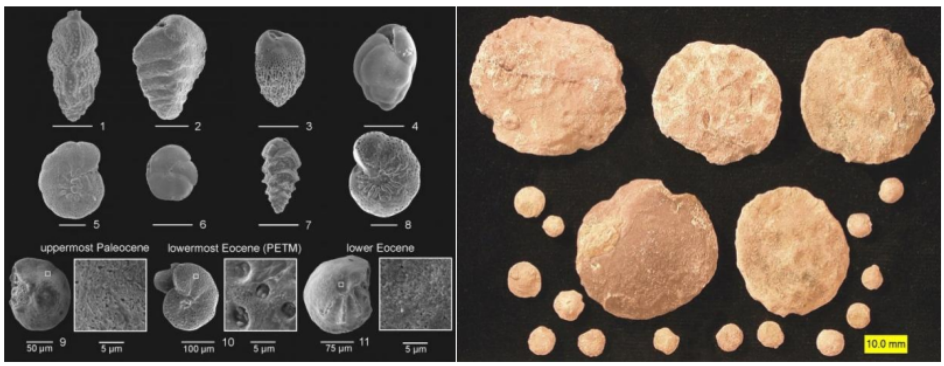

Figure 6. Nummulites, large coin-shaped foraminifera.

Source: https://websites.umich.edu/~ wstoddar/nummulite.html.

In the sun-drenched western expanse of India, Kutch transcends its identity beyond windswept deserts and affluent folklore. The hushed tales conveyed by fossilised bones, teeth, and footprints are concealed within its core- a testament to the varied orchestra of vertebrates that once harmonised in this ancient terrain (**Figure 7**). From immense dinosaurs traversing verdant prehistoric jungles to nimble mammals adapting to shifting landscapes, Kutch's repository of vertebrate fossils unveils a mesmerising tableau of life on Earth millions of years ago. Kutch in western India is renowned for its abundant fossil deposits, particularly from the Cretaceous period. The vertebrate fossils discovered in Kutch offer valuable glimpses into the ancient fauna that once inhabited the region millions of years ago.

(a) (b)

Figure 7. (**a**) Sauropod Head; (**b**) Theropods Long Necked Skeleton.

Source: https://www.theguardian.com/science/2018/may/11/dinosaur-skeleton-therapod-auction-paris.

Kutch has yielded fossils from the Cretaceous period, including herbivorous and carnivorous dinosaurs. Among them are sauropods, characterised by their long necks and tails, and theropods, which were bipedal carnivores.

Fossilized remains of ancient mammals, which coexisted with dinosaurs and those from the later Cenozoic

era, have been discovered in Kutch. In addition to dinosaurs, fossils of other reptiles, such as marine reptiles (e.g., ichthyosaurs and plesiosaurs) and terrestrial reptiles (e.g., crocodiles and turtles), have been identified in Kutch (**Figure 8**).

The fossil record in Kutch includes specimens of ancient bony fish and cartilaginous fish like sharks and rays. While less common, fossils of amphibians, vertebrates capable of living in both water and on land, may also be present in the sedimentary rocks of Kutch. The well-preserved nature of these vertebrate fossils in Kutch, owing to the region's geological conditions, enables palaeontologists to study them to gain insights into the area's biodiversity, evolution, and paleo-environment during different geological periods.

Figure 8. Plesiosaurs Marine reptiles fossil.

Source: https://www.newscientist.com/article/2156370-this-is-the-oldest-fossil-of-a-plesiosaur-from-the-dinosaur-era/.

5.8. Educational and Scientific Importance

The Kutch Basin has been a key site for studying the Jurassic-Cretaceous boundary and marine transgressions. Research publications have cited this region for its contributions to paleoclimate and sedimentology[6]. Educational tourism activities, such as fossil hunting tours and geology workshops, are already conducted informally in areas like Naredi and Jara, indicating potential for scaling educational programs. The region hosts researchers from institutions like IIT Gandhinagar and Wadia Institute of Himalayan Geology, reinforcing its academic value[36].

5.9. Contribution to Sustainable Development

The region attracts tourists for the Rann Utsav, showcasing its potential for sustainable geotourism if aligned with conservation principles. Sites like Kalo Dungar and White Desert already receive thousands of visitors annually. Local crafts such as embroidery from Bhujodi Village and tie-dye techniques from Ajrakhpur are globally renowned and can be integrated into sustainable tourism. The proposed geopark aligns with India's Sustainable Tourism Criteria for India (STCI) and can generate livelihood opportunities for local communities

5.10. Community Involvement

During field surveys, community members in Lakhpat and Dhordo expressed interest in participating in tourism and conservation activities, recognizing the potential economic benefits. Local tribes such as the Rabari and Ahir are deeply connected to the region's cultural heritage. Including them in geopark activities can strengthen community ownership and involvement. Initiatives like the Living and Learning Design Centre (LLDC) in Kutch have successfully demonstrated how community involvement can lead to the preservation of local crafts and traditions.

5.11. Feasibility Assessment of the Kutch Geopark Proposal

The feasibility of establishing a UNESCO Global Geopark in the Kutch region depends on three critical aspects: economic viability, environmental impact, and social acceptability. A thorough assessment of these factors ensures that the geopark initiative is both sustainable and beneficial for the region.

5.11.1. Economic Viability

The establishment of a geopark in the Kutch region holds significant potential for economic growth, primarily through geotourism. The introduction of visitor centers, guided geological excursions, and eco-friendly lodges can create employment opportunities while boosting revenue for local enterprises and artisans. A relevant example is the annual Rann Utsav, a renowned desert festival that attracts a large influx of tourists, benefiting local handicraft vendors, camel safari providers, and homestay owners. This event has become an essential marketplace for traditional crafts such as Rogan art, Bandhani, Meenakari, and Zardosi, which have gained international recognition. A geopark could extend these economic advantages beyond seasonal events by promoting year-round tourism. However, the successful execution of this initiative depends on infrastructure development, such as improved road access to remote sites like the Kutch Fossil Park. Financial support from governmental bodies, private investors, and global conservation organizations would be crucial in ensuring the sustainability of the geopark. Furthermore, revenue generation through ticketed entries, guided educational tours, and geological workshops could help maintain the geopark in the long run.

5.11.2. Environmental Impact

Kutch is an ecologically sensitive region with extensive salt marshes, fossil-rich deposits, and arid grasslands that support unique biodiversity. Uncontrolled tourism and rapid infrastructure expansion may lead to environmental degradation, including soil erosion, habitat loss, and water scarcity. The Great Rann of Kutch, for instance, is home to the Indian Wild Ass (*Equus hemionus khur*), an endangered species whose habitat could be threatened by increased human activities if not managed responsibly. This region serves as a crucial habitat for the last surviving population of the khur subspecies. Additionally, climate change factors such as rising temperatures and accelerated desertification, pose further challenges. To mitigate these risks, the geopark initiative should incorporate environmental conservation strategies, such as afforestation programs to control soil erosion and the implementation of water conservation projects to support both wildlife and local communities. Sustainable tourism practices, such as regulated visitor limits and eco-friendly infrastructure, should be prioritized to preserve the region's ecological balance.

5.11.3. Social Acceptability

The success of the geopark initiative relies heavily on the engagement and acceptance of local communities. To gain long-term support, it is essential that local residents experience tangible economic and social benefits. Many people in Kutch sustain their livelihoods through traditional crafts, salt production, and pastoralism; hence, any tourism-related initiative must align with these existing occupations rather than disrupt them. For example, Ajrakhpur village is well known for its Ajrakh block printing, a traditional craft passed down through generations. A geopark could contribute to preserving such cultural heritage by integrating artisan workshops and souvenir markets into the visitor experience, thereby providing direct economic benefits to local craftsmen. Moreover, training programs to equip residents with skills for roles such as tour guides, park rangers, and hospitality staff could further strengthen community participation. However, concerns regarding land-use changes and cultural disruptions may arise, potentially leading to resistance. To address this, it is crucial to conduct consultations with village councils, tribal representatives, and business associations to ensure that local interests are taken into account before implementing policies (**Table 3**).

Table 3. Annual Tourist Data for Key Sites in Kutch (2023).

Site Name	Type	Domestic Tourists (in thousands)	International Tourists (in thousands)	Total Visitors (in thousands)
Great Rann of Kutch	Salt Desert	850	50	900
Kutch Fossil Park	Fossil Site	120	30	150
Kalo Dungar (Black Hill)	Geomorphological	200	20	220
Bhujodi Village	Cultural Heritage	300	25	325
Naredi Ammonite Beds	Fossil Site	60	10	70
Mandvi Beach	Coastal Geosite	500	45	545
Lakhpat Fort and Surroundings	Historical/Geosite	150	15	165

Table 3. *Cont.*

Site Name	Type	Domestic Tourists (in thousands)	International Tourists (in thousands)	Total Visitors (in thousands)
Dhordo (White Desert Festival)	Cultural/Geotourism	700	60	760
Dholavira (UNESCO Heritage Site)	Archaeological Site	400	50	450
Total		3280	305	3585

Source: Gujarat Tourism Development Corporation.

For example, the Ajrakhpur village in Kutch is known for its Ajrakh block printing, a traditional craft passed down through generations. A geopark can help preserve this cultural heritage by incorporating artisan workshops and souvenir markets into the visitor experience, providing artisans with direct economic benefits. Additionally, involvement in tourism services, such as training locals as tour guides, park rangers, and hospitality staff, can create employment opportunities. However, resistance may arise if locals fear land-use changes or cultural erosion. To prevent this, consultations with village councils, tribal groups, and business associations should be conducted before any policy implementation.

6. Conclusion

The Kutch region of Gujarat, India, possesses exceptional geological, ecological, and cultural significance, making it a strong candidate for recognition as a UNESCO Global Geopark. Its diverse geoheritage features, including the Kutch Fossil Park, Jurassic rock formations, tectonic fault zones, and unique landforms like the Great Rann of Kutch, offer immense scientific, educational, and aesthetic value. These attributes, coupled with the region's rich cultural heritage and traditional craftsmanship, present significant opportunities for geotourism, community development, and global recognition. This study demonstrates that the Kutch region aligns with several UNESCO criteria for geopark designation, particularly in terms of geological significance, educational potential, and sustainable development opportunities. However, challenges such as inadequate infrastructure, limited awareness, and the absence of dedicated geoheritage conservation policies need to be addressed. Stakeholder involvement, eco-friendly infrastructure development, and the integration of local communities into geoheritage initiatives are crucial for ensuring the success and sustainability of a geopark in this region. The ichthyosaur was a dolphin-like marine reptile that primarily fed on fish and ammonites. This discovery added to India's paleontological heritage and bolstered the case for the Kutch region as a potential UNESCO Geoheritage site, given its rich geological and paleontological significance [4].

The feasibility analysis underscores that the Kutch region holds immense potential for recognition as a UNESCO Global Geopark, owing to its diverse geological formations, deep-rooted cultural heritage, and existing tourism framework. These elements collectively align with UNESCO's stringent criteria for geopark designation, making the region a promising candidate. However, achieving this status requires addressing several critical challenges. Infrastructure limitations, environmental sustainability, and community participation remain key concerns that must be systematically resolved. The lack of well-developed visitor facilities and accessibility to geosites can hinder tourism growth, while unregulated activities may threaten the geological and ecological integrity of the region. Additionally, local communities must be actively involved in decision-making processes to ensure equitable benefit-sharing and foster a sense of ownership over the geopark initiative.

To effectively address these challenges, a well-rounded and strategic approach is essential. Sustainable tourism practices should be prioritized by developing eco-friendly infrastructure, regulating visitor access, and enforcing responsible tourism policies to minimize environmental degradation. Additionally, educational initiatives play a crucial role in fostering awareness about geoheritage by integrating relevant programs into school and university curriculums, as well as organizing guided tours to enhance public engagement and scientific understanding. Equally important is the establishment of collaborative governance, where government agencies, researchers, conservationists, and local communities work together to ensure balanced decision-making and sustainable management. By integrating these strategies, the proposed geopark can achieve long-term success while preserving the region's unique geological and cultural heritage. By integrating these measures, the Kutch region can successfully achieve UNESCO Geopark status, ensuring the

long-term conservation of its unique geoheritage while simultaneously driving socio-economic development. A well-planned geopark will not only protect the region's geological treasures but also serve as a catalyst for education, cultural preservation, and sustainable economic growth, ultimately benefiting both present and future generations.

Author Contributions

Conceptualization, V.C.L., V.R.S., U.R., K.K., C.M.M.; methodology, V.C.L., A.P.M. M.S., K.K.; research, V.C.L., R.P.S., C.M.M., K.K., S.K.Y., M.S.; writing—original draft preparation, V.C.L., C.M.M., M.S., S.K.Y.; writing—review and editing, V.C.L., U.R., C.M.M., R.P.S., A.P.M., K.K., S.K.Y.; supervision, V.R.S., K.K., M.S., C.M.M.; project administration, V.C.L., A.P.M; V.R.S.; manuscript submission, A.P.M., V.C.L. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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