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Interdependence of Biodiversity and Geodiversity: A Focus on Odisha's Ecological and Geological Richness

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ABSTRACT

The interplay between non-living (abiotic) and living (biotic) components of nature underlies the structure and function of ecosystems. *Geodiversity* encompassing geological, geomorphological, pedological, and hydrological variation provides the foundational physical template upon which biodiversity unfolds. Theoretical and empirical research increasingly suggests a positive relationship between geodiversity and biodiversity, but challenges remain regarding consistent definitions, measurement, and integration into conservation. In this study, the interdependence of biodiversity with geodiversity in Odisha has been examined, a state in eastern India renowned for its rich geological formations (Eastern Ghats, mineral-rich plateaus and mountains), diverse soils, river systems, and coastal ecosystems (e.g., the Chilika Lagoon). The Geodiversity and biodiversity data were synthesized, focusing on key regions such as the Similipal Biosphere Reserve, Bhitarkanika mangroves, and Chilika lagoon, highlighting how geological substrates, soil types, topography, and hydrological processes influence species distributions, habitat heterogeneity, and ecological functions. Biodiversity was evaluated using the Shannon–Wiener Diversity Index (H'), while geodiversity was quantified through a composite Geodiversity Index (GDI). The relationship between abiotic and biotic diversity was statistically assessed using Pearson's correlation analysis. Similipal recorded the highest biodiversity ($H' \approx 3.8$) and geodiversity (GDI ≈ 0.92), followed by Bhitarkanika ($H' \approx 3.3$) and Chilika Lagoon ($H' \approx 3.1$). Statistical analysis revealed a strong positive correlation ($r \approx 0.84$) between geodiversity and biodiversity, indicating that greater geological and geomorphological heterogeneity supports higher species richness and ecological complexity. Further, the key threats, including mining, deforestation, and climate change to both geodiversity and biodiversity, propose integrative conservation strategies (e.g., geosite mapping, geodiversity indices, policy intervention, community participation). Preserving and restoring geodiversity is essential for sustainable Odisha's biological heritage. This work contributes to the broader discourse by offering a regional case study and actionable recommendations for incorporating geodiversity into conservation planning.

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1. Introduction

It is a common approach to consider nature through biological diversity, or biodiversity. Yet nature is an entity that comprises both living and non-living elements. However, in the last decade, there has been growing appreciation of the wider values of geodiversity and its links with landscape and biodiversity conservation, economic development, climate change adaptation, sustainable management of land and water, historical and cultural heritage, and people's health and well-being (Gray, 2013). Geodiversity terminology is inconsistently applied across literature, the definitional critique presented by Maliniemi et al. (2024) helps to establish a clear and standardized conceptual foundation for how geodiversity is used throughout this manuscript.

The natural diversity, or the abiotic diversity of the Earth surface and subsurface, is also known as geodiversity. It comprises geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), pedological (soil) and hydrological features and is found from local to global scales (Gray, 2013). It includes the variation of abiotic features and processes from the smallest scale (such as tiny particles) to regional (e.g. landforms) and continental (e.g. mountain ranges) scales (Serrano and Ruiz-Flaño, 2007; Zarnetske et al., 2019). Sometimes, atmospheric or climatic variation is also considered part of geodiversity. Geodiversity is often seen as the foundation of biodiversity, where the abiotic conditions set the stage for the living nature by creating variation, e.g. in topographical and climatic conditions (Gray, 2013; Beier and de Albuquerque, 2015). Yes, geodiversity plays a crucial role in fostering biodiversity. Therefore, the prevailing assumption is that geodiversity and biodiversity are positively connected. These diverse geological features create different habitats and ecological conditions, which are essential for supporting a wide range of species. Kubalíková et al. (2025) demonstrate cutting-edge methodological and conceptual advances in geodiversity and geoheritage, particularly GIS-based mapping and ecosystem-service integration, underscoring the contemporary relevance of embedding geodiversity perspectives within the present study. Drawing on the conceptual and bibliometric synthesis by Herrera-Franco et al. (2022), this study is positioned within emerging global frameworks that emphasize the increasing recognition of abiotic– biotic linkages in biodiversity science. Integrating geodiversity information into biodiversity research and conservation has considerable potential to improve our understanding of biodiversity patterns and dynamics, to enhance protection of biodiversity. The concept of geo-diversification proposed by Stojilković and Gray (2024) provides essential temporal depth, enabling the manuscript to frame Odisha's present-day biodiversity patterns as the outcome of long-term geological evolution. This study follows a process-based framework in which geodiversity provides the physical foundation of ecosystems. Variations in rocks, landforms, soils, hydrology, and topography create habitat heterogeneity, leading to different microclimates, soil conditions, and moisture regimes. This heterogeneity controls key ecological processes such as nutrient cycling, primary productivity, species movement, and hydrological connectivity. Together, these processes regulate the availability of resources and environmental conditions that shape biodiversity patterns, including species richness, community composition, and ecosystem functioning. In regions like Odisha, long-term geological evolution further influences present day biodiversity by supporting ecological resilience and adaptation. Without the contribution of geodiversity, many ecosystem services essential to life on the Earth would not exist or would require costly technological alternatives.

2. Methodology

This study adopts a qualitative and quantitative synthesis approach to examine the interdependence between geodiversity and biodiversity across Odisha. Secondary data were compiled from peer-reviewed scientific literature, government and environmental reports,statistical analysis using softwares IBM SPSS, R softwares, Microsoft Excel and biodiversity databases to identify consistent ecological patterns and environmental drivers. The analysis focuses on three representative ecosystems; Similipal Biosphere Reserve, Chilika Lagoon, and Bhitarkanika Mangrove Ecosystem, selected for their contrasting geological and ecological characteristics. Biodiversity patterns were assessed using the Shannon–Wiener Diversity Index (H′), a widely accepted ecological metric for species richness and evenness (Magurran, 2004).

$$\mathrm{H}' = -\sum p_i \ln(p_i)$$

Geodiversity was quantified using a composite Geodiversity Index (GDI), integrating geological, geomorphological, pedological, and hydrological variability following (Pellitero and et al., 2017).

$$\mathrm{GDI} = \frac{N_{\mathrm{g}} + N_{\mathrm{l}} + N_{\mathrm{s}} + N_{\mathrm{h}}}{A}$$

To evaluate the relationship between abiotic and biotic diversity, Pearson's correlation coefficient was applied, a standard statistical method for measuring linear association between two variables (Zar, 2010).

$$r = \frac{\sum(x_{\mathrm{i}} - x^{-})(y_{\mathrm{i}} - y^{-})}{\sqrt{\sum(x_{\mathrm{i}} - x^{-})^2 \sum(y_{\mathrm{i}} - y^{-})^2}}$$

The study is primarily synthetic and interpretative, relying on compiled datasets rather than primary field observations. While this approach enables regional scale comparison, it is limited by dependence on secondary data and simplified index estimation. The statistical framework applied here is consistent with established ecological and geographical analytical practices (Magurran, 2004; Zar, 2010). The reference to Kubalíková et al. (2025) is appropriate and valid, as it highlights recent methodological advancements in geodiversity assessment, particularly the integration of GIS-based mapping and ecosystem service frameworks, which support the need for more advanced spatial analysis. Future research should therefore incorporate GIS-based spatial modelling, multivariate statistics, and temporal datasets to improve analytical precision and better capture dynamic geo–bio interactions.

3. Geodiversity leads to biodiversity

Varied Habitats: Different landforms, such as mountains, valleys, deserts, wetlands, and coastal areas, create a variety of habitats. These different environments provide niches for different species to thrive, contributing to a more diverse range of life forms.

Microhabitats: Geodiversity leads to the creation of microhabitats, small, specific environments within a larger ecosystem. For example, rock outcrops, caves, or riverbeds can provide unique habitats for specialized species.

Soil Variation: Sand, Clay, Loam etc.

Water Systems: Geological features influence the formation of rivers, lakes, and aquifers. These water bodies provide varied ecosystems that support aquatic and terrestrial life. For instance, rivers can support fish populations, while wetlands might be home to migratory birds and amphibians.

Climate and Elevation: The physical geography of a region (such as its elevation, slope, and proximity to the coast) also affects local climate conditions, which influence which species can survive and thrive in those areas. This variation leads to higher biodiversity.

In essence, geodiversity provides the foundation for ecosystems by offering the physical space, resources, and conditions necessary for different forms of life to flourish. The structural-equation modelling framework of Macario-González et al. (2022) illustrates how geodiversity, limnological conditions, and species composition can be analytically linked, offering a methodological blueprint for future empirical studies in Odisha's aquatic and terrestrial systems. The geodiversity-assessment framework developed by Nieto et al. (2023) provides practical procedures for evaluating complex geological domains and identifying priority areas for conservation, informing the recommendations of this study on geosite identification and geodiversity-based conservation planning in Odisha.

4. The Direct Link: How Geology Shapes Ecosystems

4.1. Influence on Soil Composition

Precambrian Rocks, Gondwana Supergroup, Eastern Ghats Mobile Belt, Coastal Plains, Central Mountainous and Highlands, Central Plateaus and Western Rolling Uplands, Flood Plains

The underlying rock types break down to form different soil types, affecting the nutrients available for plant growth.

Mineral-rich geological formations can lead to specialized ecosystems, with organisms adapted to unique soil compositions.

4.2. Influence on Landforms and Habitats

Mountains and Plateaus: The Eastern Ghats create varied altitudinal zones, leading to diverse forest types like tropical moist deciduous and semi-evergreen forests.

Caves and Cliffs: Unique geological features like the Gupteshwar forest caves (a Biodiversity Heritage Site) and rock formations at Sitabinji provide specialized microhabitats.

River Basins and Waterfalls: The state's many rivers and waterfalls, shaped by geology, create distinct freshwater habitats. For example, the Baitarani River originates in the Keonjhar hills, an area with specific geological features.

5. Biodiversity in Odisha

Odisha, a state located on the eastern coast of India, stands as an exceptional example of this interconnection, with its rich ecological and geological diversity. Odisha is known for its remarkable biodiversity, which spans a range of ecosystems, from coastal areas and wetlands to forests and mountains.

Coastal and Marine Ecosystems: Odisha's coastal belt, with its unique habitats such as the Chilika Lake and the Gahirmatha Beach, is home to a variety of species. Chilika Lake, Asia's largest brackish water lagoon, hosts an extraordinary diversity of birds, aquatic life, and is a crucial breeding ground for the endangered Olive Ridley sea turtles.

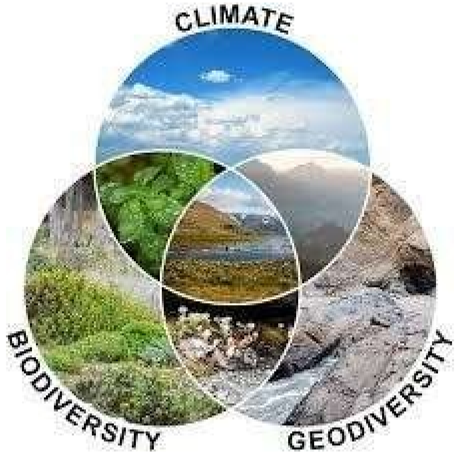

Fig. 1. Interlink between Geodiversity, Biodiversity and climate (modified from Beggs (2013)).

Forest Ecosystems: The state has extensive forests, particularly in regions like Similipal and the Satkosia Gorge. These forests are home to a variety of flora and fauna, including Bengal tigers, elephants, leopards, and numerous species of birds, amphibians, and insects.

Wetlands: Odisha's wetlands, such as the Kolleru Lake and the Mahanadi River Delta, provide critical habitats for migratory birds, fish species, and other aquatic organisms. These ecosystems help maintain water quality and support local communities' livelihoods.

Endemic Species: Odisha also hosts a number of endemic species, including certain varieties of orchids, amphibians, and reptiles, that are found nowhere else on the planet.

6. Geodiversity in Odisha

Geodiversity refers to the variety of geological, geomorphological, and soil features within a given region, and Odisha is renowned for its geological richness. Some of the notable geodiversity features of Odisha include:

Geological Diversity: Odisha's geology is dominated by a mixture of Precambrian rocks, sedimentary rocks, and mineral-rich deposits, such as those found in the rich mineral belt of Keonjhar and Sundargarh districts. This region is significant for the extraction of iron ore, bauxite, limestone, and coal, which play a key role in the state's economy.

Mountain Ranges: The Eastern Ghats run through Odisha and are crucial for shaping the region's topography and climate. The mountains influence rainfall patterns and are home to several endemic species of plants and animals. Similipal, a biosphere reserve, is part of the Eastern Ghats and holds immense geological significance.

Rivers and Wetlands: The Mahanadi River system, along with its tributaries, is a major geographical feature of the state. It has a significant impact on Odisha's topography, creating fertile plains and sustaining agriculture and aquatic biodiversity. The river systems are crucial for maintaining biodiversity in the surrounding wetlands and forests.

Coastal Features: The state's coastline, stretching along the Bay of Bengal, showcases unique geomorphological features such as estuaries, delta formations, and sand dunes. These features are vital for coastal ecosystems and the species that inhabit them, from mangroves to saltwater fish species.

7. Interdependence Between Biodiversity and Geodiversity

The relationship between biodiversity and geodiversity is complex and interconnected. In Odisha, various geological features shape the habitats and ecosystems that sustain biodiversity, while the living organisms help maintain the integrity of the geological processes.

Soil Formation and Vegetation: Odisha's diverse geological formations directly influence soil types and vegetation. Soil formation and vegetation in Odisha are closely interlinked, with the soil types and topography of the region influencing the types of vegetation that grow there. The state's varied geography, ranging from the coastal plains to the dense forests of the Eastern Ghats, gives rise to a wide variety of soils and plant life. These plants, in turn, provide food and shelter to various species of animals, birds, and insects. Alluvial soil found primarily in the river basins of Odisha, especially along the Mahanadi

River and its tributaries. These soils are rich in nutrients and ideal for agriculture. Alluvial soils are fertile and support a variety of crops, including rice, pulses, and vegetables. Red and Yellow Soils found in the Eastern Ghats and some parts of the plateau. These soils are formed from the weathering of the parent rocks and are typically low in fertility but can support dryland agriculture if properly managed. The red soils are acidic, and the yellow soils have higher iron content, giving them their color. Tropical Dry Deciduous Forests found in the plateau regions and in areas like Malkangiri, Rayagada, and Nabarangpur. These forests shed their leaves during the dry season and are home to species like sal, bamboo, tamarind (Tamarindusindica), and sundri (Heritierafomes). These forests support a variety of wildlife, including elephants and tigers, and help prevent soil erosion during the dry months. Grasslands found in the plateau regions, especially in parts of Kandhamal and Kalahandi. The vegetation consists mainly of grasses like Andropogon, Themeda, and Cenchrus, with shrubs like bamboo. These grasslands support several species of grazing animals, including wild boar and nilgai. Laterite Soils found in the highland areas of the Eastern Ghats and Khondalite hills. These soils are rich in iron and aluminum oxides and are typically poor in nutrients but may support certain types of vegetation, especially tropical evergreen and semi-evergreen forests. Laterite soils are often used for construction, as they harden when exposed to air. Mixed Deciduous Forests are found in the Eastern Ghats, with species like bamboo, sal, and acacia. The vegetation is a mix of both deciduous and evergreen trees and provides important resources for local communities, such as timber, fruits, and medicinal plants. Black Soils found primarily in Kalahandi, Rayagada, and parts of Nabarangpur districts. These soils are rich in lime, calcium, and magnesium and are particularly fertile, supporting crops like cotton and groundnut. They are often referred to as Regur soils. Saline and Alkaline Soils found in the coastal plains and areas near Chilika Lake. These soils have a high salt content and are typically unsuitable for agriculture unless treated with proper irrigation and drainage systems. Coastal Vegetation found along Odisha's coastline, including the Chilika Lake area which Includes mangrove forests, which provide protection against coastal erosion and support marine biodiversity, and sand dunes with salt-tolerant vegetation like coastal grasses and casuarina. Mangrove species such as Avicennia, Rhizophora, and Sonneratia thrive in these saline areas. Wetland Vegetation found in Chilika Lake, Balukhand-Konark Wildlife Sanctuary, and other wetland areas characterized by aquatic plants such as water lilies, reeds, and water hyacinth, which support diverse birdlife, including migratory species like flamingos. Forest Soils found in the forest-covered areas of the state. These soils are rich in organic matter and nutrients, supporting lush vegetation. Tropical Wet Evergreen Forests found in the eastern hills and coastal plains, especially in Simlipal, Kandhamal, Kalahandi and parts of Kendujhar and Gajapati. These forests have a high density of evergreen trees and are rich in biodiversity, with species like Sal (Shorearobusta), Teak (Tectonagrandis), Jamun (Syzygiumcumini), and Neem (Azadirachtaindica). These forests play a vital role in regulating the local climate, controlling soil erosion, and supporting wildlife.

Water Systems and Biodiversity: Odisha is home to significant wetlands like Chilika Lake, one of the largest coastal lagoons in Asia, and the Hirakud reservoir. These wetlands support a wide variety of aquatic species, including fish, amphibians, and waterfowl. The water quality, seasonal fluctuations in water levels, and nutrient load from rivers directly affect the biodiversity in these wetlands. The Mahanadi River and the Chilika Lagoon's water quality, for instance, is largely dependent on geological features such as the region's sedimentary layers and soil composition. It supports over 160 species of migratory birds and is a vital breeding ground for fish species such as the "Chilika Prawn." The biodiversity in the lake depends on the freshwater influx from the Mahanadi River and the salinity balance that occurs through the flow of water into the Bay of Bengal. Rivers like the Mahanadi, Brahmani, and Baitarani not only provide water for agriculture and human consumption but also sustain terrestrial ecosystems. Forests along these rivers are home to a range of species, including elephants, tigers, and leopards. The river systems support vegetation and forests through their annual floods, which deposit fertile silt, rejuvenating the soil and promoting the growth of various plant species. The Sundarbans and the Bhitarkanika mangrove forest in Odisha are prime examples where the water systems specifically the interaction between river water and seawater which creates ideal conditions for species such as the saltwater crocodile, mangrove crab, and various bird species.

Climate Regulation and Biodiversity: Odisha's mountain ranges play a key role in regulating the regional climate. They influence the monsoon rains, which in turn supports the state's diverse flora and fauna. The forests act as carbon sinks, helping to regulate the local climate and mitigate the effects of global climate change. Odisha's forests, wetlands, and mangroves play an important role in carbon sequestration, helping regulate the local climate. Forests in Odisha, especially those in the Similipal Biosphere Reserve and the Khandadhar hills, store large amounts of carbon, acting as carbon sinks. The Sundarbans and other coastal mangroves help mitigate climate change by absorbing CO2. Odisha's coastline, which is highly vulnerable to climate change, is protected by ecosystems like mangroves and salt marshes. These ecosystems act as buffers against sea-level rise and coastal erosion. They also provide critical habitat for various species, including the endangered Olive Ridley turtles. The climate regulation in Odisha, including the monsoon systems, is influenced by the state's natural ecosystems. Deforestation or disruption of wetland areas can alter local weather patterns, leading to irregular rainfall, droughts, or floods, which in turn affect biodiversity.

Mineral Extraction and Conservation Issues: In Odisha, the interdependence between mineral extraction and conservation issues is a complex and significant topic. Odisha is one of India's major mineral-rich states, with abundant deposits of minerals such as coal, iron ore, bauxite, chromite, and limestone. The extraction of these minerals contributes significantly to the state's economy but also creates various challenges related to environmental conservation, social well-being, and sustainable development. The extraction of minerals, such as iron ore and bauxite, can impact both geodiversity and biodiversity in the state. Mining activities can lead to habitat destruction, pollution, and changes in water systems, thereby threatening the biodiversity of the affected areas. Sustainable mining practices and proper conservation efforts are critical to balancing economic development with the preservation of ecosystems. Large areas of forests are cleared for mining operations, impacting ecosystems and wildlife habitats. The forests of Odisha, especially in regions like Kalahandi, Koraput, and Sundargarh, are rich in biodiversity and home to indigenous tribes. The loss of these forests reduces the state's capacity to act as a carbon sink, further contributing to climate change. Mining activities often lead to the contamination of local water bodies due to the release of harmful chemicals like mercury and acid mine drainage. Dust and emissions from mining and transportation operations contribute to air pollution, affecting the health of local communities and surrounding ecosystems. Key wildlife sanctuaries and national parks, such as the Simlipal Biosphere Reserve, Satkosia Tiger Reserve, and Kandhamal, are under threat from mining operations. Many of these areas are home to endangered species like tigers, elephants, and leopards, and mining in these regions can lead to the destruction of these habitats. Odisha is home to a large number of indigenous communities who rely on forests and natural resources for their livelihoods. The mining activities often displace these tribal populations, leading to the loss of their traditional way of life. These communities depend on forests for sustenance, medicinal plants, and cultural practices. When mineral extraction leads to deforestation and the destruction of their habitat, it significantly impacts their socio-economic stability.

8. Chilika Lake: A Brackish Water Ecosystem

It is located on India's eastern coast in Odisha, covering the districts of Puri, Khurda, and Ganjam. The largest coastal lagoon in India and the second largest in the world. A designated Ramsar site since 1981, recognizing its international ecological importance. An estuarine ecosystem where freshwater from rivers mixes with saltwater from the Bay of Bengal.

Geological History

It is formed thousands of years ago during the Pleistocene epoch. Once a part of the Bay of Bengal, the coastline shifted eastward due to geological processes. The formation was driven by the silting action of rivers and strong coastal currents. A sandy spit, known as Rejhansa, separated the lagoon from the sea, leading to its formation as a bar-built estuary.

Geodiversity

This is India's largest coastal lagoon, formed by the geological processes of river runoff and tidal inflow from the Bay of Bengal. The water quality, seasonal fluctuations in water levels, and nutrient load from rivers directly affect the biodiversity in these wetlands. The Chilika Lagoon's water quality, for instance, is largely dependent on geological features such as the region's sedimentary layers and soil composition. The lagoon is divided into four main sectors based on depth and salinity: the Northern, Central, Southern, and Outer Channel. It is dotted with numerous islands, such as Nalbana, Kalijai, and Honeymoon Island.

Biodiversity

Irrawaddy dolphins: The lake is home to one of the world's largest population of endangered Irrawaddy dolphins, a significant tourist attraction.

Fish and crustaceans: A thriving fishery supports over 200,000 local fisherfolk. The lagoon contains numerous commercially important and rare species of fish, prawns, and crabs, including Indian salmon and mud crabs.

Birds: Chilika is a major wintering ground for migratory waterfowl, with the Nalaban Island Bird Sanctuary at its center. Over a million birds from places as far away as the Arctic and Central Asia visit annually, including flamingos, herons, and white-bellied sea eagles.

Reptiles and amphibians: The lake and surrounding area support numerous species of reptiles and amphibians, including the endangered limbless skink *Barkudia insularis.*

Flora: Diverse plant life thrives here, including flowering plants, grasses, and mangroves. The ecosystem also includes important communities of microalgae and benthos (bottom-dwelling organisms).

9. Bhitarkanika: A treasure of biodiversity and geodiversity

Bhitarkanika is a deltaic region in Odisha's Kendrapara district, situated where the Brahmani and Baitarani rivers converge before meeting the Bay of Bengal. It is India's second-largest mangrove ecosystem and a Ramsar site. It is often called the "Mini Amazon of India," it is a protected area comprising a wildlife sanctuary, a national park, and the Gahirmatha Marine Sanctuary. This unique ecosystem supports an extraordinary array of flora and fauna.

Geodiversity

Deltaic formation: The landscape is shaped by the alluvial deposits of the Brahmani, Baitarani, and Dhamra rivers. This process has created a network of meandering creeks, tidal mudflats, and islets.

Estuarine environment: The regular tidal cycles from the Bay of Bengal and the freshwater influx from the rivers create a highly dynamic estuarine ecosystem. The salinity of the water fluctuates seasonally, impacting the types of species that thrive there.

Coastal features: The area includes extensive sea beaches, sand bars, and sand dunes, which support unique coastal vegetation. Gahirmatha beach, in particular, is a critical nesting site. Soil composition: The region is characterized by a sandy loam soil coast.

Biodiversity

Mangrove species: Bhitarkanika is home to 55 of India's 58 mangrove species, a higher diversity than even the Sundarbans. Key species include: *Heritiera fomes,Excoecaria agallocha,Ceriops decandra,*

Estuarine crocodile (Crocodylus porosus): The park has the highest density of saltwater crocodiles in India, and it holds the Guinness World Record for the largest crocodile. The crocodile conservation program has successfully increased the population.

Olive Ridley Sea Turtles: Gahirmatha beach is the world's largest rookery for these turtles, with nesting events involving half a million turtles annually.

Birds: A major breeding and wintering ground for resident and migratory waterbirds, with a heronry supporting over 30,000 birds of 11 species. Notable species include: Indian Skimmer,White-bellied Sea Eagle,Mangrove Pitta,Brown-winged Kingfisher,

Mammals: Various mammals inhabit the park, including: Spotted deer,Wild boar,Fishing cat,Leopard cat

Aquatic life: The estuary serves as a major nursery for brackish water and estuarine fish species.

10. Geodiversity and Biodiversity of Similipal Complex

Geodiversity

The Similipal Biosphere Reserve is rich in both geodiversity and biodiversity. It is located in the Chhotanagpur biotic province and is part of the Eastern Ghats geological system. The hills are mainly made of volcanic sedimentary rocks, which form the characteristic landscape of the region. These rocks are arranged in unique concentric ring structures, making the area geologically important. Outcrops of metamorphic sandstone and quartzite are also found in many places. These different rock types create hills, valleys, waterfalls, and varied landforms.

Biodiversity

Similipal is also one of India's richest biodiversity areas. It has dense forests that support a wide variety of plants and animals. The reserve is home to the Royal Bengal tiger, Asian elephant, leopard, gaur, sambar deer, and many other mammals. It also has numerous species of birds, reptiles, amphibians, insects, and medicinal plants. Many rare and endangered species are protected here. The rich biodiversity of Similipal helps maintain ecological balance and makes it an important area for wildlife conservation.

11. Comparative study

Comparative study showing Interdependence of Biodiversity and Geodiversity in Chilika, Similipal and Bhitarkanika biosphere reserves

PARAMETERS	CHILIKA	SIMILIPAL	BHITARKANIKA
LANDFORMS	Dark to olive yellowish grey clay	Rolling hills, Valleys and plateaus with volcanic origin	Mangrove swamps, tidal flats and Estuaries
ENVIRONMENT OF DEPOSITION	Brackish lagoon	Volcano-sedimentary basin, shallow marine, tidal influence and fluvial/lacustrine conditions	Deltaic
FLORA	Sea grass Fringing shoreline mangroves	1076 species including Sal, teak, jamun and red cotton	63 to 71 species of mangroves
FAUNA	Irrawaddy Dolphins Siberian birds Pelicans	42 species of mammals 242 species of birds 30 species of reptiles	Olive ridley turtles, crocodiles

12. Conservation Efforts and Challenges

To maintain the balance between biodiversity and geodiversity, Odisha has made significant strides in conservation. Protected areas like Similipal and Chilika Lake serve as critical refuges for threatened species. Efforts to reduce deforestation, protect wetlands, and conserve coastal ecosystems are ongoing. However, challenges remain, particularly in balancing development with environmental preservation.

Odisha protects its rich biodiversity through national parks, wildlife sanctuaries, and biosphere reserves such as Similipal, Bhitarkanika, and the Mahanadi Delta. These protected areas help conserve plants, animals, and the geological features that support their habitats. The state also promotes sustainable mining practices, including land reclamation and tree plantation, to reduce the harmful effects of mining and restore damaged land. Local communities also play an important role in conservation by protecting forests and coastal areas. Ecotourism is growing in Odisha, allowing local people to earn a livelihood while helping to preserve the state's natural beauty and wildlife. Odisha has undertaken various conservation initiatives to protect its water systems and biodiversity. For example, the Odisha government has worked on the Chilika Development Authority to ensure sustainable use of the Chilika Lake, preserving its water quality, and managing the pressures of fishing and tourism. Bhitarkanika Conservation Area has also been a focus for protecting the mangrove ecosystem and the species that rely on it, including the saltwater crocodile. The focus on Integrated Water Resource Management (IWRM) has been crucial in balancing water usage for agriculture, drinking, and industry, while ensuring the protection of biodiversity. The operational framework presented by Nieto et al. (2023) provides a practical basis for recommending targeted geosite identification and the development of geodiversity-based conservation zones in Odisha. Following the evidence from Salminen et al. (2023) incorporating geodiversity metrics into conservation planning can meaningfully improve the precision of biodiversity prioritization and management strategies. Following the evidence from Anderson et al. (2014) which suggests that although the individual ranges of many species may shift with climate change, the spatial pattern of total biodiversity will remain associated with the enduring geophysical properties of the land. Species are also sensitive to the physical structure of soils and landforms. Current recommendations for addressing climate change in conservation planning largely focus on predicting future habitat for individual species based on climatic envelope models. Although these models have helped catalyze attention, and clarify the thinking about climate change effects, their utility has come under question because they are hindered by large uncertainties, and often unrealistic assumptions.

13. Results and Interpretation

The comparative analysis of Odisha's ecosystems reveals clear variation in both biodiversity and geodiversity indicators, supported by complementary qualitative patterns. Similipal Biosphere Reserve exhibited the highest biodiversity, with a Shannon Index of approximately 3.8 and the greatest species richness ($\sim$1100 species), alongside the highest geodiversity index (GDI ≈ 0.92). Qualitatively, this ecosystem is characterized by complex terrain, elevation gradients, and heterogeneous soil types, which together create multiple ecological niches and support diverse forest communities. In contrast, Chilika Lagoon showed high biodiversity ($H' \approx 3.1$), largely shaped by hydrological variability, seasonal salinity fluctuations, and lagoon geomorphology, resulting in dynamic habitat conditions that support migratory birds, aquatic species, and estuarine life forms. Bhitarkanika Mangrove Ecosystem demonstrated moderate to high biodiversity ($H' \approx 3.3$), where deltaic landforms, tidal influences, and mangrove vegetation create specialized habitats, particularly for reptiles, birds, and estuarine organisms. Qualitative observations further indicate that ecosystems with greater environmental heterogeneity tend to exhibit higher habitat diversity, niche differentiation, and ecological complexity. Forested and mountainous regions support more stable and stratified communities, while coastal and deltaic systems show higher temporal variability due to hydrological and tidal dynamics. Anthropogenic pressures such as mining, land-use change, and hydrological alteration were observed to reduce habitat heterogeneity and simplify species composition. The Pearson correlation analysis ($r \approx 0.84$) confirms a strong positive relationship between geodiversity and biodiversity, and the qualitative evidence reinforces this finding by demonstrating that abiotic variability through landforms, soils, and water systems plays a critical role in shaping species distribution, ecosystem functioning, and resilience.

14. Discussion

The findings support the growing research trend emphasizing the foundational role of geodiversity in shaping biodiversity patterns (Gray, 2013; Hjort et al., 2015). The high biodiversity observed in Similipal can be attributed to: geological complexity, elevation gradients and soil heterogeneity. These factors create diverse ecological niches, consistent with findings by Salminen et al. (2023) who demonstrated that geodiversity enhances biodiversity modelling accuracy. In Chilika Lagoon, biodiversity is primarily regulated by hydrological processes, including freshwater and marine interactions and salinity gradients. This aligns with Macario-González et al. (2022), who highlighted the role of abiotic conditions in aquatic ecosystems. Bhitarkanika's biodiversity is strongly influenced by deltaic geomorphology and tidal processes, supporting mangrove ecosystems and associated fauna. Anthropogenic pressures such as mining, deforestation, and hydrological alteration were found to reduce ecological heterogeneity and biodiversity, reinforcing conclusions by Comer and et al. (2015). Overall, the study demonstrates that geodiversity acts as a critical driver of ecological resilience, particularly under climate change scenarios.

15. Conclusion

This study highlights the fundamental interdependence between geodiversity and biodiversity in Odisha. The results demonstrate that regions with greater geological, geomorphological, and hydrological diversity support higher species richness and ecological complexity. Similipal Biosphere Reserve emerges as the most diverse system due to its complex geological framework, while Chilika Lagoon and Bhitarkanika illustrate the importance of hydrological and coastal geodiversity. The strong positive correlation between geodiversity and biodiversity confirms that abiotic heterogeneity is a key determinant of ecological patterns. From a conservation perspective, integrating geodiversity into biodiversity planning is essential for: enhancing ecosystem resilience, improving conservation prioritization, supporting climate adaptation strategies. Future research should focus on spatial modelling, geodiversity mapping, and long-term monitoring to strengthen geo–bio integration in environmental management.

CRediT statement

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Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in this paper.

AI-use disclosure statement

During the preparation of this manuscript, the authors used AI tools to improve the language and readability. After using this tool, the authors reviewed the content and made changes wherever necessary. The authors take full responsibility for the contents of this publication.

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