Indian Journal of Spatial Science
Special Issue: 2024:15(A) pp.28 - 32

Indian Journal of Spatial Science
Peer Reviewed / Refereed Journal
EISSN: 2249 - 4316 Homepage: www.indiansss.org ISSN: 2249 - 3921

Assessment and Mapping of Geodiversity in Darjeeling Hills, West Bengal, India

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Article Info

Article History
Received on:
14 July, 2023
Accepted in *Revised Form* **on:**
15 February, 2024
Available *Online* **on and from:**
21 March, 2024

Keywords
Geodiversity,
Lithology,
Topography Roughness,
Darjeeling Hills,
Slope,
Sub-Himalayan Foothills,
Geotourism.

Abstract

Geodiversity is a multifaceted idea that emphasizes how crucial it is to comprehend and protect the geological characteristics and processes that define the Earth and affect how it interacts with other living things. The purpose of this paper is to map and identify the geodiversity sites present in the Darjeeling Hills. With its rich green environment, mountain terrain, valley, and steep streams, Darjeeling Hills has tremendous potential for developing a Geodiversity site. The geodiversity of the Darjeeling Hills is assessed by analysis of lithology, soils, aspect, slope, topography roughness, and drainage density. The Geodiversity Mapping of Darjeeling Hills is categorized into five classes. These are very high (8.44%), high (23.45%), moderate (32.42%), low (23.92%), and very low (11.76%) Geodiversity zonation. After the fuzzification of Geodiversity Zonation, a significant multitude of alterations became evidenced in the spatial arrangement of geodiversity. These are very high (16.57%), high (26.18%), moderate (26.71%), low (19.91%), and very low (10.62%) Geodiversity zonation. Due to its geological attributes, steep watercourses, and mountainous vistas, the Darjeeling Hills hold immense potential for evaluating geodiversity. The Darjeeling Hills hold substantial promise for developing a geo-tourism destination because of their well-formed geological composition, rugged terrain, thick woodlands, and proximity to biodiversity hotspots in the Himalayan region.

Introduction

Geodiversity is a broad term encompassing the geological features and processes that make up our planet. Understanding and preserving geodiversity is crucial because it provides a valuable record of our planet's history, supports a wide range of ecosystems, and provides us with the resources we need to survive. The natural environment is a complex system of interacting abiotic and biotic components. The abiotic elements, such as sunlight, water, and soil, provide the physical conditions that support life. The biotic components, such as plants, animals, and microorganisms, interrelate with each other and with the abiotic components to produce a diverse and dynamic structure (Najwer et al., 2016). Geodiversity corresponds to biodiversity in the non-living realm, encompassing the diversity of geological, geomorphological, pedological, and hydrological features and processes (Ahmadi et al., 2022; Alahuhta et al., 2018; Crofts, 2019; Matthews, 2014; Stavi et al., 2019).Geodiversity is utilized for the administration of protected natural areas. This approach encompasses the non-living components of the natural surroundings and acknowledges that geodiversity serves as a comprehensive principle for the preservation and control of the non-biological heritage(Lira et al., 2021; Serrano Cañadas & Ruiz Flaño, 2007; Sharples, 2002).

There has been a tremendous increase in conservation research and general interest in heritage during the past 25 years. The majority of geosite research to date has concentrated on identifying, categorising, and rating them; more lately, though, interest has turned to map geosites (Coratza et al., 2021).The term "geodiversity" denotes to the variety of abiotic elements found in nature, such as rocks, topography roughness, aspect, landforms, geology, slope, and soils, as well as the natural processes that led to their formation and transformation. This is a vital component of the planet's natural capital that supports geosystem services (Gray, 2019).In contrast to the word biodiversity, geodiversity has emerged as a tool in the supervision of protected areas (Serrano &Helvetica, 2007). Geodiversity is a fundamental tenet of conservation and place preservation (Gray, 2004). The practical application of geodiversity encompasses features of hydrology, geology, topography and soils, as well as the relationships between these components and those that sustain life (Serrano &Helvetica, 2007). Researchers have devised various ways to use numbers and specific measures to understand how diverse and varied the geological features are in a particular location. They rely on information gathered by going to the area, using advanced technologies to collect data from a distance, like satellite imagery, or by carefully studying maps to determine the level of geodiversity present (da Silva et al., 2019; Forte et al., 2012; Gonçalves et al., 2020, 2022; Manosso et al., 2021; Pereira et al., 2013; Santos et al., 2017; Stepišnik & Trenchovska, 2016; Tukiainen et al., 2023).

To function as a geo-ecosystem, Darjeeling Hills must have a variety of properties, such as lithology, topographic roughness, slope, and ecology, which interact with one another both on and below the surface. The key purpose of this article is to Assessments & Mapping of Geodiversity sites in Darjeeling Hills based on the Geodiversity Index.

Darjeeling Hills has strong potential for developing geo-tourism sites due to the establishment of biodiversity hotspots in the Himalayan region. Darjeeling Hills has a massive possibility for emerging geodiversity sites with its lush green scenery, mountain topography, valleys, and hilly streams. The majestic pine trees, the spectacular view of the Kangchenjunga framing the horizon on clear days, and the chilly, refreshing environment have all contributed to developing Darjeeling Hills as a Geotourism site. The main objective of this article was to look at the possibility and potentiality of geodiversity in Darjeeling Hills and demonstrate their mapping.

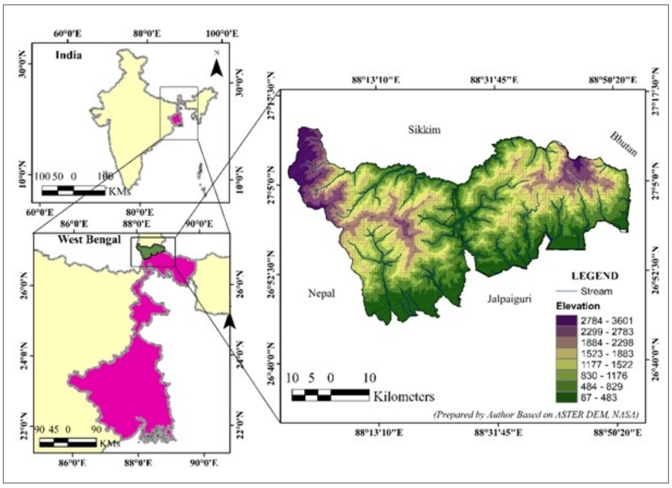

Fig.1: Location Map of the Study Area.

The Study Area

The gorgeous and well-known Darjeeling Hills are situated in the Indian state of West Bengal (Fig: 1). Positioned in the northeastern expanse of India, cradled amid the foothills of the Eastern Himalayas, this locale is famed for its awe-inspiring natural splendour, extensive tea estates, and diverse cultural tapestry, drawing visitors globally (Das, 2004; Das & CIANDA, 1987; Mitra et al., 2018; Starkel, 1972). Darjeeling, affectionately known as "Queen of the Hills," is an ideal entryway for people in tune with nature, nestled among the swelling slopes with the gleaming Mt Kanchenjunga soaring above the azure sky. This is the home of the muscatel-flavoured Darjeeling tea, which is highly regarded by enthusiasts worldwide. Darjeeling Hills conjures images of snow-capped mountains, tranquil green hills steeped in splendour, and a country of enormous beauty topped by the mighty Himalayas. Darjeeling Hill is one of the world's topmost attractive mountain spots(Basak et al., 2021; Basu, 2013; Besky, 2017; Bhutia, 2014; Pramanik, 2016; Roy & Saha, 2019).The variety of geological factors that have shaped the landscapes, ecosystems, and cultural history of the Darjeeling Hills is encapsulated by its geodiversity. The Darjeeling Hills possess substantial geodiversity potential owing to their multifaceted geological attributes and intricate landscape. The geodiversity present in Darjeeling Hills can enhance the tourism sector by providing avenues for Geotourism. This allows visitors to explore and educate about the region's remarkable geological phenomena.

Data and Methodology

Data

For assessments and mapping, the biodiversity zone mainly used secondary spatial data. These are presented in Table - 1.

Method

The components of the physical environment that makeup geodiversity can be used to define it. The term "geodiversity" pertains to the inherent assortment of geological structures, topographical configurations, and soil blankets in the environment. It also encompasses the interconnections, attributes, and impacts these elements exert on other facets of the natural and cultural surroundings. (Chrobak et al., 2021).

The geodiversity of Darjeeling Hills is evaluated by analysis of lithology, soils, aspect, slope, topography roughness, and drainage density. The compound geodiversity (Gd) assessment of Darjeeling Hills is determined using the formula suggested by Serrano and Helvetica (2007), as follows:

$$Gd = (Eg \times R) / \ln S$$

where, Gd is the Geodiversity Index, Eg is the number of physical components in the unit, R is the coefficient of topography roughness, S is the surface area unit (Sq. Km), and Ln is the natural logarithm.

We used six physical elements to identify the Geodiversity zonation in Darjeeling Hills (Fig: 2). The slope map (Fig: 2, A) of Darjeeling Hills is prepared using Aster DEM. The following classes make up the slope gradients, measured in degrees: < 8; 8-16; 16-24, 24-32; 32-40; 40-48, 48-56, and > 56. The aspect map (Fig: 2, B) of Darjeeling Hills is prepared using Aster DEM. Flat surfaces are also found, and an aspect raster is constructed using an eight-direction model. For analysis of the variety of soil (Fig: 2, C) in Darjeeling Hills, the FAO World Soil Map has been used. Adequate information about soil diversity in Darjeeling Hill is obtained from the used soil map. The lithology map is prepared using the Bhukosh Lithology Map (Fig: 2, D). The following classifications are made based on the physical and mechanical characteristics of the rocks and their origin: Carboniferous Early Permian, Holocene, Permian, Pleistocene, and Meghalayan. Topography roughness (Fig: 2, F) is analyzed in this area using Aster DEM. The formula applied for the analysis of topography roughness is: $TRI = (DEM_{smooth} - DEM_{min}) / (DEM_{max} - DEM_{min})$

Where: DEM_{min}= the minimal elevation raster, DEM_{max}= the maximum elevation raster, and DEM_{smooth} = smoothed elevation raster.

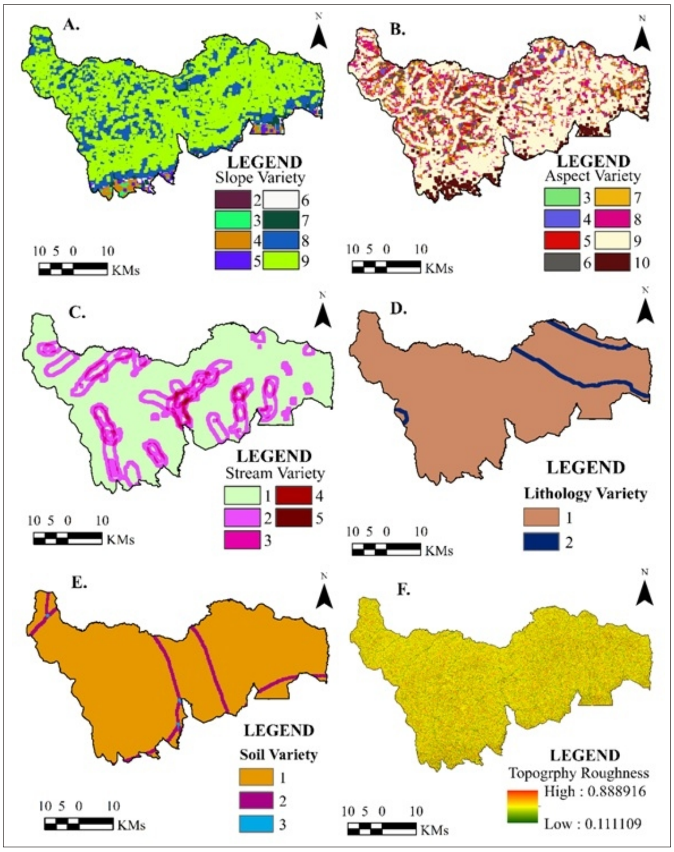

Fig.2: Variety of physical components, **A.** - Slope, B.- Aspect, **C.** Stream, **D.** Lithology, **E.** - Soil, **F.** - Topography Roughness in Darjeeling Hills.

The Focal Statistic tool (ArcGIS) calculates the number of physical components in the Darjeeling Hills, Rectangle, size 1000 x 1000 M, (Rectangle), Statistics type Variety. To calculate the complicated coefficient of variety (Eg), the variety layers formed by soils, lithology, aspect, slope, topography roughness, and drainage density are added together. The result is then multiplied by the topography roughness index (TRI), which was used to calculate the roughness coefficient (R) (Nikolova & Zareva, 2022). The equal interval approach is used to categorise the geodiversity index raster into five levels: very high (8.44%), high (23.45%), moderate (32.42%), low (23.92%), and very low (11.76%).]

The second Geodiversity Index Map is prepared using fuzzy logic (fuzzy Membership tool, ArcGIS). The value of the Geodiversity Index ranges from 0 1. The resulting raster is divided into fivezonations: very high (16.57%), high (26.18%), moderate (26.71%), low (19.91%), and very low (10.62%).

Results

Geodiversity denotes the variety of geological features, materials, processes, and landform in a specific area. The total component varieties and the roughness coefficient are multiplied to get the complex geodiversity index. The Geodiversity Index is categorized into fivezonations (Fig: 3): very high (8.44%), high (23.45%), moderate (32.42%), low (23.92%), and very low (11.76%).

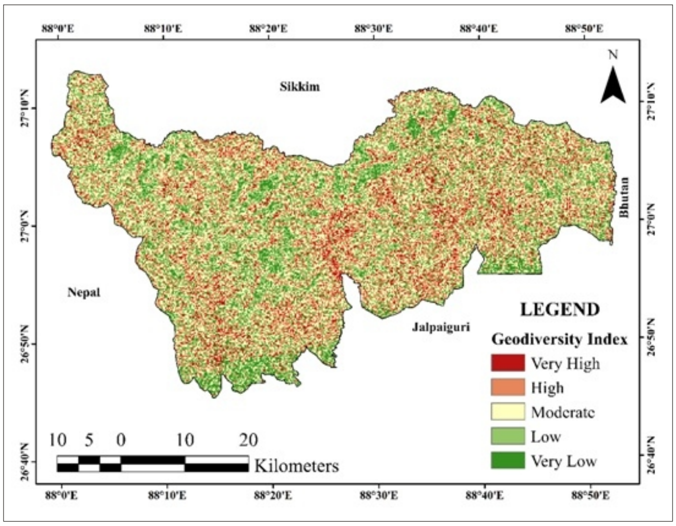

Fig.3: Spatial distribution of the geodiversity index

Very High Geodiversity Zone: About 8.44 % of the area of Darjeeling Hills has a very high geodiversity, indicating a greater variety of slopes, lithology, and topography roughness. High concentrations of Very High Geodiversity Zonation are found in surrounding areas of Teesta Valley, Sandakphu, and Neora Valley National Park.

High Geodiversity Zone: A high geodiversity zone covers about 32.42% of the Darjeeling Hills. The bulk of the high geodiversity zone is positioned near the area of extremely, very high geodiversity. Singalila National Park, Darjeeling, Kurseong, Bijanbari, Lava, and Tiffin Dara are situated in this zonation.

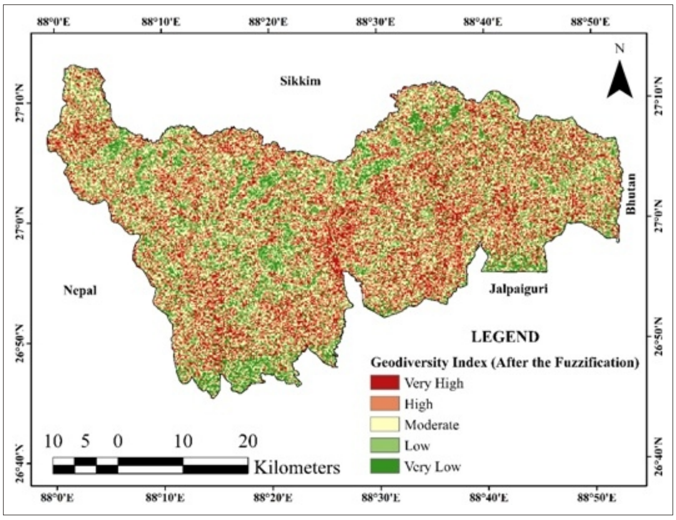

Fig.4:Fuzzification of geodiversity index

Moderate Geodiversity Zone: This zone covers 32.42% of the area of Darjeeling Hills. Moderate geodiversity zones are scattered all over the Darjeeling Hills. This zonation encompasses Kalimpong and the regions of Sukhia Pokhri, Takdah, Chatakpur, Sittong, and Mirik.

Low Geodiversity Zone: It is scattered all over the Darjeeling

Hills. A high concentration of Low Zonation is found in the southern part of Kurseong and Mirik Block. A low geodiversity value indicates a lesser variety of slopes, along with topography roughness. The low zone of geodiversity covers23.92% of the area of Darjeeling Hills.

Very Low Zonation

The low geodiversity zonation encompasses 11.76% of the area in the Darjeeling Hills. This zonation is not suitable for geodiversity. The southern part of Darjeeling Hills mainly contains the low geodiversity zone. After the fuzzification of Geodiversity Zonation (Fig: 4), many changes were observed in the spatial pattern of geodiversity. Fuzzification raster is categorised into three classes: very high (16.57%), high (26.18%), moderate (26.71%), low (19.91%), and very low (10.62%).

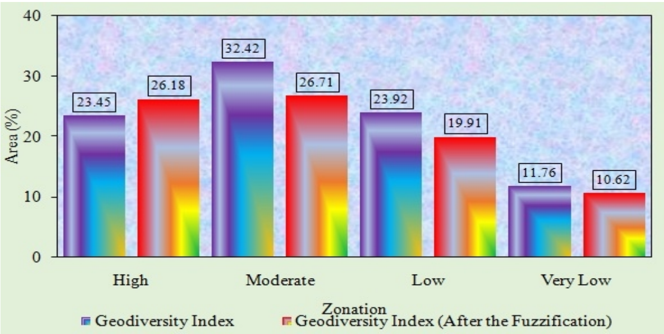

Fig.5: Area under Geodiversity Index Zone, and Post-fuzzification of Geodiversity Zones

After fuzzification, regions with moderate, low, and very low geodiversity index are reduced to 5.71%, 4.01%, and 1.14 %of Darjeeling Hills. In contrast, regions with very high and high geodiversity index are boosted, respectively, to 8.13% and 2.73% (Fig.5).

Conclusion

The present study constitutes a part of a comprehensive strategy aimed at fostering the growth of geodiversity sites within the Darjeeling Hills. The possibilities for sustainable development, educational enrichment, cultural appreciation, and supporting the conservation and protection of geological assets within an area are highlighted by the interaction between geodiversity and tourism. The variety of geological features, materials, processes, and landforms can significantly impact the options and experiences for tourists. Geotourism is supported and promoted in large part by geodiversity. Geotourism aims to draw visitors interested in learning about the geological history of a place and enjoying its natural wonders by emphasising the region's distinctive geological features, landscapes, and processes. A persuasive justification for Geotourism is made by the various and engaging geological aspects of geodiversity in combination with chances for learning, experiencing culture, and having an adventure.

Geodiversity is crucial for promoting conservation efforts in various ways, such as Ecosystem Stability, Geological Heritage Preservation, Educational Value, Geotourism, Biodiversity Support, etc. The preservation of geodiversity contributes to safeguarding the Earth's natural heritage and promoting the welfare of natural ecosystems and human communities. By acknowledging the inherent worth of geodiversity, societies can strive for a more balanced and environment-friendly interaction with the natural world. In addition to being important from a scientific standpoint, the Darjeeling Hills' geodiversity influences the area's ecology, hydrology, and general environmental health. In essence, the intricate interplay between geodiversity and the natural environment contributes to the holistic balance and sustainability of the Darjeeling Hills.

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Table - 1: Data Sources of Geodiversity Index.

Main Criteria	Data Type	Data Sources
Slope, Aspect and Stream Variety	Aster DEM	https://search.earthdata.nasa.gov/
Lithology Variety	Bhukosh Geospatial Data	https://bhukosh.gsi.gov.in/Bhukosh/Public
Soil Variety	Spatial Data	https://www.fao.org/soils-portal/en/
Topography Roughness	Aster DEM	https://search.earthdata.nasa.gov/

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