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Valuing Geodiversity: Scope and Aspects in Chittagong Hill Tracts, Bangladesh

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Abstract: The Chittagong Hill Tracts (CHT) is one of Bangladesh's floristically diverse hill systems. This hilly area, located in southeastern Bangladesh, has been selected as a study area as an important regional spot of geodiversity and tourism. The main approach of this research was to explore the geodiversity of CHT using topographic and meteorological information. Several quantitative approaches were used to produce geodiversity information on CHT. Elevation data was the primary source of GIS analysis. The fuzzy approach was applied for the quantification of geodiversity. SAGA (System for Automated Geoscientific Analysis) GIS tool used to quantify geodiversity and primary and secondary data collected in this region's most attractive tourist spot. Bandarban has a very low area left for a low geodiversity area, and most of the location of this district has medium to high geodiversity. Rangamati and Khagrachhari districts also have a broader medium to high geodiversity scope. Though the elevation of Chittagong and Cox's Bazar districts is less than 300m, some areas belong to medium geodiversity. The area is distinguished by an extensive network of trellis and dendritic drainage, which is made up of several important rivers that flow to the Bay of Bengal. The main rivers are Karnafuli, Sangu, Matamuhuri, Feni, and their fluvial processes enriched the geodiversity of the area. The highest positive correlation (more than 50%) between geodiversity and explanatory variables was TRI (Terrain Ruggedness Index), and slope, which means the topographical variations contribute to the generation of geodiversity. Soil carbon stock and elevation also positively contribute around 35%. Temperature and TWI (Topographic Wetness Index) correlates negatively with geodiversity, and precipitation has a slightly positive relationship. Hill forests consist of tropical evergreen and semi-evergreen vegetation in this area. These forests cover an area of roughly 1.40 million ha and are located in the Rangamati, Bandarban, and Khagrachhari Hill Tracts, Chittagong districts.

The tourism potentiality of the high geodiversity area is also significant in this region, where 51% of people visit the place for recreation. Additionally, 27% of people visited for knowledge and 11% for research. A family tour was 9%, and only 2% of people were for their business purpose. The hilly area has substantially wealthier geodiversity and has significant tangible values. The highly intricate processes that produce soil, climate, and terrain have taken thousands of years. But at the moment, tourism is eroding the land. Soil erosion is further aggravated by removing trees for agricultural farming or tourism attractions. Some significant Buddhist temples also exist, showing the area's cultural value.

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Introduction

Mountainous terrain covers 24% of the global land area, influencing the life of half of the Earth's human population directly or indirectly (Messerli & Ives 1997; Kapos et al. 2000). The preservation of biodiversity in the hilly region is of great importance nowadays. Biodiversity can simply be defined as the variation of life at a given site or ecosystem. However, it is through this diversity that natural systems adapt, evolve, and thrive. Diverse ecosystems usually have "increased stability, increased productivity, and resistance to invasion and other disturbances" (Quinn 2011). It is these features that make biodiversity desirable within a given biological community/biome. To highlight the importance of biodiversity, the following is a quote from the CBD (Convention on Biological Diversity): "At least 40 percent of the world's economy and 80 percent of the needs of the poor are derived from biological resources. In addition, the richer the diversity of life, the greater the opportunity for medical discoveries, economic development, and adaptive responses to such new challenges as climate change" (Shah 2014). However, it is difficult and expensive to collect spatial data on biodiversity in remote areas. The conservation of biodiversity requires the spatial information of all biological features of the target area. The most straightforward approach to assessing conservation priorities would be directly mapping those features and taking necessary actions (Hjort et al. 2012).

The Chittagong Hill Tracts (CHT) is a series of hilly areas at the southern boundary of Bangladesh. In the Chittagong Hill Tracts, the Upper Tertiary sandy-argillaceous sediments have been folded into a series of long sub meridional (NNW-SSE) anticlines and synclines represented in the surface topography by elongated hill ranges and intervening valleys. The folded structures are characterized by en-echelon orientation with an increasing degree of intensity and complexity toward the east. There are around 3,611 species of angiosperms in the country, 2,260 of which have been found in the Chattogram area alone. The nation has a rich biological history (Khan et al., 2007). This is why this area is rich in geodiversity and this study aims to evaluate the geodiversity and tourism potentiality of this study site.

State of the art

Globally, there is a significant disparity in the distribution of species, which can be seen in gradients of increasing species diversity from the poles to the equator, in the transition from arid to humid regions, and in the transition from low-lying, flat terrain to mountainous regions with distinct elevational zonation (Mutke et al. 2011, Brummitt et al. 2021). Geographically, areas of very high species richness that are well-known for their vascular plants are layered across gradients of geographic variety (Körner 2021). High levels of geodiversity, or the environmental variability and small-scale diversity of habitats brought on by steep climatic and biological gradients in fragmented and topographically different terrain, are linked to the above-average species richness in mountain areas (Hossain, 2001).

Due to its unique geographical position, the Indo-Myanmar region is one of the most significant hot spots for biodiversity and wide biological variety. Bangladesh's vegetation is a component of this region (Khan et al., 2007). There are around 3,611 species of

angiosperms in the country, 2,260 of which have been found in the Chattogram area alone. The nation has a rich biological history (Khan et al., 2007). However, due to political instability and the general remoteness of this region, the CHT remains the least explored area in Bangladesh (Khan 2015). Consequently, very little biodiversity survey work has been done in the area, and no systematic surveys have been carried out.

Aim and objectives of the study

The main aim of this study was to explore the CHT region's values and evaluate the region's geodiversity, and value the recent tourism potentiality of this area.

The main objectives of the study area are:

i. Quantification of the geodiversity of the CHT Region.
ii. Valuing the geodiversity of the CHT area and evaluating its tourism potential.

Materials and Methods

Study area

The Chittagong Hill Tracts are part of a 1,800 km-long mountain range oriented from north to south in parallel ridges, incised by deep gorges from the eastern Himalayas in China to western Myanmar (Fig 1). The CHT comprises 10% of the total land area of Bangladesh (Creative Conservation Alliance 2016) and lies within the Indo-Burma Biodiversity Hotspot (Myers et al. 2000) with many globally threatened species (Creative Conservation Alliance 2016). The climate of the region is tropical, with a mean annual rainfall of 2,666 mm. A dry, cool season occurs in the area during November-March, followed by a hot and sunny pre-monsoon season during April-May, and a warm, cloudy, and wet monsoon season from June-October (Khan 2015). The CHT is undoubtedly the wealthiest biodiversity hotspot in Bangladesh. Table 1 shows the basic information about the five districts in my study area, and the highest population is in Chittagong district as this is the second largest populated city in Bangladesh.

Besides the population, the number of tourist spots is also high in Chittagong district. The notable number of hills in Bandarban is significant, and Rangamati also has some essential hills. The area is distinguished by an extensive network of trellis and dendritic drainage, which is made up of several important rivers that flow to the Bay of Bengal. The main rivers are Karnafuli, Sangu, Matamuhuri, Feni, and their fluvial processes enriched the geodiversity of the area. Hill forests consist of tropical evergreen and semi-evergreen vegetation in this area. These forests cover an area of roughly 1.40 million ha and are located in the Rangamati, Bandarban, and Khagrachhari Hill Tracts, Chittagong districts. The forest department controls 0.67 million ha, and the remaining 0.73 million ha are unclassified state forests under the control of the Hill District Councils. The species richness gradually decreases with the elevation of these hilly regions, and the dominant families are Dipterocarpaceae, Euphorbiaceae, Lauraceae, Leguminacae, and Rubiaceae, which are semi-evergreen (deciduous) to tropical evergreen.

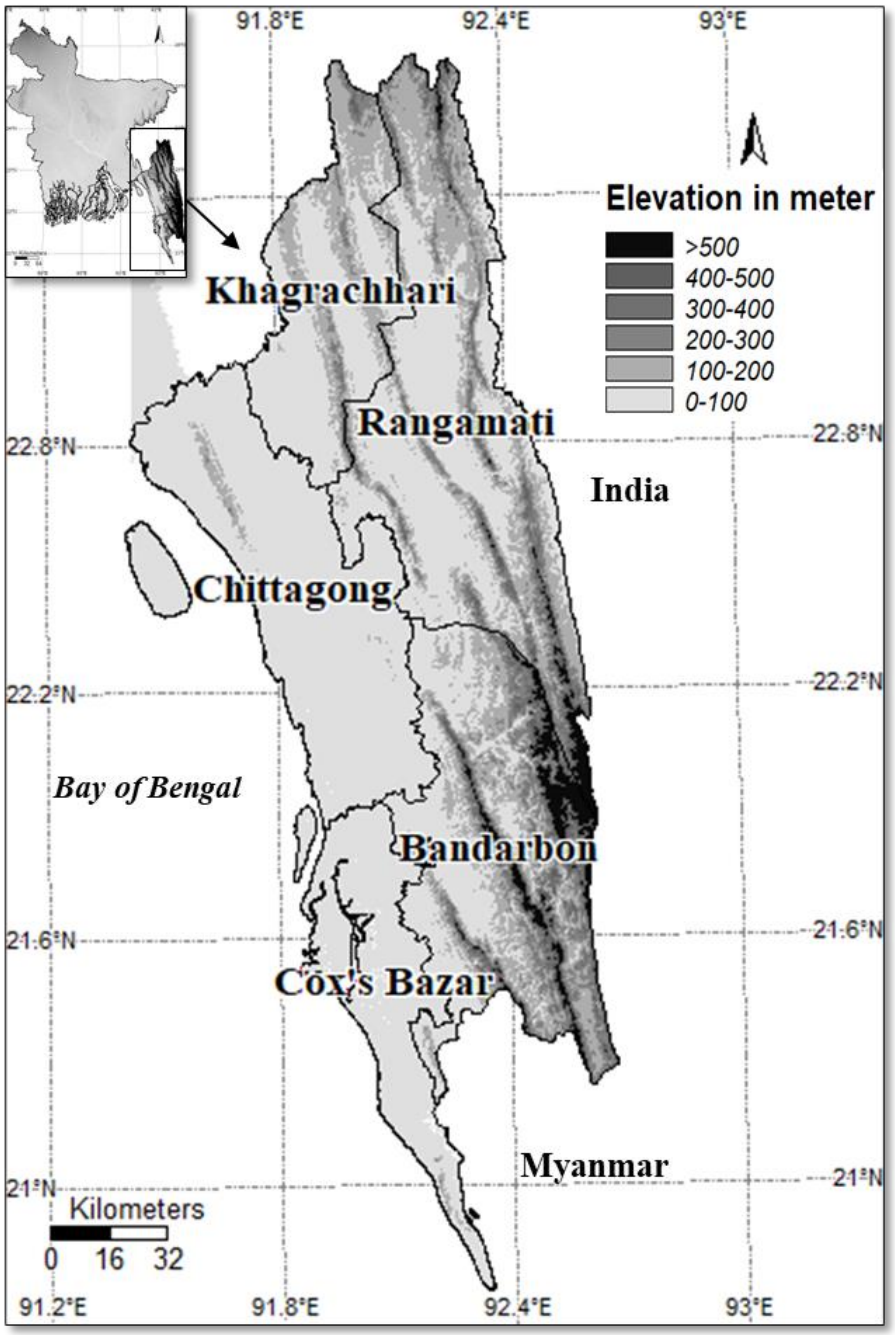

Figure 1: Location of Chittagong Hill Tracts (CHT). Source: Author 2023.

Table 1: Some basic information on the five districts in CHT. Source: Banglapedia 2021.

Districts	Area in sq km	Population	Number of notable hills	Indigenous community	Tourist spots
Khagrachhari	2699.55	525664	7	4	4
Rangamati	6116.13	508182	9	14	12
Bandarban	4479.03	298120	13	8	5
Chittagong	5282.98	6612140	10	-	30
Cox's Bazar	2491.86	1773709	-	-	19

Data Sources and Methods

I compiled six topographic and climate-based variables in this study and one soil variable (Table 2) to cover the most commonly used abiotic resource. Climate data was collected from the IPCC Site Data Distribution Center, and I downloaded mean temperature and precipitation data from 1961-1990 (https://www.ipcc-data.org/observ/clim/get_30yr_means.html). I fuzzified all the variables separately to quantify geodiversity, and this method normalized data. This classification was elaborated using GIS techniques (SAGA 9.0.1), involving morphometric and morphoclimatic variety. The spatial analysis in SAGA GIS is a cross-platform open-source GIS software developed by the Departments of Physical Geography in Göttingen and Hamburg (Conrad 2007, Conrad et al. 2015). Morphometric variables obtained from the SRTM digital elevation model (DEM; NASA). I used the DEM-based topographical data collected from the variables elevation, slope, topographic wetness index (TWI), terrain ruggedness index (TRI), and climatological variables (temperature and precipitation) and soil carbon stock (SCS) to quantify the geodiversity map. Information about soil carbon stock was downloaded from the Soilgrids website (https://soilgrids.org/). Table 2 shows the explanatory variables that were used in the GIS analysis. Besides GIS analysis, a literature survey took place to value the study area qualitatively.

Table 2: Explanatory variables used in GIS analyses.

Variables	**Type of variable**
Precipitation	Continuous (in mm)
Temperature	Continuous (in °C)
Elevation	Continuous (in m)
Slope	Continuous (in degrees)
Topographic ruggedness index (TRI)	Continuous
Topographic wetness index (TWI)	Continuous
Soil carbon stock (SCS)	Continuous (g/kg)

Results

Quantification of Geodiversity

The elevation map of Bangladesh shows the highest elevated areas are in the southeastern part of Bangladesh (Fig. 1), and hills of more than 500 m are located mainly in Bandarban and Khagrachhari districts. The average temperature between 1961-1990 was 21.77 to 24.4°C, and the average precipitation range was 174.5-284.48 mm in the study area. Using the and operator in the fuzzy logic, I created three classes of geodiversity between the range of 0-0.12, Low geodiversity (0 < 0.04), Medium geodiversity (0.04 < 0.08), and High geodiversity (0.08 < 0.12) (Fig 2). Bandarban has a very low area left for a low geodiversity area, and most of the location of this district has medium to high geodiversity. Rangamati and Khagrachhari districts also have a broader medium to high geodiversity scope. Though the elevation of Chittagong and Cox's Bazar districts is less than 300m, some areas belong to medium geodiversity.

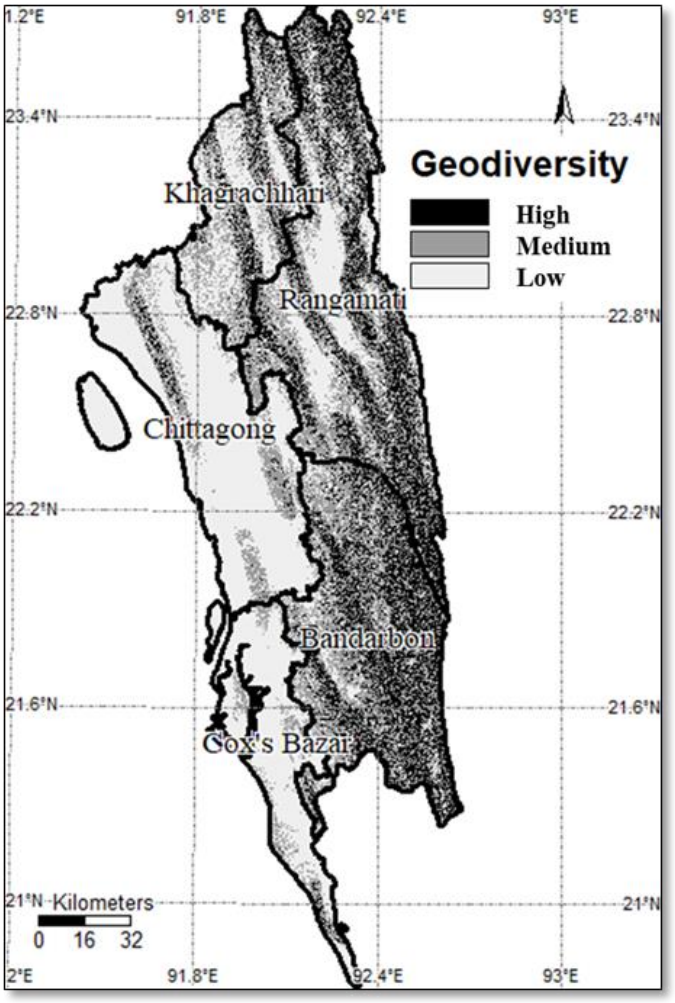

Figure 2: Geodiversity of Chittagong Hill Tracts. Source: Author 2023

The correlation between all explanatory variables and geodiversity was calculated (Fig 3), and four variables have a positive correlation: elevation, slope, SCS, and TRI. TWI and temperature have a negative correlation, and precipitation has a slightly positive relationship with geodiversity.

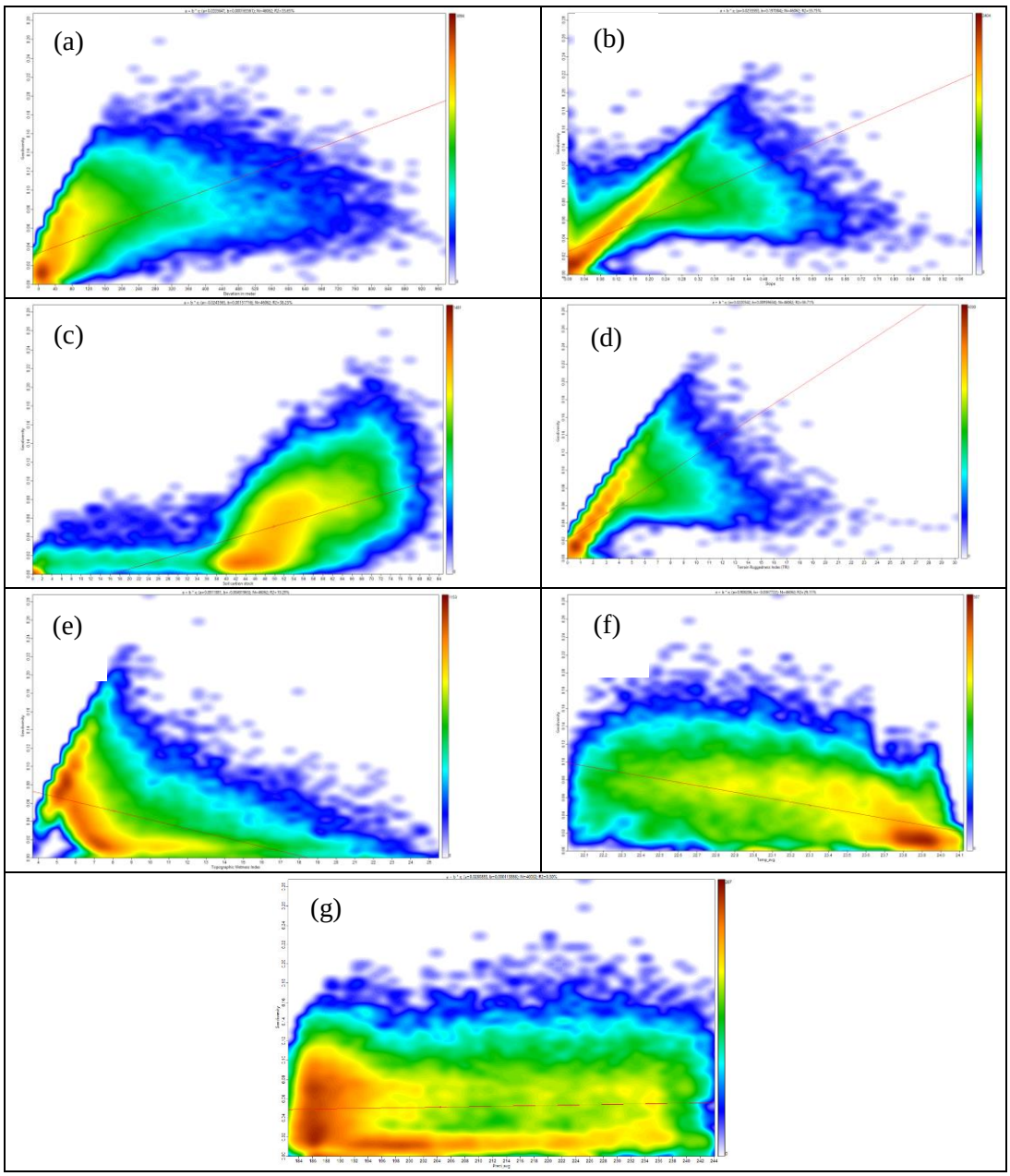

Figure 3: The relationship between Geodiversity and all explanatory variables. (a) Elevation vs. Geodiversity, (b) Slope vs. Geodiversity, (c) SCS vs. Geodiversity, (d) TRI vs. Geodiversity, (e) TWI vs. Geodiversity, (f) Temperature vs. Geodiversity, (g) Precipitation vs. Geodiversity. Source: Author 2023

The highest positive correlation (more than 50%) between geodiversity and explanatory variables was TRI, and slope means the topographical variations contribute to the generation of geodiversity (Table 3). Soil carbon stock and elevation also positively contribute around 35%. Temperature and TWI have a negative correlation with geodiversity and precipitation has a slight positive relationship.

Table 3: The relationship (R^2) between Geodiversity and all explanatory variables.
Source: Author 2023

	Elevation	Slope	TRI	SCS	TWI	Temperature	Precipitation
Geodiversity	35.65	55.75	56.71	38.23	-19.29	-29.11	0.30

Valuing geodiversity in the CHT

a) *Intrinsic or Existence Value:*

This value refers to the ethical belief that nature's geodiversity is essential simply for what they are rather than what humans can use for them (Gray, 2004). It involves moral and philosophical dimensions of the relationships between society and nature.

b) Cultural Value:

Cultural value means the value placed by society on some aspect of the physical environment by reason of its social or community significance.

i) **Folklore (geomythology):** Primitive societies believe supernatural forces generate the origin of rock formations or landforms and are very significant to them. Tribal people believe Ram Pahar in Kaptai Upazilla and Sita ghat beside Karnafuli river are sacred places for them as Ram and Sita visited them.

ii) **Archaeological and historical value:** Our early ancestors had a very close relationship with their physical surroundings, and in that case, the crucial role played by geology and landscape of that area (Gray, 2004). Chisty (2014) listed the historical sites of Chittagong that have significant cultural landmarks and need to be under conservation (Table 4).

Table 4: List of Historical Sites of Chittagong, Source: (Chisty, 2014)

Period	Name	Location
Sultani: Monuments	Badr Auliya Tomb: Known As Bara Auliyar Desh	Boxirhat
	Shah Qatal Tomb: A Square Tomb	Katalganj, Sulokbahar
Mughal: Monuments	Anderkilla Shahi Jame Mosque	Anderkilla
	Hamza Khan Mosque And Tomb	Panchlaish
	Hazi Mosque Now In Ruins	Pahartali Mauza (Beside The Railway Track West Of Dewanhat Over Bridge)
	Mullah Miskin Mosque And Tomb	Ward-2, On The Eastern Slope Of A Hill Known As Madrasa Pahar Chandanpura Mahallah
	Wali Khan's Mosque: Built By Mughal Fauzdar Wali Beg Khan	Chawkbazaar
	Kadam Mubarak Mosque	Jamal Khan Ward
Colonial Times:	Darul Adalat: Now In Ruins	Madrasa Pahar (Mohsin

Institutional/Government Use		College Campus)
	Court Building (1892-3) And Site	Court Hill Anderkilla
	General Hospital: (1840) Including The Hill Site	Anderkilla
	Nachghar 2 Storied Red Building (Fire Brigade Station Chandanpura)	Enayet bazaar Opp. Chandanpura Mosque
	Central Railway Building: (1872)	Enaye tbazaar
	Wooden Bungalow No L/1: (1887)	SegunBagan, Pahartali Enayet bazaar
	Dc's Bungalow Dc Hill	Buddhist Temple Road
	Mirzar Pool: Bridge On The Hathazari Road	Muradpur, Sulokbahar
	Battali Railway Station: (1896)	Battali near new market
	Karnaphuli Railway Bridge (Known As Kalurghat Bridge) (1931)	Kalurghat
	Old Circuit House (Zia Sriti Jadughar): 1913	Bag monirum
	Pahartali Railway Workshop	Pahartali
	Chittagong Police Hospital	Lalkhan Bazaar
	Police Armory	Bag monirum
	The European Club	Pahartali
	J.M. Sen Hall (Town Hall)	Dewan Bazaar
	Water Works	Bag monirum
Residential Houses (Private)	Malum Bari Wooden Bungalow	Maddahya Halishahar,Ward-38
	K. Sen's House Seven Storied Masonry Structure	Sadarghat Ward
	J.M. Sen's House	Rahmatganj
	N.N. Paul Building With Banyan Tree (Opposite Dc Hill)	Dc Hill
	Ispahani Manzil	Sarson Road
Religious Buildings	Chandanpura Mosque	Chandanpura, Anderkilla
	K.S. Abdul Hakim Mosque	Mansurabad
	St. Mary's Church	Jamal Khan Ward-21
	Patharghata Church	Patharghata Ward
	Love Lane Church	Jamal Khan Ward-21
	Second World War Graveyard	
	Shadur Pahar	North Of Ctg., Cantonment Ward-01
Pakistan Period	Jamuna Bhaban	Sk. Mujib Road, Agrabad

iii) **Spiritual value:** Tribal people have their own stories about the world's origin and regard the Earth as sacred; some even see ploughing as wounding or violating the land (Gray, 2004). Many natural sites are regarded as sacred, where people can communicate with good and evil spirits.

iv) **Sense of place:** Human societies strongly bond with their physical surroundings and value these ties for cultural and economic reasons. Some societies have complex relationships with the rivers on which they are sited, depending on them for water for agricultural and domestic use but fearing the impacts on life and property of flood events. Agrarian communities depend on soil quality and have long valued the material their living depends on. Coastal communities often feel a strong relationship and respect for the sea and coastal landscapes, frequently due to their dependence on fishing. Coastal topography provides navigational landmarks such as headlands and islands and thus increases the sense of place.

c) Aesthetic Value:

The aesthetic value of geodiversity in the CHT is more tangible and refers to the visual appeal of the physical environment. This could be landforms at all scales from hill tracts to coastlines, Kaptai Lake, and all have value because of the diversity of topography they provide for residents or travelers (Bourassa, 1992; Gray, 2004)

i) **Local landscapes:** Local landscapes of CHT have an aesthetic appeal. The aesthetic value bestows economic value and social status. We can see that the sea view or hill-top locations are always attractive to advanced societies. The hills, beaches, and lakes are not only of geomorphological importance but are part of the beauty and scenery of our country.

ii) **Geotourism and leisure activities:** Geotourism is linked to ecotourism, and the present-day practice of geotourism is increasing to conserve the natural diversity. Geotourism ensures the general value of scenery, wilderness and environment, often promoted as part of national tourism campaigns (Fennell, 1999). There is an increasing interest in touring and walking holidays and the general attraction of rural landscapes for day trips and short breaks by increasingly urban populations.

iii) **Artistic inspiration:** The landscape is an essential source of inspiration for artists, musicians, poets, writers, and others. The unique culture of CHT provides Biju Sangrai Baisabi festival, Hal Palani festival, Pala Gan, Pahari Lokageeti, Geeti Nritya Natak (dance drama), Garaiya dance, Jhum dance, Bamboo dance, Bottle dance etc.

d) Economic Value:

Rock, minerals, sediment, soil and even fossils, all have economic value, though this varies depending on the nature of the material involved.

i) **Mineral fuels:** Brown coal, salt from brine water, and minor beds of limestone and conglomerate are found in Chittagong.

ii) **Construction minerals:** The greatest volume of geological materials are used in construction work, and a very diverse range of geomaterials is used in many applications. Although biomaterials are used in building construction (e.g. timber frames, thatched roofs, wooden cladding), urban environments are dominated by bulk minerals in ways that should make the value of geodiversity very evident to their inhabitants.

e) Functional value:

Soils, sediments, landforms, and rocks all have a functional role in physical and biological environmental systems.

i) **Utilitarian functions:** Geodiversity results in a diversity of utilitarian, functional values of different parts of the landscape. Particular combinations of landforms, bedrock types, or soils make some areas best suited for agriculture, others for urban

development, still others for hydroelectric power. The land surface provides a platform or foundation for development and all human activities. This gives the land a functional and economic value.

The physical Earth is particularly important in the role of soil and peat as carbon stores. Other examples of the abiotic environment acting as important stores include water stored in sub-surface aquifers or surface lakes, oil and gas stored in geological traps and mineral resources stored in ore bodies, sediments, and so on. The physical environment also plays a role in recycling earth materials. For example, leaf fall leads to humus production and recycling of nutrients through the soil and tree roots.

ii) **Geosystem function:** River channels transport water and sediment from land towards the sea, and their capacity is adjusted to the stream discharge. The form of this channel affects the flow of water in it and, through erosion and deposition (Gray, 2004).

iii) **Ecosystem function:** The physical environment generally plays a considerable role in providing diverse environments, habitats, and substrates that create biodiversity. So the ecological system depends on physical diversity, which is high in the CHT region.

f) Research and Educational Value

The physical environment is a laboratory for future research. The study of the geological record is critical to geologists. Samples from the sediments in lakes and bogs are able to provide the effects of human activities on the environment as pollution records. Dynamic sites are essential in allowing researchers to understand the processes at work in active systems and have implications for pure and applied research. CHT is an ideal place where students and teachers can have various landform sites for their research.

A short questionnaire survey of 110 tourists has conducted in the Khagrachhari and Rangamati hill area about the geodiversity value of that area. The results showed that 51% of people visit there for aesthetic value and recreation, and 27% visit to explore the area and gather knowledge. 11% of people were there for their research and education. A family tour for recreation and leisure activities was 9%, and only 2% of people were for economic value or business purposes. This survey proved that the tourism potentiality is still high for the high geodiversity of CHT.

Discussion and conclusion:

CHT is the most significant and unique place in the floodplain of Bangladesh. This region's high geodiversity is essential for its physically diversified landforms and the abundance of rich biodiversity. The most important abiotic factor contributing to geodiversity are slope and topographic ruggedness index. The climate variables were not highly correlated to quantify geodiversity as the differences in the range of values are not so high.

Some values sometimes overlap, *e.i.* Sea beaches or hills have both aesthetic and economic value. Values may conflict as the economic values of geological materials and the need for modern society to exploit them often conflict with the aesthetic values of the landforms and landscapes that would be impacted by quarrying (Gray, 2004).

Some scientists, politicians, and conservationists name the current epoch the Anthropocene, while increased human activity on global biodiversity will cause irreversible devastation (Environment, 2019; IPBES, 2019; Lorimer, 2015). Convivial (literally: 'living with') conservation offers a new approach to understanding and

practicing environmental conservation. The CONVIVA research project is part of the broader convivial conservation movement and is conceptualised as one stream within a wider societal transformation to sustainability. This project critically analyses the dynamics and politics of human-wildlife conflict and coexistence from the local level and tries to explore alternating mechanisms (Fig. 4). This project analyses environmental justice and human-wildlife interactions from a local to a global focus.

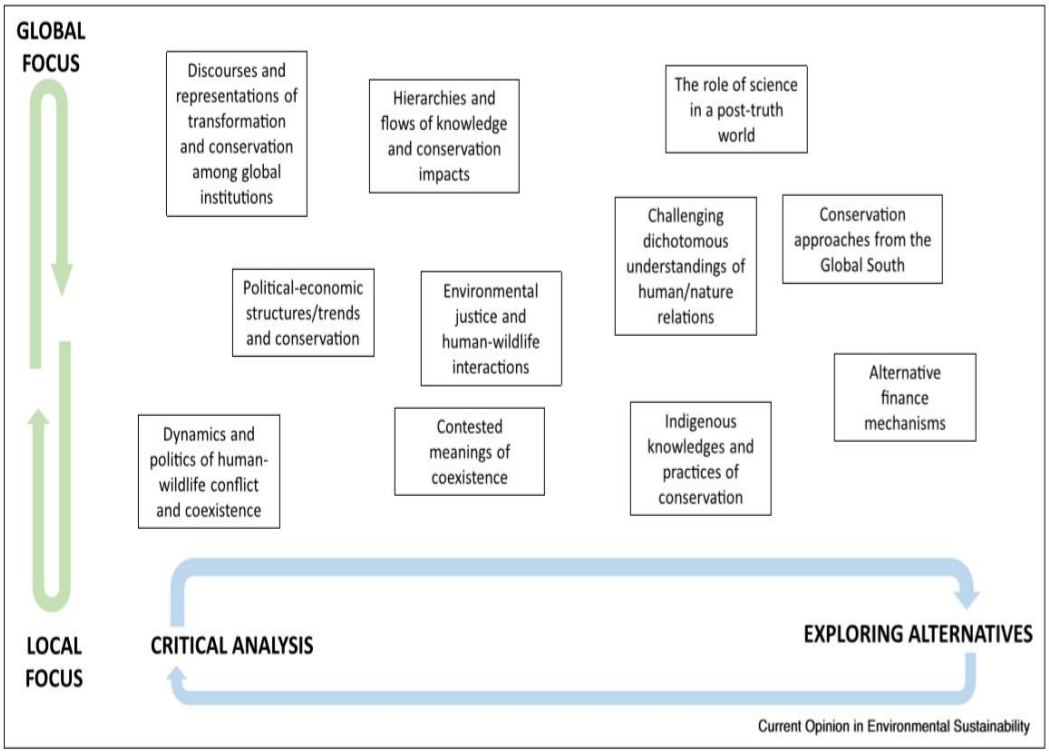

Figure 4: Summarising CONVIVA themes and showing how they interconnect across scales of inquiry (green arrows) and research approaches (blue arrows) Source: (Massarella et al., 2021).

One of the CONVIVA-related projects, 'Mapping Environmental Justice,' indicated six cases in the Environmental Justice Atlas of the coastal area of Chittagong (Fig 5). These cases were made to protect the physical properties of the coastal zone and its surrounding human settlement and biodiversity. Table 4 highlights these six cases which are destroying the nature and quality of natural resources of the Chittagong division.

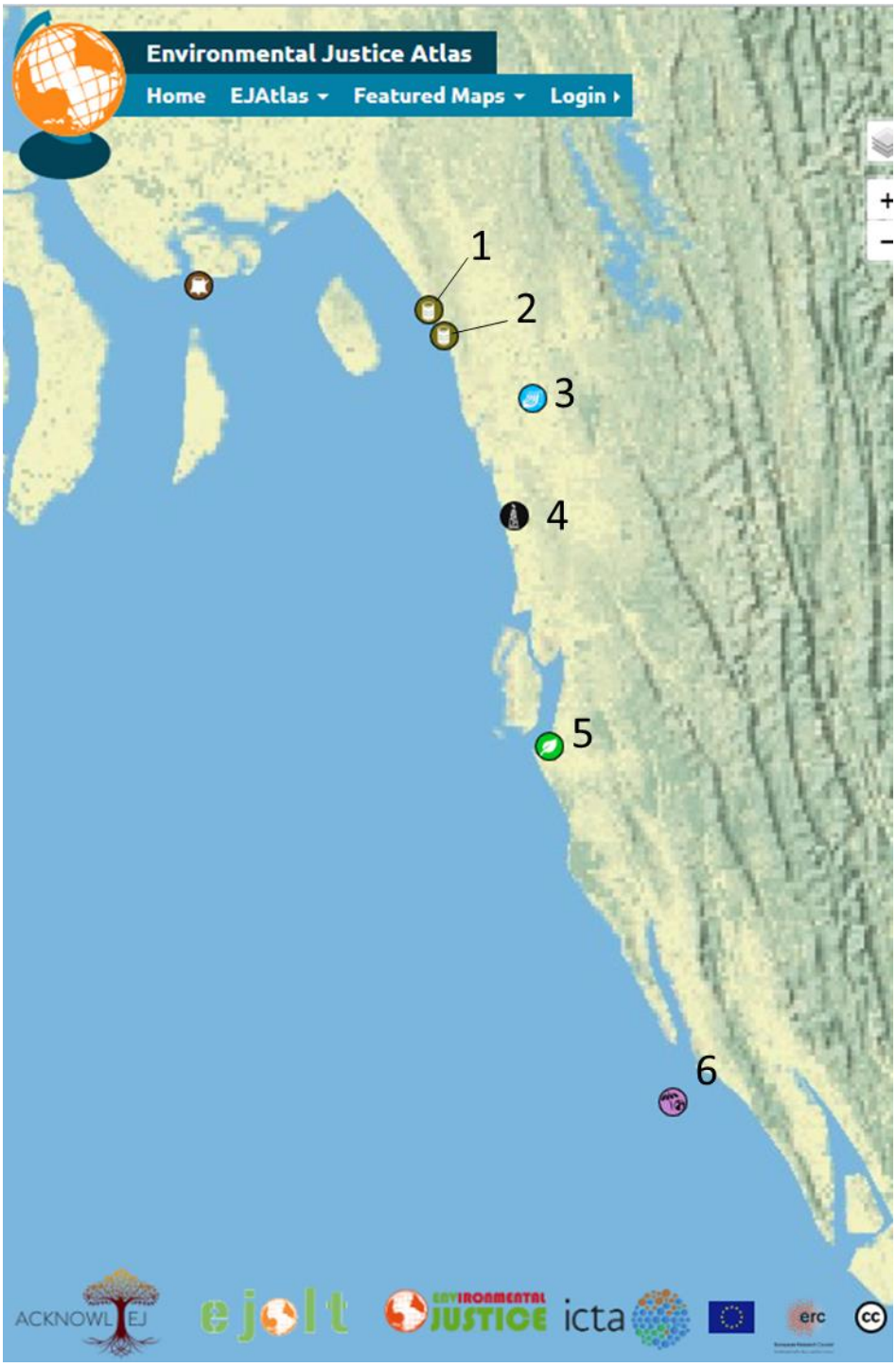

Figure 5: Six cases in the Environmental Justice Atlas. Source: https://ejatlas.org/, 2023, modified by the author.

Table 4: Environmental degradation-related cases from the Environmental Justice Atlas. Source: : https://ejatlas.org/, 2023.

No.	Location	Cases
1	North Sea Producer shipbreaking	*Violating international law, the Maersk ship containing radiation ends up on the beach of Bangladesh for breaking purposes.*
2	Dirty and dangerous shipbreaking in Chittagong	*Chittagong is one of the largest shipbreaking yards in the world. The industry has been criticized for contaminating the environment and exposing low-paid workers to high risks.*
3	Industries cause water scarcity in 5 villages Chittagong district	*No water to drink due to the industrial withdrawal of groundwater*
4	Banshkhali coal power station, Chittagong	*Agitation in the Gondamara ward against a very large (imported) coal-fired power plant resulted in several villagers being killed in April 2016 and again in February 2017.*
5	Jilanja Mouja-Attempted Conversion of Reserve Forests for Housing of Public Officials	*Illegal conversions of reserve forest plots for the housing of government officials are successfully contested by civil society and the court.*
6	Unregulated tourism in eco-sensitive coral island	*Despite categoric directions from the judiciary, unregulated tourism in the eco-sensitive and only coral island of Bangladesh is causing erosion and loss of biodiversity, including two species of globally threatened turtles, scenic vistas, and water contamination.*

Though the environmental justice cases had been made in the coastal zone, the hilly parts should have been kept safe for geodiversity and biodiversity conservation. The wild animals should be kept in their habitat, not in the cities begging for money to survive (Fig. 6).

Figure 6: An elephant is begging in Dhaka city. Source: Author 2022.

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