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An Overview of Geography and Biodiversity in the Himalayan Region

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Abstract

The Himalayan region is a geologically dynamic and ecologically rich mountain system, spanning diverse climate zones and altitudes. Its unique geography supports a wide range of ecosystems, from tropical forests to alpine meadows, and harbors significant biodiversity, including endemic cold-water fish like *Schizothorax* spp. and *Tor putitora*. However, climate change, glacial retreat, habitat degradation, and invasive species threaten both ecological balance and local livelihoods. This review highlights the interlinked geographical and biological features of the Himalayas and emphasizes the need for integrated conservation and sustainable management strategies.

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Introduction

The Himalayas represent one of the most impressive mountain ranges globally, shaped over millions of years through tectonic collision between the Indian and Eurasian plates. The Indian Himalayan Region with geographical coverage of over 5.3 lakh kilometre square, extends over 2,500 kilometres in length between the Indus and the Brahmaputra river systems and its starting from the foothills in the south (Siwaliks), extends up to Tibetan plateau in the north (Trans-Himalaya). Three major geographical entities, the Himadri (Greater Himalaya), Himanchal (Lesser Himalaya) and the Siwaliks (Outer Himalaya), extending almost uninterrupted throughout its length, are separated by major geological fault lines. The region is responsible for providing water to a large part of the Indian subcontinent. Many rivers considered holy like the Ganga and Yamuna flow from the Himalayas. The study of the Himalayas' ecological health and environmental importance is vital for understanding regional climate change implications and sustainable development.

Mountains are globally significant as 'water towers' of the Earth, as core areas of biodiversity and as source regions for important natural resources and ecosystem services. The ecological integrity of mountain environments is increasingly threatened by global environmental changes including climate change and Precipitation patterns to which physical and ecological systems in mountains are highly vulnerable. Global warming rates have been higher in mountain regions compared to the global mean and have strongly affected the cryosphere, mountain biota and ecosystem processes.

The impacts of human activities on the bio-geophysical and socio-economic environment of the Himalayas are man-induced activities which have accelerated ecological degradation and threatened the

equilibrium of Himalayan mountain ecosystems are stated as: unplanned land use, cultivation on steep slopes, overgrazing, major engineering activities, over-exploitation of village or community forests, lopping of broad leaved plant species, shifting cultivation in north-east India, tourism and recreation. Monoculture in forests, erosion and landslides have resulted in one–third of the total Himalayan land area becoming environmentally derelict. Cold desert conditions prevail in 41,500 km^2 of north-west Himalayas and are encouraged by traditional pasturalism. The geo-morphological conditions are major factors responsible for landslides which cause major havoc every year in the area. Other physical problems exist, such as eutrophication, drying up of the natural springs, the recession of the glaciers and changes in surface and ground water hydrology. Wild fauna, like musk deer (*Moschus moschiferus*) and the snow leopard (*Panthera uncia*), are now under threat partially due to changes in their habitat and the introduction of exotic plant species. Population pressure and migration are major factors responsible for poverty in the hills. The emigration of the working male population has resulted in the involvement of women as a major work-force. This work includes trekking for hours to collect fodder, timber and drinking water in addition to household duties. In the wake of changing climatic variables and a range of linked population, land use and river impoundment and conversion pressures across the Indian Himalaya, there is an urgent need to understand the behaviour of these non-native fish species and identify factors which provide them an ecological advantage over native fish species. This can support a case for cessation of stocking with alien species. Further collection of long-term field data, integrative quantitative models, public awareness and education programmes could greatly assist in addressing these knowledge gaps and identification of effective control measures.

Geological formation of the himalayas

The Himalayas originated around 50 million years ago as a result of the collision between the Indian Plate and the Eurasian Plate. This tectonic activity resulted in the uplift of sediments and volcanic materials forming the highest mountain mass on Earth. The Himalayan orogenic process continues today, leading to frequent seismic activity (Choudhury and Sanyal, 2014). The Himalayan mountain range was formed as a result of the tectonic collision between the Indian Plate and the Eurasian Plate, a process that began over 50 million years ago during the Cenozoic era. The collision is the most recent phase of the ongoing Himalayan orogeny, a tectonic activity characterized by intense folding, faulting, and uplift of sediments accumulated in the Tethys Ocean basin (Yin and Harrison, 2000). The convergence of these two plates has resulted in the uplift of the Himalayan massif, creating the tallest mountain system on Earth with peaks such as Mount Everest rising above 8,848 meters. The geodynamic process is still active today, leading to frequent seismic activity in the region, which continually shapes the Himalayan geology and landscape (Bishop *et al*., 2018).

The Himalayan region is geologically diverse, with a complex stratigraphy comprising various rock formations, including sedimentary, metamorphic, and magmatic rocks. The sediments originally deposited in the Tethys Ocean were thickly folded and thrust over each other and subsequently uplifted during the Himalayan orogeny (Ray, 2014). The ongoing collision continues to exert immense pressure, causing faulting and mountain-building processes that contribute to the rugged topography. This geological activity is also associated with the formation of deep valleys, uplifted plateaus, and extensive fault systems like the Main Himalayan Thrust, which is responsible for major earthquakes in the region (Ni and Barazangi, 1994). The Himalayas thus represent a dynamic and evolving geological entity that continues to influence the region's physical landscape and seismic activity.

Geographic extent and topography

This mountain range spans five countries: India, Nepal, Bhutan, China, and Pakistan. The Himalayan terrain features towering peaks like Mount Everest (8,848 meters), the deepest valleys, extensive glaciers, and intricate river systems originating from snow-fed glaciers (Bishop *et al*., 2016).

The Himalayan mountain range extends approximately 2,400 kilometers in length, stretching across five countries: India, Nepal, Bhutan, China, and Pakistan. Its width varies from 200 to 400 kilometers and encompasses a complex network of peaks, valleys, and plateaus. The topography of the Himalayas is characterized by extremely high peaks, deep gorges, and extensive glaciers and snowfields. The range begins in the west at the Hindu Kush and extends eastward to the border of Myanmar, forming the northernmost boundary of the Indian subcontinent. Notable peaks such as Mount Everest (8,848 meters), K2, and Kanchenjunga dominate the skyline, making it the highest mountain system globally. The topographical features influence regional climate, ecosystems, and hydrological processes, serving as critical watersheds for major rivers like the Ganga, Brahmaputra, and Indus (Bengal, 2014).

The complex geological processes responsible for shaping the Himalayas have resulted in a highly rugged terrain with significant variations in elevation over short distances. The region's topography includes numerous high-altitude plateaus such as the Tibetan Plateau, which acts as the 'Roof of the World.' The Himalayas are also marked by prominent features like the Great Himalaya Range, the Lesser Himalayas, and the Outer Himalayas, each with distinct geological compositions and structural features. These features contribute to the diverse ecosystems and habitats that support a wide range of flora and fauna. The dynamic tectonic activity continues to uplift and shape the Himalayas, leading to frequent seismic events and ongoing landscape evolution (Lasek *et al*., 2010). Overall, the geography and topography of the Himalayas are fundamental in understanding regional climate patterns, hydrology, biodiversity, and geological stability.

Climate zones of the Himalayas

The Himalayan region exhibits a complex range of climate zones due to its vast altitudinal variation and geographical span across several countries. These zones include the tropical, subtropical, temperate, subalpine, alpine, and nival zones, each supporting distinct vegetation and climate characteristics. For instance, the southern foothills experience warm, humid conditions conducive to dense forests, while the higher elevations above 5,000 meters are permanently snow-covered with minimal vegetation. This vertical zoning significantly affects local weather patterns, hydrology, and agricultural practices in the region (Singh *et al*., 2011).

Ecological and biodiversity zones

The Himalayas harbour ecosystems from tropical forests to alpine meadows, hosting numerous endemic species. These zones are sensitive to climate change, affecting treeline dynamics and habitat distribution (Kumar and Raj, 2020). The Himalayas are globally recognized as a biodiversity hotspot, comprising a wide range of ecological zones that support a unique array of flora and fauna. These zones transition from tropical and subtropical forests in the lower altitudes to alpine meadows and cold deserts at higher elevations. This ecological diversity is attributed to variations in altitude, climate, and soil type, making the region home to endangered species like the snow leopard, red panda, and Himalayan monal. Conservation strategies in the Himalayas are crucial, as these zones are increasingly threatened by human activity and climate change (Myers *et al*., 2000).

Flora and Fauna

Rich biodiversity includes the Bengal tiger, snow leopard, red panda, Himalayan monal, and numerous medicinal plants. The forests comprise oak, pine, fir, and rhododendron species, with a high level of endemism (Sharma and Verma, 2019). The Himalayan region, stretching across several South Asian countries, is one of the most biologically rich and ecologically diverse areas in the world. Its immense altitudinal gradient—from tropical forests in the foothills to alpine meadows and permanent snowfields—supports a wide range of flora and fauna. The vegetation varies dramatically with elevation, ranging from subtropical forests dominated by sal (Shorea robusta) and chir pine (Pinus roxburghii) in the lower altitudes, to temperate broad-leaved and coniferous forests, and ultimately to alpine shrubs and mosses at higher elevations (Singh and Singh, 1992).

The Himalayan fauna is equally diverse, housing iconic species such as the snow leopard (Panthera uncia), Himalayan tahr (Hemitragus jemlahicus), red panda (Ailurus fulgens), and numerous species of pheasants. In terms of aquatic biodiversity, the Himalayan rivers and lakes host a wide range of cold-water fish species, many of which are endemic. The high-altitude river systems, especially those originating from glacial melt, such as the Indus, Ganges, and Brahmaputra, serve as critical habitats for species like snow trout (Schizothorax spp.) and golden mahseer (Tor putitora), a prized game fish and an important component of local subsistence fishing (Nautiyal, 1994).

Fishery resources in the Himalayan region are vital not only for biodiversity but also for local livelihoods and food security. However, these resources face increasing pressure from climate change, habitat degradation, pollution, and overfishing. The changing hydrological patterns due to glacial retreat and altered river flow have had adverse effects on fish breeding and migration. Efforts toward sustainable fishery practices, habitat restoration, and community-led conservation are crucial to preserving this unique ecological niche (Vass *et al*., 2010).

Glacial dynamics and water resources

Glaciers act as water reservoirs, feeding major rivers such as the Ganga, Yamuna, and Brahmaputra. Climate change accelerates glacier melting, threatening water security and hydropower potential (Singh and Joshi, 2021).

Glacial dynamics in the Himalayan region play a critical role in shaping the hydrology of South Asia, directly influencing freshwater availability, aquatic ecosystems, and fishery resources. The Himalayas are home to some of the largest ice reserves outside the polar regions, often referred to as the "Third Pole." Glaciers act as natural water reservoirs, releasing meltwater seasonally into river systems such as the Ganges, Brahmaputra, and Indus. This glacial melt sustains river flow during dry months, supporting not only agriculture and drinking water needs but also freshwater fish habitats (Immerzeel *et al*., 2010).

The dynamics of glaciers—accumulation, melting, and retreat—are being rapidly altered by climate change. Rising global temperatures have accelerated glacier retreat across the Himalayas, leading to changes in river discharge patterns, increased frequency of glacial lake outburst floods (GLOFs), and reduced seasonal flow regularity. These hydrological shifts have profound implications for cold-water fish species, particularly in high-altitude streams where species like snow trout (Schizothorax spp.) and golden mahseer (Tor putitora) depend on specific thermal and flow regimes for breeding and survival (Bhatt *et al*., 2012).

The alteration of water volume and temperature affects fish physiology, spawning cycles, and migration patterns. Moreover, increased sedimentation and habitat fragmentation due to glacial disturbances threaten aquatic biodiversity. Fisheries dependent on consistent cold-water flows are especially vulnerable, as erratic flows can lead to population declines and reduced fishery productivity. Sustainable management of glacial-fed rivers, incorporating climate modeling and ecological monitoring, is essential to protect the integrity of fish habitats and ensure long-term viability of fisheries in the Himalayan region (Sharma *et al*., 2007).

Human settlements and cultural significance

Numerous communities live in the valleys and foothills, practicing traditional agriculture and pastoralism. The Himalayan region is also the cradle of rich spiritual and cultural traditions, with pilgrimage sites like Mount Kailash and Lhasa (Thapa, 2019).

The Himalayan region, stretching across countries such as India, Nepal, Bhutan, and parts of China and Pakistan, is home to a rich diversity of human settlements, cultures, and natural resources. While traditionally known for its towering peaks and spiritual significance, the Himalayas also support diverse aquatic ecosystems that are integral to the livelihoods and cultures of indigenous communities.

Human Settlements and Livelihoods: In the Himalayas are often small, scattered villages located near rivers, lakes, and glacial streams. These water bodies are vital for drinking water, irrigation, and importantly, inland fishery. While agriculture remains the dominant livelihood, fishery—especially small-scale and subsistence fishing—plays a critical complementary role. For example, communities living along the Teesta, Ganga, and Brahmaputra river systems in the Eastern and Central Himalayas rely on seasonal fish harvests for protein intake and income (Sharma *et al*., 2019).

The cold-water fisheries of the Himalayas are primarily based on indigenous fish species like *Schizothorax, Tor putitora* (Golden Mahseer), and *Neolissocheilus hexagonolepis* (Copper Mahseer). These species are not only ecologically important but are also embedded in local cultural and religious practices.

Cultural Significance: Fish and aquatic biodiversity hold spiritual and cultural value among Himalayan communities. In many regions, rivers are considered sacred—such as the Ganges (Ganga) in India and Nepal—and the fish inhabiting them are often revered. The Golden Mahseer, for example, is regarded as a holy fish in Hindu mythology and is often protected in river stretches near temples and shrines (Nautiyal, 2014).

Moreover, festivals and rituals in regions like Uttarakhand and Sikkim involve the ceremonial release of fish into rivers, symbolizing life, purity, and renewal. This reflects a traditional conservation ethic that has helped preserve fish diversity despite increasing environmental stress.

Environmental challenges

The Himalayan region, a cradle of biodiversity and source of major river systems in South Asia, plays a vital role in supporting aquatic ecosystems and cold-water fisheries. However, rapid environmental changes are threatening the sustainability of fishery resources in this ecologically sensitive zone. The fisheries in the Himalayas, which include rivers, lakes, and glacial streams, are particularly vulnerable due to their dependence on clean, cold, and oxygen-rich waters. This page note outlines the key environmental challenges impacting Himalayan fisheries and provides an overview of the threats and necessary conservation strategies.

Climate Change and Glacial Retreat: Rising temperatures in the Himalayan region are accelerating glacial melt and altering hydrological regimes. Changes in river flow patterns, seasonality, and temperature are directly affecting cold-water fish species such as *Schizothorax, Tor putitora* (Golden Mahseer), and *Neolissocheilus hexagonolepis*. These species are sensitive to temperature and rely on specific ecological conditions for breeding and migration (Bhatt *et al*., 2022).

Hydropower Development and River Fragmentation: The surge in hydroelectric projects across the Himalayas has led to the damming of many rivers. This disrupts natural river connectivity, blocks fish migratory routes, and alters sediment and nutrient flows essential for aquatic life. The fragmentation of rivers has been linked to the decline of fish populations, particularly of migratory species (Vass *et al*., 2010).

Pollution and Habitat Degradation: Increasing urbanization, tourism, and agricultural runoff in Himalayan states contribute to the degradation of aquatic habitats. Untreated sewage and pesticides enter rivers, reducing water quality and oxygen levels. High-altitude lakes and streams are particularly at risk due to their low resilience to nutrient enrichment and chemical contamination (Sharma *et al*., 2016).

Overfishing and Invasive Species: Unsustainable fishing practices, including the use of explosives and poisons, pose a serious threat to native fish populations. Additionally, the introduction of exotic species such as Common Carp (Cyprinus carpio) has led to competition and displacement of native cold-water fish (Nautiyal, 2014).

Overview and Conservation Outlook: The environmental challenges facing Himalayan fisheries are interconnected and complex, often exacerbated by a lack of scientific monitoring and inadequate regulatory frameworks. Addressing these threats requires an integrated approach that includes; Ecosystem-based management, Strategic environmental assessments for hydro projects, Promotion of community-led conservation and sustainable fishing practices, Strengthening of transboundary cooperation for river and biodiversity management.

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