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History of Geological Studies in the Nepal Himalaya and Their Implications for Sustainable Geotourism Development

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Abstract

Nepal has a long history of geological investigations due to the diversity of geological settings, and the paper has synthesized the historical evolution of geological research in Nepal to trace the journey from occasional observations in the 19th century to present-day interdisciplinary studies for promoting the importance of formulating the scope of geotourism. The history of geological studies began with pioneering naturalists like Hooker in 1854 and Medlicott in 1875, succeeded by the systematic surveys by Toni Hagen in the 1950s, Stöcklin, and Bhattarai, who mapped the detailed geology of the central Mahabharat Range in 1977, and subsequent growth of studies from international groups and Nepalese researchers. Growing interest in geological studies in the Nepal Himalaya is because of unique geological characteristics within the Himalayan mountain system, making geology a fundamental academic discipline for understanding natural resources, geohazards, hydropower development, etc. The establishment of the geology department in 1968 at Tri-Chandra College, Tribhuvan University, and the master's program in 1976 have fulfilled the needs of geological education over the past several decades and have played a vital role in graduating skilled geologists. The history of geological explorations has provided a significant effort in academic activities and prospects of geological studies in Nepal. An exceptional preservation of geological records in the Nepal Himalaya makes it a natural laboratory for investigating mountain-building processes and disaster risk management that highlights the importance and scope of Himalayan geodynamics for sustainable geotourism development.

Keywords: geological history, geoscience development, geohazards, geotourism, Nepal Himalaya

History of Geological Studies in the Nepal Himalaya and Their Implications for Sustainable Geotourism Development

Among the world's youngest and highest mountain ranges, the Nepal Himalaya represents a central segment formed by the collision of the Indian and Eurasian plates that initiated approximately 50–60 million years ago (Yin & Harrison, 2000), which resulted in crustal shortening, uplift, and the formation of a complex fold-and-thrust belt extending across the Himalayan Arc (Gansser, 1964). The Nepal Himalaya offers the best natural cross-sections, which expose a thorough sequence of geological zones delineating the records of different stages of the mountain evolution process (Dhital, 2015). These different geological zones extend east–west throughout Nepal, which are separated by major north-dipping thrust faults, thereby shortening crustal thickness within the mountain belt (Upreti, 1999). Such incomparable geological diversity within a short span has attracted geoscientists for over many years, establishing Nepal as a central point of attraction for understanding collisional orogenesis. The different lithological units of Nepal Himalaya are important not only for tectonic studies but also for geotourism, which focuses on the promotion of geological heritage, landscapes, and earth science education (Newsome & Dowling, 2010).

The history of geological investigation in Nepal reflects the different phases of evolution, ranging from descriptive natural history through systematic mapping to quantitative analysis of each event. Each phase has contributed exclusively to the understanding of Himalayan tectonics and landform development. The dissemination of geological information beyond academic circles has remained limited, yet.

In the present context, geotourism is a new approach to explore the Earth's geological features along with their history of evolution in the present state. It links science and the public, making people understand and love the Earth's processes. The Himalaya is the youngest mountain in the world, which contains unique mountains comprising different types of rocks. The dynamism of the mountain is represented by moving tectonic plates that create varying scales of earthquakes in the region of the Himalaya. The inhabitants of the region have a strong connection to their local landforms, making it an incredible place to develop geotourism. This can bring new opportunities to the area for helping the local economy and preserving the natural scenery of the Himalaya. By combining science, culture, and tourism, it can create a real difference in people's lives and the environment. It helps to raise awareness and make people understand processes in the Earth system and its geological wonders, while also supporting the livelihood of communities.

Nepal Himalaya, in the central part of the entire Himalayan range, is still a tectonically active zone. The tectonic processes within the Himalaya resulting from the collision of the Indian Plate and the Eurasian Plate have created geological complexities. These intricacies have made Nepal a crucial geological hub for the study of tectonics, stratigraphy, geomorphology, and natural hazards. Understanding geology is essential for sustainable development in the Himalayan region, particularly for hydropower projects, mineral exploration, groundwater resources, and disaster risk management. Thus, geology nowadays has become an excellent field for academic and scientific research in this region. Tribhuvan University, Nepal's oldest university, has played a leading role in the development of geological education through departments and constituent campuses.

The historical trajectory of geological studies in the Nepal Himalaya has highlighted the synthesis of key geo-scientific contributions and their significance to evaluate the emerging field of geotourism by focusing on the approaches linking geological sites and tourism. Thus, this paper has evaluated the historical development of geological studies to reveal the importance of geological features that have shaped diverse Himalayan landscapes due to active tectonics and resulting geohazards, making Nepal an important tourism destination for geological explorations.

Historical Development

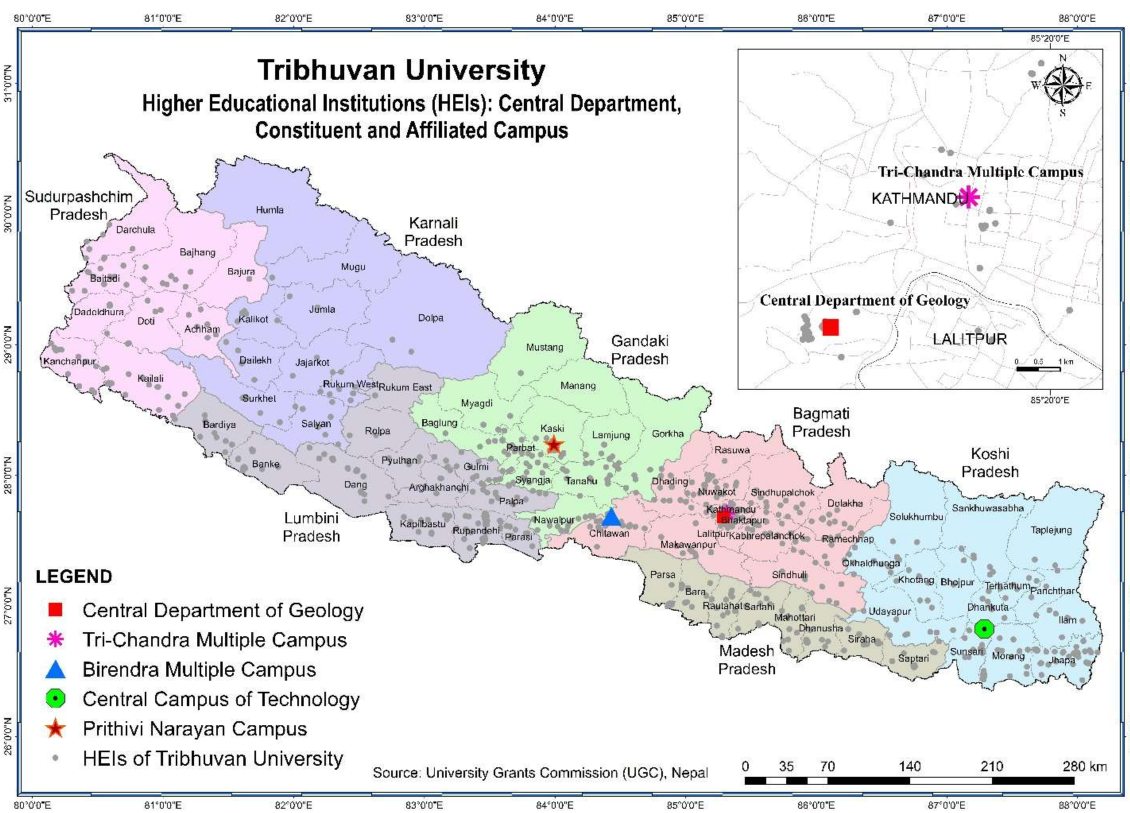
Nepal Himalaya preserves a historical record of geological evolution as a natural laboratory for understanding mountain-building processes. It is intended to review the historical development of geological studies in Nepal, from sporadic observations in the 19th century to modern multi-disciplinary investigations and describe their implications for the emerging field of geotourism. Pioneering naturalists like Hooker (1854) and Medlicott (1875) began the geological study in Nepal, followed by Toni Hagen in the 1950s, who carried out the first systematic surveys. Subsequent contributions in this field were made by different international research groups (e.g., Gansser, 1964; Bordet, 1961; Hagen, 1969; Le Fort, 1975; Searle et al., 1987). The concept of plate tectonics, which evolved in the late 1960s, shifted the tectonic understanding towards collision dynamics in the origin of the Himalaya. Based on scientific research advances, this region, containing five major tectonic units spanning from the Terai foreland to the Tethys Himalaya, has fostered growing interest in geotourism due to varying landforms and their origin. Several studies carried out in the Pokhara valley and Annapurna region at different times have documented potential geologically interesting sites, and these areas have been observed to have the geological features integrated with cultural heritage to create unique tourism experiences. The combination of historical background and local concepts provides valuable insights into the geotourism potential and sustainable development.

History of Geology Education

The historical development of geological education began with the establishment of the Department of Geology in 1968 at Tri-Chandra College to conduct classes of B.Sc. in Geology under Tribhuvan University. M.Sc. in Geology was started in 1976 and shifted to the Central Department of Geology (CDG), which was established in 1986 at Kirtipur Campus of Tribhuvan University. Recently, the bachelor's program of geology has also been running in other constituent campuses of Tribhuvan University, Nepal as shown in Figure 1.

Figure 1

Higher Educational Institutions (HEIs) of Tribhuvan University showing geology department



Courses offered in geology are designed to enhance employability through the acquired knowledge and pragmatic skills. The syllabuses are not only theoretical and laboratory-based teaching, but it also conducts intensive fieldwork mapping techniques to enhance the students' capacity to work in various engineering fields, such as hydropower, bridges, dams, mining, and mineral resource exploration, etc. Graduates are working in government organizations such as the Department of Mines and Geology, Department of Irrigation, Nepal Electricity Authority, Electricity Development Board, and other research institutions or private sectors, especially in the hydropower sector.

Geological Studies and Historical Development

The existing Mountain belt in the Himalayan region was formed by the collision of the Indian and the Eurasian Plate, approximately 50–60 million years ago (Yin & Harrison, 2000), which is continuing now. This collision process has resulted in crustal shortening, mountain upliftment, and a complex folded and thrusted rock sequence across the Himalayan Arc (Gansser, 1964), which made this region unique in the world's geological history. The major geo-tectonic divisions within the Nepal Himalaya comprise the Sub-Himalaya (Siwalik), Lesser Himalaya, Higher Himalaya, and Tibetan-Tethys Himalaya. These geological divisions are demarcated by major north-dipping thrust structures such as the Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), and Main Central Thrust (MCT) (Upreti, 1999; Dhital, 2015). These geological features separate distinct landscapes of active tectonic landforms, fossil localities (plant/animal), and various natural disasters, making Nepal an important destination for geological tourism and education. The historical development of geological studies in Nepal is described as:

Period 1850–1950 is the initial phase of pioneering observations, with the earliest geological observations in Nepal being made during the broader natural history explorations. A renowned British botanist and naturalist, Joseph Dalton Hooker, conducted the first recorded geological observations during his expeditions to eastern Nepal during 1848–1850. In the "Himalayan Journals," dedicated to Charles Darwin, Hooker (1984) describes the different rock types along the Tamur valley.

In 1875, Henry Benedict Medlicott, a pioneer geologist from the Geological Survey of India, traversed the old foot trail from the Nepal-Indian border through Hetauda, Chisapani, Kulekhani, and Thankot to reach Kathmandu. During his traverse, he identified the rare fossil-bearing sites at the Chandragiri Pass within the Lesser Himalaya.

More detailed geological studies began in Nepal after 1930. J. B. Auden from the Geological Survey of India carried out several field traverses across eastern and central Nepal after the devastating 1934 Bihar–Nepal Earthquake. He revisited the fossil site at Chandragiri Pass as previously noted by Medlicott and assigned the age of the fossils to be Early Paleozoic, which was later refined to the Cambro–Ordovician Period. Auden identified that the fossil-bearing strata form the core of a synformal structure known as the

Mahabharat Syncline and traced across the metasedimentary rocks, which were found to be a normal stratigraphic sequence (Auden, 1935).

Later, Arnold Heim and August Gansser (1939) brought together various geological findings from the Kumaon Himalaya and nearby parts of Nepal, including the Kali Gandaki and Tinkar valleys. Their work led to the identification of major Himalayan thrust systems such as the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT), which remain fundamental to present-day understanding of Himalayan tectonics.

From 1950 to 1970, Tony Hagen, a Swiss geologist introduced the concept of nappe based on his geological studies in the Kathmandu region, where Auden had already recognized the Mahabharat syncline. In geological terms, the nappe refers to a large-scale sheet of rocks displaced from their original state by tectonic forces. He distinguished between two major geological formations: the "Kathmandu Series" and the "Nawakot Series". The Kathmandu Series consists of high-grade metamorphic and crystalline rocks found in the syncline's core, which Hagen interpreted as erosional remnants of crystalline nappes that were thrust southward from the Central Crystalline region. The Nawakot Series, on the other hand, includes weakly metamorphosed sediments that form the Midland belts surrounding the valley. Hagen suggested that these sediments were overlain by the more deformed Kathmandu Series rocks, forming a layered, tectonically complex structure in the region (Hagen, 1969).

Alongside Tony Hagen's work, several international mountaineering expeditions provided opportunities for geological research. Geologist Jacques Lombard from France joined Everest expeditions to study the region's geology. Pierre Bordet (France) conducted the geological study in the Makalu area and published his findings in 1961. French teams also conducted geological studies in the Annapurna, Manaslu, and Ganesh Himal regions in the western part to understand the details about the Tethyan Zone, an area rich in fossils from the Palaeozoic and Mesozoic eras. These studies provided the fundamental geological frameworks for understanding the region's rock sequences and their geological history of evolution.

During 1970–2000 phase, the plate tectonics revolution and international collaborations started with the advent of plate tectonics in the late 1960s, which reshaped geological research by realizing the fact that the Himalaya is formed as a “collided range”, focusing on stress and effects of subduction. The Main Central Thrust (MCT) gained significant attention in research and was understood within the framework of continental collision and subsequent post-collisional activities according to Le Fort (1975, 1986).

French teams conducted systematic geological mapping in central Nepal and identified inverted metamorphism due to MCT (Le Fort et al., 1982; Bordet, 1961). At the same time, mapping projects by the Geological Survey of India expanded into Nepal, and researchers from Austria and Germany, like Fuchs and Frank, carried out detailed studies in western Nepal (Fuchs, 1967; Frank & Fuchs, 1970).

The first systematic geological mapping of the Kathmandu region and central Mahabharat Range was carried out by Stöcklin & Bhattarai (1977), who demarcated the Lesser Himalayan metasedimentary rock sequence from the overlying Kathmandu Nappe and identified the Main Central Thrust (also called Mahabharat Thrust) as the tectonic boundary. Their work exhibited that the Kathmandu Complex represents an allochthonous crystalline nappe over the underlying autochthonous lower-grade rocks of Nawakot Complex, with distinct metamorphic grades and a structural boundary. The mapping program also documented Quaternary Lake sediments in the Kathmandu Valley, interpreting them as a tectonically formed intermontane basin. A series of tectonic zones running from east to west (Sub-Himalaya, Lesser Himalaya, Higher Himalaya, and Tibetan-Tethys Himalaya) were formed during the formation of the Himalayas because of the collision between India and Eurasia, which was detailed by Stöcklin in 1980 and these zones are demarcated by south-verging main frontal thrust (MFT), main boundary thrust (MBT), and main central thrust (MCT).

Modern research in geology has started since 2000 and has now expanded its arena into various fields, encompassing both fundamental (classical) research and applied research. It is a phase of significant shift towards understanding and managing the region's natural hazards, resources, and seismic activity. Geological research in the Nepal Himalaya is performed by universities, government authorities, and international collaborators (I/NGOs). Recent research focuses on the use of field-surveyed/monitored data incorporating numerical modeling for evaluating cut slopes to large-scale landslides (Thapa et al., 2023; Phuyal et al., 2025; Shrestha et al., 2025) and addressing the challenges of the tunneling process for optimization of tunnel support systems (Thapaliya et al., 2025; Shrestha et al., 2026), etc.

Importance of Geological Studies

Geological studies have been growing considerably due to their importance in natural resource management, disaster risk reduction, promoting sustainable development, understanding climate change, etc. Past and ongoing present research in Nepal is the fundamental basis of geo-scientific knowledge for the national development of the country.

Scientific Importance

The Nepal Himalaya provides an exceptional opportunity for studying the processes of continent-continent collision and the mountain-building process. Significant scientific contributions consist of collision and active tectonics to understand earthquake history from strain accumulation in the Himalaya. Stratigraphic record in Nepal from the onset of the collision between the Indian and Eurasian plates to the subsequent mountain-building process. Field observation and interpretation of geological features are key components of geo-scientific studies and are the most common techniques for investigation, as shown in Figure 2.

Figure 2

Fieldwork of Geological Studies (A) Observation, (B) Measurement of Rock Outcrops

Applied Significance

Mineral and Energy Resource

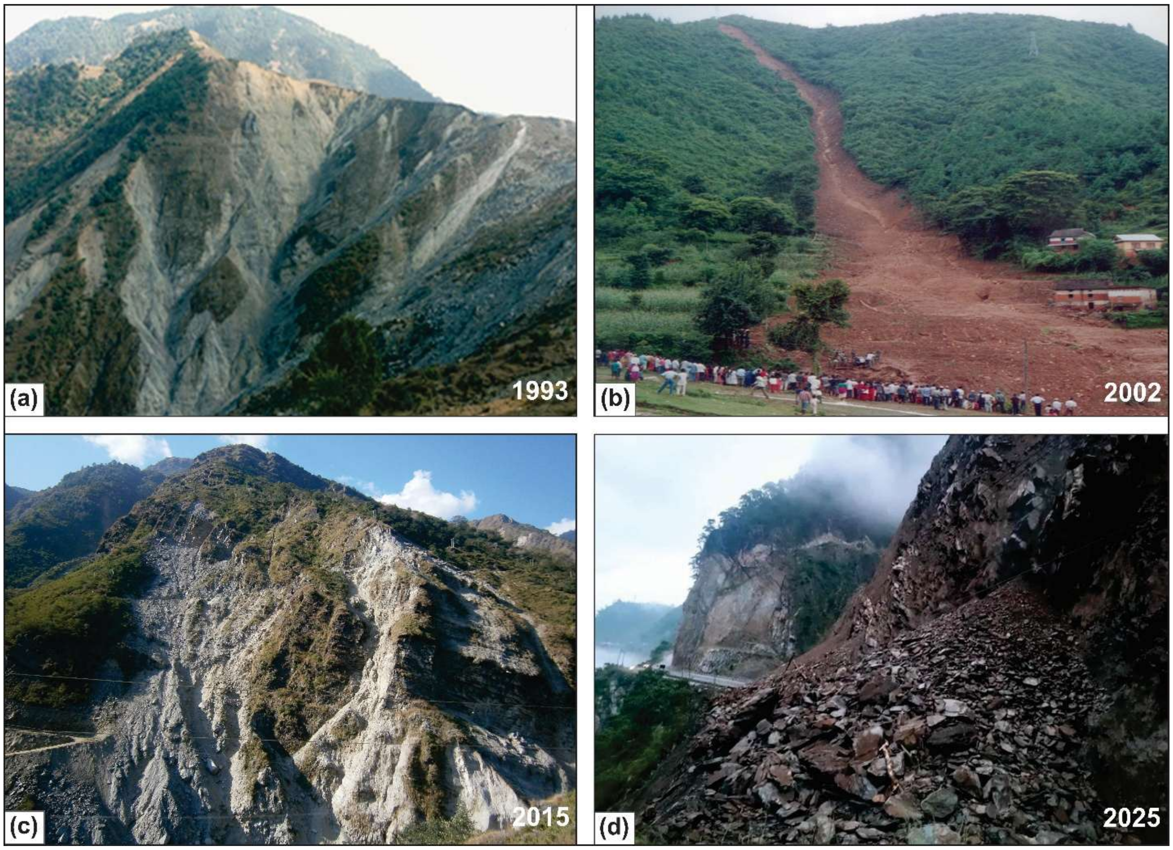
Mineral occurrences (iron, copper, lead-zinc, magnesite, talc), coal and lignite deposits, hydrocarbon potential in the Siwalik and foreland basin, and geothermal systems connected to tectonic structures are investigated to identify as natural resources. Gondwana coal, Dhaubadi/Phulchoki iron deposits, Kharidhunga magnesite, etc., are important historical resources.

Disaster Risk Reduction

It encompasses the identification and evaluation of hazards like landslides, debris flows, earthquakes, and floods, improving early warning and risk sensitive land use planning (Fig. 3). Geological research forms the basis for assessing earthquake risk (fault identification, studying past seismic events, analysing ground response), predicting areas prone to landslides, and evaluating the potential for glacial lake outburst floods (GLOFs).

Figure 3

Historical Evidence of Slope Instability in Nepal (A) Extreme Event-Induced Slides, (B) Landslide/ Debris Flow (C) Earthquake-Triggered Landside, (D) Cut-Slope Failure Along Highway



Infrastructure Development

Investigations of road and tunnel construction, urban growth, and hydropower projects (immense potential of Nepal) are mainly based on engineering geological research.

Water Resource

Hydrogeological studies provide an understanding of aquifer systems in the Terai and intermontane valleys, spring distributions in the mid-hills, and water resources associated with the glacial environment in the Higher Himalayan terrains.

Environmental Protection and Climate Change

It is necessary to understand river dynamics for watershed and ecosystem management. Tracking glacier retreat and the landscape evolution process provides information for climate change strategies in the mountain regions of the Himalaya. Climate change is often the phenomenon of extreme weather events (e. g., July 1993) in Nepal, causing extensive mass movements and resulting in the loss of development gains.

Geotourism Implication

Geotourism emphasizes the fundamental role of geology in shaping landscapes and the vital elements forming significant geosites, geotrails (routes linking geosites), geoparks (strategic areas with geological heritage), and geoconservation (geological features for future generations).

Geodiversity/Geosite Potential

Peculiar geodiversity in Nepal that has resulted from the historic geological research has promoted it as a remarkable geotourism potential. Recent systematic studies have documented geosite distributions across various regions of the country. The Kathmandu valley is a unique geotourism destination where fluvial geomorphology, paleo-lacustrine evolution, active Himalayan tectonics, and cultural heritage converge within a confined geographic setting.

The Pokhara valley is another geodiversity in Nepal for national and international visitors and is located about 200 km west of Kathmandu, offering excellent geotourism opportunities, with a wide range of appealing geological features. The valley has many geosite spots with mapped public spaces and developed as geotourism sites, as well as some sites are being mapped to be managed properly. Pokhara is a geotourism paradise for everyone to enjoy and learn in a live museum. The valley's geodiversity is truly remarkable, with a wide range of geological features and attractions to explore.

Spiritual Beliefs and Geotourism

The relationship between carbonate rocks, karst landscapes formed in them, and human belief systems in Nepal represents a deep-rooted connection of geology and culture. These natural processes are interpreted through spiritual and religious frameworks in society. Limestone and dolomite rocks, as carbonate rocks, are highly susceptible to chemical weathering through the dissolution process and lead to the development of karst features like caves, sinkholes, underground drainage systems, springs, stalactites, and stalagmites in different scales as per their type locality. Although these features have a scientific explanation through hydrogeological and geochemical processes, they are perceived very differently through cultural and religious beliefs in Nepal. Particularly within Hindu and Buddhist traditions, they are deeply embedded in the cultural and spiritual consciousness of society, where these kinds of peculiar natural landscapes are often regarded as manifestations of divine forces as seen in Figure 4.

Figure 4

Linkage of Spiritual and Religious Frameworks: Features Characteristic of Carbonate Rocks

Large-scale caves developed in carbonate terrains are regarded as the most prominent examples of geo-spiritual sites. Many caves in Nepal are not only geological formations but also function as sacred spaces for worship, meditation, and pilgrimage. For example, Gupteshwor Mahadev Cave is considered a shrine dedicated to Lord Shiva, where various sizes of stalagmites formed by dissolution of carbonate rocks are considered as 'Shiva Linga,' which is the symbol of divine presence in Hinduism. Siddha Cave, the largest cave located in western Nepal, is associated with spiritual practices as a place of spiritual energy. Similar types and scenarios are found in Halesi, Khotang, and in other parts of the country, too. These spiritual and religious interpretations have transformed speleothems (formed through the precipitation of calcium carbonate as *stalactite* and *stalagmite*) into sacred objects, which have transformed geological processes into metaphysical meaning. The darkness, silence, and isolation of caves further reinforce their perception as gateways to the divine, which are often believed to be the holy places where many sages meditated and attained their enlightenment.

Karst water systems also embrace deep religious significance in Nepal. Spring water emerging from limestone aquifers are commonly regarded as sacred (holy water sources or tirthas) and are consumed with the thoughts of purifying and healing properties. This belief relates to the perception that water originating from the Earth's interior carries divine blessings. Taudaha Lake is a notable example for this which is closely associated with Nāga (serpent deity) mythology in both Hindu and Buddhist traditions.

Geoconservation

Geoconservation in Nepal is still in its early stages, despite a wealth of geoheritage. There is no specific legal framework that safeguards geological sites; however, certain locations receive indirect protection within national parks (Chitwan, Langtang, Mt. Everest) or conservation areas (Annapurna). Many geosites are at risk from quarrying, haphazard road construction, and extensive soil erosion. Recent studies show the in-situ geoconservation approaches, which involve targeted protection efforts at scientifically important sites. Visitor management to safeguard sensitive elements, and educational initiatives can encourage responsibilities.

Geopark Potential

Numerous regions in Nepal demonstrate potential for geopark development with reference to UNESCO Global Geopark criteria, encompassing geological heritage of worldwide importance and sustainable development approaches. The *"Pokhara-Lumbini-Gandaki region"* is an attractive destination that integrates diverse geosites (e.g. lakes, caves, hot springs, fossil hunting), cultural heritage, such as Lumbini (birthplace of the Buddha), Muktinath (pilgrimage site), etc., current tourism infrastructure, and research history that provides a scientific foundation.

Geological Heritage and Sustainable Development

The socio-economic aspects of geotourism support sustainable development in many ways. Direct economic advantages include jobs for guides, hospitality services, and sales of local products. Some sites in Pokhara are systematically managed to generate income through entrance fees, indicating economic sustainability. Community-driven tourism models in Ghandruk are a typical example, and other villages can also benefit similarly.

Conclusion

The geological studies in Nepal have evolved over many years from pioneering naturalist observations to multi-disciplinary research that is addressing the Himalayan geodynamics and various kinds of disaster management perspectives. Geological records in the Nepal Himalaya have pointed out the importance of geo-scientific investigation.

Historic observations and studies indicated that the Himalaya is the seismotectonic active range in understanding continent-continent collision and resulting landform evolution. Realizing the potential value of unique geological features has provided a basis for geo-scientific exploration. The geodiversity of Nepal comprises major tectonic geological zones that are coupled with deep cultural connections to the landscape, creating geotourism potential. The identification of geosites ranges from hot springs and caves to fossil localities and geological exposure sites. Such opportunities can encompass increasing attractions for educational travel and tourism infrastructure. Linkage of spiritual and religious frameworks in Nepalese society is an important aspect of geotourism, which is the attraction of geological features of limestone and dolomite rocks. Moreover, ongoing infrastructure development in Nepal needs to manage natural hazards and implications of geological observations due to growing interest among the decision makers, researchers, and/or visitors. Thus, this research has offered insights of framework for sustainable geotourism development in the Nepal Himalaya.

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