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Maan Bahadur Rokaya
Shalik Ram Sigdel *Editors*

Flora and Vegetation of Nepal

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Plant and Vegetation is a Springer book series that shares current knowledge and new perspectives on global vegetation. It examines vegetation patterns and changes at all spatial and time scales – from individual plants to plant communities, and from landscapes to biomes. This series provides a source of diverse and validated information covering key issues including land cover, climate interactions, ecosystem functions, invasive species, and dynamic responses to anthropogenic influences, amongst others. It is a valuable resource for graduate students and researchers with an interest in vegetation science, geography, biodiversity, applied ecology and related disciplines. This contemporary knowledge also aims to inform managers and decision-makers involved in landscape planning, biodiversity conservation and restoration projects around the world.

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Preface

Nepal, located in the center of the great Himalayan ranges, stretches for around 800 km from the Mahakali River in the west to the Mechi River in the east. In Nepal, botanical research first began in 1802–1803. The first person to collect plants in Nepal was Francis Buchanan, later known as Francis Hamilton but often referred to as Francis Buchanan-Hamilton, a Scottish physician who was a former Superintendent of the East India Company Botanic Garden in Calcutta, India. Since then, for more than two centuries, studies on flora have been performed. After the Rana government was toppled in 1951, several people were allowed to visit the country. They traveled to various locations to carry out vegetation surveys. These investigations have improved the detailed botanical knowledge of various plants and vegetation types in Nepal. Although a long-term objective of publishing a complete Flora of Nepal (covering both higher and lower groups of plants) in 15 volumes was decided in July 1997, but the project has not yet been completed as planned. There is already a sizable database on different plant species (covering both higher and lower groups of plants), vegetation, medicinal plant species, etc. The number of basic and applied research on plant diversity is ever increasing rapidly.

Existing information about Nepal's flora and vegetation is very dispersed and challenging to find in a single source. The literature on the flora of Nepal is either out-of-date or primarily focuses on lists of species (Dobremez 1972, 1976; Polunin and Stainton 1984; Stainton 1988). There are exceptions, though, for Pteridophytes (Fraser-Jenkins et al. 2015; Fraser-Jenkins and Kandel 2019; Kandel and Fraser-Jenkins 2020), Algae (Rai and Dhakal 2020), Bryophyta (Pradhan and Shrestha 2021, 2022), Lichens (Baniya et al. 2022), Gymnosperms (Rajbhandari et al. 2018; Pandey et al. 2020), and angiosperms (Hara et al. 1978, 1982; Hara and Williams 1979; Press et al. 2000; Singh 2001; Shrestha et al. 2022). In addition to this, there are many scientific articles in journals that are focused on ecological studies, economic significance, invasive species, climate change, etc. Here, we gathered all the available information about flora and vegetation of Nepal for a wider readership.

The current book primarily focuses on the flora and vegetation of Nepal, and it has 15 chapters that cover different aspects of the flora of the country, botanical explorations and phytogeography, vegetation, the fossil flora of the Siwalik sediments, a review of algal explorations, fungi, bryophyta diversity, lichens, ferns and fern-allies, gymnosperms, flowering plants, economically important plants, current knowledge on invasive species, impacts of climate change on plants, and status, policies, and laws related to plant diversity in Nepal.

Introduction to Nepal (*Chapter* 1) provides the fundamental knowledge required to comprehend the country's physical features, climate, hydrology and river system, soil, biodiversity, and land use patterns. The information in this chapter has been significantly expanded and updated. Due to its varied topography and climate fluctuations, Nepal is rich in plant diversity and has drawn researchers from all over the world. These collections were the basis for numerous flora publications and were the subject of numerous floristic studies. In addition to Good (1974) and Takhtajan (1986), Miehe et al. (2015), Nepal's flora has relationships with other regions as being at the crossroads of many floristic regions. Thus, *Chapter* 2 provides information on the flora and phytogeography of Nepal. The classification of Nepal's forests and vegetation according to altitudinal ranges (tropical to nival zones), as well as an attempt to explain the many categorizations approaches currently in use, is provided in *Chapter* 3.

An updated account of the paleofloristic and paleoclimatic changes that occurred from the middle Miocene to the early Pleistocene period in the Siwalik deposits in Nepal has been provided in *Chapter* 4, in order to provide an understanding of fossil plants. The Siwalik Group's overall fossil assemblages indicate that there may have been tropical and subtropical evergreen rain forests with warm, humid conditions and heavy rainfall. The fossil plant remains also suggest that changes in regional aridification and temperature seasonality were responsible for the vegetation shifts.

Although scientists and naturalists have been documenting the diversity of algae in freshwater bodies since the early 1900s, systematic research into this topic only really took off after 1950s. Recently, there has been a huge increase in interest in algal exploration in Nepal. The main areas of research in Nepal have been taxonomical studies to categorize different species of algae and understand their distribution, as well as ecological surveys to understand their ecological roles. *Chapter* 5 summarizes and illustrates the exploration of trends and patterns in algal research in Nepal.

There are various fungi species, and fungal research in Nepal covers their diversity, unique features, use as food, medicine, and other benefits for humans. Despite their abundance, only a small number of Nepal's fungi are legally protected, and permission is needed to collect them. *Chapter* 6 provides a short summary of the current situation of fungi in Nepal. Future research on ecological studies, nutritional value, efficacy, toxicity, and the analysis of secondary metabolites should be focused on to further our understanding of the diversity of fungi in Nepal.

There are around 1217 different bryophyte species in Nepal, of which 10 are endemic to the country and five are on the International Union for Conservation of Nature's (IUCN) Red List. *Chapter* 7 provides information on the exploratory work, studies related to bryophyte ecology, diversity and distribution, habit and habitat, and identification features. In addition, the economic significance, research gaps, and future perspectives are provided.

A quick summary of the current situation with regard to lichen diversity in Nepal is given in *Chapter* 8. This chapter provides information about lichen investigations, literature related to different kinds of studies, diversity and distribution, lichen conservation, and the economic significance of lichens. The difficulties of studying lichen are also discussed, with a focus on how future research should prioritize demography studies, nutritional value studies, efficacy studies, toxicity studies, and secondary metabolite investigations.

Chapter 9 provides information on ferns and fern-allies (pteridophytes) found in Nepal. The species are spread out between 60 and 5000 meters, according to the information. Additionally, it provides details on uses such as food, medicine, ornamental plants, biofertilizers, and phytoremediation of soil or water. It additionally includes an overview of distribution, research, pertinent literature, identification characteristics, economic significance, and conservation status.

Chapter 10 details the diversity, distribution, economic importance, and prospects of gymnosperms in Nepal. There have been mentions in this chapter of a total of 29 taxa of wild and 18 taxa of cultivated gymnosperms in Nepal. The chapter describes the phytogeographic zones, demonstrating their pattern of distribution, economic importance, and state of conservation. It also emphasized the necessity for continued research in fields including biogeography, dendrochronology, functional characteristics, and the effects of climate change on distribution, as well as the most current advancements in gymnosperm research.

The current knowledge of angiosperms in Nepal is summarized in *Chapter* 11. It discusses a wide range of subjects, such as the different angiosperm species, their geographic distribution, and their exploration in Nepal. Reports on species richness and endemism are available for the angiosperm families at the district level. This chapter provides an overview of recent angiosperm studies and a brief overview of Nepal's relict flora.

As previously mentioned, Nepal has a wide variety of plants, making it home to many useful plants that are used to meet daily needs. *Chapter* 12 provides an introduction to economically significant plants, which can be divided into several groups based on their usage, along with information on their conservation status, economic prospects, and threats. This chapter strongly recommends further research on commercially important plants since it will be crucial to the management plans needed for conservation.

The chapter on plant invasion in Nepal (*Chapter* 13), which has been significantly updated and expanded, is based on a paper with the title Plant Invasions in Nepal: Knowledge Gaps and Research Needs that was published in a proceeding of the International Conference on Biodiversity and Bioprospecting (June 22–24, 2023) (pp. 1–14). The knowledge is, however, updated and expanded as this chapter first provides insight into diversity and distribution, then ecological and socioeconomic implications, policy responses, and management techniques and issues in Nepal. The chapter also covers ten other subjects, ranging from introduction pathways to various sorts of invasive species, including flowering and non-flowering species as well as microorganisms. Overall, invasive plant threats and issues are significant in Nepal, but existing management and policy approaches are insufficient, impeding the country's efforts to safeguard biodiversity and achieve sustainable development goals.

As Himalayan region is one of the fastest warming places in the world, the plants that grow there are crucial archives for identifying and tracking the effects of climate change on the structure and functions of vegetation. To increase the predictability of plants' responses to climate change, aspects that need to be researched have been briefly mentioned in *Chapter* 14. Numerous studies on regeneration, growth patterns, the distribution range of woody plants, and the modification in functional traits have demonstrated the effects of climate change. As certain species benefit from a warmer climate while others experience negative feedback due to warming-induced moisture stress, it has also been made clear that plant responses to climate change vary depending on the site and species.

Last but not least, *Chapter* 15 mentioned that Nepal is at the forefront of developing and putting into effect legal frameworks for the preservation of plant biodiversity. Multilateral environmental agreements, regional geopolitical environments, transboundary cooperation, and national social-ecological and political situations all influence these frameworks. Nepal's legal frameworks include the constitution, acts, policies, strategies, plans, and related policy documents. For conservation, sustainable use, access to genetic resources, and equitable benefit sharing, collaboration between all governmental levels and other stakeholders is crucial. In addition, legal frameworks should guide and promote the implementation of international agreements and national policies, acts, strategies, and action plans at subnational levels.

We believe that anybody interested in Nepal's flora and vegetation, both domestically and internationally, will find this book to be a beneficial resource for required information. We hope that it will be a valuable resource for botanists, mycologists, bryologists, ecologists, lichenologists, palaeobotanists, phycologists, vegetation scientists, invasion ecologists, conservationists, governmental and non-governmental organizations, as well as people with an interest in Nepal and those conducting research there.

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Chapter 1
Nepal: An Introduction

Sher Bahadur Gurung, Shalik Ram Sigdel, and Maan Bahadur Rokaya

Abstract Nepal's location in the Himalayan range is characterized by diverse biophysical features. Its diverse biogeographical and physiographical settings make it an exceptional location for scientific studies. It has diverse climatic zones, from tropical to nival ecosystems, and glaciers. These diverse conditions have a significant impact on the country's climate and biodiversity. This chapter describes Nepal's physical features, climate, hydrology, biodiversity, soil, and land use patterns. This information is presented to aid in understanding the status of the country's flora and vegetation in response to changing environmental conditions.

1.1 Introduction

Nepal is located in the center of the great Himalayan mountain ranges, which were created when two large landmasses known as the Indian subcontinent and the Eurasian plate collided approximately between 40 and 55 million years ago (Molnar and Tapponnier 1977). Tectonic movement, gravity, and erosive forces have shaped physical features, soil, climate, and hydrology in Nepal, as elsewhere on the Earth's surface (Le

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Pichon et al. 1992). Nepal harbors eight mountains that exceed 8000 m above sea level (m asl) and more than 100 mountains that exceed 7000 m asl (CDG 2002), including the highest peak in the world, Mount Everest, which is 8848.86 m asl (Xie et al. 2021).

There are five major tectonic zones in Nepal, and each one is distinct from the others in terms of rock types, ages, metamorphism, structures, and geological histories. The five tectonic zones are the Tarai, the Siwaliks, the Lesser Himalayas, the Greater Himalayas, and the Tibetan-Tethys Himalayas (Upreti 1999).

1.2 Physical Features

Nepal has an area of 147,516 km^2 and is located between 26°12′ to 30°27′N and 80°4′ to 88°12′E. It is narrow and rectangular in shape. It is surrounded by India to the east, south, and west, and China to the north (Fig. 1.1). It is approximately 885 km long from Mechi to Mahakali (east to west), and its width ranges from 145 to 241 km, with a mean of 193 km from north to south.

Nepal Standard Time is based on the longitude 86°15′E, passing through Mt. Gaurishankar (7134 m asl), and Nepal Standard Times is 5 h 45 min ahead of Greenwich Mean Time (GMT). It was introduced in Nepal from Baishakh 1, 2042, B.S. (April 13, 1985 A.D.).

Nepal's physiography is characterized by a variety of landscapes (Fig. 1.2a–i) and can be subdivided based on rivers, climate, altitude, and geographical distribution. Nepal

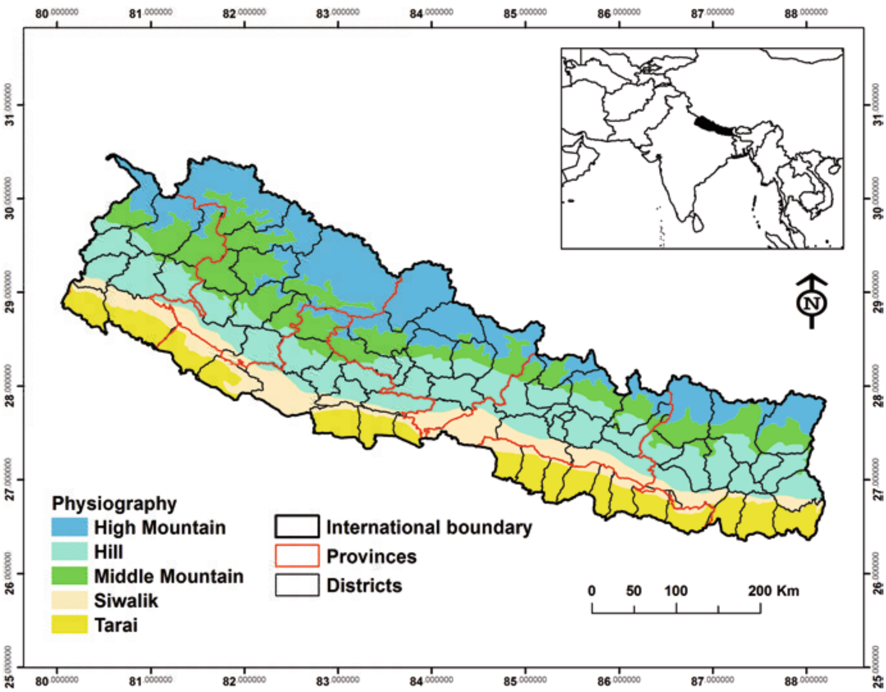

Fig. 1.1 Nepal in southeast Asia and physiographic regions of Nepal. *Map prepared by* Bishnu P. Bhattarai

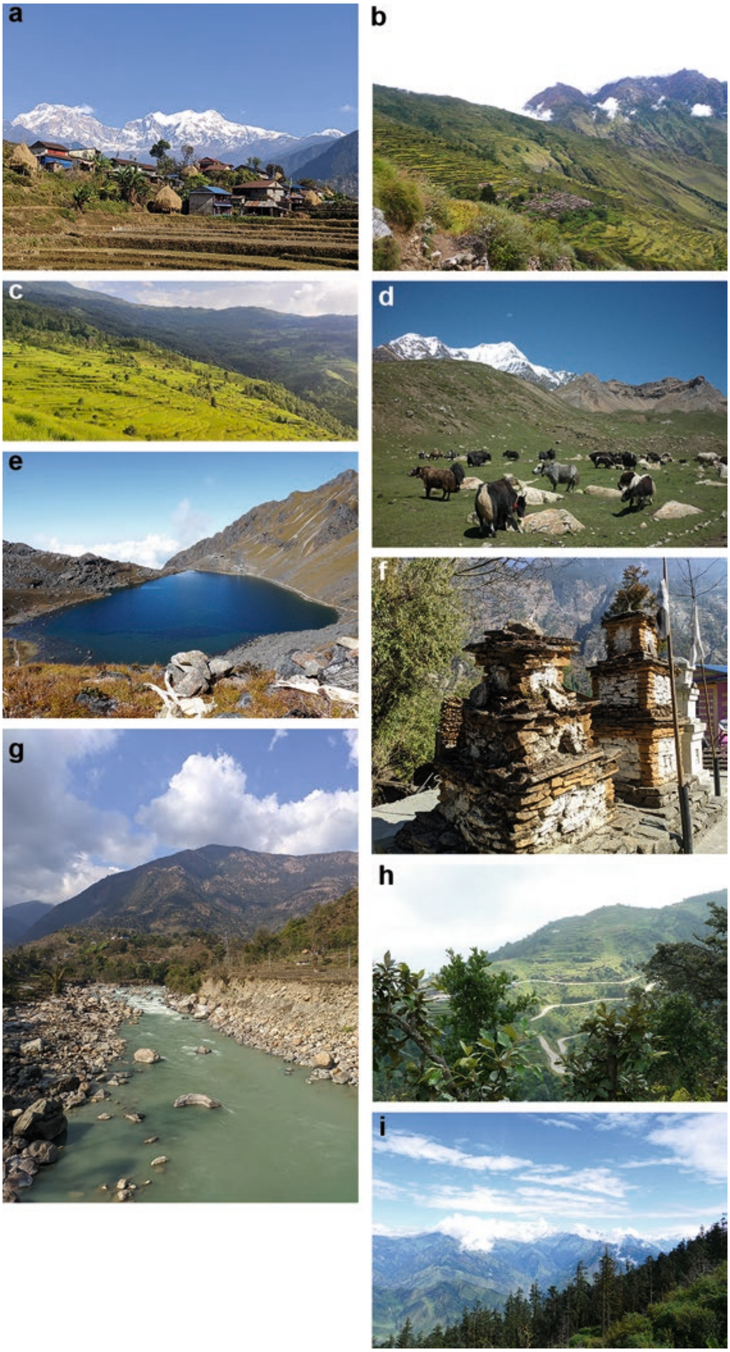

Fig. 1.2 Different landscape types in Nepal. (**a**) A Beautiful village in hilly region. *Photo by* Bashu Dev Neupane. (**b**) A mountain village. *Photo by* Maan B. Rokaya. (**c**) Cultivated land in hilly region. *Photo by* Maan B. Rokaya. (**d**) High altitude pastureland. *Photo by* Maan B. Rokaya. (**e**) Holy lake, Gosaikunda. *Photo by* Maan B. Rokaya. (**f**) *Mane*, religiously important monument at the side of the road. *Photo by* Bashu Dev Neupane. (**g**) River, important source of water. *Photo by* Bashu Dev Neupane. (**h**) Road in hilly region, Makwanpur. *Photo by* Maan B. Rokaya. (**i**) Silver fir forest. *Photo by* Maan B. Rokaya

is divided politically into seven provinces, 14 zones, and 77 districts (SD 2021). Based on altitude, there are five major physiographic regions (Tarai, Siwalik, middle mountains, high mountain, and high Himal) (Fig. 1.1). The Tarai and Siwalik cover 27% of the land, the middle mountains cover 30% of the land, the high mountains cover 20% of the land, and the high Himal cover 23% of the land (Dobremez 1976; LRMP 1986). Nevertheless, Upreti (1999) has divided Nepal into additional physiographic units based on formation age (see Table 1.1). Likewise, Nepal is divided into three regions based on watershed catchment (Koshi, Gandaki, and Karnali), six regions based on bioclimate (tropical, subtropical, temperate, subalpine, alpine, and nival), and three regions based on geographical features (Tarai, hills, and high mountain).

Table 1.1 Physiographic units of Nepal based on formation age (Upreti 1999)

Physiographic unit	Width (km)	Altitudinal range (m)	Age	Main rock types
Tarai (Bhabar, middle and southern zones)	10–15	100–200	Recent	Alluvium, coarse gravel in the north at the foot of the mountains, gradually becoming finer southward, foreland basin deposits
Churia (Siwalik) range	10–50	200–1300	Mid-Miocene to Pleistocene	Molasse deposits of the Himalaya. Sandstone, mudstone, shale, and conglomerate
Dun valleys	5–30	200–300	Recent	Valleys withing the Siwalik hills filled up by coarse to fine alluvial sediments.
Mahabharat range	10–35	1000–3000	Precambrian and Palaeozoic also Cenozoic	Schist, phyllite, gneiss, quartzite, granite, limestone belonging geologically to the lesser Himalayan zone
Midlands	40–60	200–2000	Precambrian, Palaeozoic to Mesozoic	Schist, phyllite, gneiss, quartzite, granite, limestone belonging geologically to the lesser Himalayan zone
Fore Himalaya	20–150	2000–5000	Precambrian	Gneisses, schists, phyllites, marbles mostly belonging to the northern edge of the lesser Himalayan zone.
High Himalaya	10–60	>5000	Precambrian	Gneisses, schists, migmatites, and marbles belonging to higher Himalayan zone
Inner and trans-Himalayan valley	Narrow	2500–4300	Precambrian and Cambrian to cretaceous	Gneisses, schists, migmatites, and marbles belonging to higher Himalayan zone and Tethyan sediments (limestones, shale, sandstone, etc.) belonging to the Tibet-Tethys zone

1.3 Climate

During the summer and winter, respectively, the westerlies and the Indian monsoon have the greatest impact on Nepal's climate (Putkonen 2004). Diverse environmental and climatic patterns have been noted throughout the country as a result of its diverse terrain (Karki et al. 2016). Even within a fairly its short vertical distance (about 200 km), it displays a broad climatic gradient, ranging from tropical to nival climates (Fig. 1.3). However, due to the rain shadow effect of massive mountain ranges, some inner valleys, and trans-Himalayan regions at higher elevations (Manang, Mustang, Dolpo) have semiarid climates (Sigdel et al. 2020). The mountains serve as a natural barrier to prevent the circulation of humid air. Similar to this, there are significant climatic differences even across very small distances. For instance, the microclimate on the leeward and windward sides differs significantly. In addition, slopes facing north are cooler and more humid than slopes facing south. The Nepal Himalayas have six bioclimatic zones, from tropical to nival, with elevation-dependent climates (Karki et al. 2016).

Below 1000 m asl, the tropical climate is predominant. Winters are frigid, but summers in this area are quite hot (Pradhan et al. 2013). The tropical environment is hot and humid, with summer temperatures that can reach 40 °C in some places and winter temperatures that can range from 1 °C to 23 °C. Higher precipitation is

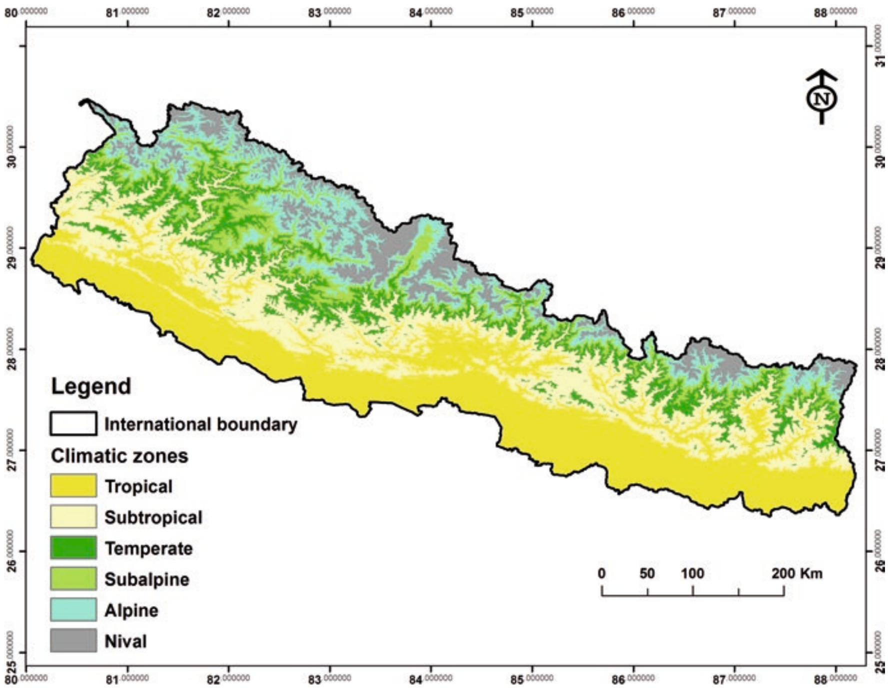

Fig. 1.3 Climatic zones of Nepal. *Map prepared by* Bishnu P. Bhattarai

seen in the eastern than in the western parts of Nepal because the summer monsoon is mostly driven by the Indian monsoon.

In the Siwaliks and inner valleys of the midhills, where the altitude is between 1000 and 2000 m asl, there is a subtropical climate with warm summers and chilly winters. The subtropical climate is hot and humid, with annual precipitation ranging from 1000 mm to 2000 mm and temperatures between 15 °C and 35 °C (Shrestha 2012).

Warm- and cool-temperate temperature zones can be found in between 2000 and 3000 m asl (Shrestha 2012). According to Paudel et al. (2021), this climate zone extends from the upper portion of the middle mountain physiographic region to the lower portion of the high mountain region. A warm-temperate climate has temperatures between 10 °C and 30 °C and between 1000 mm and more than 3000 mm of precipitation annually. The warm-temperate climate of the lower regions (2000–2500 m asl) contrasts with the cool-temperate climate of the upper regions (2500–3000 m asl).

The subalpine climate ranges from 3000 to 4000 m asl along the lower slopes of the Himalayan mountains. Although summertime high temperature is 25 °C, wintertime low temperature is around 0 °C, and snowfall is common in winter. With elevation, precipitation declines, especially over 3000 m asl (Duncan and Biggs 2012).

The lower Himalayan mountain slopes have an alpine climate that runs from 3000 m to 5000 m asl. The alpine environment has temperatures between 0 and 10 °C, with precipitation totals of less than 500 mm, primarily in the form of snow, but only 250 mm in areas that see rain shadows (Shrestha 2012).

The nival climate, often known as tundra or cold desert, develops at 5000 m asl. Most of the time, the temperature is below zero degrees Celsius. It is mostly covered by snow and ice (Lillesø et al. 2005; Shrestha 2012).

1.4 Climatic Patterns

The analysis of the average of Climatic Research Unit (CRU) grided time series climate data across Nepal showed significant interannual variability from 1901 to 2021 (Fig. 1.4). For instance, the annual precipitation ranges from 633 mm (2014) to 1336 mm (1936), the mean annual temperature ranges 13.25 °C (1917) to 15.57 °C (2010), the mean Palmer Drought Severity Index (PDSI) ranges from −2.95 (2009) to 2.2 (1917), and the mean evapotranspiration (ET) ranges from 2.83 (1997) to 3.02 (2009) (Fig. 1.3). These patterns indicate that Nepal is getting warmer and drier. Such changes in climatic patterns have already altered the ecological systems, and agricultural and hydrological cycles (Karki et al. 2020; Kraaijenbrink et al. 2021; Li et al. 2021; Yao et al. 2022).

The four seasons—winter, spring, summer, and autumn—vary significantly in characteristics in Nepal. It is warm and dry throughout the spring (March to May). Summer (from June to August) are the humid, hot, and rainy. Autumn

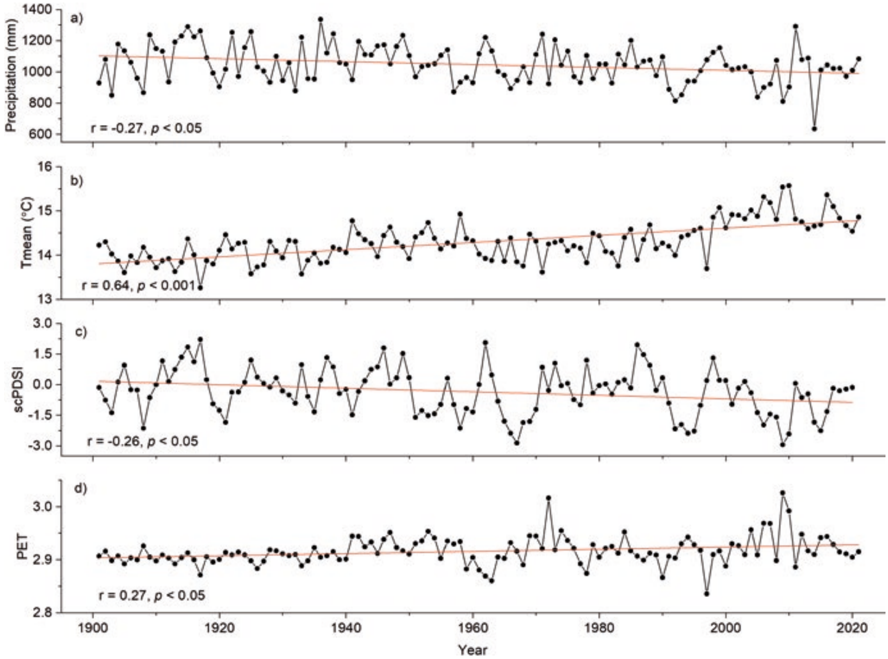

Fig. 1.4 Variation in annual climate patterns retrieved from the Climate Research Unit (CRU) TS4.06 database (1901–2021 CE) using 0.5° grids located between 80–88°E and 26–30°N. (**a**) changes in annual precipitation patterns; (**b**) changes in mean annual temperature patterns; (**c**) changes in the Palmer Drought Severity Index (PDSI); and (**d**) changes in Potential Evapotranspiration (PET). Statistics on patterns are presented in the respective figure panels

(from September to November) features beautiful skies and a mild climate. The coldest season, from December to February, sees snowfall in the upper Himalayas.

1.5 Hydrology and River System

Nepal is rich in water resources, which are abundant throughout the country in the form of snow covers, rivers, springs, ponds, lakes, and groundwater (Gyawali 1989; Aryal and Rajkarnikar 2011). The hydrology and river systems in Nepal are complex and diverse. The country is home to four major river systems: the Kosi, Gandaki, Karnali, and Mahakali. These rivers originate in the Himalayas and flow through a variety of terrain, including mountains, valleys, and plains. The hydrology of Nepal is influenced by a number of factors, including the monsoon, snowmelt, temperature, and precipitation (Immerzeel et al. 2013). The monsoon brings the majority of Nepal's annual precipitation, which peaks in July and August. Snowmelt from the Himalayas also contributes to river flows, especially during the spring and summer. Precipitation is another important source of water for Nepal's rivers, but it is more variable than the monsoon or snowmelt. The rivers also support a variety of ecosystems, including forests, wetlands, and grasslands.

The hydrology and river system in Nepal are facing a number of challenges. Glaciers play an important role in the hydrology of the Nepal Himalayas. They store fresh water during the winter and spring in the form of snow and ice and then release it as water during the summer and autumn, which makes a significant contribution on drinking water supply, agriculture, and hydropower generation. The melting of glaciers is having a significant impact on the hydrology of Nepal, as most of the major rivers originate from the glaciers. There are about 3252 glaciers in Nepal, covering a total area of 5323 km^2 (Bajracharya et al. 2011). Climate change is accelerating the glaciers melting/retreating rate, which is reducing the amount of water available for rivers in the Nepal Himalayas (Immerzeel et al. 2013; Salerno et al. 2015; Sigdel et al. 2020). Deforestation is also a problem, as it reduces the amount of water that can be absorbed by the ground. There are more than 6000 rivers with a total length of about 4500 km, and most of them originate from the Himalayan ranges and flow down to the Ganga River in India (Fig. 1.5). Rivers that are fed by snowmelt and monsoon rains are seasonal, with high flows during the monsoon season and low flows during the dry season.

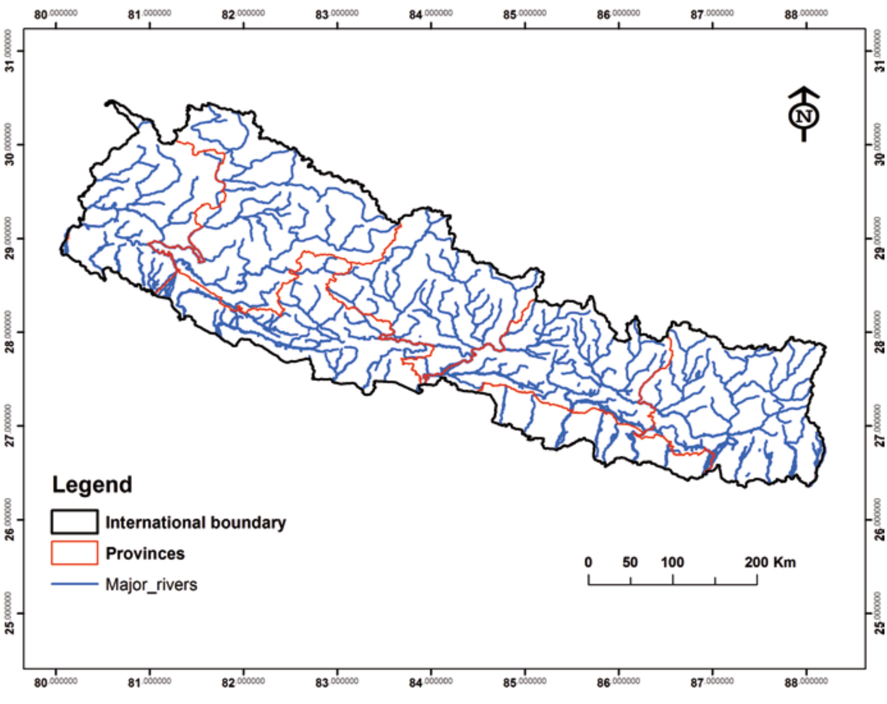

Fig. 1.5 River systems in Nepal. *Map prepared by* Bishnu P. Bhattarai

1.5.1 Major River Systems

There are four river systems in Nepal. They are described below:

1.5.1.1 Koshi River System

The Kosi River system drains between the Kanchenjunga range in the east and Gosainthan (Langtang) in the west. Major tributaries are as follows: Tamor, Arun, Dudh Koshi, Likhu Koshi, Tama Kosi, Sun Kosi, and Indravati. This river system covers 33,000 km^2 and has a length of 513 km on average. The hydropower capacity of this river system is 220,000 MW (Anonymous 2019). It is Nepal's largest river. It is known as the "sorrow of Bihar" for its history of urban flooding in Bihar, India (Danish et al. 2013).

1.5.1.2 Gandaki River System

It flows from Gosainthan (Langtang) in the east to Dhaulagiri in the west. Its total catchment area is 26,000 km^2, and its average length is 332 km. It has a hydropower potential of 210,000 MW (Anonymous 2019). It is also known as Narayani in Chitwan and Gandak in India. Major tributaries are as follows: Trishuli, Budhi Gandaki, Marsyangdi, Madi, Kali, Seti, and Daraundi.

1.5.1.3 Karnali River System

This is the longest river flowing inside Nepal, and the Karnali river flows between Dhaulagiri (east) and Byas-Rishi Himal (west). The total catchment area is 49,000 km^2 with an average length of 507 km. It is called Ghagra in India. Its hydropower capacity is 32,000 MW (Anonymous 2019). Major tributaries are as follows: Humla Karnali, Mugu Karnali, Seti, Tila, Bheri, and Babai within Nepal, and Rapti.

1.5.1.4 Mahakali River System

Most of the Mahakali basin's catchment area (64.6%) is in India, while 35.4% is in Nepal. It flows between Byas-Rishi Himal (east) and Limpiyadhura (west). Its hydropower capacity is 2262 MW (Jha 2020).

In addition to rivers, there are many lakes, ponds, dams, and other small wetlands in Nepal (Shrestha et al. 2020). Because all of these water bodies are significant, Nepal has committed to the conservation of wetland and water bodies as a signatory country of the Ramsar Convention held in Ramsar, Iran, in 1971, beginning on April 17, 2018. Ten wetlands in Nepal are listed as Ramsar sites (Table 1.2).