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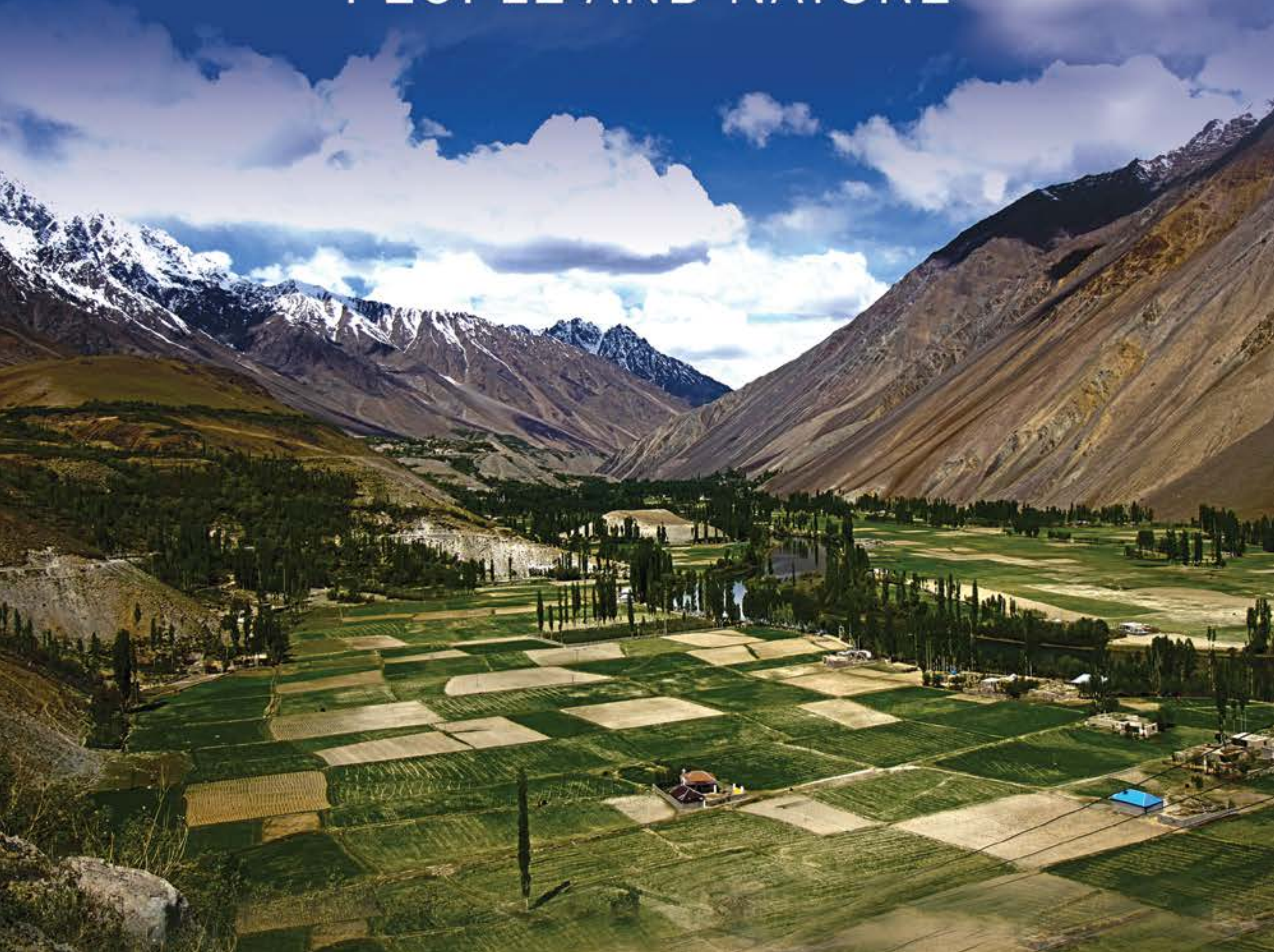
MOUNTAIN STUDIES

UNDERSTANDING AND MANAGING MOUNTAINS FOR PEOPLE AND NATURE



Mountain Studies

Understanding and Managing Mountains for People and Nature

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Foreword

Mountain ecosystems are globally significant because they support biological, cultural, and physical diversity, and cover roughly a quarter of the world's land area. As, John Muir says, and I quote "*Keep close to Nature's heart... and break clear away once in a while, climb a mountain or spend a week in the woods. Wash your spirit clean*". Mountains are pivotal for the existence of a significant proportion of humanity, because mountains' socio-ecological system is well integrated and aligned with the sustainability of livelihoods and the supply of natural resources to the highland and lowland societies. Rich mountain endowments like hydropower, freshwater, forests, minerals, and wildlife resources have always been beneficial to the lowlands and the national economy. So, the mountains are centers for bio-cultural, bio-physical, and traditional ecological knowledge patterns that helps to preserve mountain chain, and also, serves as a springboard for economic growth.

The mountains of Hindu Kush Karakoram Himalaya (HKH) are home to the largest ice deposits after the two poles (also called third pole), diverse cultures, flora and fauna, pastures, and peaks. There are ten major basins in the HKH region. The Indus River System plays as a backbone for the agro-based economy of Pakistan and meets 60-70% water needs of the country. The peculiar mountain ecosystem is forerunner for the ecosystem services.

The mountain ecosystems, on the other hand, have been faced with a multitude of local, regional, and global challenges such as climate change, natural disasters, air and water pollution, population explosion and overexploitation of natural resources. The quality of the mountain ecosystem has been continuously deteriorating in the last few decades. The recent climate impacts in the region in the form of flash and riverine floods, torrential rains, debris flows, landslides and avalanches have exposed the vulnerabilities of the region. To cater to these challenges, capacity building at the institutional and community levels, a review of the curriculum and intensive thematic research in the universities of the region is required to deal with the challenges faced. This also includes, mobilizing the youth of the region to develop a better understanding of the challenges and opportunities of the region and develop sustainable solutions for these challenges.

This book, *Mountain Studies,* gives interdisciplinary and transdisciplinary researchers and practitioners insights about the mountain eco-system, mainly authored by the consortium of mountain universities of the HKH region. The Karakoram International University, Gilgit, played a lead role in teaming with the faculty of the six Universities of the region i.e., Karakoram International University and University of Baltistan in Karakoram; Women University AJ&K Bagh and COMSATS University Abbottabad Campus in Himalaya; University of Chitral and Shaheed Benazir Bhutto University Sheringal, Dir Upper in Hindu Kush. The book has taken a holistic view of the challenges and opportunities of the HKH region with special reference to Pakistan.

The book is a valuable academic resource that should be taught as a core course to all students at the universities in the mountain region of HKH in Pakistan and other similar geographical settings around the world, so that they can develop a better understanding of the issues and expected solutions. The course can be very easily integrated with the existing curricula under the outcome of sustainability. In some programs, the course can be easily adjusted in the existing courses, partially or completely. The youth of the region are also custodians of their ecosystems, and learning through the proposed course will create awareness and environmental stewardship among them.

I appreciate the hard work of the editorial team and all chapter authors for their efforts. As an important outcome of the U.S. – Pakistan University Partnerships Grants Program (UPGP), which is administered by the United States Educational Foundation in Pakistan and funded by the United States Government, this collaboration has also provided better coordination among the mountain universities of the region. This project expects that in future, under Mountain Universities Consortium of Pakistan (MUCP), better coordination will be available among the partner Universities for an improved and sustainable future of the region.

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Introduction

The Hindu Kush-Karakoram-Himalayan (HKH) Mountain Ranges in Pakistan

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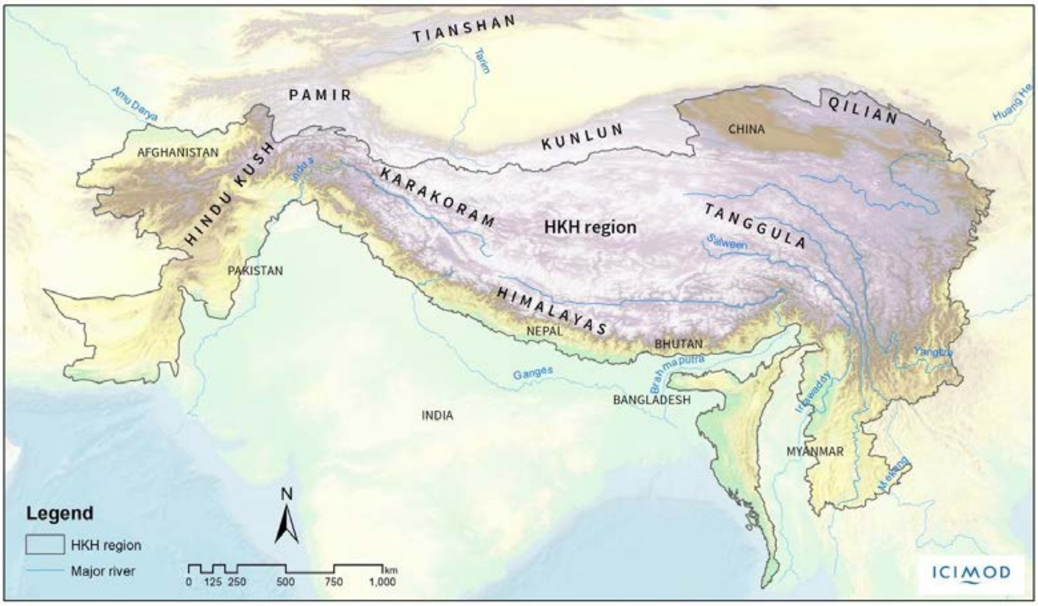

Hindu Kush-Himalayan region (Courtesy: ICIMOD)

HKH Mountain Ranges

The Hindu Kush-Himalaya (HKH), is an extensive high mountain system stretching over 3,500 km across eight countries, including Afghanistan, Pakistan, China, India, Bangladesh, Nepal, Bhutan, and Myanmar. The presence of massive glaciers, permanent snow, and permafrost makes the region known as Asia's Water Tower, the Third Pole, and the Planet's Pulse because it serves as a barometer of planetary health, displaying climate change impacts long before they appear elsewhere.

In Pakistan, almost 61% of the geographical area is mountainous, accommodating nearly 40 million people (Rasul & Hussain, 2015). The Himalayas, Hindu Kush, Karakoram, Koh-e-Sufaid, Suleman, Kirthar and Salt Range are the major mountain ranges in Pakistan.

Himalayan Range

The Himalayas, which physically and culturally separate South Asia from Central Asia, form the northern fringes of the subcontinent. It runs for approximately 2,500 kilometers from west to east between Nanga Parbat (8,126 m) in the Pakistani territory of Gilgit-Baltistan and

Namcha Barwa (7,756 m) peak in China's Tibet Autonomous Region (Burki & Ziring, 2022). Its width ranges between 200 and 400 km, with a total land area of approximately 595,000 square kilometers (Bishop et al., 2022). To the northwest are the Hindu Kush and Karakoram Mountain ranges, and to the north is the high and vast Tibetan Plateau. It constitutes the most incredible mountain system on Earth.

The Himalayas divide into four parallel ranges from north to south, namely the Tethys Himalayas, the Great Himalayas (highest peaks), the Lesser Himalayas (with 3,700–4,500-meter peaks), and the Outer Himalayas (lowest peaks). The Himalayan arc brings heavy rain and snow to the south but aridity to the north. The glaciers and snows of the mountains form the headwaters of 19 major rivers, including the Indus, Ganges (Ganga), and Brahmaputra. Five of the 19 rivers in the HKH region, the Jhelum, the Chenab, the Ravi, the Beas, and the Sutlej, with a total catchment area of about 132,000 square kilometers, belong to the Indus system. The western Himalayas occupy the entire northern part of Pakistan. Extending about 320 km, it separates Kashmir and northern Pakistan into three distinct ranges, from south to north, known as the Pir Panjal Range, the Zanskar Range, and the Ladakh Range (Burki & Ziring, 2022).

Karakoram Range

The Karakoram Mountain range in Pakistan connects borders with China and India towards the northeast, and its northwest portion extends to Afghanistan and Tajikistan. The federally administered Gilgit-Baltistan of Pakistan covers most of the Karakoram Mountain range and its highest peak in the Karakoram region is K2 (8,611 m), which is the second highest in the world. It starts from the Wakhan Corridor (border with Afghanistan) in the west and spans into Ladakh and Aksai Chin, controlled by India and China, respectively. The Baltoro region of the Karakoram range is home to the highest peaks, including K2, as well as three other peaks that rise above 8000 meters. These higher mountains include Gasherbrum I, Broad Peak, and Gasherbrum II. Notably, the Karakoram Range is one of the most heavily glaciated areas outside the polar region and contains the largest glaciers. Among them, the Biafo-Hispar Glacier (105 km), Siachen Glacier (76 km), and Baltoro Glacier (63 km) are particularly well-known (Allan et al., 2022).

Hindu Kush Range

In the north-west, the Hindu Kush Range represents the Afghan-Chitral boundary, and the largest portions of the eastern high Hindu Kush range are situated in Gilgit-Baltistan, Pakistan, and Afghanistan. The Hindukush range largely encompasses the Yasin and Ishkoman valleys of the Ghizer district, which extends into Pakistan's Chitral region as well. According to Burrard and Hayden (1908), the Karakoram-Hindu Kush Mountain ranges are diverse units of the same crustal fold. The eastern part of the fold is documented as the Karakoram range, while the western segment is known as the Hindu Kush Range. However, no precise natural feature exists for the range's name. Furthermore, for the benefit of geographers, they systematically projected the water divide between the Hunza and Gilgit rivers, which is located nearly 10 km east of meridian 74°, which separates the Karakoram and Hindu Kush ranges. However, the systematic partition at specific places is not convincing. Searle and Tirrul (1991) have presented that the Karakoram continues from Lake Pangong up to Afghanistan, and the Karakoram Range combines into the Hindu Kush Range and contains many high mountains. The Tirich Mir (7,690 m) peak in Chitral is the highest peak in the Hindu Kush Range. The other mountain ranges in the country are as follows:

Hindu Raj Mountains Range

The Hindu Raj Mountain Range is situated in Gilgit-Baltistan between the mighty Karakoram and Hindu Kush Mountain Ranges. It includes the area between the Phunder River and the Yarkun River. Several people believe that it is an integral part of the Hindu Kush Mountains, but some geographers consider the Hindu Raj a distinct mountain range. Koyo Zom (6872 m) is the highest peak in the Hindu Raj Mountain Range.

Salt Range

The Salt Range covers the northern parts of Punjab, where most rocks are sedimentary in origin. The well-known salt mines of Khewra, Mayo, Warcha, and Kalabagh are situated in the Salt Range hill system and contain vast rock salt deposits of Precambrian age. The hills around the Jhelum and Indus rivers are parts of the Salt Range.

Sulaiman Range

The Sulaiman Mountain Range is located in the northern Balochistan area of Pakistan and the Zabul area of Afghanistan. It has a border with the Indian subcontinent and the Iranian Plateau and is west of the Indus River. In Balochistan, the Sulaiman Mountains Range with its 3,487-meter-high peak is known as the Takht-e-Sulaiman, meaning the Salmon's Throne.

Kirthar Range

The Kirthar Mountain Range is located between Balochistan and Sindh provinces. It stretches nearly 300 kilometers south from the Mula River in Balochistan to Cape Muari, Karachi's westernmost point on the Arabian Sea. In the Sindh province, the maximum height of the Kirthar range is almost 2895 m above sea level and is considered the highest peak in the province.

Significance of HKH mountain ranges

Mountains, covering a quarter of the Earth's surface (Kapos et al. 2000), are remarkable places, particularly for their biodiversity richness and cultural significance. Mountains are home to one-third of all terrestrial species (Körner, 2004). Mountains provide vital goods and services to people living in and around them and in the valleys and plains downstream (Adler et al., 2022).

As the source of Asia's ten major river systems, the HKH irrigates one of the world's most extensive food baskets. It supports approximately 240 million people in the mountains and hills and another 1.9 billion in the valleys and plains downstream (Wester et al., 2019). Ecological flows of the HKH support riverine, deltaic, and coastal ecosystems and fishing communities. The HKH mountains provide food and other vital ecosystem services to approximately three billion people—nearly one-third of humanity. HKH is the region's economic backbone, contributing an estimated US$3.471 trillion annually through ecosystem services (Hu & Tan, 2018).

The HKH is a global treasure trove with the largest reserves of ice and snow, as well as biological and cultural diversity, with more than 600 languages. The HKH, with four global biodiversity hotspots, 12 ecoregions, 335 Important Bird Areas (IBAs), 348 Key Biodiversity Areas, and a network of 575 protected and conserved areas, is a repository of biological diversity (Chaudhary et al., 2022). It is exceptionally rich in biological diversity at ecosystem, species, and genetic levels. The snow leopard (*Uncia uncia*), Tibetan brown bear (*Ursus arctos pruinosus*), giant panda (*Ailuropoda melanoleuca*), markhor (*Capra falconeri falconeri*), red panda (*Ailurus fulgens*), Marco polo sheep (*Ovis ammon polii*), and semi-domesticated yak (*Poephagus grunniens*) are the flagships of the HKH region (Xu et al., 2019).

Challenges to the HKH mountains in Pakistan

The Hindu Kush Himalaya, like other mountainous regions around the world, is currently affected by the three planetary crises of climate change, biodiversity loss, and pollution. The effects of these planetary crises on the Hindu Kush Himalaya are evident in the increased glacial melting, species extinction, and water pollution. A brief account of these challenges is given below:

Climate Change

The climate of the HKH region has changed over the last few decades and is predicted to change even more dramatically over the coming decades. A 1.5°C rise is thought to be too hot for the HKH because of elevation-dependent warming (Wester et al., 2019). It will increase the risk of species extinction and extreme events. Dust and black carbon settling on Himalayan glaciers will accelerate melting. Changing rainfall patterns will adversely impact agriculture, water and sanitation, hydropower, and fisheries, with far-reaching consequences for human and environmental health. Scientists have projected that at 1.5 °C, the region will lose about one-third of its glacier mass by 2100 (Wester et al., 2019). With increasing emissions from agricultural fields, brick kilns, wildfires, and automobiles, the HKH and its adjoining plains are becoming the most polluted regions of the world.

Studies show that glaciers are melting faster than at any time in the past. As a result, more and larger glacier lakes appear, increasing the risk of glacial lake outburst floods; flash floods from streams and rivers strike violently and unexpectedly, disrupting communication, transportation, infrastructure, and supply chains; mountain flora and fauna species are rapidly disappearing from their natural habitats, being replaced by invasive species from warmer areas; and unpredictable and unusual weather patterns and events are occurring.

While humanity is experiencing unprecedented adverse impacts from a changing climate worldwide, the HKH mountains are no exception. Be it the recent destruction from cyclone Strang in Bangladesh, the catastrophic floods in Pakistan in August 2022, or the long spell of drought and heat waves in China, disasters are increasing at an alarming scale and frequency in the HKH region, just as they are occurring in many other parts of the world. The mountain communities of the HKH region are particularly vulnerable to climate change because of widespread poverty, high dependence on natural resources for livelihoods, and higher exposure to climate risks. Mountain ecosystems, with their many threatened and endemic species, are more susceptible to climate impacts and are affected faster than other terrestrial habitats.

Biodiversity loss

Excessive exploitation of natural resources for local use and trade, such as illicit cutting of forests and hunting of wild animals and birds for use and trade, habitat destruction and conversion, and drainage and pollution of soils and water bodies, are root causes of biodiversity loss in the HKH region. Climate change and human-wildlife conflict intensify and accelerate biodiversity loss in the mountain areas (Khan et al. 2022). According to studies, one-fourth of the endemic species in the Indian Himalayas may become extinct due to overexploitation, and 70–80% of natural habitats in global biodiversity hotspots will be lost by the end of 2100 (ICIMOD, 2020).

Although global warming has apparently accelerated green growth at higher altitudes, alien and invasive plant species have also altered the quality and composition of alpine vegetation significantly (Wang et al., 2015; 2022). Invasive species are rapidly spreading, colonizing, and invading protected areas, agricultural lands, freshwater ecosystems, and high-altitude pastures and grasslands (Everard et al., 2018; Pathak et al., 2019; Thinley et al., 2020 ; 2022). The aggressive and rapid spread of invasive species at higher elevations endangers biodiversity and food security, with substantial economic costs (Sheergojri et al., 2022).

Pollution

Although the effects of air pollution are most visible, water and soil pollution also have an impact on the HKH region (Dhimal et al., 2021). Air pollution in the HKH is on the rise, and regional air quality has worsened in the past two decades (ICIMOD, 2020). Nine out of the world's 10 cities with the worst air pollution are in South Asia (World Bank, 2022). Ambient air pollution is a public health crisis for the region, not only imposing high economic costs but also causing an estimated 2 million premature deaths each year (World Bank, 2022).

Air pollution sources include solid fuel combustion in the residential sector for cooking and heating; small industries, including brick kilns; burning high-emission solid fuels; the current management practices of municipal waste in the region, including burning plastics; the inefficient application of mineral fertilizer; fireworks; and human cremation. Air pollution is also generated in agriculture, including through the burning of crop residues, the generation of secondary particulate matter in the form of ammonia (NH_3) emissions from imbalanced fertilizer use, and livestock manure that reacts with nitrogen oxides (NO_x) and sulfur dioxide (SO_2) gases from energy, industry, and transportation sources. In the western part of

South Asia, natural sources such as dust, organic compounds from plants, sea salt, and forest fires are an important source of air pollution (World Bank, 2022).

Persistent winter fog and haze have increased across South Asia, more so in urban and peri-urban settings, leading to reduced visibility and elevated air pollution just south of the HKH and affecting air quality in the HKH as well as in the IGP. The winter fog reduces crop yields and affects tourism, impacting the lives of millions of people.

The HKH is sensitive to climate change; air pollutants originating within and near the HKH amplify the effects of greenhouse gases and accelerate the melting of the cryosphere through the deposition of black carbon and dust, the circulation of the monsoon, and the distribution of rainfall over Asia (ICIMOD, 2020).

Why and how to care about the mountains?

The HKH mountain ecosystems provide vital ecosystem services and goods such as food, water, fiber, fodder, medicine, firewood, and hydropower to around 2.4 million people living in the mountains and support another 1.9 billion people living in the river basins downstream (Wester et al., 2019).

With a changing climate, several plant species are likely to disappear from their natural habitats (Manish, 2022). An increase in wildfires, droughts, and storms would impact floral species' distribution, abundance, composition, phenology, and physiology and affect ecosystem structure, functions, and productivity (Adler et al., 2019). Grasslands will predominantly change; invasive species will intrude on pastures; several medicinal and aromatic herbs will decline and disappear from their habitats; the upper limits of agriculture will expand, but the nutritional value of certain cereals may decline. Peatlands are predicted to shrink across the region, and human-wildlife conflict will increase with the changing cryosphere (Khan & Wangchuk, 2022).

Mountain communities in the developing world are particularly vulnerable to change because of widespread poverty, high dependence on natural resources, social exclusion, lack of knowledge, adaptive skills, and opportunities, and high climate vulnerability. Mountain issues are complex and interlinked and thus need a careful and considerate pragmatic approach for addressing the existing and emerging socio-ecological, economic, and climate issues.

ICIMOD (2020) recommends the following six urgent actions for the HKH region:

1. Co-develop knowledge and evidence that is mountain focused and HKH specific about key situations and trends and share it with partners to fill data gaps and help make evidence-based policies and programs.
2. Enable decision makers with scientific data and evidence to recognize and prioritize the uniqueness of the HKH mountains – its people and environment in national, regional, and global decision-making forums and processes.
3. Promote concerted actions to keep global temperature below 1.5˚C by 2100, with regional, national, and local actions on sharply reducing short-lived climate pollutants (SLCPs) and achieving carbon-neutral societies in the HKH.
4. Take accelerated actions to achieve the Sustainable Development Goals in the HKH based on the nine mountain priorities, focusing on transformative adaptation, tackling poverty and inequality, inclusive development, and leaving no one behind.
5. Enhance ecosystem resilience by halting biodiversity loss and land degradation, and sustainably managing forests, rangelands, and other ecosystems in the HKH through promoting transboundary cooperation for landscapes and river basins.
6. Promote and strengthen regional cooperation at all levels across the HKH region and take actions at national, regional, and global scales to improve mountain livelihoods and sustain the HKH as a regional and global asset.

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PHYSICAL LANDSCAPES AND ASSOCIATED CHALLENGES

Chapter 1

Mountain Geography and Geology

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The junction of Hindu Kush-Karakoram-Himalayan mountain ranges near Gilgit, Pakistan, © Tasawar Baig

Introduction

Pakistan is home to some of the most stunning and highest mountain ranges in the world, attracting visitors, researchers, and geoscientists alike. The Hindu Kush, Karakoram, and Himalayas (HKH) mountain region is regarded as a geological museum of the world due to the variety of rocks present, the physical landscape, and the formation of its physical features. The three major mountain ranges converge in Gilgit Baltistan (GB) and contain several peaks above 7,000 meters above sea level (masl) and five of the world's 14 peaks over 8000masl. The highest mountains in Pakistan's Himalayas and Hindu Kush ranges are the Nanga Parbat (8,126m) and Tirch Mir (7,690m), while K2 has the highest peak in the Karakoram range (Hewitt, 2014). More significantly, the HKH region contains numerous glaciated peaks that feed the regional rivers supplying water to the entire country. The HKH mountain ranges were formed after the collision of the Indo-Pak landmass with the Eurasian plate. These mountain ranges gradually morph from low hills in the south to elevated peaks towards the north. This area is therefore considered the third pole outside the polar regions.

Geological landscape of HKH region

The Himalayas have been undergoing tectonic uplift for about 130 million years. The widely distributed metamorphic rocks found at the core of the Himalayas were yielded in the Tertiary period and formed by regional orogeny[1] triggered by the India-Asia collision (Searle et al., 2016). This crystalline and metamorphic[2] belt mainly comprises granites[3], gneisses[4], schists[5], and sediments[6].

The HKH region hosts rock units from all geological periods; the Archean rocks found in the eastern Himalayas are more than 2.5 billion years old, such as gneisses among the basement rocks, while the lowered ranges adjacent to the southerly margin contains an intricate suite of the youngest Tertiary sedimentary layers, encompassing coastal deposits by watercourses mounting onto lowlands from the Himalayas (Searle et al., 2016). The HKH region in Pakistan contains three main fragments inside the tectonic network of the Himalayas.

The major rock types of the Karakoram block are meta-igneous and meta-sedimentary suites, whereas the Kohistan Island arc contains mafic-ultramafic complexes. The Indian plate is subducted under the Asian plate along the Indus Suture zone. Concerns remain, though, regarding the timing of these plates' collision (Chatterjee et al., 2013; Ziabrev et al., 2004).

Shah et al. (2011) assert that Kohistan sequential rocks represent intra oceanic subduction environment, whereas volcanic – Chalt-Shamran volcanic, Yasin metasediments and Purit formation – and sedimentary units along the plate boundary carrying several granitic intrusions (Petterson, 2010). Petterson (2010) reported that Yasin meta-sediments are dominated by Chalt volcanic, which have tholeiitic- and boninite-series, basalt-andesites and meta basalts composition (Khan et al., 1998; Petterson & Windley, 1991). The basaltic-tholeiites nature of Chalt volcanic is substituted by andesites to rhyolites, whereas, Yasin Group sediments indicate an overlying intra-arc basins environment which contains undeformed and metamorphosed volcanic rocks (Petterson, 2010; Searle et al., 1999). The Karakoram block is shaped in the south border of Asiatic plate and is situated in the western side of south Tibet, which splits Karakorum fault from southern Tibet. The Northern Sedimentary Basin (NSB) dominantly contains various shales (Kazmi & Jan, 1997).

Global and Regional Tectonics

Global tectonics

A tectonic plate (also called lithospheric plate) is a massive, irregularly shaped slab of solid rock, generally composed of both continental and oceanic lithosphere (Condie, 2013). In plate tectonics, the earth's lithosphere (crust and upper mantle are broken into units called plates), which are fairly brittle and are moving around on top of the mantle like a boat. The

[1]The process of mountain building

[2] **Metamorphic rocks** arise from the transformation of existing rock to new types of rock in a process called metamorphism. *(Wikipedia. https://en.wikipedia.org/wiki/Metamorphic_rock. Accessed December 2022)*

[3]**Granite** (/ˈɡrænɪt/) is a coarse-grained (phaneritic) intrusive igneous rock composed mostly of quartz, alkali feldspar, and plagioclase. It forms from magma with a high content of silica and alkali metal oxides that slowly cools and solidifies underground. *(Wikipedia. https://en.wikipedia.org/wiki/Granite. Accessed December 2022)*

[4]**Gneiss** (pronounced NICE) is a common and widely distributed type of metamorphic rock. It is formed by high-temperature and high-pressure metamorphic processes acting on formations composed of igneous or sedimentary rocks. Gneiss forms at higher temperatures and pressures than schist. Gneiss nearly always shows a banded texture characterized by alternating darker and lighter colored bands and without a distinct cleavage. *(Wikipedia. https://en.wikipedia.org/wiki/Gneiss. Accessed December 2022)*

[5]**Schist** (pronounced SHIST) is a medium-grained metamorphic rock showing pronounced **schistosity**. This means that the rock is composed of mineral grains easily seen with a low-power hand lens, oriented in such a way that the rock is easily split into thin flakes or plates. This texture reflects a high content of platy minerals, such as micas, talc, chlorite, or graphite. These are often interleaved with more granular minerals, such as feldspar or quartz. (W*ikipedia. https://en.wikipedia.org/wiki/Schist. Accessed December 2022)*

[6]**Sediment** is a naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice or by the force of gravity acting on the particles. For example, sand and silt can be carried in suspension in river water and on reaching the seabed deposited by sedimentation; if buried, they may eventually become sandstone and siltstone (sedimentary rocks) through lithification. Sediments are most often transported by water (fluvial processes), but also wind (aeolian processes) and glaciers. Beach sands and river channel deposits are examples of fluvial transport and deposition, though sediment also often settles out of slow-moving or standing water in lakes and oceans. Desert sand dunes and loess are examples of aeolian transport and deposition. Glacial moraine deposits and till are ice-transported sediments. *(Wikipedia. https://en.wikipedia.org/wiki/Sediment. Accessed December 2022)*

plates vary from a few hundred kilometers wide to thousands of kilometers across; the Pacific and Antarctic Plates are among the largest ones. These plates are parts of the continental and oceanic crust, where mid oceanic ridges and largest fault boundaries represent the weak zones to the occurrences of earthquakes. The Earth's lithosphere consists of 15 to 20 moving tectonic plates (Figure 1.1) and have dynamic boundaries, which are sites of the orogeneses, a term from the Greek orthodox meaning mountain building. Tectonic plates can move because Earth's lithosphere grasps the largest mechanical power compared to the underlying asthenosphere. The abrupt density versions inside the mantle result in convection, that is, the gradual creeping motion of Earth's solid mantle (Gill, 2012). The rigid tectonic plates of Earth move due to convection currents within the planet's fluid, molten core. Seafloor spreading is the process of tectonic plates drifting apart in regions where convection currents rise in the direction of the crust's surface (Gill, 2012). Along the plate boundaries, convergent, divergent, and transform faults exist. These movements are what cause mid-oceanic ridges and mountain-building to occur.

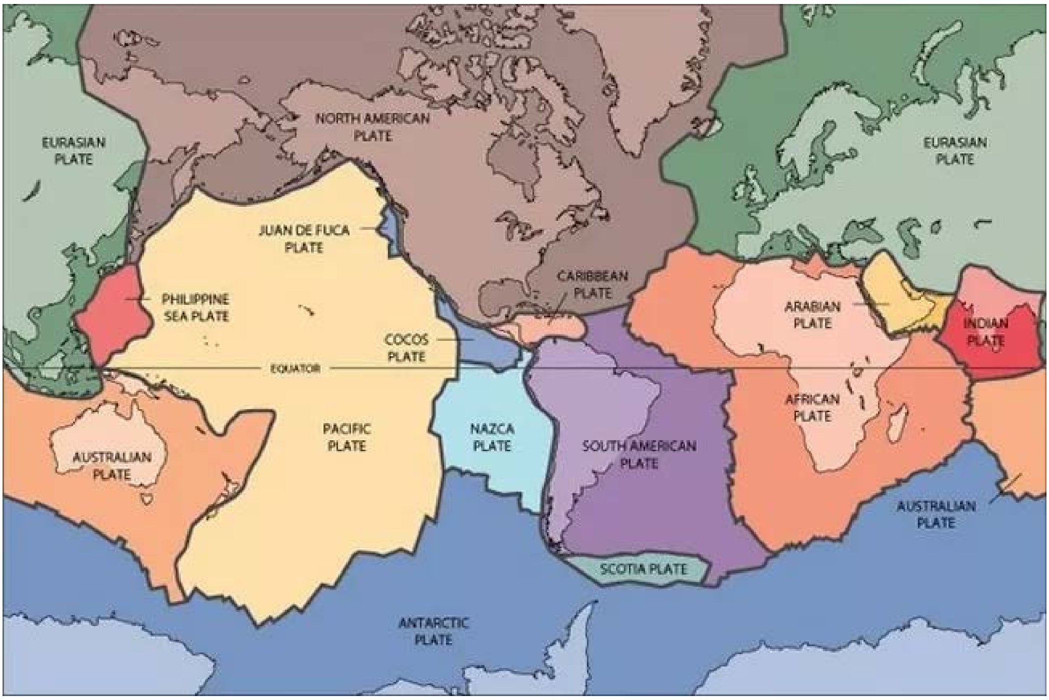

Figure 1.1 The map showing major tectonic plates of the world (Source: Kious and Tilling, 1996).

Continental drift theory

In 1912, the German meteorologist (Wegener), proposed a novel and comprehensive theory of continental drift based on extensive geological and paleontological data. Wegener (1912) claimed that earlier in the geological time, all continents of the world were once together, forming a supercontinent, which he called Pangea (Figure 1.2 a). Nearly 251 million to 199.6 million years ago, Pangea split into parts and started to move away from one another. A Great Ocean named Panthalassa was surrounding this supercontinent. In Du Toit (1940), a South African geologist, improved Wegener's hypothesis by arguing that two ancient continents once existed (Figure 1.2 b) were given the names Laurasia in the north and Gondwanaland in the south. The Tethys Sea was situated between Laurasia and Gondwanaland. The Gondwanaland was composed of the subcontinent, South America, Africa, Australia and Antarctica, while the northern Laurasia landmass covered North America, Greenland, Europe and most of Asia. Both Laurasia and Gondwanaland continued to break into several smaller continents today (Figure 1.2 c & d). The continental physical features were the evidential support of this theory. Similarly, the South American and African coastlines facing each other have a prominent match while the western coastline of India seem to have been united with Africa and Madagascar. Several other pieces of evidence, such as fossils of different animals and plants, glaciers and climate, have been studied and indicate the presence of a supercontinent where all continents were once together.

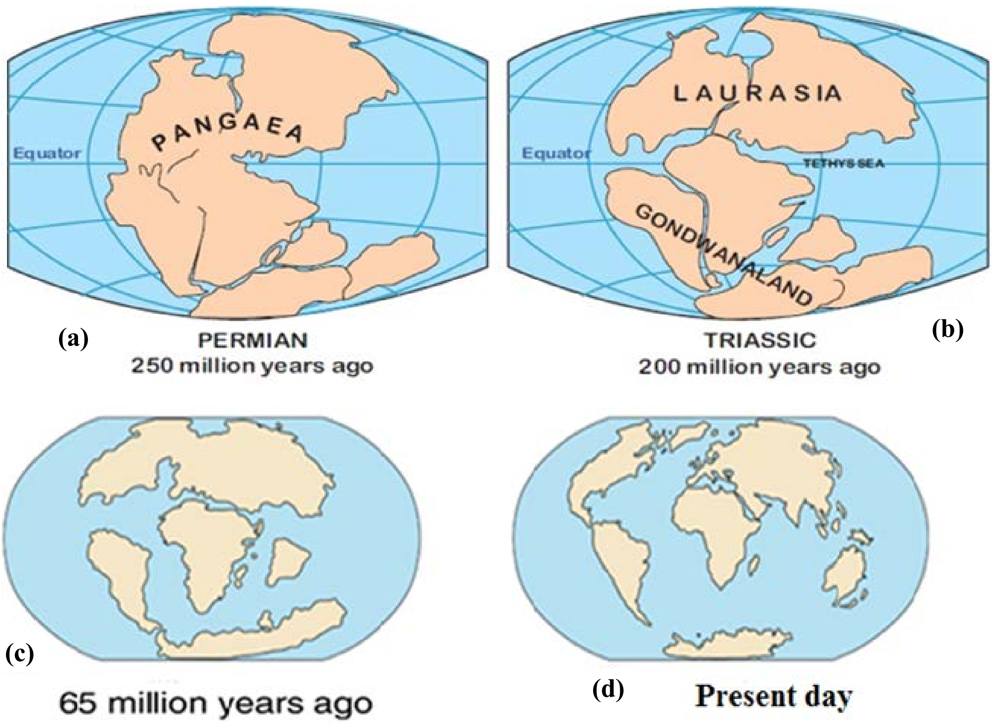

Figure 1.2 (a) shows the supercontinent Pangaea; (b) indicates its fragments Laurasia and Gondwanaland; (c) and d) represent positions 65 million years ago and in the present-day. (Source: Kious and Tilling, 1996).

During the late Jurassic period, the Pakistan-India landmasses split off from Africa, Madagascar, Antarctica, and Australia. It then began to drift northwards across the Indian Ocean, pushed by newly formed oceanic spreading centers in the Indian Ocean. Approximately 50 million years ago in the early Eocene time, the Indian plate collided with the Asian plate at equatorial latitudes. Since then, India has progressively moved northward by about 2,000 km, indenting into Asia and forming mountain belts along the north (Himalaya, Karakoram), west (Sulaiman-Kirther-Chaman ranges along the Pakistan-Afghanistan border), and east (Indo-Burma ranges). The Himalayan ranges are part of the northern margin of the Indian plate, whereas the Karakoram and Pamir ranges, together with most of the Tibetan Plateau, belong to the southern margin of Asia (Burg, 2011).

Regional tectonics

The Pakistan-India plate was detached 100 million years ago at a speed of 12cm/year. Finally, the Tethys Sea, which was situated between Laurasia and Gondwana landmasses, started shrinking and ultimately disappeared, owing to a continental collision between Indo-Pak landmasses and the Eurasian plate nearly 55 million years ago. In the Pakistan section, a large intra-oceanic Island arc termed the Kohistan Island Arc was trapped between the Indian plate to the south and Asian Plate to the north. Following the tectonic collision and accretion of the first Kohistan arc to the south, then the Indian plate, mountains were built through processes such as crustal thickening, metamorphism (change of sedimentary and igneous rocks to crystalline rocks through increased temperature and pressure), and crustal melting (producing granites). The collision of the Indian shield with the Eurasian plate is the result of the formation of the HKH ranges. The Karakoram Range with the Hindukush and Hindu Raj to the west, and the Lhasa block of Southern Tibet to the east, formed the southern margin of Eurasia prior to the collision of the Indian plate around 50 million years ago (Zanchi & Gaetani, 2011). The continents have moved constantly and changed their positions throughout the earth's history. This process will continue as usual. The major tectonic terrains (Figure 1.3) formed due to the subduction of the India-Pakistan plate underneath the Eurasian plate. These terrains are from north to south known as the Karakoram plate, Main Karakoram Thrust (MKT), Kohistan Island Arc, Indus Suture Zone or Main Mantle Thrust (MMT), and Nanga Parbat Haramosh Massif (NPHM).

The Karakoram Block: The Karakoram range stretches for over 650 km from the far northwest of Pakistan with Afghanistan to the far northern part of India in Ladakh to the western extremity of Tibet (Kazmi & Jan, 1997). Along the Hunza valley profile, three major zones are traversed, a northern sedimentary zone, a central granitic zone (the Karakoram Batholith), and a southern metamorphic zone. Between Chalt and Gilgit, the Hunza Valley cuts through the northern part of the Kohistan Island Arc, a cretaceous oceanic arc was accreted to Asia prior to the Indian plate collision (Fraser et al., 2001).

Main Karakoram Thrust (MKT): The Main Karakoram Thrust (MKT), also known as Karakoram-Kohistan Suture Zone (KKSZ), Northern Suture Zone (NSS), or Shyok Suture Zone (SSZ) is the western extension (branch) of the Indus Tsangpo Suture Zone (ITSZ) of southern Tibet (Searle, 2010). The MKT separates Kohistan Paleo-Island Arc (KIA)/microplate to the south from Karakoram Terrane to the north. In the east, it is well represented as Shyok Suture, because of the Shyok River, which splits the Ladakh Arc from the Karakoram Terrane (Petterson, 2010). The MKT runs along the northern boundary of the KIA from the Chitral region in the west, enters the lower Yasin and Ishkoman Valleys in Ghizar, and then goes to the lower Hunza region.

A sequence of highly deformed ultramafic and volcanic rocks near Chalt in the lower Nagar Valley marks the location where the KIA collided with the Asia Plate margin (Tahirkheli, 1979a). The suture zone along the southern margin of Kohistan runs from the Babusar Pass region across to Jijal-Patan region in the Indus valley. This is the Main Mantle thrust zone, which extends eastwards to become the Indus Suture Zone in Ladakh and South Tibet, the zone of actual collision between the Indian and Asian plates (Rehman et al., 2011). There are two types of lithospheres identified: *oceanic* and *continental*. Among them, the oceanic crust is relatively denser than the continental. The thickness of the continental and oceanic crust is different. The thickness of the oceanic crust is 5 to 10 km, while the continental thickness is 40 to 100 km. The crust and part of the upper mantle known as the lithosphere is 100 km thick, and the less dense material below it floats.

The collision of the Indian shield with the Eurasian plate results from the formation of Hindukush-Karakoram and Himalaya (HKH) Ranges. Thrusting and compression along significant faults like the Main Central Thrust (MCT), Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT), during the collision, were extended (Le Fort, 1986; Valdiya, 1976). Pakistan divides the margins between the Indo-Pakistan, Arabian, and Eurasian plates, which have been subjected to their past and present interaction between them. In the north, the Indus Suture Zone separates the Greater

Himalayan sequence overlain by the Tethyan Himalayan System, whereas the Indian shield rocks comprise both ortho and para-gneisses along with eclogites exposure in the Nanga Parbat Haramosh Syntaxis.

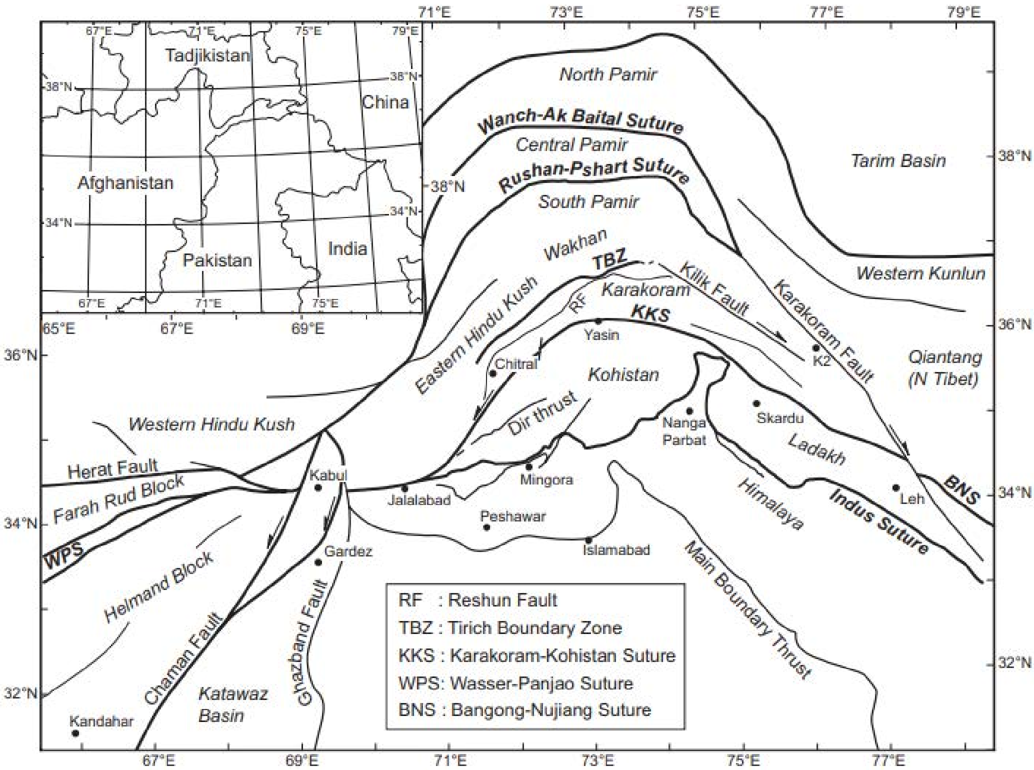

Figure 1.3 Tectonic map of Pakistan. (Source: Kazmi and Jan, 1997)

Indus Suture Zone (ISZ) or Main Mantle Thrust (MMT): The Indian plate is truncated against the Cretaceous Kohistan Island arc along the ~65 Ma old suture zone termed as the southern suture or Main Mantle Thrust (MMT), (Bard, 1983; Tahirkheli, 1979b; Treloar et al., 1989). The MMT is the westerly extension of the Indus suture. It is an irregular but generally northward dipping thrust, folded around later structures developed in the underlying Indian plate. The suture is intensely deformed, but it is frequently specified with similar schistosity. Various mélanges covering ultramafic rocks, piedmontite schists, blue schists and green schists have been reported from Bajaur, through Dargai (Hussain et al., 1984), Shamozai near Mingora (Kazmi, 1984; Shams, 1980), and Shangla - Alpurai and Allai (Shah & Majid, 1985) to Babusar Pass (Chamberlain et al., 1991). Jan and Jabeen (1990) have described various mafic and ultramafic complexes along the Indus suture (MMT) in Pakistan. Some of these complexes are closely associated with the Kohistan arc sequence and represent cumulates at the bottom of the Kohistan arc, e.g., the Chilas, Tora Tigga, and Jijal complexes.

The uplifting of the Indus Suture Zone (Zeitler et al., 1982) eroded all the unmetamorphosed sediments bordering it, thus no stratigraphic evidence is found to constrain the time of formation of the suture. The age of the suture is determined from the available isotope data and the evidence from Ladakh, where some good stratigraphic sections are preserved.

Nanga Parbat Haramosh Massif (NPHM): The Nanga Parbat Haramosh Massif, situated in the northernmost part of the Western Himalayan Syntaxis, reveals itself as an unusual north-south expansion of Indian crust that ranges from the foothills of the Himalaya into the Karakoram within the massif that contains Indian shield basement gneisses (Zeitler et al., 1989) and covers rocks of unknown age (Butler & Prior, 1988). The Kohistan and Ladakh Arcs are separated from the Himalayan rocks by the Main Mantle Thrust (MMT) (Tahirkheli, 1979b). With the over-thrusting of the Kohistan arc and consequent Early Tertiary metamorphism, the NPHM underwent a rapid and accelerated unroofing. The quicker uncovering is considered to be at least moderately responsible for starting decompression melting and high-grade metamorphism.

Mineralogy/Gemology

Although some gemstones are not actually minerals, but some stones become valuable when they are cut and polished, including p lapis lazuli and amber etc. and can be used to make jewelry due to their unique characteristics of being extremely beautiful, rare, durable, and compliant after cutting and polishing.

Geologically, the HKH ranges have unique landscapes with the youngest and thickest mountain chains, meeting at the confluence of the Indus and Gilgit Rivers at about 32km from the main administrative city of Gilgit. The land of Gilgit-Baltistan has strategic importance nationally and internationally, as it hosts vast treasures of precious metals, rare earth metals and gemstones. The presence of diamond-bearing rocks suggests the occurrence of diamond in the HKH region. In the HKH region of Pakistan, more than 50 varieties of semi-precious and precious stones have been recognized. Numerous miners have been engaged in the exploration, mining, advertising and marketing of the uncut and unpolished gemstones domestically as well as internationally.

Minerals can be grouped into two categories: gemstones and ore. Gemstones can be classified into four groups for trade and commercial purposes, which are as follows:

a. Fine specimens

In this category minerals and gems must be on a rock matrix (Figures 1.4 a, b, c) without damaging any portion of the stones. The presence of more gems in a single rock signifies an additional value of the stones.

(a) (b) (c)

Figure 1.4 The photograph shows. (a. Tourmaline, b. aquamarine, c. topaz specimens) © Hawas Khan

b. Crystal sample

The crystal samples (Figure 1.5 a, b) are also unique due to the perfect development of their crystal system and crystal termination. The color and size of any gem is always important for its perfection.

(a) (b)

Figure 1.5 Crystal termination (a. twin aquamarine, b. crystals) © Hawas Khan

c. Lapidary: Lapidary or Cutting grade

Cutting grade gemstones need transparency/clarity, size and color (Figure 1.6). Damaged stones can be made usable through proper and skilled cutting. Inclusion, inappropriate color and size can affect the value of stones.

Figure 1.6 Rough (uncut) aquamarines © Hawas Khan

The All-Pakistan Commercial Exporters Association reports export sale proceeds of US$ 12.6million of rough and un-polished precious and semi-precious stones (Khan, 2013). Gilgit-Baltistan contributes almost 90 per cent in the total export of gemstones from the country, despite the use of primitive and unscientific mining techniques. The inadequate mining activities in the region damage the products and significantly reduce the value of crystals and fine specimens. However, damaged stones for the cutting grade can be recovered if accurate cutting and polishing techniques are applied.

Crystal and fine specimens have much higher prices in the international market as compared to cutting grade stones. Due to the lack of technical knowledge, institutional support, and a proper legal framework, the potential of this sector is still far from being fully realized. One of the major shortcomings is the lack of an appropriate geological survey of gem-bearing deposits, which could reveal the potential areas through a reliable catalog for the region. Other factors include lack of appropriate skills at each level of the value chain, premier interest, technological limitations, and so forth, which are responsible for the slow development of this sector in Gilgit-Baltistan.

The entire HKH region of Pakistan has no proper processing lab facility for gemstone cutting, polishing and testing of minerals for identification. Although, some organizations have lately started working on cutting and polishing gemstones, there is still no certification being done at any level. The rough and unpolished gemstones are transported abroad for extra processing or to export raw material at lower prices. The local markets in major cities like Peshawar, Karachi, Islamabad, and Lahore are also providing further processing of stones, especially in Peshawar, where people have been traditionally involved in this occupation for a long time. The gemstone dealers from Afghanistan operate several shops in the center of Peshawar, where they sell gemstones after transporting them to Peshawar. The recently established Gemological Training Institute at the Karakoram International University is the first formal training facility in gem processing. However, according to an estimate, 85 per cent of the gemstones mined in Pakistan are exported in raw form to different countries. Only 15 per cent of Pakistan's cut gemstones are exported.

The gems sector is known as having one of the least transparent business practices in the HKH region. Most trading of stones is performed secretly, in isolation, and under the table, which clearly shows no scientific valuation of trading gems and related products. Without certification facilities, the gems produced are sold below market price. However, most of the gems are sold to Peshawar or other southern markets.

In the HKH region of Pakistan, various concessions are being granted to miners, but due to the absence of any mineral testing lab facility, the lessees, licensees and the local communities, face difficulties in testing the mineral samples collected during exploration.

In the HKH region, the local communities need education and training for sustainable development in the gems sector and reducing poverty. Presently, several organizations are working in the area for training in gemstone cutting, polishing, and marketing locally. The value addition and certification through authentic laboratory testing of gems will boost the local economy.

Structural geology

It is a branch of geology which deals with the geometry, distribution, and evolution of geological features in rocks. Structural geology covers a diverse and vast scope, varying in sizes, from the most minor level of lattice flaws in minerals to mountain belts and plate margins. Structure is a particular and geometrical configuration of the rock components. Structures can be classified into two broad types:

Primary structures

These structures emerged as a result of two processes: rock deposition and rock crystallization. In almost all sedimentary rocks, the suspended solid particles settle down from the liquid medium; while in igneous rocks, the dissolved mineral grains from the liquid are crystallized. After deposition, the lithification and diagenesis processes (sedimentary unit development) begin, and distinct primary structures develop in various sedimentary layers, for instance, cross bedding, ripple marks, mud cracks, etc.; and crystallization (igneous rock solidification in the ocean) produced rock formations such as pillows and lava structures in the igneous body.

The primary structures are produced throughout the sedimentation or crystallization of rock occurrence, such as pillows (igneous rock solidification in the ocean), or rapidly after deposition (sedimentary unit development) like cross bedding, ripple marks and mud crack etc. Some important primary structures are discussed as follows:

Bedding: It is also known as stratification in sedimentary rocks, where the main body of splitting beds with a diverse constitution, including various colors, cement, and textures, represent various sources of sedimentary process, and environments where depositions took place. They emphasize outcrop by parting and differential weathering and erosion (Salvador, 1994).

Pillow lava: Pillow lavas typically contain pillow-like structures connected to the ejection of the lava beneath water, or subaquatic solidification. Most pillow lava comprises of komatiite, picrite, boninite, basaltic andesite, andesite, dacite and rhyolite. Generally, silica is rich in felsic composition and tends to have an intermediate nature. The larger the pillows, the more significant to the flow in viscosity of the ejecting lava. Pillow lavas are usually basaltic (Kuroda et al., 1988).

Secondary structures

The secondary structures result after host rock is formed, and afterwards, progressively more deformation is visible in the structures such as folds, faults, joints, and sills (Singh, 2009). The following discussion includes some important secondary structures:

Fold: A type of geologic structure that appears due to the bending or deforming of rock surfaces. Folds are tectonically secondary structures that result after sedimentation takes place and compressional stress takes an active part, in such a way that when initially solid and planar rock surfaces are deformed, the resultant deformed rock surfaces are bent (Figure 1.7) or permanently curved (Laplanche & Ergün, 2019). In sedimentary rock folding, the original material is bent before lithifying. Folds in rocks differ in their dimensions, from tiny lines to mountain-sized folds. These structures appear in a particular unique folding system and are a widespread fold series of diverse classes, in various sizes.

Anticline: It is a type of fold that is curved upward (Figure 1.8) where the oldest rocks are exposed at the center of an anticline and entire units dip away from the axis (Bates & Jackson, 1984). Structurally, the anticline is an important feature for hydrocarbon deposits.

Figure 1.7 The red arrow indicates folding in Chalt volcanics due to compressional force near Main Karakoram Thrust (MKT), Goru-Gilgit © Hawas Khan

Syncline: Syncline is the down-ward fold in which the youngest visible rocks coincide with the fold axis and all strata dip towards the axis.

Figure 1.8 An example of anticline (type of a fold) in rocks (Courtesy: Sot de Chera, Valencia, Spain)

Seismology

Seismology is a field that focuses on investigating earthquakes and the propagation of seismic waves over the earth. It is a branch of geophysics that has provided a significant amount of information regarding the structure and condition of the planet's interior (Britannica, 2020).

Seismicity

Seismicity is a measure consisting of a tremor's frequency, type, and magnitude at a certain geographical position (Stacey & Davis, 2008). Pakistan is known for having large areas of strong seismicity and several seismotectonic features caused by identified active faults. When the Chaman town was destroyed in 1892, the main indication of an active fault was confined to earthquakes. This was also the first time the typical Chaman Fault was exposed/noticed (Griesbach, 1893). The 1945 Makran earthquake proved an underwater active fault, built a number of small offshore islands, and created them in a line parallel to the coast (Sondhi, 1947). Kazmi (1979) reports that Pakistan has a number of active faults, but generally, it is believed that Pakistan's main fault system is generally thought to be seismically passive (Nakata et al., 1991).

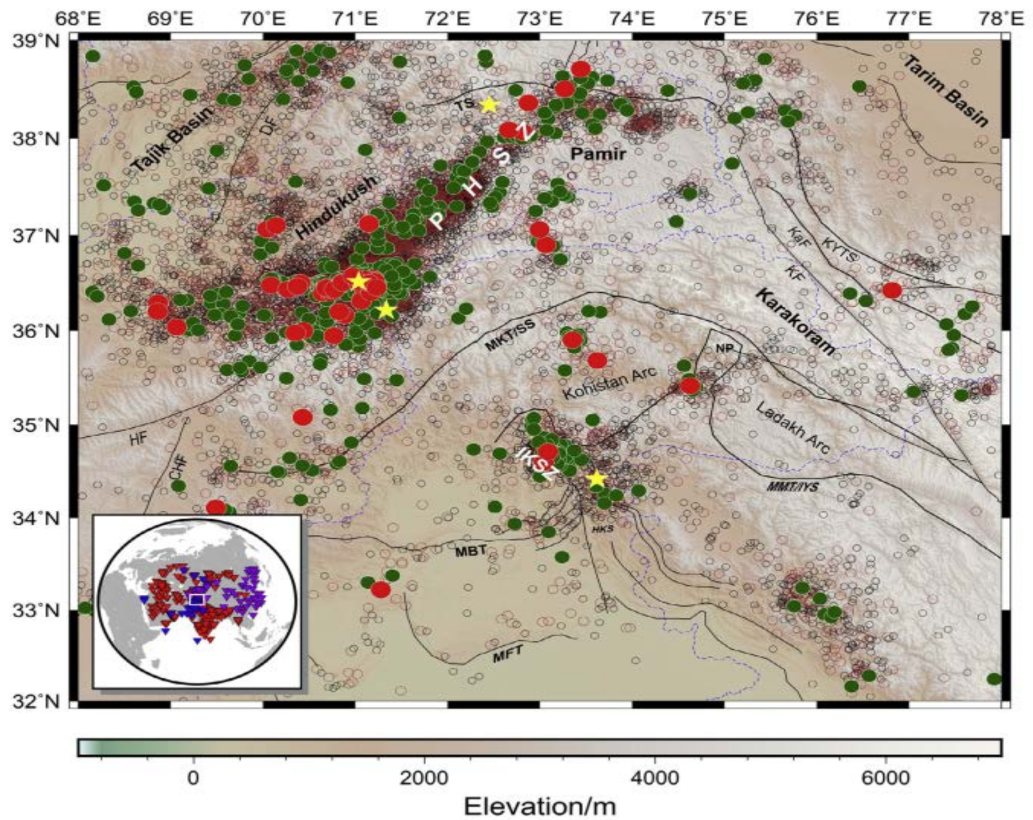

Figure 1.9 Topographic map of HKH showing the major tectonic features (faults and sutures) (HeF = Herat Fault, ChF = Chaman Fault, MFT = Main Frontal Thrust, MBT = Main Boundary Thrust, MMT/IYS = Main Mantle Thrust/Indus-Yarlung Suture, MKT/SS = Main Karakoram Thrust/Shyok Suture, KF = Karakoram, Fault, DF = Darvaz Fault, TS = Tanymas Suture KYTS = Kashgar-Yecheng Transfer System, KF = Karakoram Fault, KaF = Karakax Fault, NP = Nanga Parbat Syntaxis, HKS = Hazara Kashmir Syntaxis, IKSZ = Indus Kohistan Seismic Zone, PHSZ = Pamir-Hindukush Seismic Zone) and epicenters of the earthquakes since 1950 are also shown as: yellow star (Mw > 7.0), red circle Mw > 6, green circle Mw > 5 and brown circle Mw > 4). The inset at the lower left corner shows the location of seismic stations: red triangles are ISC

stations, blue triangles are PMD stations and purple triangles are the CNEC stations. The white box shows the location of the study area (Source: Bhatti et al., 2018).

Based on the region's geological and seismic history, including current and past seismicity, and if available, paleo-seismological data and seismic hazard analysis should be conducted (Kumar et al., 2006). Additionally, the relevant evidence at this point typically includes information on earthquake rupture processes, faulting modes, stress fields, source mechanisms and other elements that can be helpful with understanding the local geodynamics.

The Western Syntaxis is a significant part of the Himalayan orogenic system and covers mainly two major seismic zones known as the Indus-Kohistan Seismic Zone (IKSZ) and the Pamir-Hindukush Seismic Zone (PHSZ), while the Indian plate subducts beneath the Hindukush and Karakoram Mountains chains (Burtman & Molnar, 1993). The Kohistan-Ladakh arc (KLA), which is sandwiched between the Indian and Eurasian plates and is a portion of the Western Syntaxis (Figure 1.9), evolves in complex structural and tectonic processes.

The northern portions of the Main Karakoram Thrust (MKT) and the Indus Suture (MMT) separate the Kohistan arc from the Asian plate and the Indian plate, respectively (Figure 1.9); (Li et al., 2008; Zhou et al., 2015; Bhatti et al., 2018).

Under the Pamir-Hindukush region, focal mechanism solutions (FMS) point to a combination of strike-slip and NW-SE oblique compression at shallow depths. The Hindukush is being subducted beneath the Indian plate, according to the NE-SW trending seismicity. There is an event cluster that is NS trending with an EW expansion in the crustal region along 73°E.

The Indus-Kohistan seismic zone is in Pakistan's Northwestern Himalayas (IKSZ). The IKSZ earthquake was a devastating earthquake that struck on October 8, 2008, killing hundreds of people and displacing tens of thousands. The Main Boundary Thrust (MBT) runs parallel to the Hazara Kashmir Syntaxis (HKS) in the IKSZ, which are characterized by thrust earthquakes with depths of 30 to 40 km.

Seismotectonic investigation

Models for possible earthquake sources that may have an impact on the site's hazards are developed using the geological and seismological data. The two main components of source characterization are: the seismic hazard map for the National Seismic Design Code of Pakistan (i.e., the Building Code of Pakistan) which is derived using the probabilistic seismic hazard assessment (PSHA) approach; and modeling of area sources based on the geologic history of the region in general and on earthquake occurrence statistics (historical and contemporary seismicity catalogues) in particular. The evidence revealed the standard earthquake catalogs, data on tremor rupture processes, faulting modes, stress areas, and source mechanisms that can help us better understand the geodynamics of the region. Seismograph recordings show that the region of high seismicity has many earthquake epicenters spread across several locations. The active faults are prevalent and capable of strong seismicity in the collisional mountain ranges. However, the stable Indus Platform is regarded as having low seismicity (Kazmi & Jan, 1997). Owing to their strong seismicity, the following seismic zones in the HKH region can be further elaborated.

Seismic Zone of the Hindu Kush and West Karakoram

The Tirich Mir region and the surrounding Afghan terrain are included in this zone. With frequent earthquakes of magnitudes 5-7 and focal depths of 100–200 km, it is seismically extremely active (Kazmi, 1979). A fault plane that extends down to a depth of roughly one hundred kilometers and a twenty-five-kilometer-thick deformed Benioff zone in the upper mantle are both indicated by focal mechanism solutions and the spatial distribution of earthquakes and their hypocenters. These characteristics are typical of places of active lithospheric subduction, according to (Billington et al., 1977). The Waser-Rushan Pshart Suture, which is the eastern extension of the Herat Fault or the

Akbaytal Fault of Afghanistan, runs through this region (Sengor et al., 1988; Boulin, 1990).

Seismic Zone of Yasin

Yasin's local area is seismically active, and there is a concentration of multiple earthquake epicenters with magnitudes of 3 to 5 and focal depths of under 50 km. The Main Karakoram Thrust passes through this region, and it is possible that this is where the earthquakes are coming from. Seismic data indicate that the major faults encircling this tectonic block are made up of a network of active faults. High seismic activity has been recorded close to Yasin, which has been attributed to the Main Karakoram Thrust (MKT), also known as the Northern Suture, which separates the Karakoram Block from Kohistan (Kazmi & Jan, 1997).

Seismic Zone of Hamran

There is a portion of the Ghizar Range that is remarkably seismically active. The south of Gupis, in the Hamran Valley, with frequent earthquakes of 3 to 5 magnitude and hypocenters between 50 and 100 km deep. These earthquakes have previously left Gupis and surrounding areas severely damaged. The main mechanisms for certain epicenters in this zone (Chandra, 1978) suggest thrusting on northwest trending nodal planes, despite the fact that no distinct active fault has yet been documented in this area (Kazmi & Jan, 1997).

Seismic Zone of Indus-Kohistan (IKSZ)

A telemetered seismic network that covered the region between longitudes 69 and 75 and latitudes 30° 30' and 35° 30' in northern Pakistan recorded data from about 10,000 earthquakes between 1973 and 1977 (Seeber, 1979). According to this study, the Salt Range and the Trans-Indus Ranges exhibit moderate seismicity, whereas the northwest boundary of the Indian plate, north of the MBT, has a zone of high seismicity. The NW-SE oriented Indus Kohistan seismic zone is located between the MMT and the Hazara-Kashmir region. This region's tectonic activity caused the 1974 Pattan earthquake (Jackson & Yielding, 1983). A wedge-shaped feature with a surface that slopes northeasterly and is 10 to 12 km deep is responsible for the majority of the seismicity in this region. (Seeber, 1979).

The roughly 500 km-long fracture that makes up the spectacular strike-slip Karakoram Fault defines the eastern terminus of the Karakoram Block. Along this fault, right-lateral displacement has been hypothesized (Burtman & Peive, 1963; Srimal, 1983). Along the fault, several earthquake occurrences have taken place. Right-lateral strike slip movement on this fault has been confirmed by the interpretation of seismic data from the 1975 Kinnaur earthquake (Ni & Barazangi, 1985).

Nine additional actions were noted by the International Karakoram Project in the area of Skardu, the majority of which took place along prominent lineaments visible on satellite images and from the ground. Particularly, the structures along the Shigar, Thala, Hushe, and Lower Shyok Valleys are likely to be active faults (Kazmi & Jan, 1997).

The Nanga Parbat-Haramosh Massif, northernmost promontory, overlies the Himalayan tectonically active structure, which is distinguished by current uplift rates of > 7 mm/yr (Zeitler, 1985). In this zone, a considerable seismicity (King & Yielding, 1984), and active faulting (Lawrence & Ghauri, 1983; Madin et al., 1989; Treloar & Coward, 1991) were previously identified. There is strong field evidence that the Raikot-Sassi Fault zone is an active fault feature, regardless of whether the MMT is offset by the Raikot Fault of Madin et al. (1989) along the western margin of the Nanga Parbat-Haramosh Massif or whether it extends for a significant portion of its length (Treloar et al., 1989).

In the Holocene gravels at Raikot, a 5km- to 10km-thick brecciated zone has formed along the Karakoram Highway. The gneissic sequence of Nanga Parbat within this fracture zone has developed the slickenside (Lawrence & Ghauri, 1983). The Raikot-Sassi Fault area is made up of a number of parallel faults farther to the north. These faults, the Hurban and Sassi-Dassu Faults, run over Holocene colluvium and Late Quaternary glaciated sediments near Sassi village (Shroder, 1989). This fault zone exhibits both thrusting and right lateral strike slip faulting.

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Chapter 2

Glaciology and Mountain Watershed Hydrology

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Passu Glacier, Hunza, Pakistan © Zafar Khan

Introduction

The Hindu Kush-Himalayas (HKH) region, also known as the third pole of the world, contains the largest snow and glacial ice mass after the polar regions. These glaciers feed 10 major rivers of Asia that serve as the main source of water for downstream areas and the Indus River is one of those flowing into Pakistan. Approximately 54,252 glaciers of various sizes and lengths exist in the HKH region, with a total area of 60,054 km^2 (Bajracharya & Shrestha, 2011), of those about 5,300 exist in Pakistan's part of the HKH region (Pakistan Meteorological Department [PMD], 2022). According to an estimate, almost 85 per cent of the main glaciated areas lie between 4,000 and 6,000 meters above sea level (m.a.s.l) in HKH region, and this elevation zone has been critical in terms of climate change impacts over the last many decades. These regions are also at high risk of glacier-induced hazards. Some glaciological phenomena can have significant effects on a society over a short time scale (minutes or days), such as ice/snow avalanches and glacial lake outburst floods (GLOFs). Other related hazards can also be threatening such as glacier surging, advance or retreat, or volume fluctuations that may induce water supply problems however, relatively less harmful when measured on a high time scale of months, years, and decades.

Glaciology

Glaciology is the scientific study of one of the Earth's cryosphere components. The term cryosphere originated from the Greek words *Kryos* meaning cold, frost or ice, and *sphere* meaning globe. This term is used for those parts of the Earth's surface where fresh forms of solid water bodies exist such as lake ice, sea ice, river ice, snow, glacier, ice sheets, ice caps, and permafrost (frozen ground). Glaciology is a broad and interdisciplinary subject that involves geophysicists, geologists, geomorphologists, geographers, climatologists, meteorologists, hydrologists, and many others. Glaciology subject can be classified into various branches, but the most important branches are as follows:

Physical glaciology: Physical glaciology is the main branch of glaciology that deals with the study of glaciers, their structure, internal processes, and physical properties.

Hydrometeorological glaciology: This branch of glaciology is concerned with the interaction of glaciers and the atmosphere and hydrosphere.

Geological-geomorphological glaciology: This is a branch of glaciology that mainly focuses on the interaction of glaciers and the earth's crust.

History of glaciology

Glaciology is an emerging field of natural sciences that commenced in the mid-twentieth century, and scientists (Clarke, 1987; Cunningham, 1990; Walker & Waddington, 1988) investigated the early history of glaciology. Various scientists around the globe have studied the flow of ice masses. Altmann (1751) clearly identified that glaciers move due to the force of gravity, later concluding that the sliding of ice over the glacier bed was the main cause of glacier movement.

In the late eighteenth century, Bordier suggested that many of the glaciers do slide over the bed, but the ice itself could flow like a very viscous fluid. A major contribution was made by Agassiz & Bettannier (1840), who coined the idea of glacier fluctuation over time. The authors concluded that the volume of glaciers was much more extensive than it is today. Clarke (1987) and Lliboutry (1994) argued that the known glaciological processes might have been identified in the nineteenth century if modern technology was available at that time. Since the advent of technology in 1990 like supercomputers, remote sensing, and geophysical dating techniques, many researchers undertook groundbreaking research and made a significant contribution to the field of glaciology.

Glaciology and glaciers

Glaciology is an extensive and dynamic field. It encompasses a wide range of research topics from snow to permafrost. This chapter covers glaciers and the process of their formation. The word *glacier* is derived from Latin meaning *ice*. Glaciers are large masses of ice that form where the accumulation of snowfall constantly exceeds the snowmelt and sublimation. Glaciers move slowly away from the center of accumulation, or down a mountain valley, due to gravity and stresses caused by their own weight. Figure 2.1a presents the example of an alpine-type glacier i.e., Hoper glacier in the Nagar valley of the Karakoram region of Pakistan, where the main stem is fed by several tributary glaciers. Figure 2.1b shows general geological and glacial features (moraines, crevasses, horn, cirque, snout, etc.) of a common type of alpine glacier.

(a) (b)

Figure 2.1 Glacier valley and different geological features (a.) Hoper glacier, Nagar; (b) Different geological features of a common alpine (valley) glacier. Source (a) WWF Pakistan; (b) Hambrey and Alean (1992)

Glacier formation

Glacier formation (Figure 2.2) is a complex natural process that takes years, often centuries. Snowfall in any area where the mean annual temperature is close to the freezing point is the first step for glacier formation. In the transformation of snow to ice, the snow initially changes into firn at a density of 400-830 kg/m^3. Due to the greater pressure of the overlying snow layers, this firn changes into glacier ice at a density of around 917kg/m^3. The mechanism of transformation of snow into glacier ice varies from place to place depending on the temperature of the area. For example, in temperate regions snow transforms into ice much more rapidly due to the refreezing of wet snow. In Antarctica, this process is slow because of the temperature which is well below the freezing point throughout the year.

Figure 2.2 Transformation of snow into glacial ice. (Source: Hambrey and Alean, 1992)

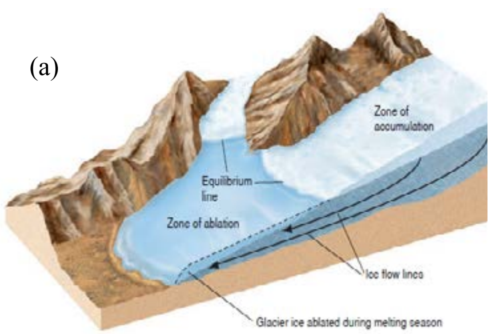
Glacier types based on size and occurrence

Glaciers are classified into two major types, namely *alpine glaciers,* and *continental glaciers* (Figure 2.3).

Alpine glaciers are mostly found in mountainous regions or terrains known as mountain glaciers. There are various types of alpine glaciers such as valley glaciers, hanging glaciers, cirque glaciers, tidewater glaciers, piedmont glaciers, and conical glaciers (Figures 2.3a and 2.4). Alpine glaciers are mostly found in the HKH region. This glaciated region is also called the *third pole* of the world, based on available frozen freshwater resources. Other areas include the alpine regions of the Cascade Range, the Alps, the Andes, and the Rocky Mountains in the United States.

Continental glaciers often occupy large areas (thousands of kilometers) such as a continent (Figure 2.3b). These types of glaciers commonly occur on flat terrains. These glaciers are further classified into two types: *ice sheets* (covering more than 50,000 km^{2} $^{area)}$ and *ice caps* (covering less than 50,000 km^2 area)**.** The most common examples of continental glaciers on the planet are the Antarctic and the Greenland ice sheets**.**

(a)



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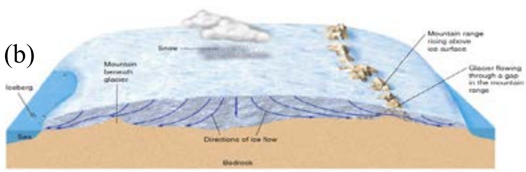


Figure 2.3 Images showing cross section of glacier around the world. (a. alpine glaciers, b. continental glaciers). (Source: Carlson, Plummer, and Hammersley, 2009)

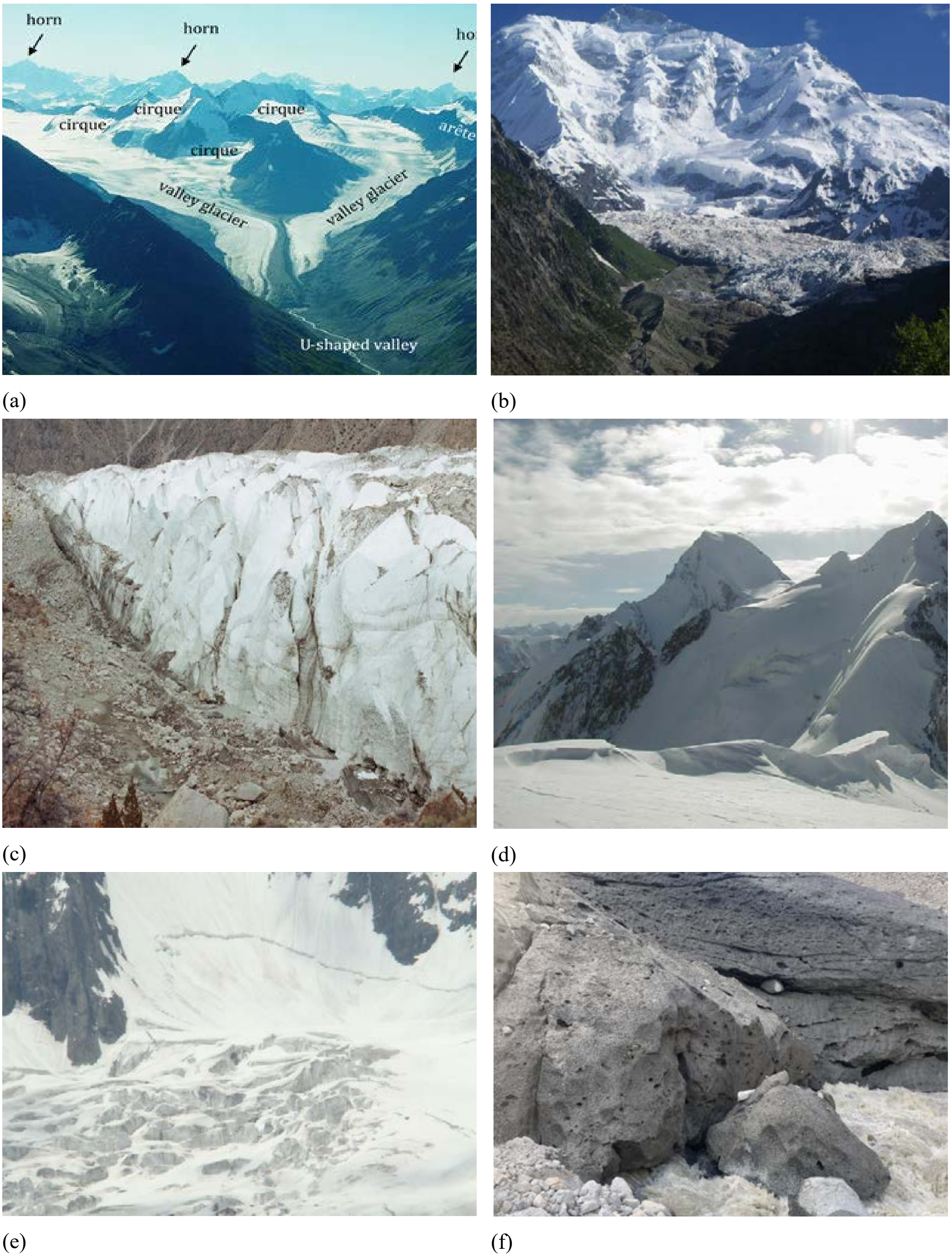


Figure 2.4 Various types of alpine glaciers found around the HKH region in Pakistan (a. Valley glacier; b. Hanging glacier; c. Piedmont glacier; d. Conical glacier; e. Cirque glacier; f. Tidewater glacier). Photo credits: Molnia and Post (1995); Bayliss et al. (2018) (2.4 a); Garee Khan (2.4 b, c, d, e, f)

Glacier types based on temperature

Thermal conditions are also to classify glaciers, namely *temperate, polar, and sub- polar glaciers* (Figure 2.5).

A **temperate glacier** is also known as a warm glacier, whose ice is at the pressure of melting throughout the year. Figure 2.5 shows the distribution of glaciers: temperate mostly on the continents of North America, South America, Europe, Africa, and Asia, on both islands of New Zealand, and on the island of Irian Jaya. Additionally, some of the glaciers of the Antarctic Peninsula and some of Greenland's southern outlet glaciers are temperate.

The **polar glacier** ice temperature is always below the freezing point throughout the year (Most of the world's glaciers exist in the polar regions, in areas like Greenland, the Canadian Arctic, and Antarctica. Glaciers can also be found closer to the Equator in some mountain regions).

A **Sub-polar glacier** is a combination of *two* thermal types of glaciers where the temperature is below the freezing point at the surface and at the base; the temperature rises to the pressure melting point due to geothermal heat below the surface.

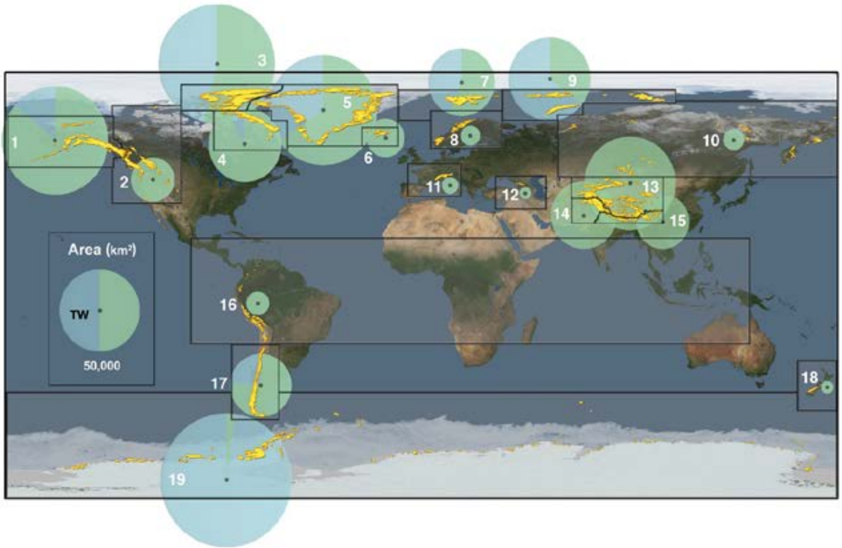


Figure 2.5 Global distribution of glaciers. The diameter of the circle shows the area covered by a glacier. Tidewater glaciers are shown in blue. The number refers to the RGI region (Source: Vaughan et al., 2013).

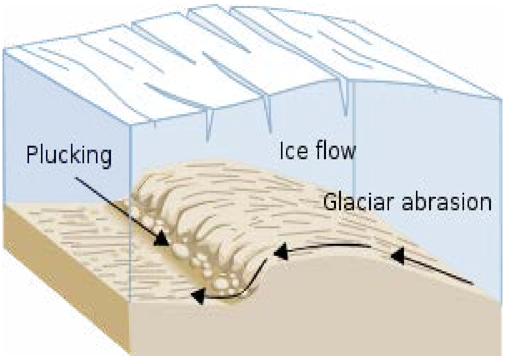
Glacial Landscape and Depositions

Glaciers may move up to few meters every day. Most glaciers move partly by plastic flow, and partly by shear movements. In the high-gradient valleys, a mountain glacier flows down the slope under gravity, much like a stream of water. Nevertheless, in basin-shaped, flat, or upland areas where the ice cannot move under gravity, the glaciers move due to differential pressure within the ice mass. The first type of movement is called the "gravity flow," and the second is called the "extrusion flow."

Over thousands of years, glaciers may erode their substrate to a depth of several tens of meters by this mechanism, producing a variety of streamlined landforms typical of glaciated landscapes. A glacier during its lifetime creates various landforms, which may be classified into two major types such as, **erosional** (forms when glaciers sculpt, carve, and carry away the land beneath them) and **depositional** (created by deposition, or what a glacier leaves as it retreats or melts away) landforms.

Glacial Erosion: A glacier's weight and movement can reshape the landscape over hundreds or thousands of years. The ice erodes the land surface and carries the broken rocks and soil debris away *via* different glacier processes such as *plucking / quarrying* (loosening and lifting blocks of rock), *abrasion* (sediment in ice acts as giant "sandpaper" which creates rock flour and striations (Figure 2.6a), and *frost wedging and bulldozing* (meltwater enters the ice cracks, refreezes and expands up to 11 per cent; while rock fragments firmly embedded in the ice scratch and grind the rock surface over which they move (Figure 2.6 b). These scratch-es and grooves left on the bedrock and boulders are called striations, indicating the direction of ice movement.

Some of the prominent erosional landforms of the glaciers are *cirque/corris*, which are deep, long, and wide troughs or basins with very steep concave to vertically dropping high walls at their head and sides. They are bowl-shaped depressions formed due to the erosional activity of glaciers. When these depressions are filled with water, they are called cirque lake, corris lake, or tarn lake.



(a)

(b)

Figure 2.6 Glaciers Processes (a. Glacier abrasion and plucking, b. Striations) (Source: Bayliss et al., 2018)

Hanging/U-shaped Valleys & Fjords*:* The glacier does not create a new valley like a river but deepens and widens a pre-existing valley by smoothening the irregularities (Figure 2.7). These valleys are formed by glacial erosions and assume the shape of the letter U hence the name. They are also called Hanging Valleys.

A fjord (*pronounced 'fyord'*) is a deep glacial trough filled with seawater and made-up shorelines. A fjord is formed when a glacier cuts a U-shaped valley by ice segregation and abrasion of the surrounding bedrock, and this valley gradually gets filled with seawater (formed in the mountains nearby a sea).

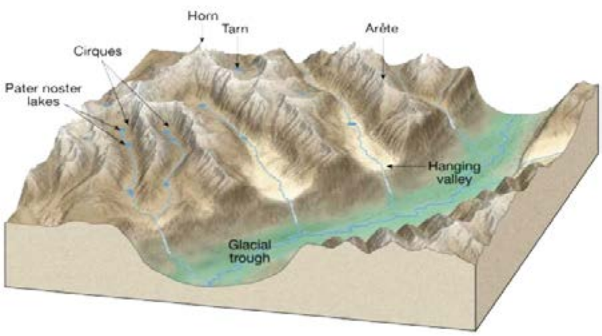


Figure 2.7 Glacier erosional landforms (Source: Bayliss, Tudor, and Hurst, 2018)

Horns and Aretes: *Horns* are sharp-pointed and steep-sided peaks. They are formed by headward erosion of the cirque wall. When the gulf between two cirque walls gets narrow because of progressive erosions, it forms a saw-toothed ridge called *Arete*.

Glacial deposits

There are two types of glacial deposits: The first one is *glacial till* (un-assorted coarse and fine debris), and the second is *outwash* (assorted roughly stratified deposits).

Moraines are long ridges of the deposits of glacial till (Figure 2.8). When these deposits are at the end of a glacier, they are called terminal moraines; when the deposition are on both sides, they are called lateral moraines. When lateral moraines of two glaciers join, they form medial moraines. The lateral moraines of both sides of a glacier join to form a horseshoe shape. Ground moraines are deposits left behind in areas once covered by glaciers.

Figure 2.8 Types of Moraines (medial and lateral). © *Sher Sultan Baig*

Eskers: When glaciers melt in summer, the water because of melting accumulates beneath the glacier and flows like streams in channels. Very coarse materials like boulders, blocks and some minor fractions of rock debris are carried away by these streams. They later get deposited in the valleys themselves, and once the ice melts completely, they are visible to the surface as sinuous ridges. These ridges are called Eskers.

Drumlins: They are smooth oval-shaped ridge-like structures composed mainly of glacial till. It has the shape of an inverted spoon, with the highest part called the stoss end, and the lowest, narrow part is called the tail end. They are the result of glacial movement over some minor obstructions like small surface rocks, where glacial till gets deposited, while the glaciers' movement shapes these deposits like an inverted spoon.

Distribution of glaciers in the HKH region

The HKH region is regarded as the third pole outside the polar regions because of the huge glaciated area present in the region (Figure 2.5 and 2.9). The region hosts 54,252 glaciers, covering a total area of 60,054 km2, and an estimated ice reserve of 6,127 km3 (Bajracharya & Shrestha, 2011). A major river basin originating from the HKH–TP (Tibetan Plateau) region where cryosphere contributions to river flows are highly significant and extremely susceptible to climate change is Upper Indus Basin (UIB) (Khan, 2015), which straddles three great mountain ranges and is the abode of some of the

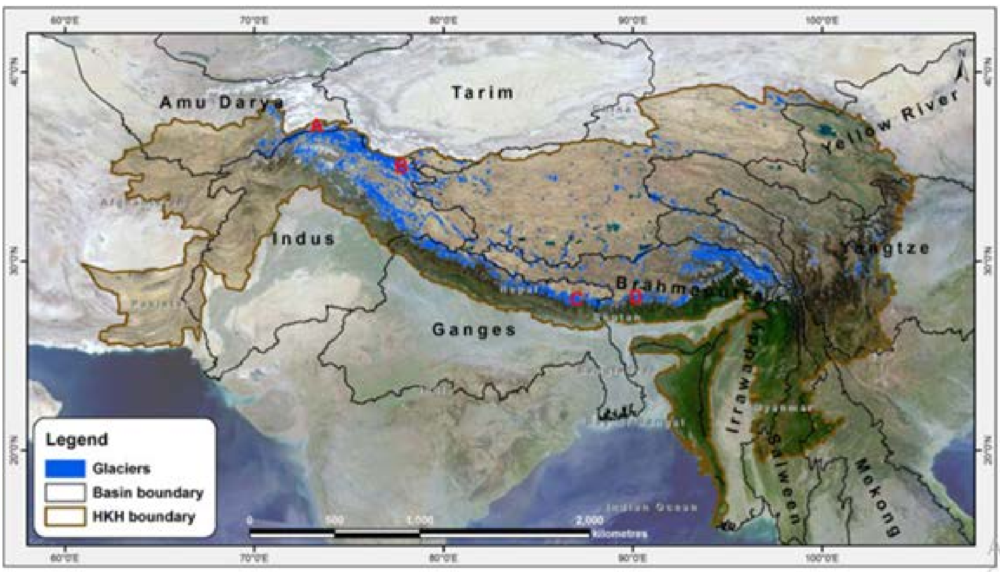


Figure 2.9 Distribution of glaciers in the Hindu Kush, Karakoram, and Himalayas region; red letters – A: Wakhan Corridor, Afghanistan; B: Shyok Basin, Pakistan; C: Imja Valley, Nepal; D: Lunana area, Bhutan – indicate the representative glaciers for which decadal changes are shown. (Source: Bajracharya & Shrestha, 2011)

remarkable glaciers, such as Siachen, Baltoro, Biafo, and Hispar, and surrounds snow-covered mountain peaks and slopes (Mukhopadhyay & Khan, 2014). The UIB contains 11,413 glaciers covering an area of 15,061.74 km2 (Bajracharya & Shrestha, 2011). The UIB has a total drainage area of about 172,000 km2 and extends across different parts of Pakistan, India, and China (Ali & De Boer, 2007; Khan, 2015).

Contrasting Behavior of Glaciers in the Upper Indus Basin

According to the Global Land Ice Measurements from Space (GLIMS) report by Kargel et al. (2014), many glaciers exhibit retreating, stationary, or advancing termini. The presence of a longitudinal gradient in the frequency of advancing and retreating glaciers, such that glaciers in the westernmost portion of Pakistan (Hindu Kush) appear to be dominantly retreating (Gul et al., 2020), whereas towards the east an increasing number of glaciers have advanced in Baltoro-Mustagh region, near K2 Mountain in the Karakorum. This longitudinal gradient in the frequency of advancing glaciers is most likely related to climate forcing. Previous climatological, hydrological, and glaciological studies suggested that the north-eastern portion of the country has received more precipitation and the glaciers may be responding differently to climate forcing, and to changes in temperature during summers as compared to others elsewhere in the Himalayas.

Glaciers and Climate Change

Mountain areas are particularly vulnerable to climate change, and the HKH region is no exception. Several noticeable impacts related to climate change have already been documented. The glaciers of these regions show signs of shrinking, thinning, and retreating (Bajracharya & Shrestha, 2011). The consequences of any change on glaciological hazards and water resources are complex and therefore unpredictable. The general trend appears to be one of the glacial retreats, as in many mountain areas across the world, but observations of individual glaciers (Figure 2.10) indicate that the annual retreat rates vary from basin to basin (Bajracharya & Shrestha, 2011). At the same time, growing glaciers and increasing ice mass balances have been reported in the western Karakoram mountains (Hewiitt, 2005, 2010; Scherler et al. 2011). Unpredictable variations in glacier response are more likely a complex pattern of climatic changes within the Himalayas (Bajracharya & Shrestha, 2011).

(a)

(b)

Figure 2.10 Glaciers in the HKH region. (a. A glacier snout exposed with the outlet; b. Proglacial Lake formed at the snout of Darkut glacier), © Garee Khan

The HKH terrain makes the world's lightest and most extended mountain range, occupying massive glaciers. These mountain ranges extend in the east-west direction between China and South Asia, in Pakistan. The ice reserves in the HKH region appear as a treasure of solid ice and are the primary water source for downstream areas. Most glaciers around the globe are vulnerable to degradation, with a few exceptions to Andes and Alps in Europe. Polar ice sheets and Greenland glaciers, followed by a Himalayan glacier, are at the top in terms of deglaciations around the world. During the last two decades, there has been a huge uproar on global deglaciation, which would ultimately be manifested as sea level change, water scarcity over the plains, and change in the mountain ecosystem. In the HKH region of Pakistan, in the last couple of decades, the exothermic dynamics of heat in upslopes have increased on a pentad basis. The climatological data has revealed that the 30^{o} C isotherm elevation had gone up by 725m in 28 years (Rasul et al., 2008), while the heat wave duration and frequency had also doubled (Rasul et al., 2008). This has influenced an increase in thunderstorms and lightning events in the HKH region. Such changes in the HKH climate are an example of anthropogenic climate change, which has directly influenced glacier dynamics, accelerated the rate of glacial diminution, as recorded on the Siachen glacier, which retreated about 2km of its length and 17% of mass since 1989 (Rasul et al., 2008).

Glaciers as the Main Water Resource

Mountains are regarded as the "water towers" of the world (Messerli & Ives, 1997). Densely populated regions near the Himalayas are more vulnerable to the impact of deglaciation (Barnett et al., 2005). Pakistan's HKH mountain region has vast frozen mass of ice that serve as the country's rooftop water tank (Figure 2.11 a, b), whose regulation is associated with temperature. Over 80 per cent of the primary feeders of the upper Indus River are spread in less than 20 per cent of its area. The Trans-Himalayan contribution comes from an area of about 20,000 km2 of the largest glaciated basin (Hewitt, 2010).

(a)

(b)

Figure 2.11 Melting of glaciers in HKH region (a. Ghulkin glacier, Hunza, b. Formed supra glacier lake at the Bonny glacier Chitral), © Garee Khan (a), Sher Sultan Baig (b)

Glacier Dynamics

Similar to the flow of water, ice also moves under the influence of gravity. The timescale for the movement of ice depends on multiple factors such as temperature, steepness of topography, and the presence or absence of underneath water. For large ice sheets like a continental glacier, the timescale for the ice flow takes millions of years. Similarly, for glaciers covering smaller areas, such as valley glaciers, it takes decadal, annual, or even sub-annual years. The rate of flow of glaciers can be calculated with help of Glen's flow law which represents the relationship between stress and the strain rate, where stress is related to ice density (Janes & Bush, 2012).

The simplified scenario for the origin of the glacier is mass accumulation at a high elevation which flows down the slopes to a lower elevation where it melts. The accumulation at a high elevation that is equal to net loss is known as equilibrium line altitude (ELA). This depends on temperature and net snowfall (Janes & Bush, 2012). If the ELA is generally higher than the surrounding topography, then the existence of a glacier is precluded. Therefore, the increase of ELA due to climate change is a matter of concern for the glaciers near the top of the topographic environment.

Rheology

Rheology is basically concerned with the flow and deformation of matter/ice. For glacier behavior, the dynamics of a glacier depend on its rheology. Ice is basically brittle in nature and is prone to fracturing when stress is applied. And it behaves like plastic when the applied stress has a relatively slow timescale. This timescale separates this behavior and is known as Maxwell time which represents the ratio of the kinematic viscosity of ice to the shear modulus of ice deformation. Fractures on the glaciers are caused by brittle behavior which results in the formation of crevasses when the flow of glaciers is over the topographic features.

Glacier fluctuations

Non-surging glaciers are usually regarded as one of the "quieter" natural hazards due to their direct effects on society. Normal glacial advances are often non-catastrophic, and it is doubtful that any lives would be lost because of these occurrences. The largest possibility of risk is the disruption brought by the inundation of land, buildings, and infrastructure. Communities may be at risk from glacial advances, however, most of the Himalayas' non-surging glaciers have been retreating throughout the 20th century (Mayewski & Jeschke, 1979). Numerous indirect risks can also be created by variations in glacier flow velocities or fluctuations in glacier terminal placements. Variations in ice flow velocity have the potential to cause slope collapses by undermining valley sides and/or terminal moraines. According to MacDonald (1989), erosion and flow changes along the Bualtar and Barpu glacier edges in Pakistan's Karakoram-Himalaya have resulted in the loss of land and property. Over time, the cumulative damage brought on by such frequent small-magnitude occurrences can be as devastating as larger, more catastrophic events.

Glacier surges

A glacier surge is defined as a dramatic, order-of-magnitude increase in ice movement across a glacier over a brief period, often weeks to months (Sharp et al., 1988). As the wave of enhanced ice flow descends the glacier, a rise in the height of the glacier's surface and an increase in crevassing are often observed. It is difficult to forecast the behavior of surges since they frequently occur in cycles unique to specific glaciers that are not in sync with global climate patterns. The glacier terminal may move many kilometers in comparison to its pre-surge location in certain situations, while other surges may be confined inside the glacier. Rapid snout advances when a surge approaches the glacier terminal can cause issues with flooding of land, property, and infrastructure (Wenjing, 1992). The damming and subsequent breakout flood of Russell Fjord, Alaska, in 1986 (Mayo, 1988) is a good example of how the damming and subsequent outbreak flood of local rivers or fjords may be temporarily caused by the advancing glacier tongue of Shishper (Figure 2.12b) and retreating glacier behavior of Ghulkin glacier (Figure 2.12a). With 26 documented surges involving 17 glaciers in the previous century, the Karakoram-Himalayas region is thought to have the largest frequency of advancing glaciers outside of the Arctic islands of Svalbard and the Alaskan Yukon Mountain of North America (Hewitt, 1998). For instance, the Chiring glacier in north-central Pakistan had a surge that resulted in enhanced crevassing and reorganization of the glacier's structural elements both during and after the surge. The surge was confined by the glacier, but large regions of seracs were formed, increasing the possibility of an ice avalanche. The overall number of glaciers, impact on their location, and the underlying mechanisms remain unknown, and Himalayan glacier thinning is still only sometimes documented.

(a)

(b)

Figure 2.12 (a) Gulkhin Glacier snout after a surge ended in year 2020; (b) Shishper Glacier surging 2019 © Garee Khan.

Glacial-induced hazards and impacts

The project of IGCP415's (Glaciation and Reorganization of Asia's Network of Drainage) major goal is to investigate the magnitude and timing of Late Quaternary glaciation in Asia (Figure 2.13), as well as the influence of glacier fluctuations on the continent's hydrological systems. The retreat of glaciers from their Neoglacial maximum reveals glaciological and glacial-geological processes that influenced the region throughout the Late Quaternary and following glacial events. The current threat posed by glaciers (Figure 2.12 a, b) and their consequences on human actions is linked to these mechanisms. A glacial hazard is any glacier or glacier-related feature or process that has an unfavorable effect on human activities, either indirectly or directly (Figure 2.15 a, b). This includes a wide range of mechanisms, such as glacier retreat brought about by climate change, which results in increased water storage underneath destabilizing moraine dams at high altitudes, catastrophic glacial lake outbursts damage critical infrastructure, and avalanches endangering the lives of farmers.

In one of the biggest documented occurrences, glacial debris flow crossed a hill 150 meters high. With a 500-meter-wide and six-storey-tall debris flow front, and traveling at speeds exceeding 80 kph, it approached the peak of the hill before descending on the town of Yungay in Peru in 1971 (Oliver-Smith, 1979). At Huascarán in the Cordillera Blanca, 20,000 people had lost their lives within 5 minutes of the tragedy (Lliboutry et al., 1977).

Glacial risks draw attention towards two primary reasons: (a) the potential for fatalities; and (b) the grave threat they pose to expensive facilities like hydropower plants, highways, etc. Conflicts with glacial dangers are becoming increasingly obvious as human activity moves further into high alpine regions of the planet. In Peru, glacial lake outbursts have affected almost 32,000 people this century; in the Himalayan mountains, numerous individuals and cattle have perished in the previous 50 years due to being carried away in the catastrophic outflows from lakes high in the mountains. Due to rising land-use constraints and resource exploitation, commercial ventures in Asian nations are unintentionally expanding into regions vulnerable to glacial hazards. For example, an established hydroelectric power project worth over $500 million was destroyed in Nepal. Since one or more generations might be affected by the repercussions of such a loss of generating capacity, and the economic progress of a nation could be jeopardized by a significant and extremely catastrophic occurrence. Even the perception of danger from glacial hazards may be enough in extreme circumstances to limit national investment in rural development. As a result, host governments in the Himalayan area are currently addressing this hazard at the national level (Chhetri, 1999).

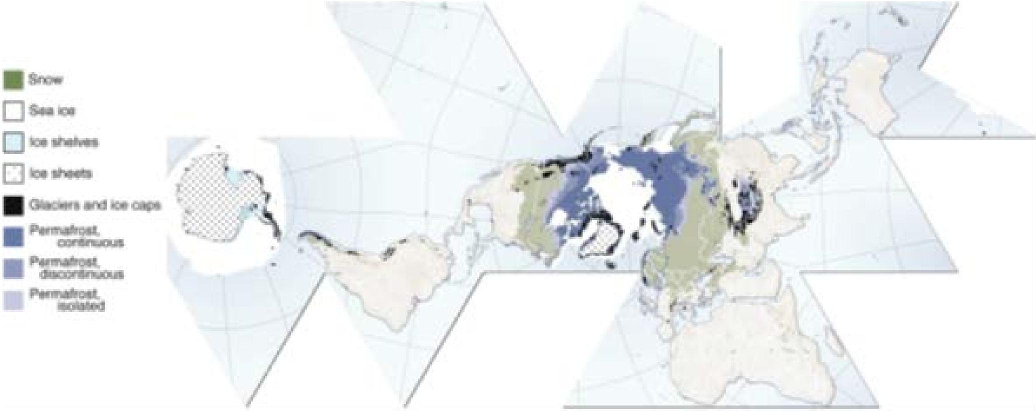


Figure 2.13 Distribution of the cryosphere (Source: Jones, 2008).

Indirect hazards associated with deglaciation

Rock avalanches and landslides can be sparked by meltwater from glaciers and snowbanks in conjunction with freeze-thaw temperature pattern (Hewitt, 1998). Slope collapses can create secondary hazards by obstructing rivers or operate as a primary hazard by directly flooding towns and infrastructure. In 1841, a flood from a rockslide-dammed lake on the Indus River to the northeast of Nanga Parbat, Pakistan, destroyed a Sikh Army camp at Attock more than 200 km downstream (Richardson & Reynolds, 2000). 1858, the breach of a landslide across the Hunza valley caused a 9-meter rise in river level at Attock in less than 10 hours (Evans et al., 2011). Sarez Lake, in the Pamir Mountains of Tajikistan is currently attracting attention of the popular scientists (Ives, 2004). The lake, which is 60 km long and up to 500 m deep, was dammed by a landslide in 1911, but is now showing increasing signs of instability (Strom, 2010). Similarly, in Gilgit-Baltistan, Pakistan, the Shishper and Badswath glacial lakes outburst floods catastrophically damaged infrastructure and agriculture in the recent past (Figure 2.14).

(a) (b)

Figure 2.14 GLOF Events in Gilgit-Baltistan. (a) Banks erosion caused by Shishper GLOF event 2020; (b) Agricultural land eroded by the Badswath GLOF event 2021, © Garee Khan.

Types of glacial hazards

Two basic categories of glacial risks exist (Table 2.1). Avalanches, glacier outbursts, and glacial expansions are examples of direct glacial hazards, sometimes known as glacier hazards, which include the direct action of ice and/or snow. As a by-product of a glacial feature or process, indirect glacial hazards might be catastrophic lake breaching caused by blocked moraines or issues with water supply brought on by melting glaciers and climate change. Any particular glaciological phenomenon must first demonstrate human susceptibility in order to be labelled as a threat.

Table 2.1 Types of glaciers, glacial, and related hazards (Richardson & Reynolds, 2000)

Category	Hazard event	Description	Time scale
Glacier hazards	Avalanche	Slide or fall of a large mass of snow, ice, and/or rock	Minutes
	Glacier outburst	Catastrophic discharge of water under pressure from a glacier	Hours
	Jökulhlaup	Glacier outburst associated with subglacial volcanic activity	Hours-days
	Glacier surge	The rapid increase in the rate of glacier flow	Months-years
	Glacier fluctuations	Variations in ice front positions due to climatic change, etc.	Years-decades
	Glacial Lake Outburst Floods (GLOFs)	The catastrophic outburst from a proglacial lake, typically moraine-dammed	Hours
	Debacle	The outburst from a proglacial lake (French)	Hours
	Aluvion	Catastrophic flood of liquid mud, irrespective of its cause, generally transporting large boulders (Spanish)	Hours
Related hazards	Lahars	Catastrophic debris flow associated with volcanic activity and snowfields	Hours
	Water resource problems	Water supply shortages, particularly during low flow conditions, are associated with wasting glaciers and climate change, etc.	Decades

Snow/ice avalanches

The most well-known and investigated glacier and snow-related dangers are avalanches. Snow avalanches may be categorized according to the amount of debris involved in a particular event, and the vertical plunge it undergoes. Only orders of magnitude are used to estimate the intervals between events, which range from 104 yr-1 for sluffs to maybe two extreme snow avalanches every century. The track, the beginning zone, and the runout-deposition zone are the three basic components of an avalanche route. Avalanche style may be divided into two categories: slab avalanches, which are generally more deadly, and loose-snow avalanches, which rely on the kind of initiation mechanism and beginning zone failure patterns (Figure 2.1b).

In Central Asia's high mountainous regions, no such methods are used. For instance, the local people in Himalayan valleys are more likely to be familiar with the regular snow avalanche trails based on their prior experiences. By refraining from using the land near known avalanche paths, the susceptibility of the local population to snow avalanches can be frequently decreased. Ice avalanches' unintended consequences are a far bigger issue. Large ice avalanches might choke up river valleys for a while. When they crash into moraine-dammed glacial lakes, even little ice avalanches from overhanging or calving glaciers can pose a major secondary hazard.

Glacial floods

In addition to outbursts of glacial lakes that have been blocked by ice and moraine, glacial floods can also be discharged directly from a glacier that is sub-, en-, or supra-glacial. Both jökulhlaup and a glacier outburst refer to the rapid release of water under pressure from a glacier (Table 2.1).

The Icelandic word jökulhlaup was used first to describe the kind of flood connected with a subglacial volcanic plosion Thorarinsson (1939) and has subsequently been used as synonymous with glacier outburst. A catastrophic breach through the ice may occur if melting ice within the glacier is able to build up pressure to the point that the hydrostatic pressure surpasses the limiting cryostatic pressure. Water may enter the subglacial drainage system already in place, where it may then empty into the glacier snout. Because it frequently develops over the course of only a few minutes and provides little advance notice to the towns downstream, the accompanying flood surge is exceedingly deadly (Haeberli, 1983).

(a) (b)

Figure 2.15 Damage caused by GLOF Events of 2021 in Gilgit-Baltistan. (a. Shishper, Hunza; b. Badswat, Ghizer). Photo credits: Garee Khan

Ice-dammed lakes can discharge either by flotation of the ice dam and subglacial discharge, by erosion of an over-flow stream into the reservoir surface, by ice peripheral drainage where the glacier dam meets the valley side, and/or by mechanical failure of the dam. Through the gradual expansion of subglacial channels, mathematical models have been created to describe the processes of subglacial and ice-dammed lake drainage (Clarke, 1982; Nye, 1976). When the thinnest portion of the ice dam starts to float, the simulated floods start. Water may release mechanical and/or thermal energy when it flows beneath the dam, most likely in one major channel or a network of smaller channels. As the channel(s) become larger, the water flow increases, allowing for even further channel enlargement. Drainage stops when the static pressure around the channel exceeds the decreasing water pressure, which causes the channel to close quickly. As a result, the flood hydrograph often features a lengthy rising limb followed by a sharp descending limb. This process can happen instantly or over a time span of several, giving no time to take precautionary action.

Outbursts from lakes with moraine dams normally happen when the lake water overflows, eroding the moraine dam until it catastrophically fails, when the hydrostatic pressure surpasses the lithostatic pressure that restrains it. Typically, a trigger mechanism is needed, such as a displacement wave from an ice or rock avalanche or a dissolving ice core inside the dam. Later, greater in-depth consideration is given to factors influencing the creation and collapse of moraine dams. There are several names for eruptions in moraine-dammed lakes. The term "Glacial Lake Outburst Flood" (GLOF) has been used frequently to refer to the catastrophic outburst. Lliboutry et al. (1977) of proglacial moraine-dammed lakes (Figure 2.14

and 2.15).

GLOFs in Asia have mostly been seen in the central and eastern Himalayas, as well as the Qentanglha and Benduan Mountains of south-eastern Tibet (Reynolds et al., 1998; Yamada, 1998). GLOFs have also been frequent in northern parts of Pakistan in the past few decades.

Possible mitigations, including early warning systems

There are a lot of high-risk glaciers and associated glacial lakes in the HKH region. It has recently been a top concern in this area to effectively mitigate dangers caused by glaciers and the associated GLOFs. An effective and crucial instrument for reducing hazards associated with climate change is real-time glacier monitoring and a GLOF early warning system (EWS). It is a key component of an integrated risk management approach. Disasters' negative effects on the economy and society are lessened and the loss of life is prevented. Lake level changes, end-moraine displacement, ice breakup, and downstream runoff are all being monitored by the EWS. Radio, speakers, Google Chrome, Yahoo, satellites, and a mobile network are just a few of the communication channels through which the monitoring data can be sent to the data center. One of the most cutting-edge systems is the EWS scheme. The most practical approach to minimizing possible risks to high-risk glacial lakes is to have an early warning system in place. The EWS system is less expensive than remedial work for glacial lakes at high risk, as well as helpful for corresponding actions, such as lake dam immobilization, open cuts, tunnelling, siphon, converting into artificial dams for power generation, etc., artificial drainage projects, and offers more useful environmental monitoring data in high mountains (Zhang et al., 2022).

Glaciers and hydrological modeling of mountain watersheds

Mountains have a significant impact on the volume of water that flows to the downstream areas through major regional tributaries, such as the Indus, Brahmaputra, Mekong, Ganges, Irrawaddy, Mekong, Salween, Yellow River, and Yangtze. The source of eight important river systems is the Himalayan range. The glaciers, ice, and snow that provides freshwater, depend on one-sixth of the world's population. They serve as a lifeline for the residents of the downstream communities in the Hindu Kush-Himalayan (HKH) mountain range. Snow and glaciers also serve as natural water basins that continuously supply the Indus River and its offshoots (Garee, Chen et al., 2017).

To prognosticate the process of snow and glacier melting, various models have been utilized, oscillating from simple algorithms, such as the temperature index-based algorithms, to sophisticated algorithms (Garee et al., 2017; Tahir et al., 2011).

Pakistan's economy is primarily based on agriculture, which is largely supported by the Indus Basin Irrigation System (IBIS), one of the major integrated irrigation systems in the world. The Indus River System (IRS) may be irrigated by rainfall from the northern watersheds of the Upper Indus Basin, snowmelt, and glacier runoff, which cover 2,200 km^2 of permanently glaciated land. Almost 65 per cent of the total annual flow of the IRS is produced above 3,500 meters above sea level by glaciers and permanent snowfields. The fact is that these glaciers are very dynamic, have significant flow rates (100–1,000 m/year), and frequently traverse different temperature zones (Young & Hewitt, 1990). Gilgit-Baltistan (GB) is a mountainous region in northern Pakistan with a range of elevations between 2000m to 8611m above sea level, harboring distinctive glaciers. Snow cover direction is both an opportunity and a challenge for researchers to explore more about the hydrological procedures taking place in the area (Garee et al., 2017).

Various impacts of climate change on regional hydrological regimes differ from basin to basin, water temperature, streamflow volume, evapotranspiration, amplitude, frequency, overflow, soil moisture, and floods are a few variables that could influence hydrological processes. Additional environmental factors are facing effects like nutrient movement into water bodies, sedimentation, and plant development. Human activities – electricity generation, agricultural production, water supply and use in industries and urban areas – wildlife, and the biotic ecosystem would all be impacted by the effects of such hydrological changes (Zhang et al., 2007).

Local hydrological processes have an impact on climate change under the same climate conditions and scenarios, despite regional differences in the hydrological environment. Numerous studies have been conducted to determine how the size of watersheds or river basins in the Upper Indus Basin (UIB) will change because of snow, glacier, and their associated hydrological processes of melting.

Planning for water supplies and many other elements of glacier study depends on models of glacier hydrology. As we have learned more about the glacial system, model complexity has also grown. Reliant on the usage of the modelled outcomes, various models might be applied. The primary models to simulate glacier emancipation were stochastic ones. Such models' popularity has decreased since they are difficult to operate and necessitate substantial site-specific calibrations. For calculating discharge from glacierized basins, conceptual models are the most often employed models. The idea of linear reservoirs is frequently used for movement, melting and rainwater water across (Garee et al., 2017; Tahir et al., 2011).

As a result, various efforts have been made in the past to create experiment-based models that encompass every process in the glacier hydrological system. These models nevertheless produce good results despite the inherent difficulties. Due to their low data requirements and simplicity of use, conceptual models will likely continue to lead monitoring and prognostication in applied hydrology, whereas physically based models will likely assume a greater significance in glacial hydrological research (Garee et al., 2017; Tahir et al., 2011).

A majority of conceptual, rather than physical and regionally distributed hydrological models, are utilized for the UIB. Several hydrological regimes in the UIB are especially vulnerable to conditions brought on by climate change, notably those connected to temperature and precipitation patterns. To fully grasp how severely climate change affects both people and natural resources, it is imperative to do local and regional climate trend studies.

Except for those who used several factors to examine the data to comprehend the behavior of glaciers at the size of river basins, no one has yet adopted multi-objective or multi-variable calibration methodologies (Tahir et al., 2011). Most models used for UIB are essentially temperature index-based models, created from specific input information to obtain watershed's physical attributes (Garee et al., 2017; Tahir et al., 2011).

It is scientifically interesting and practically useful to model glacier hydrology. So far glacier hydrology has greatly benefited from modelling work. Models to anticipate glacier runoff have developed as a result of the increased area where humans are abundantly affected by glacier overflow. The optimization of hydroelectric generating schemes, reservoir operation, water supply, and flood foretelling are just a few of the many applications for such models in watershed management. They are also frequently used to determine how much the melting of glaciers contributes to sea level rise. Considering predicted increase in glacier retreat and global warming, the need for modeling is particularly underlined.

Watershed management

A watershed is an area consisting of lakes, ponds, estuaries, and rivers that is solely responsible for shedding and draining water in a specific water receiving body e.g., a river, sea, or lake. In the watershed, as rainwater or snowmelt flows downward, silt and other elements are picked up, transported, and dumped into the receiving waterbody (Heathcote, 2009).

Watershed management is the process of implementing land use and water management practices to safeguard and enhance the quality of water and other natural resources by controlling them in an all-encompassing way (Heathcote, 2009).

Watershed features and a natural resource inventory should be the initial steps in comprehensive watershed planning. To adequately plan for the enhancement of the watershed's resources and to quantify such changes, it is crucial to create a baseline for the nature and quality of the watershed.

The process of watershed management planning yields a plan or blueprint for how to best safeguard and enhance the water quality and other natural resources in a watershed. Very frequently, watershed boundaries cross political boundaries into neighboring states and/or municipalities. Since all affected municipalities are located within the watershed, a thorough planning process is crucial for effective watershed management (Blomquist & Schlager, 2005). Significant volumes of pollutants can enter a lake or river because of overflow from rains or snowfall. Watershed management recognizes different types of pollution present in the watershed area, the ways in which pollutants are carried, and new recommendations on how to lessen or remove the sources of pollution.

The activities that have a harmful impact on the health of the watershed are fully identified by watershed management planning, and recommendations are made on how to effectively handle them to lessen the negative effects of pollution. Political boundaries do not coincide with watershed limits therefore, decisions made locally in one municipality can have an equal or greater influence on the land and water resources of another municipality upstream. The efforts at town-level in downstream areas to regulate pollution can occasionally be undermined by effects from upstream sources. The health of the watershed's resources depends on comprehensive planning, including involvement and commitment from all the towns in the watershed.

Planning and management for watersheds

The partners or "stakeholders," in the watershed should be identified and included in the planning process. Public knowledge and support may also increase because of the growth of local partnerships. Involving local communities and their capacity building regarding glacier dynamics in watershed areas, those who frequently get more active in both hands-on preservation and restoration work and the decision-making process. By encouraging such participation, watershed management increases the possibility of success in management plans by fostering a feeling of community, assisting in the resolution of conflicts, and increasing commitment to meeting environmental goals (Evans et al., 2011).

Local collaborations

A timeframe for completing pollution reduction, resource and habitat improvements should be established as part of the watershed management planning process. This planning should also identify possibilities to reduce pollution or solve other urgent environmental challenges. The highest priority for control and reduction may be given to those problems that represent the greatest harm to human health, specific resources, or preferred uses of resources. Plans for watersheds management should specify precise objectives, visions, and ways forward, such as:

- Upgrading the infrastructure. Repairing or replacing insufficient stormwater treatment systems, maintaining municipal stormwater systems more frequently, finding and removing unauthorized (i.e., non-stormwater) connections to municipal stormwater systems.
- Reducing paved areas and other impermeable surfaces, particularly those close to wetlands and water bodies.
- Determining the best locations for designing greenways, acquiring open space, and creating vegetated buffer zones around water bodies and wetland regions.
- Identifying additional good housekeeping practices for landowners and homeowners such as promoting the use of vegetated buffers next to water bodies and wetlands, minimizing the amount of fertilizer and pesticides used in lawns, washing cars on lawns rather than driveways so that rinse water can drain into the lawn rather than into storm drains etc.
- Locating and assessing potential non-structural flood prevention opportunities.
- Increasing recycling, pollution prevention, and waste management initiatives at public buildings and commercial establishments within the watershed.

Education and awareness

The success of watershed management can be significantly impacted by the level of public education and involvement in the planning process. The public can be involved in watershed management in a variety of ways, including education. Living in an inclusive society, every individual shares the benefits and hazards of natural resources. The world is facing serious water-related challenges; therefore, all stakeholders must devise a policy for water resource management and educate the society to take ownership of this vulnerable natural resource.

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Chapter 3

Land Use Land Cover in Mountain Regions

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Built-up area and agriculture fields expanding into forest landscapes, a village in Minimarg valley, Astore, Pakistan © Zafar Khan

Introduction

Land Use Land Cover (LULC) refers to the distinction between natural landscape elements and human activities on land usage. It is further classified and categorized using geospatial data techniques such as remote sensing and Geographical Information System (GIS) methods. These modern techniques are reliable in terms of data accuracy in detecting and monitoring LULC and patterns of change that occur on the surface. The data depicts changing patterns in mountain areas caused by both man-made and natural factors. Growing urban structures, population growth, tourist influx, and industrial activities are some of the anthropogenic contributions. In contrast, natural disasters include Glacial Lakes Outburst Floods (GLOF), landslides, flash floods, and debris flows. Most land use scientists believe that mountain ecosystems are distinguished from other types because they have distinct management practices resulting from implementing specific policies. When combined with external factors such as tourism and mining, these practices can significantly impact LULC changes. Fair environmental policies, solid laws, and valuable human inputs can all contribute to more sustainable natural resource management.

Overview of LULC

Land cover refers to the ground's surface cover, which includes urban infrastructure, vegetation, bare soil, water, and other features, whereas land use refers to how people use land for socioeconomic purposes. Although the terms land use and land cover are frequently used interchangeably, each has a distinct meaning. Land use refers to the purpose of the land, such as agriculture, wildlife habitat, or recreation. The physical material that covers the earth's surface is referred to as land cover. The identification of land cover forms the basis for activities such as change detection analysis and thematic mapping.

The growing and diverse user community recognizes and adapts to global standards of land cover and land use for development but in a more locally contextualized manner. Similarly, by adopting sustainable green policies and their implementation on land use, conservation, and restoration initiatives, the monitoring of sustainable development through Earth system modeling applications has become widespread (Potapov et al., 2022). Long-term changes in land cover may reveal a response to climate variations on a local, regional, or global scale. Remote sensing-detected temporal landscape evolution provides a better understanding of the dynamics of the environment in mountainous areas (Ali et al., 2019). Rapid population growth leads to overexploitation of natural resources, causing widespread concern about the world's future. As a result, Land Cover Change (LCC) analysis is critical for rational planning, land cover development decision-making, and optimal use of natural resources (Beuchle et al., 2015).

Mountain ecosystems are among the most vulnerable on the planet earth. Modernization processes, such as urbanization, population growth, tourism, and ill-planned development activities, are constantly disrupting natural settings, causing climate change and negatively affecting the Hindu Kush, Karakoram, and Himalayan (HKH) mountain environments (Coppin et al., 2004; Qamer et al., 2016). Urbanization, resource exploitation, agricultural development, and natural drivers are the major environmental issues that have a significant impact on land cover processes. As previously stated, the HKH region is highly vulnerable to natural disasters. Glacier lake outburst flooding (GLOF), landslides, flash floods, and debris flows further degrade the mountainous landscape (Bajracharya and Shrestha, 2011; Yu et al., 2007). Land deterioration in mountainous watersheds is a common phenomenon in developing countries and is a result of poor planning and mismanagement of watershed resources (Ali et al., 2019).

Remote sensing and GIS have numerous applications in environmental science, forestry, natural resource management, glaciology, agriculture, integrated environmental impact assessment, and many other fields. The negative impacts on ecology and vegetation cover in natural environments have led researchers to prioritize LULC studies (Mallupattu & Reddy, 2013). Presently, remote sensing data from satellites is widely used as the most useful and potential source for detecting and monitoring changes in LULC as it gives extensive spatial and temporal coverage (Zaidi et al., 2017). Inventories and monitoring of LULC changes play a critical role in investigating and understanding the change mechanism and its modeling to assess impacts at various scales of the environment and its associated ecosystems (Chen et al., 2003).

Change detection is the process of identifying changes in an environment, object, or phenomenon at different times (Alqurashi & Kumar, 2013). Identification and generation of LULC data through remote sensing and GIS establish baseline information for creating thematic maps and change detection analysis. Land cover is the physical appearance of materials on the earth's surface, whereas land use refers to how people use land for socioeconomic gains.

Need of LULC assessment and mapping

Economic and social developments contribute significantly to a society's growth and well-being. Unsustainable land use in the pursuit of socio-economic goals puts pressure on land resources. Socio-economic surveys provide pertinent information on land utilization and are therefore crucial during data collection. This is the primary reason for conducting socio-economic surveys, which use datasets from both spatial and non-spatial sources. Creating LULC maps is critical to designing, managing, and monitoring programs at the local, regional, and national levels. This contributes to a better understanding of land use issues while being essential to devising policies and programs for socioeconomic development. Monitoring the changing patterns of LULC over time is critical for developing and implementing sustainable development strategies. To ensure sustainable urban development and avoid the haphazard growth of towns and cities, urban development authorities must create eco-friendly planning models that allow every available piece of land to be used most logically and efficiently possible. This exercise requires knowledge of the area's past and present LULC. We can use LULC maps to study changes in our ecology and surroundings. Detailed LULC information can help develop legislation and launch programs to protect the environment in the target area.

Approaches and techniques of LULC assessment and mapping

Classification of LULC

One of the most utilized applications in remote sensing is LULC classification. The following approaches identify and discuss the major classifications:

Unsupervised classification: This kind of categorization relies solely on a computer's analysis of an image rather than on sample classes supplied by the user. It entails categorizing pixels based on their similarities and characteristics. The computer employs techniques and algorithms to identify and classify related pixels. Users can choose the software algorithm and the number of output classes desired, but more is needed with classification and categorization. Thus, the user needs to be familiar with the classification area (such as bare land, urban areas, vegetation type, water bodies, etc.).

Maximum likelihood supervised classification: The classification type is predicated on the notion that a user can choose sample pixels from an image based on prior knowledge. This knowledge is characteristic of particular classes, instructing image processing software to utilize these training sites as references for categorizing all other pixels in the image. When selecting training sites, also known as testing sets or input classes, the user's knowledge is considered. The user specifies the format by defining a threshold for how similarly other pixels must be clustered. These limits are frequently established by using the spectral properties of the training area, plus or minus a specific increment (often based on "brightness values" or the strength of reflection in specific spectral bands). The user can also specify how many classes an image will be divided into.

Segmentation of the image: Segmentation is the division and collection of the image's homogeneous parts. The segmentation findings satisfy the requirements of gray consistency, border smoothing, and connectedness. The traditional segmentation technique employs spatial cleaning based on measurement space. A critical process in remote sensing is the extraction and classification of features from high-resolution images. The main image segmentation methods include the following:

<u>Threshold-based segmentation:</u> The most straightforward approach for segmenting images is threshold segmentation, which is also one of the most popular parallel segmentation techniques. It is a typical segmentation algorithm that splits the processing of grayscale picture information depending on the multiple targets'

varying gray values.

Edge detection segmentation: The object's edge is represented by discontinuous local image features, which are the most notable local brightness variations in the image, including changes in texture, color, and grayscale value. Discontinuities are used to identify edges and accomplish image segmentation goals.

Regional growth segmentation: The fundamental idea behind the regional growth segmentation method includes segmenting a common serial region algorithm, where pixels with similar qualities are grouped into regions. In this method, a seed pixel is chosen, and then identical nearby pixels are combined into the area where the seed pixel is situated.

Normalized Difference Vegetation Index (NDVI)

The ratio of near-infrared reflectivity (NIR) minus red reflectivity (VIS) over the near-infrared reflectivity plus VIS ratio is known as the Normalized Difference Vegetation Index (NDVI). Most remote sensing analysts utilize this index.

NDVI=(NIR-VIS)/(NIR+VIS)

NDVI was created in 1977 by Compton Tucker, a NASA scientist. The foundational idea is based on the fact that leaves reflect much light in the near-infrared due to the spongy layers found on their undersides as opposed to most non-plant objects. The leaves reflect lesser NIR light than the same quantity of visible light when the plant is stressed or thirsty because the spongy layer collapses. Thus, by statistically integrating these two signals, it is possible to distinguish between plants and non-plants, and between healthy and diseased plants. The NDVI varies from -1 to +1. The negative value means it is almost water, and when the NDVI value is closer to +1, there is a possibility of dense green vegetation or leaves; when the NDVI is zero or close to zero, it could be an urbanized area with no green leaves or vegetation.

Table 3.1 Examples of LULC types and their respective classes (SATPALDA [Satellite Imagery and Geospatial Services], 2022)

LULC type	Classes
Urban area or land	• Residential buildings • Commercial and other service structures • Industrial sites • Communication and other utility infrastructure • Mixed urban area
Agricultural land	• Cropland • Pastures • Nurseries, groves, orchards, vineyards, and other ornamental horticultural areas • Confined feeding operations
Rangeland	• Rangeland • Shrub and bush rangeland • Mixed rangeland
Forest land	• Deciduous forest land • Evergreen forest land • Mixed forest land
Water	• Rivers • Streams, springs, and canals • Lakes • Reservoirs • Bays and estuaries
Wetland	• Forested wetland • Non forested wetland

Barren land	• Dry salt areas • Beaches • Deserts • Sandy areas other than beaches • Bare exposed rocks • Strip mines, quarries, and gravel pits • Transitional areas • Mixed barren land
Perennial snow or ice	• Perennial snowfields • Glaciers

Geospatial data and LULC

The increasing availability of spatial data is becoming possible due to advancements in remote sensing, monitoring networks, and Geographic Information Systems (GIS). The geospatial data include numerous qualities, such as socio-economic data from the census, and maps and locations of land use and land cover (LULC). Environmental modeling is becoming a regular feature of data recording, primarily due to advancements in the utilization and accessibility of multitemporal, satellite-derived environmental data or other thematic raster data. Remote sensing gives near real-time synoptic data on vegetation growth conditions over a vast geographic area. The NDVI, based on visible (red) and near-infrared (NIR) band reflectance produced from the most popular worldwide NDVI data sets, is used to determine the vegetation growth pattern.

LULC maps applications

The LULC maps provide information to assist users in understanding the current landscape. These maps allow for monitoring the landscapes' temporal dynamics for various purposes. Some of the applications are listed below:

- Environmental and resource management
- Wildlife conservation and protection
- Baseline mapping for GIS input
- Urban and built-up environment expansions
- Zoning and routing of seismic and resource exploration
- Damage assessment and delineation (tornadoes, floods, volcanic eruptions, earthquakes, fire)
- Administrative and legal boundaries, including property evaluation
- Identifications of various infrastructure, including roads, bridges, buildings and other target areas
- Environmental planning and monitoring

LULC evidence from HKH region, Pakistan

In a recent study, Ali et al. (2019) reported a significant change in the LULC of the Gilgit River basin. Glaciers, rangeland, water bodies, agricultural cover, and built-up areas are the major categories altered by large-scale contributions from anthropogenic and natural drivers. Between 1976 and 2015, the land cover of river basins changed with a decrease in the areas covered by rangelands and glaciers (from 45 per cent to 12 per cent; and from 13 per cent to 8 per cent, respectively), while built-up/agriculture and water bodies increased from 1.3 per cent to 3.25 per cent, and from 0.66 per cent to 0.91 per cent, respectively.

Manan et al. (2018) used satellite images to determine the changes in forest cover from 1998 to 2018 in the Margalla Hills National Park, Islamabad, at the foothills of the Himalayan Mountains. They reported a significant reduction in forest land from 40,936.77 ha to 36,709.23 ha, an increase in agricultural land from 4,220.46 ha to 10,374.64 ha, and the built-up areas from 1,497.60 ha to 5,395.12 ha.

Gul et al. (2022) conducted another study to detect variations in LULC from 1991 to 2017 in a segment of the Hindu Kush range in the Malakand Division of Khyber Pakhtunkhwa (KPK) province, Pakistan. The study relies on secondary datasets obtained from the US Geological Survey (1991, 2001, 2011, and 2017 imageries) and the United Nations Office for the Coordination of Humanitarian Affairs (UN

OCHA) website. The findings were based on six major land use classes: agricultural built-up area, vegetation cover, water bodies, snow cover, and barren land. The results show a significant decrease in snow cover and barren land from 1991 to 2017. A known change in the built-up area has been recorded –an increase from 1.02 to 6.2 per cent – a change of 5.18 per cent of the total land. The area of vegetation covering water bodies had also grown; the vegetation cover increased from 28.89 to 44.67 per cent of the total area, while the barren land decreased from 45.68 to 40.29 per cent. Furthermore, the built-up area increased from 1.02 to 6.2 per cent of the total area, while water covers increased from 0.63 per cent (1991) to 0.86 per cent (2017).

Drivers of change in LULC

LULC is directly linked with the improvement in human society's well-being and population growth. While several factors contribute to LULC, the main drivers of this change are associated with the socio-economic systems and livelihood patterns of the surrounding population (Braimoh & Osaki, 2010; Anwar et al., 2022). Population growth, unplanned urbanization, and development projects are the major contributing factors to LULC changes in Pakistan (Anwar et al., 2022). Internal migration brought on by natural and climate-induced disasters (earthquakes, floods, and droughts), man-made crises (conflict, insecurity), and urban-rural disparities, are the additional factors influencing LULC change in Pakistan. When rural residents experience some socio-economic advancement, they quickly begin relocating to urban areas in order to access opportunities for education, healthcare, and employment that are comparatively better.

Population growth is one of the major factors impacting LULC. As the 6th most populous country in the world, Pakistan relies heavily on land use for socio-economic and agricultural development. The population growth rate in Pakistan is also one of the highest. There is enormous pressure on available land resources and natural ecosystems to meet this growing population's minimum basic needs, including housing, education, health, and livelihood facilities. The interaction of the human population with nature for survival necessitates the intensification of various drivers of climate change. For example, it is estimated that urbanization is increasing by 7 per cent per year in developing countries alone (Ji et al., 2001). This causes productive agricultural land to be shifted into urban and semi-urban settlements, resulting in a significant reduction in fertile agricultural land (Adeel, 2010; Anwar et al., 2021).

These drivers of LULC changes are frequently classified as proximate drivers, such as urbanization, natural processes, infrastructure expansion, and population settlement. Routine economic activities, policies, and practices, as well as institutional changes, are known as the underlying drivers of LULC (Kindu et al., 2015; Anwar, 2021).

The LULC change drivers, proximate and underlying, vary from area to area, both within and between states. The development of socio-economic indicators, the magnitude and severity of natural and man-made crises, and institutional coping mechanisms are just a few possible explanations for the variations in drivers. Along with topographical and geographic factors, local population vulnerabilities would also affect the LULC change drivers.

The following section discusses the most common drivers of LULC changes in Pakistan, particularly in its mountain areas.

Socio-economic factors

Some of the most common socio-economic indicators and drivers for LULC changes are internal displacement and migration, poor law and order situations, political instability and interference, uncertain market dynamics, weak policies, institutions, and economic and development processes. In Pakistan, there is huge pressure on LULC due to the fragility of domestic socio-economic and political conditions. It is worth mentioning that not all LULC changes may be considered a negative onslaught. For example, with improvements in the socio-economic condition of poor households, investment in housing and livelihood opportunities could bring about a positive change in the LULC. A household's quality of life and livelihood can be increased through investments in the construction of houses and the conversion of otherwise barren and less productive land into agricultural land. A healthy and better quality of life would enable the household to have an efficient production system while investing in education and entrepreneurship. The family would be able to secure its essential needs.

On the other hand, man-made crises, political instability and interference, and weak institutions and governance systems can lead to insecurity, internal displacements, and migrations – factors causing significant LULC changes. In Pakistan, massive displacement and internal migration were seen after the 2005 earthquake and the influx of terrorism in Swat and the former tribal belt (now merged as a districts of the KPK province), in addition to other areas of the KPK and Balochistan, and major cities like Karachi. Signs of displacement, migration, and resettlement have reportedly been observed and witnessed in Islamabad, Abbottabad, and Lahore. While the LULC changes mentioned here are limited to specific cities and areas, the entire demographic and administrative system is seriously affected, placing enormous strain on service provision in urban areas. Weak institutional and regulatory mechanisms cause haphazard and unplanned urban development, leading to problems instead of improving the quality of life. With the loss of green spaces and agricultural land, environmental hazards and problems are increasing. This, in turn, impacts people's quality of life, endangers the social fabric, and threatens future food security.

Climatic-induced factors

Pakistan is a disaster-prone country that ranks eighth in the world in terms of vulnerability to climate-induced crises. Climate-related disasters have caused significant changes in the country's LULC dynamics over the last two decades. Millions of people were displaced due to the 2005 earthquake in KPK and Azad Jammu and Kashmir. Many settled in their new homes and rarely needed to return to their ancestral homeland. This was followed by the 2010 super flood, which began in the upper KPK and inundated much of the Punjab and Sindh provinces. During 2011–2017, the frequency of both annual floods and droughts increased. The 2022 floods in Pakistan drastically damaged the lives and property of the people. Official figures estimate a direct loss of $32 billion. However, the costs for rehabilitation, resettlement, and reconstruction might be even higher in the years to come. Governments can institute environmentally friendly and evidence-based policies and action plans, which could help manage future disasters. All these climate-induced crises and disasters have long-lasting impacts on LULC changes.

Population growth and urbanization

Pakistan is the sixth-most populous country in the world with a population of 220 million, according to the 2017 census. While the actual number is likely to be much more, the next census scheduled for 2023 may provide a more accurate figure. Most of Pakistan's population live in rural areas, but there is an increasing trend of rural-urban migration. Therefore, cities are expanding, and the pre-urban or urban peripheries are becoming concrete jungles. Agricultural lands, orchards, and other green spaces that provide food and fresh oxygen quickly disappear due to unplanned urbanization and population pressures. This warrants an urgent need for proper urban planning, policy development, and implementation, including placing restrictions on the conversion of productive land into housing schemes and unplanned settlements.

Mega-development projects

Pakistan is one of the fastest-growing and developing countries. Despite numerous crises, the country has completed various mega-development projects and is still pursuing others, such as transportation networks and hydropower projects. In addition to providing better services, this infrastructure development significantly impacts the country's LULC dynamics. It is essential to consider and mitigate the potential consequences of the development projects on the fragile land ecosystem.

Sustainable land use management

Land formation is the result of the interplay of various geographical forces. Different ecological processes are interconnected by land features critical to human survival and the long-term viability of a wide range of products and services. Land resources support life by providing the necessities needed to sustain life on Earth (Foley et al., 2005). Humans gain socio-economic benefits from the land through various traditional and advanced actions. Land use is a continuous and recurring process (Liu et al., 2014).

The use of land is one of the oldest human practices. Humans have remained engaged in agriculture and land use since antiquity. In modern times, especially since the industrial revolution (Zhang et al., 2012), there has been an exponential increase in the urban population (Wu et al., 2015). Subsequently, there is unprecedented demand for the necessities of life, energy resources, and urbanization, changing land use configurations altogether (Börjesson & Tufvesson, 2011; Smidt et al., 2018). As a result, the haphazard use of agricultural land and forests has severely harmed sustainable land use, leading to a decrease in the aesthetic value of land and worsening ecological conditions (Dadashpoor et al., 2019).

In 2015, the United Nations identified 17 Sustainable Development Goals (SDGs) and 169 specific goals. These SDGs evolved from the Millennium Development Goals (MDGs) established in 2000. Sustainable development is measured in three ways: *financial improvement*, *a pleasant environment*, and *community development*. The sustainable land use goals can be summed up in the following seven objectives: (i) increasing the production potential of agricultural land; (ii) encouraging concentrated and multiple uses of industrial land; (iii) building harmless, comprehensive, robust, and sustainable urban centers and anthropoid societies; (iv) preventing and mitigating land pollution; (v) restoring ecosystems and fighting land degradation; (vi) achieving secure and durable land proprietary rights; (vii) eliminating poverty (UN, 2015).

The sustainable management of land incorporates knowledge from various scientific disciplines, including geography, ecology, and the fields related to land and sustainability. In the last two decades, the study of sustainable land use has drawn much academic interest, while research has expanded in scope. The concept of sustainability has grown in complexity and is now pervasive in science and everyday life (Xie et al., 2020).

The notion of sustainable land use has gained popularity worldwide with the transformation of sustainable development into a globally recognized field of study. Land use on a sustainable basis can be described as the logical improvement, utilization, and conservation of the land capital centered on specific spatiotemporal circumstances and the adoption of necessary channels and managerial procedures. Furthermore, the whole process should ensure the harmonious development of humans and their surroundings and synchronize the connection between man and land resources. Simply put, sustainable land use means that land resources are exploited so that the demands of current and future generations are fulfilled without degrading the land. This method is helpful in two ways: it meets human needs, and it constantly enriches the quality of land resources (Kruseman et al., 1996; Xie et al., 2020). Land use on a sustainable basis is inextricably tied to improvements in regional sustainability and ecological refinement (Xie et al., 2020).

Sustainable Land Management (SLM) is "a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management... to meet rising food and fiber demands while sustaining ecosystem services and livelihoods" (World Bank, 2006, p. xiv). In other words, SLM refers to the use of land to meet the ever-changing human needs (agriculture, forestry, and conservation) while ensuring the land's long-term socioeconomic and ecological functions. SLM helps meet the needs of a growing population as it seeks to balance the complementary goals of providing environmental, social, and economic opportunities for current and future generations while preserving and improving the quality of natural resources

(Smyth and Dumanski, 1993). Improper land management can result in land degradation and significantly decrease production and service functions. According to the World Bank (2006), SLM involves:

- Improving and maintaining the productive abilities of land in arable and grazing areas, including uplands and flat and lowlands.
- Conservation of productive forest areas and potential commercial and non-commercial forest reserves.
- Maintaining the integrity of the watershed for water supply and hydroelectric power generation, water protection zones, and the ability of aquifers to support the needs of agricultural and other productive activities.
- Measures to stop and reverse degradation, or at least mitigate the adverse effects of the previous misuse that are becoming increasingly important in uplands and watersheds, mainly where pressure from resident populations is intense and where the devastating impacts of upland degradation are felt much more strongly, such as downstream areas where populations are much denser.

Sustainable land management is a critical component of the SDGs. Sustainability is a measure of the likelihood that a particular land use will remain economically, physically, and socially viable or suitable for a specific location over a significant period. Good land management has become vital to the planet's future well-being and survival. The quality of land resources needs to be improved along with production. A land-use management system can only be considered suitable if it is also sustainable. However, sustainability must be defined more clearly to achieve the desired results (Smyth & Dumanski, 1995).

Pillars of sustainable land management

Sustainable land management combines policies, technologies, and activities that aim to integrate socio-economic principles with environmental concerns to:

- Reduce production risk and improve soil capacity to buffer against degradation
- Maintain and increase output
- Be socially acceptable and guarantee access to the benefits of better land management
- Safeguard natural resource potential, prevent degradation of water and soil quality
- Be financially viable.

The five goals, known as SLM pillars, are the fundamental principles and the foundation upon which sustainable land management is built (Dumanski & Smyth, 1993). All five 'pillars' or criteria simultaneously complement each other for sustainable land use; all pillars are rated equally important in achieving sustainability aims and objectives (Smyth & Dumanski, 1995).

In the following section, some of the recommendations for the sustainable management of LULC are discussed:

Problem identification and interventions: Several ecological problems are caused by large-scale anthropogenic activity altering land use and thus changing land cover. Identification of the causes of LULC changes thus becomes pivotal to addressing them and safeguarding sustainable land management (Izakovičová et al., 2018).

The imbalances between ecologies and stakeholders should be managed so that the needs of every party (both public and private) agree with the national, regional, and local socio-economic and ecological targets. To achieve this, land management on a scientific basis is vital and can be obtained through the introduction of logical policies, regulations, and interventions. Political alliances, lobbying, negotiations, and even community activism are instrumental in formulating policies and legislation. The capacity of governments to successfully implement these policies and legal provisions can make them more effective (Nepal et al., 2020).

Land use is a dynamic process, and its indicators should be improved scientifically using modern techniques, thus providing a technical foundation to devise policies and legislative frameworks for sustainable land use. Landscape ecology theory, a strong sustainability theory, and the concept of geographical design should be incorporated into land use science to broad-en the scope of the subject (Xie et al., 2020). Several other supportive tools and techniques are available for decision-making in complicated settings, such as the Multi-Criteria Analysis (MCA) and the Spatial Multi-Criteria Analysis (SMCA). These can be used for data collection, organization, and analysis, encouraging discussion and elucidating value. This can help clarify the outcomes of various choices in sustainable land use (Izakovičová et al., 2018).

Community-Led Local Development (CLLD) is a recent and emerging integrated method that requires an advanced approach to ensure valuable results. Coordination should be inclusive in the public and private sectors at local, regional, and national levels. These techniques must be deployed at all levels to meet the requirements of mountain land use management (Dax, 2020). It is important to track the LULC changes and their respective areas to ascertain the connection between legislative measures and policy interventions (Hussain et al., 2020).

Implementation of environmental and land use policies: A majority of the land use scientists are of the opinion that mountain ecosystems are different from other types because management practices, resulting from the implementation of specific policies coupled with external factors such as tourism and mining, can have an enormous impact on the LULC changes (Grêt-Regamey et al., 2012). Updated information regarding LULC is crucial in formulating policies that can then be implemented effectively to reverse changes in LULC (Ullah et al., 2016).

Environmental factors prevailing in a mountain region can affect sustainable land use to some extent. However, efficient enforcement of policies and regulations, formulated as a response to regional land management practices, are critical for sustainable land use (De Vente et al., 2016).

Threats from population growth and its associated factors can be effectively minimized by introducing suitable laws and policies on land use. Sustainable development is realistically possible when multiple factors are considered, and clear policy measures are implemented at the local, national, and regional levels. This can also aid in the development of future models to achieve the goal of green development (Stehfest et al., 2019).

Fair environmental policies, effective laws, and valuable human inputs can all contribute to more sustainable natural resource management. Regular policy revisions at all levels can help mitigate the environmental damages caused by the dynamic LULC changes (Andriansyah et al., 2021).

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Chapter 4

Mountains and Climate Change

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Melting signs (attributed to warming effects) at the Mani glacier in Haramosh valley, Gilgit, Pakistan © Zafar Khan

Introduction

Climate change (CC) is the biggest environmental issue of this era due to the unprecedented risks it poses to the planet and its inhabitants. The data gathered over the course of a century shows that climate change is accelerating faster than ever, quickly becoming one of the most pressing issues facing our planet today (Raza et al., 2016). With the increase in population and industrialization, the temperature of the planet is rising. The temperature change is one of the major triggering factors of climate change (Raza & Wahab, 2022). The global socio-ecological patterns have been affected by the change in climatic conditions brought on by the rise in temperature, which has also altered the climate in various ways. These include more frequent and intense downpours, rising temperatures and rising sea levels, rapidly retreating glaciers, thawing permafrost, lengthening growing seasons, longer ice-free seasons in the ocean and on lakes and rivers, earlier snowmelt, and alterations in river flows. As a result, climate change impacts water sources, energy, transportation, agriculture, ecosystems, and health. The country's freshwater resources and ecosystems are at risk due to rising temperatures, which speed up the deglaciation process (Raza et al., 2015). Climate change has a particularly negative impact on Pakistan, which is the fifth-most affected nation globally. Awareness of climate change is crucial to boost the population's capacity for adaptation.

This chapter begins with an overview of CC, including its causes, indicators, supporting data, and effects on the socioeconomic circumstances in the target region. In order to counteract the effects of CC, it also includes mitigation plans and regional, national, and international regulations.

Weather and Climate: The weather at a given time in a particular area is determined by short-term variations in air pressure, temperature, humidity, wind speed and direction, rainfall, and snowfall, etc. The weather can change in a few minutes, hours, or days. On the other hand, the climate is the average of a location's long-term weather conditions, including precipitation, temperature, humidity, sunlight, wind, and other environmental indicators.

Climate Change: Climate change is a shift in the average weather of specific regions or places over a long period of time (Raza et al., 2015). These shifts may be *natural* or *anthropogenic*.

Climate change as a natural phenomenon

Climate may change through natural factors, such as variations in the solar radiations or continental drift, etc. The continental drift is a very slow process and cannot be detected in a human lifespan. However, over millions of years, the map of the world has changed. New mountain chains have emerged, old oceans have disappeared, and new oceans have appeared. The difference in temperature between the oceans and the land has altered. As a result, the frequency, moisture content, and direction of the winds have changed. All these factors contribute to natural climate change.

Climate change due to anthropogenic activities

Since the 1800s, the main cause of climate change has been the increase in human population and their activities, particularly the use of fossil fuels such as coal, oil, and gas. Fossil fuel combustion produces greenhouse gases, such as carbon dioxide and methane, that when released into the atmosphere, act as a blanket around the Earth, trapping heat from the sun and increasing temperatures. Additionally, deforestation in order to meet growing domestic and commercial needs facilitates an increase in carbon dioxide. Landfills for garbage and livestock are a major source of methane emissions. Energy, industry, transport, buildings, agriculture, and land use are among the main contributors to CC (Kolawole & Okonkwo, 2022).

Global Warming

During the last century and a half, a rising trend in the global annual temperature has been observed. This is known as global warming. The total increase in temperature observed from 1880 to 1980 was a little more than 1°C on average. Since 1880 there has been an average increase of 0.07°C (0.13°F) every 10 years. However, from 1981 onwards, the rate of increase per year has more than doubled. For the last 40 years, an increase of 0.18°C per decade has been recorded (Lindsey & Dahlman, 2020).

Global warming occurs when carbon dioxide (CO_2) and other air pollutants collect in the atmosphere and absorb sunlight and solar radiation that have bounced off the Earth's surface. Normally this radiation would escape into space, but these pollutants, which can last for years or centuries in the atmosphere, trap the heat and cause the planet to get hotter. These heat-trapping pollutants (specifically carbon dioxide, methane, nitrous oxide, water vapors, and synthetic fluorinated gases) are known as greenhouse gases (Kumar, 2018).

Greenhouse Gases (GHGs): the major cause of global warming

There are numerous greenhouse gases (GHGs) that are the primary causes of global warming. Some of the major GHGs are water vapors (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and industrial gases like hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) (Stocker, 2014). Carbon dioxide, methane, and nitrous oxide contribute 72 per cent, 20 per cent, and 5 per cent, respectively, to the total annual greenhouse gases (Pachauri & Meyer, 2014).

Table 4.1 Annual Greenhouse Gas Emissions by Sector (Pachauri & Meyer, 2014).

Sector	GHGs (%)	Carbon dioxide (%)	Methane (%)	Nitrous oxide (%)
Electric power stations	25.5	34.1		4.4
Industrial processes	15.9	20.9		
Transportation fuels	13.2	17.3		4.7
Land use and biomass burning	12.1	14.4	4.3	15.5
Agricultural production	11.6		40.8	62.5
Fossil fuel retrieval processing and distribution	10.5	4.7	34.5	6.1
Residential, commercial, and other sources	7.5	8.9	3.4	3.2
Waste disposal and treatment	3.6		16.6	3.9

Damaging effects of black carbon

Black carbon, or soot is formed by the incomplete combustion of fossil fuels, wood, and other fuels. Complete combustion would turn all the carbon in the fuel into carbon dioxide (CO_2), but combustion is never complete, and CO_2, carbon monoxide, volatile organic compounds, organic carbon, and black carbon particles are all formed in the process. The by-products of this complex mixture of particulate matter resulting from incomplete combustion have severely harmful side effects on the environment and human health.

Black carbon has a 460-1,500 times greater warming impact on the climate per unit of mass than CO_2. The average atmospheric lifetime of black carbon particles is 4–12 days. Black carbon is a short-lived climate pollutant with a half-life of only days to weeks after release in the atmosphere. During this short period of time, black carbon can have significant direct and indirect impacts on the climate, the cryosphere (snow and ice), agriculture, and human health (Wahab et al., 2022).

About 6.6 million tons of black carbon were emitted in 2015. Household cooking and heating account for 50 per cent of global black carbon emissions. Black carbon is part of the air as fine particulate matter (PM2.5). It absorbs sunlight and converts it into heat. When deposited on the surfaces of ice and snow, it accelerates melting. It hinders the formation of clouds, hence the change in rainfall and weather patterns. The following table lists some of the most common sources of black carbon.

Table 4.2 Main sources of black carbon (Climate Clean Air Coalition, 2022).

Source of black carbon	Per cent contribution
Household energy	50
Transport	26

Agriculture	8
Industrial Production	5
Waste	5
Fossil Fuel Operations	3
Large Scale Combustion	2

Evidence of climate change

The evidence of climate change manifests itself through the change in the Earth's temperature, sea level, glacier behavior, and weather patterns. The main contributors to these changes are human activities. Humans are also the primary victims of climate change. Some of the evidence that climate change is real and must be addressed is listed below:

Change in Earth's temperature

The change in the Earth's temperature has been noticed since the industrial revolution. The unprecedented industrial development has contributed to the generation of massive amounts of greenhouse gases (methane, carbon dioxide, nitrous oxide, and sulfur oxide). Carbon dioxide is the most abundant greenhouse gas regulating the earth's temperature (see figure 4.1). It traps the infrared radiation that is reflected back from the earth and heats up the Earth's atmosphere (NOAA, 2022).

According to the latest report of NOAA's Global Monitoring Laboratory, the average atmospheric concentration of CO_2 was recorded at 419 ppm in 2022 (see figure 4.2). Before the industrial revolution, the concentration of carbon dioxide was 280 ppm. The Earth's temperature rises with increase in the amount of carbon dioxide in the atmosphere because it retains infrared radiation and reflects it back to the planet (Monroe, 2022).

The carbon dioxide concentration in the atmosphere has risen by nearly 33 per cent. As shown in Figure 4.3, the annual increase in global temperature was 0.85°C in 2021, with a total increase in surface temperature of 1°C since pre-industrial times (NASA, 2022).

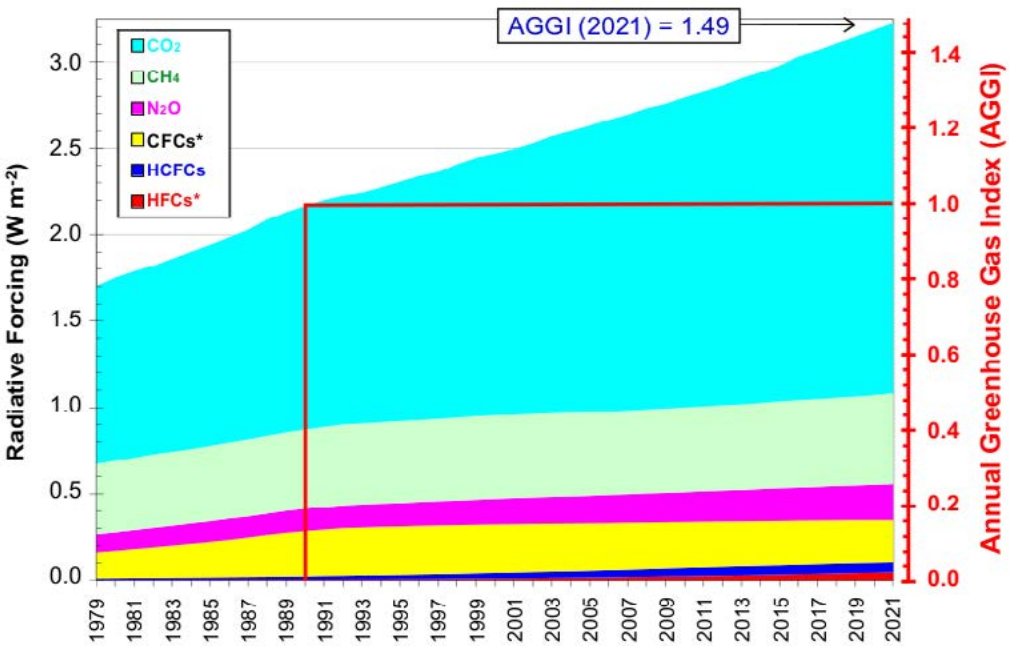

Figure 4.1 Carbon dioxide is the prominent and abundant greenhouse gas (NOAA, 2022).

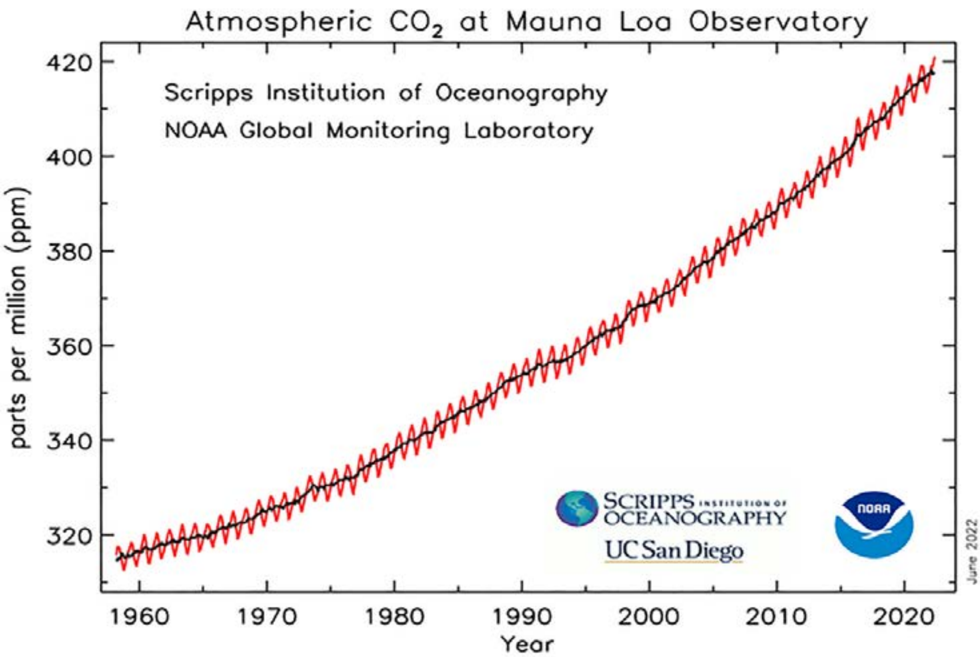

Figure 4.2 Monthly mean CO2 measured at Mauna Loa Observatory (Monroe, 2022).

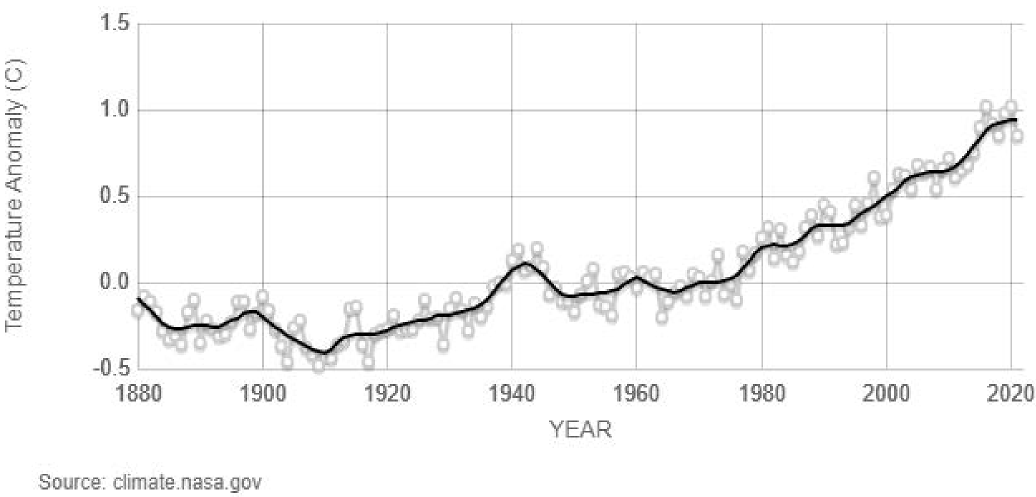

Figure 4.3 Surface temperature from preindustrial time to 2022 (NASA, 2022).

Evidence from glacier behavior

Glaciers are extremely sensitive to climate change and respond by retreating or advancing (moving forward). Less precipitation, less cloud cover, and high temperatures are the main factors that trigger the glaciers' melting. Different cases of glaciers retreating, and their devastating impacts have been reported in different parts of the world. According to UNDP

[United Nations Development Program], 2022), a total of 3,044 glacial lakes have been developed in Gilgit-Baltistan (GB) and Khyber Pakhtunkhwa (KPK). Similarly, a total of 33 glacial lakes have been determined to be dangerous, and when they burst, they severely disrupt downstream communities, infrastructure, agriculture, and human settlements. Rasul et al. (2011) observed the shift in snowline and the formation of glacial lakes in the different areas of the Himalayas, Karakoram, and Hindukush regions. Pandey & Venkataraman (2012) studied the length of the Chhota Shigri glacier using remote sensing data. The result showed the glacier's negative mass balance that receded about 950 meters from 1962–2008. Rasul et al., (2011) reported a 100m^2 pond formation at Hinarchi Glacier in 2008 (see figure 4.4). This pond expanded into a lake within three years, with a size ranging up to 1100m^2. Analysis of the Hinarchi glacier samples revealed a sizable amount of carbon soot. The carbon soot can be clearly seen in the Passu glacier. Siachen glacier has reduced (see figure 4.5) by two kilometers since 1989 (Hussain et al., 2016; Pandey & Venkataraman, 2012).

Figure 4.4 Formation of glacial lake at Hinarchi glacier (Source: Hussain et al., 2016; Pandey & Venkataraman, 2012)

Figure 4.5 Siachen glacier (Source: Bliss et al., 2014).

Evidence from ice cores

Climate history is preserved by glacial ice. Air bubbles are stored in ice during the ice formation process, where they can be used to determine the composition of air in the past and compare it to the atmosphere today. The ice coring method has been used since the 1950s. Antarctica and Greenland are the best places for investigating past climatic variability. Many studies have been done so far. Scientists have achieved success in extracting information about glacial and interglacial cycles and the concentration of greenhouse gases from approximately 10,000 years ago. The concentration of carbon dioxide during the ice ages was 200 ppm, while it was 280 ppm in the interglacial period. However, there has been an unprecedented increase in these concentrations since the beginning of the industrial revolution (Glasser et al., 2009). For the year 2022, the recorded average is 419 ppm.

Evidence from sea level rise

The rise in sea level and resultant flooding threatens the lives of people living in coastal areas. To date, 21cm to 24cm of sea level has risen globally since 1880, because of negative glacier mass balance, and thermal expansion of the oceanic water around Antarctica and Greenland. Currently, the sea level is rising at the rate of 3 mm/year, and is expected to be around 60cm of sea level rise by the end of 2100 AD. A rate of 1.1 mm/year in sea level rise has been recorded in Karachi (Solomon et al., 2007).

Evidence from tree rings

The way tree rings form reveals information about local climate change. The width, isotope makeup, and density of the tree ring are just a few of its various characteristics. Dendrochronological cross-dating was made possible thanks to this information. Some species, such as *Fitzroya cupressoides* and *Pinus sylvestris*, have long lives and have been selected to measure their past histories via radiocarbon dating. Bartholin and Karlén (1983) established a continuous and absolutely dated tree-ring width (TRW) chronology for the period AD 436 to 1981. Schweingruber (1988) succeeded in producing a chronology of maximum latewood density (MXD), which covered the period AD 445 to 1980, which is regarded as longest density record in the world. Tree-ring chronologies offer the ability to detect short-lived extreme events such as explosive volcanic eruptions in the past (Briffa et al., 1998). The *Pinus sylvestris* is used to date the climate from 445 to 1980 AD, which covers the Holocene period in northern Sweden. It describes the strong correlation between ring width and temperature change (Grudd et al., 2002). Similarly, the tree-ring width and maximum latewood density chronologies at Torneträsk, northern Sweden, were also studied. It clearly showed that the effect of climate change on tree growth is influenced by changes in temperature. Shifts in warm and cold weather patterns greatly influence growth. The coldest temperatures occur around AD 1900, which is consistent with the maximum extent of glaciers in Swedish Lapland in the last 1,500 years.

Climate change impacts

Climate change has impacted all matrices of the environment, and consequently all spheres of life have been receiving the reverberations of this change. A few of the effects are briefly discussed below:

Glacier mass balance and Glacial Lakes Outburst Floods (GLOF)

Many glaciologists have reported that most mountain glaciers are losing mass in response to climate change. The majority of the world's glaciers have shrunk over the last century and a half, according to the data. However, since the beginning of the 1980s, the rate of ice loss has increased exponentially in many regions, concurrent with an increase in global mean air temperatures. Glaciers might disappear from some mountain regions by the end of the 21st century, given the current melting rate (Bliss et al., 2014).

Because of the melting glaciers, glacier lakes in the Karakoram and Himalayas have developed. In recent years, more than three thousand such glaciers have been reported (Ashraf et al., 2012). These glacial lakes are a potential threat to the populations living downstream.

In the months of July and August of 2022, at least 30 instances of glacial lake outburst floods (GLOF) have been reported from northern Pakistan, particularly from Gilgit-Baltistan and Chitral areas.

Extreme events due to climate change

Climate change is to blame for extreme weather phenomena such as violent storms and torrential downpours. Like other regions of the world, the HKH region has also been negatively impacted by extreme weather conditions. In the summer of 2022, Pakistan experienced 375.4 mm of rainfall, 2.87 times more than the 130.8 mm that has been the national average for the past 30 years. Balochistan, Sindh, and portions of Punjab have received the majority of these rains, with Sindh receiving rainfall that is 5.7 times higher than the 30-year average and Balochistan receiving rainfall that is five times higher. According to reports from the National Disaster Management Authority (NDMA), 33 million Pakistanis were impacted by the unprecedented rainfall (GoP [Government of Pakistan], 2022).

Heatwaves and droughts

Droughts and heat waves are both extreme climate events that occur in almost every part of the world. Drought is a situation of temporary lack of water, caused primarily by climatic conditions, affecting environment and human societies (Kallis, 2008). A heat wave is a period of abnormally high surface temperatures relative to those expected over a period of several days to several weeks that can cause severe damage to society and the environment, with implications for human health, air quality, energy demand, and agriculture. Although droughts and heat waves span different time scales, their relationship is widely acknowledged (Ye et al., 2019), as they produce positive interaction and feedback together that intensify their effects. A higher temperature increases potential evapotranspiration, causing a moisture deficit at a faster rate and possibly increasing drought severity due to an increased vapor-pressure deficit. Concurrently, the moisture deficit reduces evaporative cooling, leading to increased sensible heat flux and thus increasing surface air temperature, which may result in a heat wave or exaggerate its magnitude (Zhang et al., 1995).

Droughts adversely affect the food production and agricultural sustainability of countries like Afghanistan, Nepal, Bangladesh, and Pakistan. Drought is a major driver of production risk in rain-fed agriculture in terms of lost yield and income. A major drought can hamper crop yields, force farmers to reduce planted acreage, decrease livestock productivity, and, under extreme circumstances, affect the price of irrigation water and animal feed (Enenkel et al., 2015). As water-related food security issues also spawn regional tensions (Daoudy et al., 2022), an accurate understanding of the availability and variability of water resources, particularly across geopolitical boundaries, is essential for improving food security, economic development, and regional stability.

Changing ecosystems

All over the world, significant historical changes in the ecosystems linked to climate change have been seen. Thermal stratification, bark beetle infestations, biome shifts, increased forest growth, increased forest mortality, stream intermittency, increased streamflow, accelerated nutrient flushing, wildfires, and wildlife movement are a few examples of how ecosystems are changing.

According to studies, future climate change may cause large potential forest areas in Pakistan's mountains to switch from one biome to another. In the ensuing decades, this shift would also increase the total potential area of coniferous forests, particularly warm conifer forests, as well as their net primary production (NPP) of carbon dioxide (Siddiqui et al., 1999).

Rising sea levels

Over the last one-and-a-half century, climate change has affected the entire planet. The National Oceanic and Atmospheric Association (NOAA) of the USA monitors global climate data, and here are some of the changes it has recorded. Average sea levels have increased by over 8 inches (about 23 cm) since 1880, with about three of those inches gained in the last 25 years alone. Every year, the sea rises another

0.13 inches (3.2 mm). New research (EarthSky, 2022) shows that sea level rise is accelerating and projected to rise by a foot by 2050. As a worldwide phenomenon, climate-induced sea level rise is likely to cause significant losses in land and capital endowments in many regions simultaneously. The size and scope of these losses will induce a general increase in consumer prices that will generate economic costs above those considered to be direct costs (Darwin & Tol, 2001).

Climate Change and human health

There are direct and indirect effects of climate change on human health. Thermal stress, a rise in temperature, and other extreme weather occurrences like floods, cyclones, and droughts, among others, are what have the most direct effects. It also includes impacts due to disease vectors and infectious agents induced by climate change, like the increased production of air pollutants and aeroallergens such as spores and molds (Karl et al., 2009).

Human health may also be indirectly impacted by an increase in water, food, and vector borne diseases. The spread and transmission of viral infections are significantly accelerated by rising temperatures, most likely due to an increase in viral contagiousness. (Kilpatrick et al., 2008). Heavy downpours can lead to increased sediment in runoff and outbreaks of waterborne diseases (Ebi & McGregor, 2008). Water quality degradation and increased pollution carried to lakes, estuaries, and the coastal ocean following heavy rains, especially when combined with the effects of higher temperatures, can result in the unusual growth of harmful algae and bacteria, as well as an increased risk of waterborne parasites such as Cryptosporidium and Giardia.

More precipitation makes water less transparent to ultraviolet light, which hinders sunlight's ability to disinfect surface waters and potentially increases parasite epidemics in a variety of species, ranging from zooplankton to amphibians and humans (Williamson et al., 2017).

Strategies to combat the impacts of climate change

Climate change can be managed through proper adaptation and mitigation strategies. Adaptation strategies are those actions that reduce the negative impacts of climate change, while mitigation is an intervention to reduce and control greenhouse gas emissions (Solomon et al., 2007; Stocker et al., 2014).

Mitigation actions

The purpose of mitigation action is to limit the extent of climate change. CO2 is one of the most important anthropogenic greenhouse gases because of its high concentration in the atmosphere. The amount of CO_2 in the atmosphere today is 50 per cent higher than it was before the industrial revolution.

The primary sources of CO_2 emissions are the burning of fossil fuels for electricity generation and transportation, deforestation, agriculture, and many other practices. CO_2, along with other greenhouse gases (GHG), steadily warm the atmosphere of the earth by trapping heat radiating from the earth's surface, which ultimately brings weather and climate related impacts, including heavier precipitation, flooding, heat waves, GLOF events, land sliding and rock falling. Climate change mitigation can make a difference, its purpose is to limit the degree of climate change (Lackner et al., 2012). By using renewable energy sources, efforts to combat climate change not only create a sustainable environment but also a sustainable economy.

We can mitigate climate change by using the following strategies:

- Promoting low-carbon energy sources and technologies.
- Promoting energy conservation and efficiency.
- Reducing emissions from deforestation.
- Sequestering carbon before it is emitted.
- Promoting sustainable agroforestry to naturally sequester carbon.
- Improving mass transit.

Adaptation Actions

In order to protect against climate change's negative effects on social and environmental well-being, concrete eco-friendly actions must be taken to adapt systems and educate society about the reality of the phenomenon. Three different effects of climate adaptation are possible: reducing potential losses, stimulating the economy through innovation, and providing additional social and environmental benefits (Lackner et al., 2012). Adopting a climate change strategy is not a general endeavor. The effects of climate change are not being felt equally by all countries or regions of the country. Climate change vulnerabilities change with time and place. There are many ways to help communities comprehend the risks posed by climate change and take appropriate action. Some adaptation strategies are mentioned as follows:

- Incorporating climate risks into policies and planning at different levels.
- Addressing climate impacts in various sectors.
- Community-based and local government training to adapt to climatic changes.
- Protecting the river, its tributaries, and improving water drainage systems.
- Decentralizing energy supply system
- Government should provide sufficient resources for prioritization of climate in educational institutions to educate rural people

Both adaptation and mitigation have unique benefits and vary in degrees of effectiveness from one region to another. Details on their outcomes, timetable, and implementers are provided in Table 4.3.

Table 4.3 Adaptation versus Mitigation Strategies (Lackner et al., 2012).

Aspects	Adaptation	Mitigation
Effects/Benefits	Regional/Local	Global
Timeframe	Day/Month/Years	Decades and Centuries
Implementers	Individual/local governments	National Government
Effectiveness	Hard to measure	Measurable

Relationship between Mitigation and Adaptation

Mitigation and adaptation are intertwined; if less effort is put into mitigation, there should be more plans and initiatives for adaptation; and vice versa, if more effort is put into mitigation, there should be fewer efforts put into adaptation. Figure 4.6 clearly describes the relationship between mitigation and adaptation.

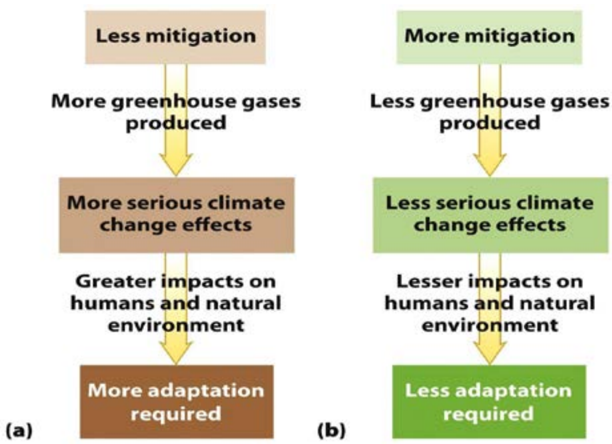

Figure 4.6 Relationship between adaptation and mitigation (Lackner et al., 2012).

What can we do in the HKH region to slow down climate change?

In the mountainous region of the HKH, climate change has already had an effect in recent years. GLOF, landslides, flash flooding, and debris flows are already being exacerbated by extreme weather events and increasing climate variability, and they have a detrimental effect on water availability and agricultural productivity. Mountain communities are more vulnerable to climate change impacts than non-mountainous regions because of poor access, poor infrastructure, limited climate information and support services, and insufficient adaptive technologies. Climate change adaptation is urgent for the HKH region, though it is a challenge for policymakers. Government responses are mostly incremental and not yet well integrated with development plans and programs in HKH (Mishra et al., 2019; Raza et al., 2016).

Along with these challenges, there are opportunities as well in the HKH regions. These opportunities may include improved operations among HKH countries, initiatives for climate literacy development, encouragement to endorse policy experiments, and boosted private sector engagement. A substantial increase in funding is also required to boost adaptation in the HKH regions. Countries and institutions located in the HKH region must work together and discuss key challenges, such as data sharing, regional cooperation, and cross-learning (Mishra et al., 2019).

Climate change policies

Climate change is a global phenomenon. In order to reach a sustainable society, it is necessary to integrate climate change measures into national policies, strategies, and planning. In this regard, international, national, and regional-level policies have been developed. A brief overview is given below:

UN Climate Change Strategy

Realizing the importance of climate change, the United Nations Framework Convention on Climate Change (UNFCCC) established an international environmental treaty to combat dangerous human interference with the climate system. This treaty was signed by 154 member states of the United Nations in Rio de Janeiro during the Earth Summit held from June 3–14, 1992. This treaty came into force on March 12, 1994.

The treaty called for ongoing scientific research, regular meetings, negotiations, and future policy agreements designed to allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened, and enable economic development to proceed in a sustainable manner.

The first set of regulations under the United Nations Framework Convention on Climate Change (UNFCCC) were put into effect through the 1997 Kyoto Protocol, which lasted from 2005 to 2020. The Paris Accord, which became effective in 2016, replaced the Kyoto Protocol. The UNFCCC had 198 parties by 2022. The Conference of the Parties (COP), its top decision-making body, holds annual meetings to review the status of efforts to combat climate change. Since the UNFCCC's adoption, it has been alleged that it has failed to reduce carbon dioxide emissions because significant signatory states are not upholding their individual commitments. The Conference of the Parties (COP) is the supreme decision-making body of the Convention. All states that are party to the Convention are represented at the COP, where they review the implementation of the Convention and any other legal instruments that the COP adopts and take the necessary decisions to promote the effective implementation of the Convention, including institutional and administrative arrangements.

National Climate Change Policy

Pakistan's National Climate Change Policy (NCCP) marked a significant turning point in the country's response to climate change. which was approved in 2012. The policy was revised and updated in 2021. The National Climate Change Policy comprehensively addresses all possible challenges of climate change adaptation and mitigation, and ensures that the ensuing climate change action plans, programs, and projects have a rock-solid foundation. The revised National Climate Change Policy aims to steer Pakistan toward climate-resilient and low-carbon development.

Provincial Climate Change Strategies

In line with the National Climate Change Policy of Pakistan, 2012, the provincial governments have approved strategies and policies to combat climate change. For example, the Government of Gilgit-Baltistan has approved the "Gilgit-Baltistan Climate Change Strategy and Action Plan 2017." This strategy has been formulated to take measures to reduce risks and vulnerabilities in diverse sectors due to a changing climate. This document has been prepared with the consultation of all stakeholders. For any plan to succeed, it is necessary to put monitoring mechanisms in place to ensure that progress is made accordingly. Therefore, this strategy has mandated that each sectoral action plan has clearly defined goals as well as a robust monitoring system in place to track progress and ensure accountability.

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Chapter 5

Mountain Hazards and Disaster Management

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Debris flow (a type of mountain hazard) in Darkot Village, District Ghizer © *Zafar Khan*

Introduction

Incidents of natural disasters have, in recent times, increased around the globe. In their wake, they leave devastation, including, but not limited to, human injury and deaths, destruction of property, and loss of livelihood and infrastructure. A disaster occurs when a hazard[1] causes damage, casualties, and disruption to a vulnerable[2] community. Natural catastrophes are extreme events that cause a loss of life and injury, hamper economic development, and damage the living environment and resources.

1 A hazard is a dangerous phenomenon, which affects human activity or livelihood, and services leading to socioeconomic disruption and environmental damages. There are some important characteristics of hazards, such as magnitude, intensity, and frequency of events.

2 Vulnerability means the risk of loss or destruction of a particular item, while risk includes the probability level of loss expected from a predictable magnitude of hazard. It also refers to a state of resilience of people, property, and livelihood, and the susceptibility of infrastructures to a hazard.

During the last two decades, every year around 200 million people have claimed to be affected by disasters (Briceño, 2018).

Disasters can have varying degrees of effects on humans and their properties according to their level of vulnerability[3]. Natural calamities are also seen as barriers to the socioeconomic development of households in a milieu shaped by widespread destruction of livestock, crops, homes, livelihoods, roads, bridges, schools, hospitals, and other facilities (Wisner et al., 2004).

The negative impact of natural disasters and associated risks have increasingly become a matter of concern worldwide. Due to inter-linkages, consequences in one region can have an impact on another and vice versa. Vulnerability is constituted by many factors related to socioeconomic conditions, technological advancements, population change, haphazard urbanization, unsustainable development in disaster-prone areas, environmental degradation, and scarcity of resources. This understanding points to a future where catastrophes could increasingly cause global economic recessions as well as hamper sustainable development efforts in developing countries.

By 2050, communities in urban areas will be highly exposed to hydro-meteorological and geologic hazards, whereas climate change will exacerbate, in both intensity and magnitude, further escalating the spatial extent of disasters. Rapid strategies are needed to deal with the increasing uncertainties of climate change and disasters, focusing on adaptation in policies, institution building, development planning and scaling up disaster resilience (Khan & Shaw, 2015).

Disaster Risk Management includes the sum of all activities, programs and measures that can be taken up before, during and after a disaster with the purpose to avoid a disaster, reduce its impact or recover from its losses.

Overview of hazards

The term hazard, in a wider sense, signifies threat, and a future source of danger, which has the potential to cause harm to people, human activity, property, and bring about a loss of environmental amenities (Smith, 2013). UN/ISDR [International Strategy for Disaster Reduction], (2009) defines hazard as a dangerous phenomenon, which affects human activity or livelihood and services, leading to socioeconomic disruption and environmental damages.

There are some important characteristics of hazards, such as magnitude, intensity, and frequency of events. A natural phenomenon, which may occur in a human-occupied area with the probability of causing loss and damages, is called a *hazard* event. A physical event in a remote area that does not affect human beings is not considered as a hazard. A hazard can arise from various sources and systems, such as the atmosphere, hydrology, oceanography, volcanology, seismic, geology and the environment (Bohle, 2001; Cutter et al., 2010).

Hazards are largely categorized as *natural* and *anthropogenic*. Natural hazards are further classified as *geophysical* (earthquake, landslides, volcanic activity), *hydro-meteorological*[4] (floods, tropical storms, drought), and *biological* (diseases, epidemics). On the other hand, anthropogenic hazards include *human-induced* phenomena such as climate change, arsons, mining of non-renewable resources, environmental degradation, and technological hazards (UNISDR, 2009).

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3 The impact depends on various factors, such as *physical vulnerability*, *economic vulnerability*, *social vulnerability*, *and environmental vulnerability*.

4 The hydro-meteorological phenomena are atmospheric and hydrologic processes that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, and environmental damage. These hazards can be tropical cyclones, thunderstorms, hailstorms, tornadoes, heavy snowfall, avalanches and coastal storm surges, floods (including flash floods), heat waves and drought.

Table 5.1 Various types of hazards (Crundall et al., 2012)

Hazards	Types
Geological hazards	Volcanic eruption, earthquake, tsunami, landslide, dam burst, mine fire
Water & climatic hazards	Tropical cyclones, floods, tornado, hurricane, drought, hailstorm, landslide, cloudburst, heat & cold wave, sea erosion, snow avalanche
Environmental and biological hazards	Contamination of the environment, deforestation, human/animal epidemics, pest attacks, desertification, infection, food poisoning, mass-destructive weapons
Chemical, industrial, and nuclear accidents	Chemical disasters, industrial disasters, oil spills/fires, nuclear
Accident-related	Boat, road, train accidents, air crash, rural/urban fires, forest fires, building collapse, electric accidents, mine flooding

Disaster risk management interventions require an accurate risk analysis of the communities exposed to potential hazards. Risk analysis can be defined as a systematic use of available information to determine how often specified events and hazards, may occur and the magnitude of their likely consequences (Buckle, Mars & Smale, 2000). It also requires an analysis of how vulnerable the elements at risk are in a particular region.

Risk (R) is the expected degree of loss due to a particular natural phenomenon. **Hazard (H)** is defined as the probability of occurrence of a natural event, within a specified time period in a given area which has the potential to cause damage. **Vulnerability (V)** means the degree of loss to a given element at risk or a set of such elements resulting from the occurrence of a natural phenomenon of a certain magnitude. **Element at risk (E)** means the population, building and civil engineering works, economic activities, public services, utilities, and infrastructure in a given area.

Vulnerability to environmental hazards

Originally, the term vulnerability was used in poverty research (Mueller et al., 2014), but now the idea of vulnerability has become a cornerstone in the study of natural hazards. Since the 1970s, the concept has been used in geography to study human-nature interaction (Khan & Shaw, 2015). Vulnerability is defined as "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard" (Wisner et al., 2004, p. 11). Vulnerability means the risk of loss or destruction of a particular item, while risk includes the probability of loss expected from a predictable magnitude of hazard.

Vulnerability and resilience are closely interlinked. The more vulnerable a community is, the lower its resilience would be and vice versa. The impact of the hazard varies depending on the type and level of vulnerability of the region. The degree of risk expected is directly linked with the severity of the hazard, the type of vulnerability and the coping capacity of the community affected (Khan & Shaw, 2015). The vulnerability of a population due to its location in relation to geophysical hazard zones usually depends on the socioeconomic characteristics of a community to cope with the effects of the event. In any community, individuals or groups become vulnerable to a hazard if they are not resilient enough against the extreme event.

Vulnerability of areas can be assessed through various components, such as physical, social, and economic characteristics, disaster awareness, level of exposure adaptive capacity, coping strategies, institutional capacity, and knowledge of past disasters. Vulnerability is multidimensional in nature and cannot be assessed based on a single factor. The degree of vulnerability also varies with hazard type and its location (Rashid, 2013).

From a theoretical perspective, vulnerability can be classified into three major premises (Müller, 2018; Cutter et al. 2010; Birkmann 2006; Greiving et al. 2006). The first of these branches forms the hazard and risk paradigm, which is constructed on human-nature interactions. This theoretical part mostly relates to the nature of the hazards, the location of the human settlements in relation to the hazardous zone, and the probable effects of the hazard. Here, a hazard is the source that produces vulnerability and explains exposure, sensitivity, and potential consequences. This part mainly evaluates the power structures, resource distribution, and the cultural and economic aspects of a community or a state. It indicates how and why a particular community is vulnerable and how and why the impacts of hazards on a community or individuals are unequally distributed. The third lineage develops the idea of resilience science to comprehend societal vulnerability to global ecological changes. This pattern of vulnerability indicates a dynamic property of a system in which humans are constantly interacting with their biophysical and socio-ecological environments (Adger, 2006).

Risk

Risk refers to the likelihood of a hazard causing harm, and to its possible negative consequences. Risk can also be expressed as the probability of damage and effects caused by an unforeseen event to humans (Alexander, 2000; Khan & Shaw, 2015). It is a complicated concept that includes both hazard and vulnerability. Risk is considered as the likelihood of occurrence or the degree of loss of an identified item projected from a specific hazard (Schneiderbauer & Ehrlich, 2004). The risk of hazards combines three overlapping factors acting concurrently: hazard, exposure, and vulnerability (ADRC [Asian Disaster Reduction Center], 2005; Birkmann, 2006). Hazards are a possible danger to inhabitants and the environment, while risk is the interaction between hazard and vulnerability.

The risk to a specific community fluctuates over time and depends on its socioeconomic, cultural, and other related attributes. The risk of natural hazards depends on both the hazard and the capability of the community to withstand shocks from disaster (Wisner et al. 2004; Cannon, 2000). The projected losses could be physical, social, economic, psychological, and ecological.

Hazards are characterized by probability and intensity, whereas vulnerabilities are the product of susceptibility and exposure (Rehman & Shaw, 2015).

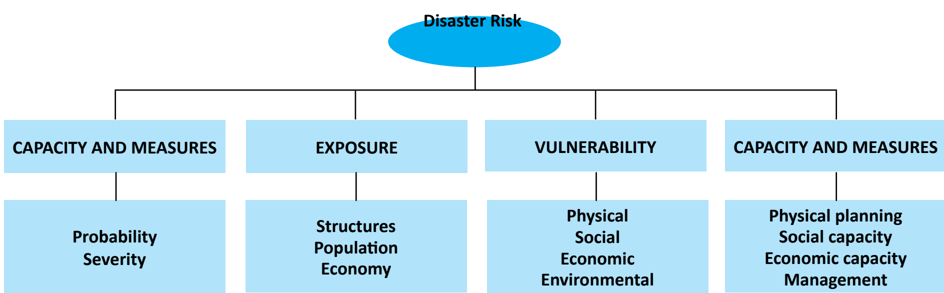

Figure 5.1 Conceptual framework to identify risk (after Davidson, 1997)

Causes of disasters in mountainous landscapes

A disaster occurs when a hazard causes damage, casualties, and disruption to a vulnerable community. A hazard is a potentially threatening situation or event that poses a risk to property, persons, or the environment (Smith, 2013). Natural hazards are dangers brought forth by natural processes, e.g., hazards with climatological, ecological, or even biological origin. Hurricanes, tsunamis, seismic activity, and volcanic eruptions are some of the examples of natural hazards (Wisner et al., 2004).

Socio-natural hazards include landslides, floods, drought, and fires because of their roots in both natural and anthropogenic factors. For example, flooding might be caused by excessive rainfall, a landslide, or the clogging of drains with human waste (Bahmani & Zhang, 2021). Man-made risks are the risks that result from human negligence associated with industry or energy producing facilities. Man-made dangers include explosions, hazardous waste leaks, pollution, dam failure, civil conflicts etc., (Langenbruch et al., 2018).

Climate change-induced disasters

Climate change is a primary factor for mountain hazards. Specifically, climate change affects hazards where water is crucial and where ice can melt (Solecki et al., 2011). Due to the peculiar geological and topographical features of mountainous areas as well as the impact of global climate change, extreme rainfall events frequently result in disasters, such as flash floods, GLOFs, debris flows, landslides, dammed lakes, and others (Ihinegbu, 2021). Part of the problem stems from the fact that mountain ecosystems have limited resiliency, while adequate time is needed for adjustment and adaptation. It is essential to recognize that not all mountain risks have apparent climatic links. Most earthquakes, for instance, are unrelated to climate. Even when a disaster is tied to climate or weather, the causal linkages to climate change are often unclear (Perry et al., 2018). Some significant effects of climate change occur when ice and liquid water coexist, such as melting snowfields, glaciers, and melting ice. The mountains in northern Pakistan combine these elements to an extreme degree.

Numerous natural and man-made hazards continue to pose threats to the Hindukush-Himalayan region, endangering the lives and ways of life of its residents. These dangers include disaster caused by natural hazards such as fires, floods, earthquakes, landslides, cyclones, and droughts, as well as, transport accidents, and industrial accidents. In the glaciated regions of the Hindukush and Karakorum, rising temperatures and melting glaciers may lead to the formation of glacial lakes. Some drain catastrophically, causing Glacier Lake Outburst Floods (GLOFs), although the majority develop, expand, and empty without any detrimental effects (Din et al., 2014). Several significant GLOFs and other glacial catastrophes have occurred in the region, resulting in the loss of life, property, and infrastructure. Like other glaciated regions, in Northern Pakistan climate change has resulted in the formation of new and potentially dangerous glacial lakes. The threat posed by these lakes require enhanced management, efficient early warning systems, and adequate response capacities.

Impacts of disasters on societies

Natural catastrophes are extreme events that cause a loss of life and injury, hamper economic development, and damage the living environment and resources. Annually, thousands of people are affected by disasters (Wei et al., 2015). The estimated toll on global economy due to natural disasters in the 1960s was up to US$ 40 billion, which swelled to US$ 70 billion in the 1970s, and rose to US$ 120 billion in the 1980s (Wilhite, 2000). The socioeconomic consequences necessitate the need for more consideration to disasters as part of the global poverty agenda. Similarly, there are growing indications that global climate change is increasing the recurrence and virulence of climatic hazards, such as hurricanes and floods in most parts of the world (IPCC, 2007). The kinds of risks confronted by poor and vulnerable people in rural areas, predominantly those involved in agriculture and other ecosystem-dependent livelihoods, are becoming a key cause of chronic poverty (Vathana et al., 2013).

A disaster may cause direct, indirect, and intangible losses to the environment and society (Petrucci, 2012). Direct losses include physical effects such as destruction of lives and livelihoods and changes that reduce the functionality of an individual, infrastructure, and vehicles. Indirect losses affect a society by disrupting or damaging utility services and local businesses. This is coupled with the loss of revenue, costs of aid efforts, shelter, food and drinking water, and costs associated with the need to drive longer distances because of blocked roads. Intangible losses include psychological impairments caused by both direct and indirect losses suffered by individuals during a disaster.

Gendered disasters

Gender, as a cultural construct, encompasses varied and complex realities (Bradshaw, Chant & Linneker, 2017). Disasters are a great way to understand how the gender dynamics work in any society and culture. The understanding of the disaster cycle [at any stage] as gender neutral is reflective of the systemic naivety that is commonly seen in association with disasters as a phenomenon.

The most fundamental understanding of the term gender begins with its differentiation from the term sex. While 'sex' is the biological difference between males and females, 'gender' strictly refers to the social and cultural differentiation (Khalid, et al. 2021). The difference between women and men within the same household, society, and culture, as well as between different cultures, is socially constructed that is reflected in the roles, responsibilities, access, opportunities and needs of men and women. Since it is a socially and culturally constructed phenomena [it is what people think it to be and not a fixed rigid concept], it changes over time and is subjected to the perceptions of people at a given time.

The admission of gender in the disaster scholarship is a relatively new development. In the early 1980s, gender components began to emerge in the disaster research (Rivers 1982), but it was not until the end of 1990s that several key publications related to 'gender and disasters' appeared on the international platform. Among them, the most notable was the first special edition of the International Journal of Mass Emergencies and Disasters on women and disasters. Even though there was plenty of literature on gender and environment, gender made a late entry to the climate change debate. The 'gendered aspect of climate change and disasters' was also invisible in the eyes of the media and experts for a long time. Even in 2005, when Hurricane Katrina hit the west coast of the United States of America, the gender aspect was invisible in the relief and response efforts even by the humanitarian groups (Enarson & Meyreles, 2004).

Mountain hazards and disasters

Mountains are fragile ecosystems with global importance as water towers for adjacent, densely populated lowlands. Mountains are the sources of forests and timber, minerals, biodiversity hotspots, cultural diversity and are home to over 600 million people, which correspond to 12 per cent of the global human population (Huddleston et al. 2003). Most mountain people live in developing countries and are among the world's poorest and most disadvantaged people due to harsh climatic and environmental conditions, political, social, and economic marginalization, and lack of access to health and education services (FAO [Food and Agriculture Organization], 2011). Mountains are therefore crucial regions for sustainable development and human well-being regarding food security and poverty mitigation (Singh et al. 2011).

Mountain regions are prone to disasters because of the high exposure to multiple hazards such as avalanches, landslides, floods, debris flows and glacial lake outbursts floods (Kohler and Maselli, 2009). Mountains by their nature are growing and changing; rain-induced soil erosion, freezing, thawing of snow and flow of water break down rock are examples of the 'liveliness' of mountains. Extreme slopes and unstable formations turn heavy rain or snow into agents of destruction. Water loosens boulders, soaked earth slips down exposed rock faces, and the melting snow breaks them. Changing climate patterns may further reduce predictability and negate tried and tested practices of hazard reduction. Thus, the projected global temperature increase will strongly influence the frequency and intensity of disasters in the mountain regions, especially with regard to hydro-meteorological events. Disasters in the mountain regions sometimes cause massive loss of life and property, and can cut off entire areas for days, weeks, or even months.

The environmental and economic costs of mountain disasters are immense. Even more serious is the loss of lives and livelihoods and their subsequent impacts on the progress of mountain communities. The more densely populated an area, the greater the disaster in human terms can be. A small landslide or minor earthquake in a populated area captures our attention, whereas a much greater event in a remote, scarcely populated one can pass without much notice. The remoteness of mountain areas often means that highways, roads, and trails on hillside slopes that creep through narrow valleys are blocked or damaged, or rivers in valley bottoms are temporarily dammed only to release their waters sometime later in a disastrous flood wave. Mountain dwellers are vulnerable in ways unimagined by those living in the plains. Living in remote scattered hamlets, they have little or no access to resources such as safe buildings, technology, or warning systems. The communication channels are scarce which means they often have no way of telling the world how and to what extent they have been affected by a disaster. Even when a large-scale disaster occurs, they may wait for days for the relief teams and relief items to reach them. Sometimes, houses must be dug out and landslides have to be cleared by hand, as there is no way to bring in heavy machinery. Even medical treatment is an unreachable luxury (Maharjan et al., 2018)

In some areas, such as the Hindu Kush and the Himalayas, the mountains are still being formed because of movements in the earth's crust which leads to earthquakes, and tremors. In other parts, volcanic activity adds to the hazards. More recently, land degradation and loss of ground cover are suspected of contributing to an increased incidence of disasters, compounded by changing climatic patterns that may reduce predictability and negate tried practices of hazard reduction.

Disaster risks in Pakistan

Pakistan is highly vulnerable to disasters and is facing serious threats and challenges from large-scale natural and anthropogenic hazards such as, seismic events, landslides, droughts, floods, fog, torrential rains, tropical cyclones, dust storms, fires, and oil spills. Geographically situated at the junction of major tectonic plates and the world's tallest and youngest ranges (the Himalayas, the Hindu Kush and the Karakoram), Pakistan is under a permanent threat of calamities due to its location in a seismically active zone. The regions of Azad Jammu and Kashmir, Gilgit-Baltistan and parts of the Khyber Pakhtunkhwa are particularly vulnerable to earthquakes and landslides. Deforestation in these areas is a major contributing factor besides increased incidents of landslides. The Kashmir region and northern areas of Pakistan are particularly prone to avalanches. Flash flooding in hills also poses a threat to the communities living in the Indus Basin and its surroundings (NDMA [National Disaster Management Authority], 2012).

Several factors aggravate the vulnerability of the people living in the vulnerable landscapes, including poor construction practices, livestock dependency, agricultural mismanagement, fragile natural environment, weak early-warning systems and communication infrastructure, lack of awareness and education, and poverty. The scant availability of safe land for construction, scattered settlement patterns and harsh climatic conditions further intensify their vulnerability. Other dynamic pressures include the human and animal population growth, environmental degradation resulting from poorly managed urban and industrial development processes, and climate change and variability.

In the coming decades, the frequency, severity, and impact of certain hazards may increase which might lead to greater social, economic, and environmental losses. The absence of a comprehensive Disaster Risk Reduction (DRR) strategy and preparedness mechanisms in the country has been a major catalyst for large-scale destruction in the past.

Disaster management cycle

Disaster management aims to reduce, or avoid the potential losses from hazards, assure prompt and appropriate assistance to the victims of a disaster, and achieve rapid and effective recovery (Seneviratne et al., 2010). Disaster risk management includes the sum of all activities, programs and measures that can be taken up before, during and after a disaster, with the purpose to avoid a disaster, reduce its impact or recover from its losses.

The four-phase disaster management illustrated here does not always, or even generally, occurs in isolation or in this precise listed order. Often phases of the cycle overlap and the length of each phase greatly depends on the severity of the disaster (Khan et al., 2008). The cyclical nature of the disaster management process focuses on the ongoing and continuous actions to prevent and manage the disasters. **Prevention** activities are aimed at trying to prevent future disasters from occurring, such as building dykes or a dam to control flooding. **Mitigation** activities attempt to minimize the impact of a disaster if prevention is not possible, such as building schools to be more earthquake resistant. **Preparedness** activities help prepare communities for a disaster, such as emergency drills or pre-stocking relief items in logistic hubs. **Response** activities try to understand needs and respond to them, including rapid assessments, provision of food and non-food items, provision of water, sanitation and hygiene services, and health and shelter interventions. In the immediate hours and days after a disaster, when search-and-rescue activities are critical, it is most often local actors who are first to respond. Information is often patchy and confused; there can be significant damage to infrastructure, and large movements of people. **Recovery** activities assist communities in returning to normal life, such as livelihood development or formal education. Recovery activities can start when the disaster has stabilized, and the affected population has access to food and water and some form of transitional shelter. This stage is sometimes divided into early recovery and medium-term recovery. **Reconstruction** activities help rebuild infrastructure and housing, which can often take years, and many activities may blend back into mitigation, such as retrofitting schools to make them more earthquake resistant (Rana et al., 2021).

Conclusion

Mountains are fragile ecosystems and are prone to disasters and multiple hazards. Pakistan is highly vulnerable to disasters and is facing serious threats and challenges from large-scale natural and anthropogenic hazards. It is at the center of risks from geophysical and hydro-meteorological hazards such as floods, earthquakes, landslides, drought, GLOF, cyclones, and heat waves. We conclude that climate change will further intensify the frequency and intensity of climate-related extreme events. This is an alarming condition, and the government must take bold steps to reduce the impact of disasters through planning, policy, programs, preparedness plans, coordination among line departments, establishment of early warning systems, resource mobilization, and build community resilience against unforeseen events.

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LIFE AND RESOURCES IN MOUNTAINS

Chapter 6

Mountain Ecosystem Types and Services

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Kutwal lake and adjacent birch (Betula utilis) forest in Haramosh, Gilgit © Zafar Khan

Introduction

Ecosystem services are defined as the benefits people get from nature. Ecosystem services are important for human livelihoods. In developing countries like Pakistan, ecosystems are degrading due to anthropogenic effects such as pollution, deforestation, conversion of land use, and climatic threat. It is important to inform all stakeholders about the significance of the sustainable flow of the ecosystem. Sustainable use of the natural resources is important to obtain benefits from nature for the current and future generations. *Natural* and *man-made* ecosystems are the two main types of the ecosystems, further divided into *terrestrial* and *freshwater* ecosystems. There are four major groups of ecosystem services, such as *provisioning*, *regulating*, *cultural* and *supporting* ecosystem services. This chapter discusses the major ecosystems and types, ecosystem concepts and classifications, ecosystems services and groups, threats and challenges to the ecosystem services and policy and management strategies for sustainable mountain development.

Ecosystems

Ecology is a science that deals with multiple levels of life forms and their interaction, from molecular to landscape le. Ecosystem ecology has become the main area of ecological research (Weber et al., 2017; Wang & Zhai, 2019). The term ecosystem was first coined by Tansley in 1935 in a study on vegetational concepts and terms. According to Tansley, organisms cannot be separated from their physical environment, which plays a fundamental role in their lives (Willis, 1997). An ecosystem has communities in which species interact with each other and with the physical environment in which they exist. There are many diverse ecosystems on the earth, yet there is a need to realize that the earth itself is an ecosystem (Vignieri & Fahrenkamp-Uppenbrink, 2017). An ecosystem is a self-sustaining, structural, and functional unit of the biosphere. It may be natural or artificial, terrestrial, or aquatic (Balasubramanian, 2017).

Components and types of ecosystems

There are two types of components in an ecosystem based on their structure and function. The structural components encompass *biotic* and *abiotic* components.

The biotic components include producers, consumers, omnivores, and decomposers. Producers are the organisms (algae and plants) that can produce food by the process of photosynthesis. There are many levels of consumers such as primary consumers or herbivores (which feed on the producers) and carnivores (which feed on the meat). Carnivores may be primary (eat the herbivores), secondary (feed on the primary carnivores, and tertiary carnivores (feed on the secondary carnivores). Omnivores are the organisms that feed both on the producers and consumers. Decomposers are the organisms that decompose the dead materials of the organisms from producers to the tertiary consumers' level.

The other component of structural type is the abiotic component, which includes all abiotic factors such as the *lithosphere* (soil texture, structure, nutrients, topography), *atmosphere* (air, wind, greenhouse gases, ozone, and ozone layer), *hydrosphere* (water quantity, water quality, chemical, and physical properties), and *climate* (temperature, wind, precipitation, radiation).

While the functional components of an ecosystem include the energy flow, food chain, and food web, the sun's energy is trapped by the producers in their chlorophyll and converted to the chemical form (carbohydrate, protein, and fats). Adenosine triphosphate (ATP) is a form of energy that is utilized to carry out activities in the organism. The energy from the producers is transferred to the herbivores (primary consumers in the food chain), and it is then further transferred to the next levels of the food chain (secondary consumer, tertiary consumer, and top consumer).

The term food web is used for a complex system in which many food chains are interlinked. In a food web, a single organism feeds on multiple organisms at each level, forming a web-like structure. Generally, the energy flow from the bottom level (producers) to the top level (consumer) decreases. It is because at each level, organisms use some of the energy to carry out activities and respiration, and in this process some of the energy is consumed and not available to the next level. In this way, the flow of energy at a trophic level forms a pyramid shape, as shown in Figure 6.1.

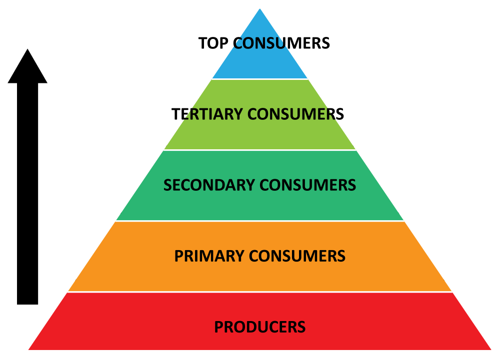

Figure 6.1 Energy flow at a trophic level

An ecosystem's size does not affect the length of a food chain, rather increases it linearly and strongly by ecosystem's productivity. Predator size and behaviour, and consumer density are considered the major drivers of changes in the food chain along a productivity gradient. Controlling drivers of food chain length vary in terrestrial and aquatic ecosystems (Young et al., 2013).

Based on the origin, there are two types of ecosystems – *natural* and *artificial*. Over time, natural ecosystems have formed or developed without any artificial or human intervention, such as forests, grasslands, lakes, and rivers. An artificial ecosystem is anthropogenic, e.g., nurseries, gardens, ponds, farms, and croplands. Natural ecosystems are of two types – *aquatic* and *terrestrial*. There are two sub-types of aquatic ecosystems: *marine* – seas, oceans, mangroves – and *freshwater* – lakes, ponds, rivers, streams, and springs. Terrestrial ecosystems encompass various ecosystems, including forest ecosystems, grassland/rangeland ecosystems, desert ecosystems, and mountain ecosystems.

Classification of ecosystem

Ecosystem classification is based on a theoretical framework whose principles are reflected in the stated meaning, structure, and notations by various organisations. The first and most widely used classification is by the Millennium Ecosystem Assessment (MA, 2005), which provides four categories namely: *provisioning services* (food, fibre, fuel, genetic resources, biochemical, ornamental resources and freshwater); *regulating services* (air quality regulation, water regulation, climate regulation, water treatment and wastewater, erosion regulation, disease regulation, pest regulation, pollination and natural hazard regulation); *cultural services* (cultural diversity, spiritual and religious values, inspiration, knowledge system, educational values, aesthetic values, social relations, sense of place, cultural heritage values, recreation and ecotourism); and *supporting services* (soil formation, photosynthesis, primary production, nutrient cycling and water cycling).

The Economics of Ecosystems and Biodiversity (TEEB) classification is based on the MA classification with minor additions, such as *provisioning services* (food, raw material, fresh water and medicinal resources), *regulating services* (local climate and air quality, carbon sequestration and storage, moderation of extreme events, wastewater treatment, erosion prevention and maintenance of soil fertility, pollination and biological control), *habitat or supporting services* (habitats for species and maintenance of genetic diversity), and *cultural services* (recreation, mental and physical health, tourism, aesthetic appreciation and inspiration for culture, art and design, spiritual experience and a sense of place).

According to the Common International Classification of Ecosystem Services (CICES), ecosystem services have three divisions, including *provisioning services* (nutrition, materials, and energy), *regulating and maintenance services* (regulation of wastes, flow regulation, regulation of physical environment and regulation of the biotic environment), and *cultural services* (symbolic, intellectual, and experiential) (Haines-Young & Potschin, 2017). The CICES system includes *final ecosystem services* that are defined as “contributions that ecosystems make to human well-being” either directly or indirectly. However, the CICES does not classify *supporting services,* as originally defined in the MA, rather considers them a component of the underlying structures and processes of the ecosystems. Provisioning services are material outputs, while regulating services are the mediation of aspects of the environment that affect people’s well-being. Cultural services include non-material and intellectual benefits.

The United States Environmental Protection Agency (US-EPA) proposed a new ecosystem services classification – the Final Ecosystem Goods and Services Classification System (FEGS-CS) – based on the final products of the ecosystems as benefits for the beneficiaries and the socioeconomic system (Landers & Nahlik, 2013). The FEGS-CS lays emphasis on the *ecosphere* (ecological processes), *beneficiary* (final ecosystem goods and services) and *economic sphere* (industrial processes and industrial goods and services) whereas the CICES classification system emphasizes the *ecological sphere* (biological structure, function, and services) and *socioeconomic sphere* (assets/commodities and production system/logistics) with benefits linking the ecological and socioeconomic spheres (La Notte et al., 2017). According to the US-EPA, goods are defined as “the tangible items that are created through a production process and that may be acquired, used, or consumed by people for use as inputs in another production process or to satisfy other needs or wants," while services are defined as "the intangible and non-storable 'flows' from the service provider to the service consumer and are measured over a period of time (e.g., hourly access to and use of a gym facility)" (Landers and Nahlik, 2013).

Ecosystem services concept and classification

The benefits that humans gain from ecosystems are called ecosystem services (MA [Millennium Ecosystem Assessment], 2005). Conceptually, environmental services, later renamed ecosystem services, have been recognized since 1970 (Wilson and Matthews, 1970; Ehrlich and Mooney 1983). However, research on ecosystem services gained momentum in 1997 and onwards (Gómez-Baggethun et al. 2010), including notable publications such as "*The value of world's ecosystem services and natural capital*" (Costanza et al., 1997) and "*Nature's Services: Societal Dependence on Natural Ecosystems*" (Daily, 1997). Research on ecosystem services also increased exponentially following the publication of five technical volumes and six synthesis reports by Millennium Ecosystem Assessment in 2005 – a UN-led global collaborative intellectual initiative project involving over 1,360 experts worldwide to give an integrated assessment of the effects of ecosystem change on human well-being, and to study the possibilities for enhancing the conservation of ecosystems and their contributions to meeting human needs. The project was launched in 2000, and its main conclusions provided information on the status and trends of the global ecosystems, and the products and services they give, including food, water and goods derived from forests and agriculture, and natural resources. The project's report also provided options for restoring or enhancing the ecosystems for sustainable use (MA, 2005).

Types of ecosystem services

Under the Millennium Ecosystem Assessment (2005), the four types of ecosystem services – provisioning, regulating, cultural, and supporting – and constituents of human well-being are illustrated in Figure 6.2. *Provisioning services* contribute to the flow of basic materials for good life and health, *regulating services* contribute to climate regulation, diseases and erosion prevention, *cultural services* contribute to health, good relations, and information, while *supporting services* support all other ecosystem services in their function and service flow.

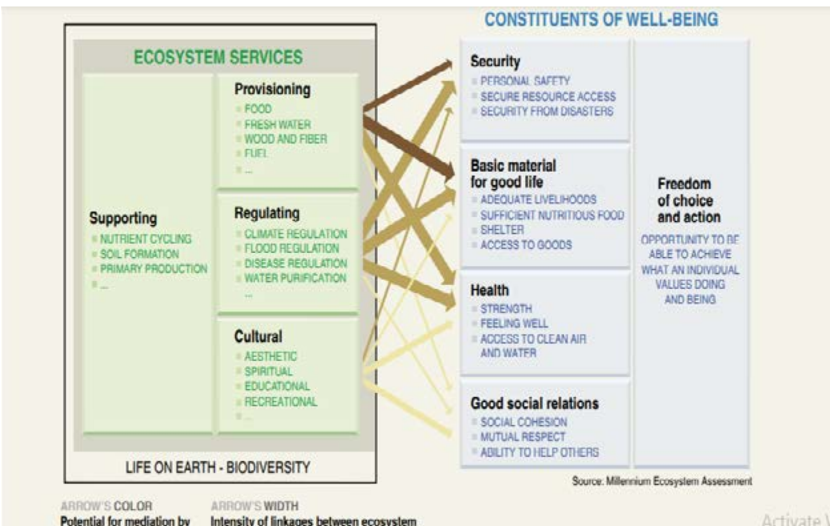

Figure 6.2 Ecosystem service types and constituents of human well-being (Source: MA, 2005)

Provisioning ecosystem services

These are the tangible goods that people get directly from the ecosystems for their well-being, such as food, fodder, wood, fibres, biofuels, biochemical and genetic resources. According to Sandra and Patricia (2013), although resources and goods are limited, they are renewable and can be traded. Crops, fruits, aquaculture, livestock, and wildlife are all sources of food. Fiber come from plants and animals, particularly sheep, goat, camel, rabbit, cotton plants, hemp, and silk. Fodder comes from pastures, forests, and agricultural land. Forests, nurseries, and individual gardens provide fuelwood and timber. Genetic resources are important in keeping biodiversity sustained for the present as well for the future generations. Biodiversity is important in the generation of ecosystem goods and services.

Climate change poses a challenge to the sustainability of biodiversity because of population growth, particularly in developing countries. Subsequently, some species are threatened, others are endangered, while some have even become extinct. It is important to conserve and protect these species which is possible only if there is genetic and species diversity, which are important for the ecosystem diversity and services.

Food security is becoming a serious issue in developing countries. This leads to malnutrition and malnourishment in highly vulnerable impoverished regions. To ensure food security, crop diversity, and agricultural biodiversity, it is necessary to take care of ecosystem services and sustain their growth. Another provisioning ecosystem service is freshwater. The primary sources of water are rain, glaciers, and water-springs. Forests and wetlands play an important role in the provision of clean drinking water for consumption.

Most of the energy used by humans from their ecosystems is produced from renewable natural resources like fuelwood, biomass, wind, and water. Plant- and animal-derived chemicals are used by pharmaceutical companies in the development of medicines. Plants have been used for ages to treat a variety of illnesses, wounds, and fractures. Medicinal plants play an important role in human well-being and therefore are used widely for the sustainable flow of services. Several studies have been conducted on the medicinal and aromatic plants of Gilgit-Baltistan, focusing on the usage of plant species and their parts, methods of farming, and ailments treated through the use of local ecological knowledge (Qureshi et al., 2007; Khan et al., 2015; Shedayi et al., 2016; Malik et al., 2018; Khan et al., 2018; Abbas et al., 2019; Wali et al., 2022).

Aquaculture and fisheries are other major sources of food and energy in the mountain ecosystems. Gilgit-Baltistan depends on water resources for power generation, and it is known as the water bank for the rest of the country. There are many power plants that are used for electricity generation.

There is a scarcity of formal studies, which may have been conducted to assess and evaluate the ecosystem services in the country. An initial study on ecosystems in GB conducted by Shedayi et al., (2019), assesses and evaluates the provisioning ecosystem services of Pakistan. While in another study conducted by Saeed et al. (2022) explore the local views on the provisioning ecosystem services and the implications of climate change in the Western Himalayas.

Regulating ecosystem services

MA (2005) defines such services as “the benefits obtained from the regulation of ecosystem processes”. The natural environment is regulated by the processes of the ecosystems. These regulating ecosystem services (RES) reduce the effects induced both by human activities and natural disasters. MA (2005) lists the services provided by the RES as air quality regulation, water regulation purification, climate regulation, erosion regulation, disease regulation, pest regulation, pollination, and natural hazard regulation.

Human actions have altered ecosystem services, which have brought significant negative consequences such as climate change and an increase in epidemics. The change in land use has had a substantial impact on the RES, raising carbon dioxide and other greenhouse gas emissions, including methane and nitrogen oxide. Carbon sequestration is a major service mainly provided by the forests and wetlands. Changes in land cover also affect water regulation in the form of the timing and magnitude of the runoff, flooding and aquifer recharge, and storage capacity of the system. Most of the conversion is made to achieve provisioning ecosystem services such as the conversion of wetlands and forest cover into croplands.

Ecosystems also perform source water purification by filtration; many chemicals and organic compounds are purified, releasing fresh clean water for consumption. Vegetation cover plays an important role in soil nutrient and sediment retention. This is especially a major issue in the mountainous region and correlates with rainfall intensity and duration. Changes in the ecosystems bring changes to the habitats and breeding sites, increasing the population of pathogens such as dengue and mosquitoes, and affecting the prevalence of pests. Climate and ecosystem changes also affect the performance and effectiveness of the pollinators, which play an important role in crop productivity, biodiversity, and silk and honey production. The coastal ecosystems, wetlands and forests reduce the damage caused by hurricanes, large waves, and floods.

Despite their obvious importance, the RES have received less attention in research because of their complexity and intangible nature. Lack of effective national and global policies regarding the RES, issues of climate change, soil degradation and erosion, pollution, and diseases have negatively affected ecosystem functions and service flows, besides cost to human lives.

Cultural ecosystem services

According to the MA (2005), cultural ecosystem services are the "non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experience." Cultural diversity, which is affected by the ecosystem diversity, is derived from such services. Many religious activities are related with ecosystem goods. Local ecological knowledge is generated through ecosystems, which are open laboratories to conduct research and act as sources of knowledge and education. Ecosystems provide inspiration for art, architecture, and folklore. Scenic locations, such as lakes, rivers, verdant pastures, springs, glaciers, and woods, offer aesthetic value and draw tourists. Social relationships differ among different types of ecosystems, e.g., fishing societies are distinct from agricultural or nomadic herding communities. Cultural heritage are the most important cultural landscapes, having unique features of nature and man-made amendments (Shedayi et al., 2022). Mountain ecosystems and cultural heritage are integrated into important ecosystems, which people visit for recreation, education, and aesthetic values. Ecosystems also provide recreational and ecotourism opportunities for local and international tourists, e.g., trophy hunting, bird watching, fishing, trekking, mountaineering, glacier climbing, and skiing.

The mountain ecosystems of Gilgit-Baltistan (GB) provide excellent destinations for the visitors. The average visitor flow is highest from May to September each year (Figure 2.3), as these months have the best weather conditions for ecotourism. Relatively fewer people visit GB in the winter, except those who come for the annual winter sports competition in Naltar and other areas (Shedayi et al., 2022). There are many emerging winter games that are gaining popularity among the local, domestic, and international sports persons. These include winter ice hockey, skiing, ice curling, ice polo, glacier and snow climbing etc. Local, domestic and international tourists visit GB to enjoy the beautiful landscape, its snow-capped mountains, lakes, rivers, spring, pastures and forests. The statistical information on domestic and international tourist flow to GB from 2010 to 2014 is shown in figure 6.3.

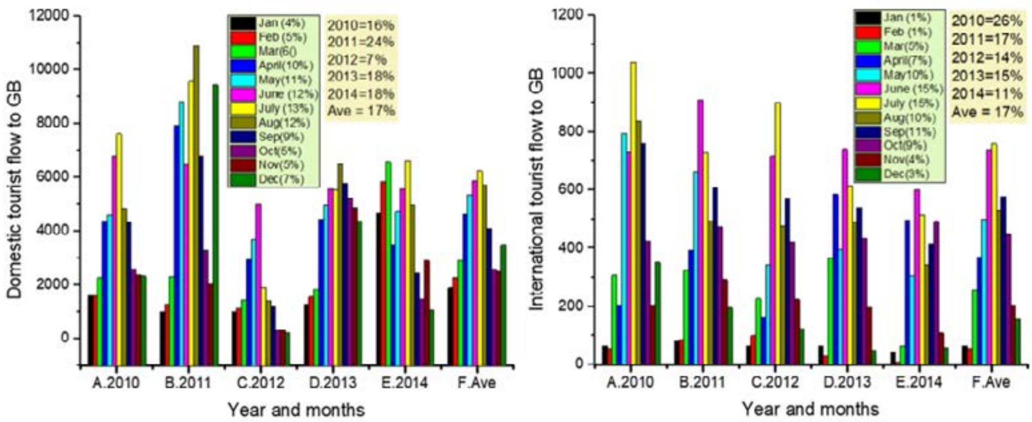

Figure 6.3 Domestic and international tourists flow to GB (Source: Shedayi et al., 2022)

Supporting ecosystem services

These types of services support all other ecosystem services in the processes, function, production and provision of the final products and services. The supporting ecosystem services have had an implicit yet pivotal impact on people's livelihoods since long. Some intermediate services of the ecosystem regulation, for example erosion regulations, are considered both in supporting and regulating services. Soil formation is an important process in food production through which soil particles and the required nutrients are provided to the plants. Soil is formed by physical, chemical, and biological processes. There are many factors that influence soil fertility for crops and plant growth. Food is prepared in a complex process of photosynthesis in the plants and plays an important role in the provision of food and energy for the living organisms. There are about 20 different elements essential for life, including nitrogen, phosphorus (MA, 2005) and potassium. There are diverse natural cycles and ecosystems that play various roles in the lithosphere, hydrosphere, atmosphere, and biosphere. For example, the water cycle is important in sustaining life and supporting other processes and ecosystems.

The study of supporting ecosystem services is overlooked for several reasons. A major problem has to do with the complexity of tracking the benefits they provide. Another issue has to do with the reclassifications of these services under different categories, leading to them being double counted under different ecosystem classification systems. The provision of the supporting ecosystem service depends on the ecosystem functions; with any change in the functions, the level of delivery of the supporting ecosystem service is changed (Kadykalo et al., 2021).

Mountain ecosystem: examples from Gilgit-Baltistan

Gilgit-Baltistan (GB) is located amidst the mighty mountain ranges of the Himalayas-Karakoram-Hindu Kush region of Pakistan, with some boundaries overlapping the Pamir Mountain range. The total area of GB is 72,971 km^2 (Kazim et al., 2015). Nearly half of the total area contains mountain peaks, glaciers, lakes, and highlands. The region has five peaks above 8,000 meters, a vast glacial area spread over 15,000 km^2 featuring at least 5,000 big and small glaciers, including three of the world's longest non-polar glaciers (Biafo, Baltoro, and Batura). Mountain glaciers cover 30 per cent of the total GB area, while another 40 per cent area is under seasonal snow cover. There are nearly 3,000 big and small glacial lakes, out of which at least 36 are unsafe with a high risk of glacial lake outburst (GB-EPA [Gilgit-Baltistan Environment Protection Agency], 2017).

Wetlands are natural ecosystems covering about 6-8 per cent of the earth's surface (Mitsch

& Gosselink, 2007). In Pakistan, wetlands comprise 2,753,375 ha or about 10 per cent of the total area (Scott 1989). Of those 225 significant wetlands are in Pakistan (10 per cent of the total area), 132 are found in Gilgit-Baltistan. The region's ecological and socioeconomic systems are strongly interdependent, as snow meltwater is the main source for agriculture and domestic use, besides running hydropower systems. GB has nearly 2 per cent cultivable land, and 80 per cent of the population are engaged in subsistence farming, producing a range of cereal crops, fruits, vegetables, and fodder for livestock (GB-EPA, 2017).

Forests cover 1,582 km^2 of the total GB area (Qamer et al., 2016). GB-EPA (2017) reports that the total natural forest cover is nearly 4 per cent while agroforestry, including the plants in arable areas, contributes nearly 6 per cent of the total area in the region. According to a study, 2.34 million ha are covered by rangelands (Khan et al. 2013), which makes up one-third of the total land area of Gilgit-Baltistan, while other estimates that the rangelands cover 52 per cent of the total area (GB-EPA, 2017). The grasslands include foothill grasslands (0.02 million ha), dry temperate grazing lands (0.28 million ha), valley grazing areas (0.21 million ha), and alpine pastures (1.83 million ha).

Climate change compounded with anthropogenic activities, like deforestation, degradation, fragmentation, and defaunation, is degrading ecosystems in many parts of the world (Malhi et al., 2019). Climate change affects the productivity, interaction of organisms, and vulnerability to biological invasions (Weiskopf et al., 2020). The interdependence of organisms on each other as well as on their environment, increases pressures on natural resources (Vignieri & Fahrenkamp-Uppenbrink, 2017).

Challenges in sustaining or regulating ecosystem functions and services

Harmful effects to the environment threaten the quality of life and the supply of ecosystem services to the people living in the mountain highlands and lowlands (Glushkova et al. 2020). Pressures on resources caused by natural catastrophes as well as anthropogenic activities have led to the degradation and deterioration of the pristine mountain systems and mountain forests. The mounting pressures on resources are primarily driven by an increase in the population. Hence, anthropogenic activities transgress the threshold leading to \encroachment into the realm of nature. As a result, the damage that is done to these mountain ecosystems and mountain forests is often irreversible. Anthropogenic activities that cause a modification to the land cover endanger the supply of ecosystem services which pose challenges to human wellbeing (Grêt-Regamey & Weibel, 2020).

Mountains being sensitive to the change in climate hold more importance than being just elevated highlands (Hock *et al.,* 2019). The communities living downstream or in the lowlands are not excluded from being prone to the havoc wreaked by natural disasters. Thus, sustainability of these ecosystem services must be at the heart of major policies and strategies devised internationally to curb climate change and to bring sustainability to the ecosystems on a globe scale (Grêt-Regamey et al., 2019). There are two main challenges to the sustainability and regulatory functions of the mountain ecosystem services: *anthropogenic activities* and *natural events*.

Anthropogenic activities exert pressure on biodiversity and cause disruption of natural habitats globally. This has led to discussions on sustainable management in land use with the concept of sustaining ecosystem services (MA, 2005). In earlier days, communication between the dwellers of highlands and lowlands was mainly due to trade of basic commodities. This changed to mass movement downstream post-development, and the resulting population explosion brought all kinds of social ills as well as environmental degradation (Iyngararason et al. 2002). Some of the anthropogenic activities that pose serious challenges to the health of ecosystems and their services have been briefly discussed in the following sections.

Deforestation

Deforestation has been one of the major

drivers affecting ecosystem services. The term refers to the clearing of an area mostly covered with trees for various purposes, such as construction, agriculture, furniture, fuel wood, and urbanization. The land use practices have changed since industrialization and urbanization. Many trees are being cut down every year to meet the demands of urbanization, resulting in a serious loss of biodiversity, loss of habitat, change in climate, soil erosion and landslides.

Forests are the hub of biodiversity since they provide the habitat for various species. Loss of biodiversity becomes visible with the change in land cover use. Many species of birds and animals lose their habitat when trees are cut down for infrastructure development or agricultural purposes (MA, 2005).

Recently, the changes induced by anthropogenic activities, resulting from management practices pushed by social, political and economic forces on ecological systems, have consequently spurred large-scale land uses and land cover changes (Halmy et al., 2015).

Trees are carbon sinks and clearing them results in greater greenhouse effects. They hold the soil together to keep the land compact. Deforestation results in soil erosion in addition to the loss of habitat and ultimately biodiversity loss and food scarcity, as trees being the primary producers feed half of the world's consumers. With deforestation, carbon storage is lost to the atmosphere at a massive level, climate change regulation is seriously affected, water holding capacity of soils is stunted with reduced water regulation and river flow, while the regional climate patterns are modulated that have negative effects on the ecological system.

Overgrazing

Overgrazing by livestock or wildlife depletes the grasslands, leaving vulnerable soil patches. The grazing of animals (herbivores) for extended periods of time reduces the plants to a point where the land gets exposed to the hazards of erosion by floods, winds, and the destruction of vegetation. Ruminant mammals overgraze, preventing the area's vegetation from recovering enough to sustain grass cover. This can also reduce the soil's capacity to carry water, which may significantly reduce the number of important medicinal plants. In extreme conditions, these medicinal plants become extinct. Thus, ecosystem services supply gets reduced and compromised.

Overgrazing also affects forests which are the major source of livelihoods of people. In areas where most of the population relies on various ecosystem services, a reduced land cover has implications for their livelihood and the biodiversity of that region (Chaudhary et.al 2017).

Over hunting

Hunting can play a significant role in wildlife management efforts, as well as provide financial support to communities and other government agencies. It is also useful in getting rid of predators that are harmful to people or domestic animals, other pests and nuisances that ruin crops, harm livestock, kill poultry, or transmit diseases. Hunting is done for trade or tourism, or for ecological preservation against invading species and overpopulation. Yet, the great majority of hunters in the contemporary era in the industrialized nations hunt and kill prey for sport. Wildlife hunting is a cruel sport that harms animals that cannot protect themselves, causing them pain, suffering, and injuries. It is another phenomenon driven by the anthropogenic activities of obtaining the products, primarily the meat and skin, for various purposes as well as entertainment by preying on animals. This can be especially problematic when the species being hunted are on the verge of extinction. The highly endangered species occupy a significant position in the ecosystem, especially playing a vital role in food web. Consumers depend upon producers, while the former are categorized as secondary and tertiary consumers, depending on the type of niche they have in the food web.

Overexploitation

Of all the aforementioned reasons, overexploitation is the factor that leads to the reduction or complete loss of the ecosystem services. Excessive use of renewable, as well as non-renewable, resources is known as overexploitation. It results in using the resources beyond the replenishing capacity, while non-renewable resources cannot be replenished at all.

Overexploitation of natural resources includes excessive mining, excessive fishing, high fossil fuel consumption, and excessive water use. Hence, practices such as overgrazing also constitute overexploitation, resulting in interruption in the supply of ecosystem services. Natural resources have been primarily utilized by human beings for the sustainability of life with food production and economic sustenance.

Overexploitation leads to serious repercussions such as irreversible degradation of ecosystems because of which human existence is highly challenged with an adverse impact on the regulatory ecosystem services. Environmental damages, ranging from contamination of water, land, and air, ecological disturbances, desertification, loss of biodiversity (flora and fauna), global warming and degradation of land, lead to degradation of the arable land (Gutti et al., 2012).

Pollution

Global warming as a serious threat has been under discussion for the last couple of decades. The recent years have been detrimental as climate-induced phenomena have been wreaking havoc around the globe, in the form of floods, forest fires and many other disasters. Global warming, being a product of pollution – air, water, or land pollution – has taken a toll on the survival of human beings. The damages caused to human settlements by flash floods, a result of heavy rains and irregular patterns of precipitation, are mounting every year. Millions of people get displaced by floods annually, and the number of climate change refugees keeps on increasing. The governments, particularly that of the third-world countries, find it extremely challenging to accommodate and rehabilitate them. In addition to causing damages to human settlements, livestock, crops and trees as well as to the natural resources, climate change, or in other words global warming, poses serious challenges to the ecosystem services that ultimately lead to serious repercussions such as interruptions in their supply as well as regulation.

Ecosystems probably get permanently damaged by the diseases and invading species, unsustainable fishing practices and harvesting of forests. Greenhouse gases impact the global climate for hundreds of years. The reaping of such benefits must be sustainable because the natural resources are limited (Lampert, 2019).

Since natural resources are greatly exploited, and that man and nature are inseparable, it calls for greater responsibility on part of human beings to treat nature efficiently with sustainability plans and policies and use effective strategies to ensure possible solutions to the environmental problems (Gutti et al., 2012).

Natural disasters

Natural disasters are equally disruptive to the supply of ecosystem services and inflict negative effects in various ways. In the last 20 years, 91 per cent of the recorded disasters, such as droughts, storms, and floods have been induced by climate change, affecting 94 per cent of the people (almost 3.8 billion). Climate change further aggravates the risks associated with disasters and impedes the development. It is declared as a key agent of damages induced by disasters in the Global Assessment Report (UNDRR [United Nations Office for Disaster Risk Reduction], 2019). Natural disasters such as droughts, elevated temperatures, and coastal inundations induced by storms depict a non-linear change in the frequency and intensity of hazards.

Flooding is a prominent natural hazard, which causes damage to crop and livestock, landslides, discharge of toxic chemicals and nutrients in waterways, and spillage of waste, such as raw sewage or animal waste. Great economic losses caused by climate-related hazards are documented, but environmental losses brought about by floods, storms and droughts have been poorly recorded. Natural disasters also affect the well-to-do ecosystems that bring disaster risk reduction through ecosystem services, while environmental degradation increases the risk of disaster.

Managing ecosystem services for sustainable mountain development

Mountain ecosystems are fragile and highly susceptible to the combined impacts of climate change, unchecked and harmful anthropogenic activities, and an increasing population (Egan & Price, 2017). Frequent natural disasters coupled with deforestation, conversion, overgrazing, and exploitation are the major causes of the depletion of mountain ecosystem services (Shedayi et al., 2016; Payne et al., 2020). According to a study conducted to get the opinion of experts on the role of ecosystem services in the achievement of Sustainable Development Goals (SDGs), there are 16 selected ecosystem services in the achievement of 12 SDGs with 41 targets (Palacios et at., 2021). Studies showed that the SDGs' targets depend on multiple ecosystem services. Most services contribute to more than one SDG target, therefore, there is a need to manage multiple ecosystem services in order to ensure human wellbeing. Both carbon sequestration and water regulation contribute to a wide range of SDG targets. It is observed that there is a trade-off between the provisioning ecosystem service and regulating ecosystem services (Wood et al., 2018). In the past, provisioning ecosystem services were achieved at the expense of regulating ecosystem service (MA, 2005). An approach centered in ecosystem services to achieve the SDGs is considered one of the most important approaches along with the legislative, economic, and socio-technical initiatives (Wood et al., 2018). The development of a rational policy is needed for sustainable ecosystem services. It is possible, when the demand for the ecosystem services does not exceed the supply (Grêt-Regamey et al., 2012). Detailed mountain ecosystem services assessment and valuation is important to inform the policymaking bodies for sustainable mountain development using robust ecosystem assessment techniques. The institutional performance regarding quality research findings, exercising efficient management plans and implementation of laws for natural resource conservation are important steps to take. Policies and strategies like population control, education and awareness, poverty reduction and community empowerment, role of youth and women in response to ecosystem degradation would be instrumental (MA, 2005).

Policies for reduction in pollution, tax on carbon emission, and solid waste management should be developed and implemented on an urgent basis. Pakistan needs to increase the forest cover area to 25 per cent from the current 4-5 per cent in the entire country. Afforestation and reforestation initiatives should be accelerated to meet the sustainable development goals. Forest cutting, illegal hunting and fishing should be banned in the entire region. Alternatives should be provided to the communities to reduce the anthropogenic pressure on natural resources. The government and other institutions should develop plans for urbanization and industrialization. Town and village planning should be done and implemented in the region. To avoid exploitation and pollution caused by mass tourism, controlled, and managed ecotourism should be promoted. Considering the detrimental effects of mass tourism, prior research also recommends promoting managed tourism.

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Chapter 7

Mountain Forests and their Significance

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Forest of Minimarg valley, Astore, Pakistan © Zafar Khan

Introduction

Forests are the primary source of timber and fuelwood, act as a potential carbon sink, and support biological diversity. In the Hindu Kush-Karakoram-Himalayas (HKH) region, forests cover an area of about 2.23 million hectares and provide multiple ecosystem services. Forests provide recreational opportunities, cultural services, essential watersheds for the Indus Basin and livelihood sources to mountain communities. A heavy dependency of mountain communities on forests, unplanned tourism, global climate change, land-use land-cover changes, ineffective management regimes, over-exploitation, pollution, and other mountain hazards threaten the mountain's forests and associated ecosystems. Therefore, conservation strategies such as afforestation and reforestation, sustainable tourism, sustainable agriculture, alternative energy and income sources, climate change mitigation, adaptation measures, and community involvement in conservation are required to sustain forests and associated ecosystem services.

This chapter briefly discusses the major forest types in HKH ranges, their management regimes, growing stock and biomass carbon dynamics, their importance, significant issues, and conservation strategies.

Global, regional, and national perspectives

Forests cover about 31 per cent (4.06

billion hectares) of the globe and significantly contribute to human well-being in many ways such as, fighting rural poverty, preserving food security and livelihoods, providing chances for green growth, and supplying essential ecosystem services like lumber, fuelwood, clean air, water, and biodiversity (Ali et al., 2019). They offer habitat for wildlife and grazing grounds for domestic animals, provide recreational opportunities and are crucial for mitigating global warming and climate change (MacDicken, 2015; Food and Agriculture Organization [FAO], 2020). Globally, 45 per cent of the world's forests are found in tropical regions, followed by temperate, boreal, and sub-tropical domains (FAO, 2015).

Mountain forests make up 23–28 per cent of all the world's forests, covering an area of approximately 9 million km^2 (FAO, 2010; Payn et al., 2015). They are crucial for providing essential resources to the livelihoods of mountain and lowland communities. The biodiversity in mountain forests is the primary source of various forest products such as timber and fuelwood, morels, medicinal and aromatic plants, nuts, honey, fruits, and other foods and fodder. Mountain forests also occupy a central position in regulating the wind and precipitation pattern, global climate, and other essential ecosystems for the planet's health. The thick green forests, patches of grasslands, Alpine pastures, and mountain valleys with narrow ravines provide unique visions of the earth, attracting human spirituality, culture, and tourism.

The HKH region is home to four global biodiversity hotspots, harboring 300 important bird areas (Wester et al., 2019). These regions are also rich in forest resources and occupy about 25 per cent of the area. The primary forest ecoregions include broad-leaved forests, sub-tropical broad-leaved, sub-tropical pine forests, temperate forests, sub-alpine forests, and alpine scrub. For billions of people, these forests sustain mountain agriculture and energy security by offering a wide range of goods like lumber, firewood, non-timber resources and various services, including carbon sequestration, recreation, livelihoods, groundwater recharge, and freshwater flows. The HKH region of Pakistan contains about 67 per cent of the total forest cover of Pakistan, from sub-tropical to alpine pastures (Qamer et al., 2016). Figure 7.1 shows some of the common trees of the HKH region of Pakistan.

(a)

(b)

(c) (d) (e) (f)

Figure 7.1: Common tree species found in HKH regions of Pakistan (a. *Quercus incana* (rein), b. *Pinus roxburghii* (chir), c. *Pinus wallichiana* (Kail), d. *Picea smithiana* (spruce) e. *Cedrus deodara* (diyar), f. *Quercus baloot* (holly oak). Photo credits: Iftikhar Shah (a, b), GB Forest Department (c, d), Adnan Ahmad (e, f)

Forest zonation and types in HKH landscapes

Sub-tropical broad-leaved forest

Also known as scrub forests, these forests can be found throughout the regions at an elevation range of 500m to 1,000m above sea level. Sub-tropical broad-leaved evergreen forest is restricted mainly to more sheltered ravines or north-facing slopes, where spring and early summer are hot, with late summers getting a rainfall of 940 mm in one year. In the Hindu Kush, these forests are found mainly in districts Malakand, Swat, Lower Dir, Buner, Bajaur and some areas of Upper Dir. In the Himalayas, they occur over the catchments of the Jhelum River, Kahuta, the lower Lehtrar Valley, and the side ravines of the Margalla Hills in Islamabad. The mean annual temperature ranges from 20 to 25 ° C, and the annual rainfall ranges from 300 to 760 mm. The major tree species include *Acacia modesta*, *Olea ferruginea*, and *Monotheca buxifolia.* Other tree species such as *Celtis eriocarpa*, *Melia azedarach*, *Morus alba*, *Ficus palmate,* and *Platanus orientalis* are also found. *Dodonaea viscosa* is the dominant shrub in these forests, along with other shrubs such as *Nerium odorum*, *Adhatoda vasica*, *Berberis lycium*. These forests provide small timber and fuelwood, grazing lands, a habitat for wildlife and play an essential role in soil and water conservation. A proper management plan should be developed in these forests, and the most suitable silvicultural system should be implemented for better management. Yield can be regulated in these forests through the area or volume method (Champion et al., 1965).

Sub-tropical Chir pine forest

A subtropical Chir pine forest (*Pinus roxburghii*) grows at elevations of 1,000 to 1,500 meters. In the Hindu Kush, Chir pine forests grow in Buner, Shangla, Swat and Malakand, and some lower and upper Dir areas. In the Himalayas, Chir forests are found in the lower parts of Galiyat, lower Swat, lower Murree, and Mansehra. The mean annual temperature varies between 15 to 20°C, and the annual precipitation is 750 to 1000 mm.

Chir pine (*Pinus roxburghii*) is the single dominant species, while other associated species, such as *Quercus incana*, *Punica granatum*, and *Celtis australis*, also grow in the region. The primary shrubs which grow in these areas are *Myrsine africana*, *Rosa moschata*, *Berberis lycium* and *Indigofera spp*. The forests are close to local communities, which is why they are the primary source of fuelwood, timber, and grazing. These forests also play an essential role as wildlife habitats and in soil and water conservation. A silvicultural system is used to manage the forest, whereas the shelter-wood system can be deployed. Yield can be regulated through the Austrian Assessment methods (Champion et al., 1965).

Sub-tropical and dry temperate ecotonal zone

These forests occur in a transition zone between the sub-tropical and dry temperate zone. However, these may also be called sub-tropical broad-leaved forests. It is an extensive formation of oak scrub forests dominated by *Quercus baloot*. This monospecific type of oak formation is found in the districts of Swat (Miadam, Bahrain, and Kalam), Dir Upper (Dir, Barawal, Sheringal, Patrak, and Barikot), and Chitral, between 1,100m and 2,000m. Mean annual temperature and rainfall varies from 12°C to 18°C and 500mm to 800mm, respectively.

Quercus baloot is the major dominant species, and other associated tree species include *Olea ferruginea*, *Parrotia jacquemontiana*, *Juglans regia*, and *Pinus gerardiana*. Some main shrub species are *Berberis lycium*, *Daphne oleoidies*, Indigofera spp., *Sophora mollis,* and *Cotoneaster nummularius*. These forests are an essential source of fuelwood, forage, domestic construction needs, soil and water conservation, and a habitat for wildlife. These forests are unmanaged, belong to local communities, and are under extreme pressure from grazing, settlement expansion, and fuelwood collection. The local communities use a traditional management system, but a coppice silviculture system can be an appropriate alternative (Champion et al., 1965).

Himalayan moist and dry temperate forests

The most significant biotopes for wildlife are the Himalayan moist temperate forest, primarily coniferous with glades of mixed deciduous and broad-leaved species. They also exist in the Murree hills, Neelum, Kaghan, and Shogran valleys, as well as eastern Swat bordering Indus Kohistan. The commonly occurring plants are *Pinus wallichiana* and *Cedrus deodara* on the drier, hotter slopes and *Abies pindrow* towards the north. The common broad-leaved species include *Pinus wallichiana, Juglans regia, Quercus dilatata, Acer caesium, Populus ciliata, Taxus wallichiana and Prunus cornuta* (Champion et al., 1965).

This zone includes the northern Himalayan ranges with less monsoon influence between 1,400m – 3,350m, extending from Nalter, Astore, Chilas, Tangir, Palas and Chitral to Koh-e-safed and Takht-e-Suleiman in Balochistan. Evergreen oak and deodar forests are typical in lower Indus Kohistan, Palas valley, Swat Kohistan, northern Dir, Chitral, and the inner valleys of Hazara.

The dry temperate forest is the most prevalent type of forest in the Hindu Kush and Karakoram regions. These forests can be found in parts of Gilgit, Chitral, Upper Dir, Swat, and Diamir districts at elevations ranging from 1,700m to 3,350m. The region experiences lengthy, bitterly cold winters. Precipitation ranges from 500mm to 1,200 mm, and the mean annual temperature ranges from 6°C to 16°C. The primary conifer species are *Cedrus deodara*, *Pinus gerardiana*, *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana*, *Juniperus excelsa*, and *Taxus baccata*. *Quercus baloot*, *Juglans regia*, *Populus ciliata*, *Platanus orientalis, Aesculus indica*, *Acer cesium, Acer oblongum, Fraxinus hookeri, Prunus cornuta, Pyrus pashia, Ulmus villosa, Ulmus wallichiana and Parrotia jacquemontiana*. *Berberis lycium*, *Rosa webbiana*, and *Cedrela serrata* are the main shrubs. The major communities in dry temperate forests are monospecific. The forests are the primary source of timber and fuelwood. They also provide excellent wildlife habitats and serve as an important watershed for Indus River and its tributaries. These forests have a wide variety of species, serve as significant carbon sinks, and store enormous amounts of carbon. Resources in the forest are managed using a selection system and various yield regulation methods such as the Austrian formula, Von Mantel's formula, and the Use Percent Method (Champion et al., 1965).

Sub-alpine forests

Sub-alpine forests cover the uppermost ranges for tree formation between the elevation range of 3,350m and 3,800m, and occur in Gilgit, Swat (Kalam), Upper Dir (Dir Kohistan, Barawal), and Chitral. The climate consists of short summers and long winters. The mean annual temperature is about 10°C, while the mean annual rainfall is 650–900 mm. Snowfall of 1.8 to 5.5 ft has been recorded. The dominant conifers are *Pinus wallichiana* and *Abies pindrow,* while *Picea smithiana* is also found. The primary dominant broad-leaved species is *Betula utilis*, and other associated species include *Salix tetrasperma*, *Viburnum nervosum,* and *Viburnum grandiflorum. Rhododendron arboreum* and *Rosa webbiana* are the primary shrubs. The primary communities in these forests are the sub-alpine Betula and coniferous community at lower elevation, while the *Betula utilis* community exist at higher elevation. The sub-alpine forests provide a vital tourism spot and are highly valuable for watersheds, wildlife, and carbon diversity conservation. A selection silvicultural management system is used for their management (Champion et al., 1965).

Alpine pastures

Alpine pastures are located at the elevation range of 3,600m–4,000m in Chitral, Swat, Gilgit-Baltistan and Dir Kohistan. Climate is harsh and experiences severe winters; temperatures vary between 1°C to 6°C, and rainfall is 600mm to 800mm. The major species are *Juniperus communis*, *Salix babylonica*, *Berberis lycium*, *Rosa webbiana*, *Rhododendron arboreum*, *Lonicera japonica, Ephedra nebrodensis,* and *Polygonum affine*. Alpine pasture provides grazing ground for large herds of local communities and nomadic grazers and is valuable as a watershed for wildlife and recreational purposes. This zone also harbors a variety of medicinal and aromatic plants (Champion et al., 1965; Schickhoff, 1995).

Forest classification and management regimes in HKH

Various categories of forests and corresponding management regimes are in practice across the HKH region of Pakistan (Table 7.1). Ownership and management regimes are regulated under statutory, customary, or traditional management practices. In the HKH, forests occupy 2.23 million ha, with different management regimes. The management regimes in the Hindu Kush range primarily exclude conservation (lack of protected areas) and communities from forest management. Similarly, significant issues are ineffective implementation of policies, weak law enforcement and monitoring, lack of staff, unstable and insecure rights, continuous bureaucratic interference, and regular conflicts between the local communities and forest departments on ownership rights (Ahmad et al., 2022a). In the Himalayas, strict law enforcement characterizes the management regime and monitoring, effective law enforcement and policies and the inclusion of conservation (more forest area is under protected areas), and communities possess stable and secure rights. The land tenure system is transparent in the Karakoram ranges, and the government has admitted all ownership rights. However, the forest department needs more trained and expert staff. Furthermore, rights are not specified in the government record. In addition, the IUCN report in 2003 revealed that the local communities consider the forests to be "no man's property" and lack a sense of ownership and responsibility, which causes forest degradation (Simorangkir, 2006).

Table 7.1 The various categories of forests and their area (hectare) in HKH region of Pakistan (Simorangkir, 2006; Yusuf, 2009; Ahmad, et al., 2022a)

Category	Management regime/characteristics	Hindu Kush	Himalayas	Karakoram	Total	%
Reserved Forest	Owned and managed by the government with no or limited rights to local communities	0	570,505	0	570,505	26
Protected Forest	Owned and managed by the government with multiple rights to local communities	341,725	103,366	64,512	509,603	23
Guzara Forest	Owned by communities and managed by the government (undivided and for collective use)	0	303,414	0	303,414	14
Malkiat forests	Privately owned but managed by the government (divided and for personal use)	0	27,615	0	27,615	1
Communal Forest	Owned by communities and managed by the government	49,451	0	0	49,451	2
Resumed Land	Private land taken over by the government under various land reforms and martial law regulation managed by government	0	14,521	0	14,521	1
Unclassed Forest	The public forest land managed by the government, and neither declared protected or reserved	0	101,000	89,350	190,350	9
Section 38 Forest	Private land offered to forest department for afforestation, soil, water, and other conservation purposes.	0	504	0	504	0.04
Private plantation	Owned by landowners – either jointly managed or managed and harvested by the owners – while movement of harvested materials regulated by government	286,245	118,077	0	404,322	18
Private forest	The owners have undisputed rights and government managed it for the best interest of owner with their consent	0	0	65,940	65,940	3
Miscellaneous		95,898	1,183	0	978,081	4
Total		**773,320**	**1,239,001**	**219,802**	**2,232,122**	**100**

Forest classification and management regimes in Hindu Kush

The Hindu Kush mountains contain about 0.77 million hectares (ha) of forests divided into three categories: Protected Forests (PF), Communal Forests (CF) and Private Plantation (PP), of which PF cover 44 per cent of the total forest area and are found throughout the region. These are inherited from the princely states. Most of the regions' coniferous forests (sub-tropical Chir, moist and dry temperate, and subalpine) are declared as PF. Local communities hold different rights such as the right of grazing, fodder, fuelwood and NTFPs (non-timber forest products) collection, the right to collect a fee from nomadic grazers, share in commercial proceed (60-80 per cent) and getting timber for domestic construction on a special permit issued by the forest department (Ahmad, et al., 2022a).

Communal forests cover about 6 per cent of the total area. In these forests, the ownership rights are set out clearly. These forests occur in the districts of Shangla, Dir Upper and Malakand. These forests belong to local communities and are managed by the forests department. However, in some areas like Dir Kohistan, local people manage these forests traditionally.

Private plantations are the ownership of landowners which the landowner and forest department jointly manage. They cover about 37 per cent area, spreading throughout the Range (Ahmad, et al., 2022a).

Forest classification and management regimes in Himalayas

Forests cover about 1.24 million ha in the Himalayan range of Pakistan. Among different categories of forests, Reserved forests (RF) cover about 46 per cent of the total forest area. They are found in Abbottabad, Haripur, Mansehra (KPK), Islamabad, Rawalpindi, Murree, and Kashmir.

In the RF of KPK, various rights such as grazing, fuelwood collection, waterways or others are permitted by the forest settlement board. Rights can only be acquired through succession, and cannot be sold, alienated, granted, or leased without the government's permission. In the RF of Punjab, various rights are granted for free or require payment. These rights are non-transferable and cannot be sold but can only be inherited. The RF (also state forests) in AJK are classified into demarcated and un-demarcated forests. The boundaries of demarcated forests are defined or declared under Section 3 of the 1930 Regulation (Simorangkir, 2006). Apart from the forest department, these forests can be under the control and management of any other department or local authority. In these forests, rights, and concessions such as grazing, grass cutting, timber (excluding deodar tree), and agricultural uses are permissible under the written permission of the forest department. These rights are granted to landowners and tenant farmers within 4.8 km of the forests' boundaries. However, the CCF (Chief Conservator of Forests) can suspend any right(s) for a certain period. Un-demarcated forests are the government's property and are under the control of the Revenue Department (Simorangkir, 2006).

Protected Forests (PF) in the Himalayan range exist in Kohistan, Mansehra in KPK, while in Punjab, these forests are found in Rawalpindi and Murree. It covers about 8 per cent of the total forest area, and the local communities have the rights of grazing, fuelwood and timber collection and grass cutting.

Guzara forests (GF) in the Himalayan range exist in Abbottabad, Battagram, Haripur, Kohistan and Mansehra in KPK, and Rawalpindi and Murree in Punjab. They cover 26 per cent of the total forest area. In KPK, the rights in GF are inherited and can also be purchased. However, purchased right holders are not entitled to free grants of trees, but some privileges, such as using dry and fallen trees, can be available to non-right holders. The primary rights in GF are grazing, fodder, and fuelwood collection (including lopping of trees), timber for domestic uses, royalty, use of wood for charcoal and kilns, and seigniorage fee. GF and Malkiat forests (MF) in the section of Himalayas in Punjab are found in Murree, Kahuta, Karor, and Lehtrar. In GF, timber from dead wood, fallen and uprooted trees, and wind-fallen trees are put to public auction, while in MF, the timber is sold at the owner's request. Of the total revenue from GF, 70 per cent goes to the village Guzara fund, 25 per cent to the central Guzara fund, and 5 per cent to staff welfare, while in MF, 70 per cent goes to the owner, 12.5 per cent to the village Guzara fund and 12.5 per cent staff welfare fund (Simorangkir, 2006). In some areas like Murree, Kahuta, and Kotli, the local communities can cut three dry fallen pine trees every three years for house construction.

Private forests cover 10 per cent area of the Himalayan range in Pakistan. These include farm forests, shelter belts, and block plantations. In the PF of AJK, the CCF can sanction the sale of trees on the landowner's written request only if 50 trees of exploitable diameter (60 cm) at breast height are available under the selection cum improvement system or 400 trees of smaller diameter under thinning cum improvement silvicultural system. Out of the sale proceeds from these forests, 75 per cent goes to the owner, and 25 per cent goes to the government. The registered forest area of PF in AJK is about 233 ha (Simorangkir, 2006).

Forest classification and management regimes in Karakoram

In the Karakoram range, forests occupy about 0.219 million ha. and consist of three categories: *protected forest*, *private forests,* and *unclassed forests*. Protected forests, covering about 29 per cent of the total area, are found in the districts of Diamer, Baltistan, Ghizer, and Ghanche. Private forests comprise 30 per cent of the total, while unclassed forests cover about 41 per cent.

In the Karakoram range, the government respects all ownership rights. The Gilgit Private Forests Regulations were enforced in the 1970s, under which rights to trees, grazing, and collection of dead/dry wood were permitted. Under customary laws, the tribal communities can decide on the usage of forests with a 60 per cent majority vote. However, the forest department can impose a 50 per cent royalty on the sale proceeds by the local tribes to contractors (Simorangkir, 2006).

The growing stock and biomass carbon dynamics in HKH

The total volume of wood in a forest is called the *growing stock*. The growing stock depends on attributes like stand density, basal area, species composition, stocking, age and size. In the Hindu Kush range, the forest covers vast tracts with variable topography, types, and productivity. In some areas like Kalam (Swat), Shangla, Kumrat (Upper Dir), and Chitral Gol National Park, the forests are well stocked and produce more wood, while in some areas such as Lower Dir, Swat, Chitral, and Malakand the forests are medium to poor stock. The coniferous forests in the sub-alpine and dry temperate ranges consisting of larger diameter and old age trees, thus providing more wood – 1,178 m^3/ha (Mannan et al., 2019).

Similarly, the forest stands in areas such as a graveyards in the subtropical zones possess a higher amount of wood. However, forest stands located within communities or near settlements are usually poor stock due to heavy biotic pressures. Overall, the mean growing stock of the regions is 205 m^3/ha, with a total growing stock volume of 159 million m^3/ha (Ahmad, et al., 2022b).

Biomass is the total dry weight of a plant. In a forest, the biomass of upper-storey vegetation (UPSV) is the product of standing tree volume, wood density, and biomass expansion factor. The biomass expansion factor is the contribution of different tree components like stem, crown, and roots in total tree biomass. The biomass of the forest floor [(Under-storey vegetation (UNSV), litter deadwood (LDW)] can be measured by taking their entire oven dry weight. The mean biomass (UPSV, UNSV, LDW) in the Hindu Kush range from 66 to 797 Mg/ha (mean=194 Mg/ha), while the total biomass of the forest ecosystem is about 150 million Mg (Ahmad et al., 2022b).

The Hindu Kush forests are important carbon sinks and play an essential role in the global carbon cycle. The forests in the region are absorbing a tremendous amount of carbon (carbon sequestration) and are storing it (carbon stock). Carbon is stored in various carbon pools, including upper-storey vegetation, under-storey vegetation, deadwood, litter, and soil. The biomass carbon of the region among different forest types varies between 33 Mg C and 399 Mg

C, with an average value of 97 Mg C/ha. Forest soil holds carbon from 20 to 72 Mg C (mean 47 Mg C/ ha). The entire region stored about 112 million Mg C carbon of this total carbon; trees hold 65 per cent of carbon, while forest soil and floor hold 32 and 3 per cent, respectively (Ahmad et al., 2022b).

In the Karakoram mountains, a representative study showed that a total above ground biomass of 12,887 tonnes exists in different forests. The Shannon diversity index was 1.82, and Simpson's diversity index was 0.813. The maximum average volume attained by different tree species in these ranges varies between 0.291 and 1.92 m^3/tree.

In the Himalayas of Pakistan, it has been reported that carbon stored approximately 181 Mg/ha to 474.1 Mg/ha. Depending on various variables, the average stem density of these forest ranges from 340 to 750 trees per ha (Manan et al., 2018). However, some research indicates that the Himalayan forests are decreasing at an alarming rate of 11 per cent per decade (Khan et al., 2020).

Land-use land cover changes across forest landscapes of HKH Regions

Himalayan mountains have subtropical and moist temperate forests of Pakistan and are rich in flora and fauna. However, these forests are quickly disappearing due to increased illegal and uncontrolled harvesting of wood, agricultural activities, and urbanization. The recent expansion of human activities resulting in illegal and uncontrolled harvesting, agricultural activities, and urbanization are causes of concern. The quantitative assessment of spatiotemporal land use and land cover changes during 1998, 2008, and 2018 and a simulation of 2028, showed a drastic increase in urbanization and forest loss in the Himalayan mountains (Table 7.2, Figure 7.2-4). In addition, a forest inventory survey of biomass and carbon sink was calculated for these subtropical broad-leaved evergreens, subtropical Chir pine and moist temperate forests as biomass was 104.33 Mg ha $^{-1}$, 350.95 ±104.33 Mg ha $^{-1}$ and 153.63 ± 104.33 Mg ha $^{-1}$ in moist temperate, subtropical Chir pine and subtropical broad-leaved forests, respectively. Meanwhile, carbon was 313.94 ± 44.78 Mg C ha $^{-1}$, 221.34 ± 44.78 Mg C ha $^{-1}$, and 131.77 ± 44.78 Mg C ha $^{-1}$ in moist temperate, subtropical Chir pine and subtropical broad-leaved forests, respectively. During the 1998 to 2028 period (Table 7.2), land-use and land cover changes showed forest land changes from 40,936.77 ha to 36,709.23 ha, agricultural land from 4,220.46 to 10,374.64 ha, and built-up area from 1,497.60 to 5,395.12 ha. The average annual biomass and carbon losses were 50.34 Gg ha^{-1}yr^{-1} and 31.33 Gg C ha^{-1} yr^{-1}, respectively. The information derived from this study could assist in the development of appropriate sustainable forest management policies in Pakistan (Manan et al., 2018)

Table 7.2: Temporal statistics of Land use Land Cover Change in Sub-Tropical broad-leaved evergreen forest (Margalla Hills), Sub-Tropical Chir Pine Forest & Moist Temperate Forest (Murree) (Manan et al., 2018)

Land use	1998 (ha)	2008 (ha)	2018 (ha)	2018 projected (ha)	2028 projected (ha)
Forest Land	40,936.77	40,545.63	39,231.90	40549.30	36709.23
Barren Mountains	14,407.29	12,758.76	10,819.17	12730.21	9456.56
Agricultural Land	4220.46	4705.65	7908.21	4700.33	10374.64
Built-up Area	1497.60	3400.05	3966.39	3906.23	5395.12
Water Body	1112.76	764.04	249.48	255.23	252.12

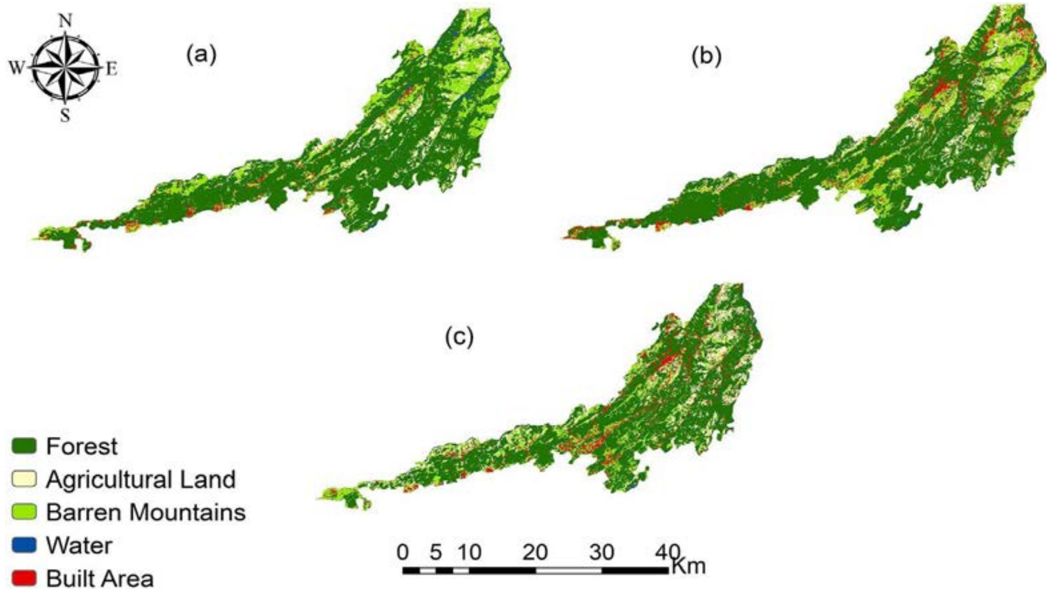

Figure 7.2 LULCC map (a) 1998, (b) 2008 and (C) 2018 (Manan et al., 2018)

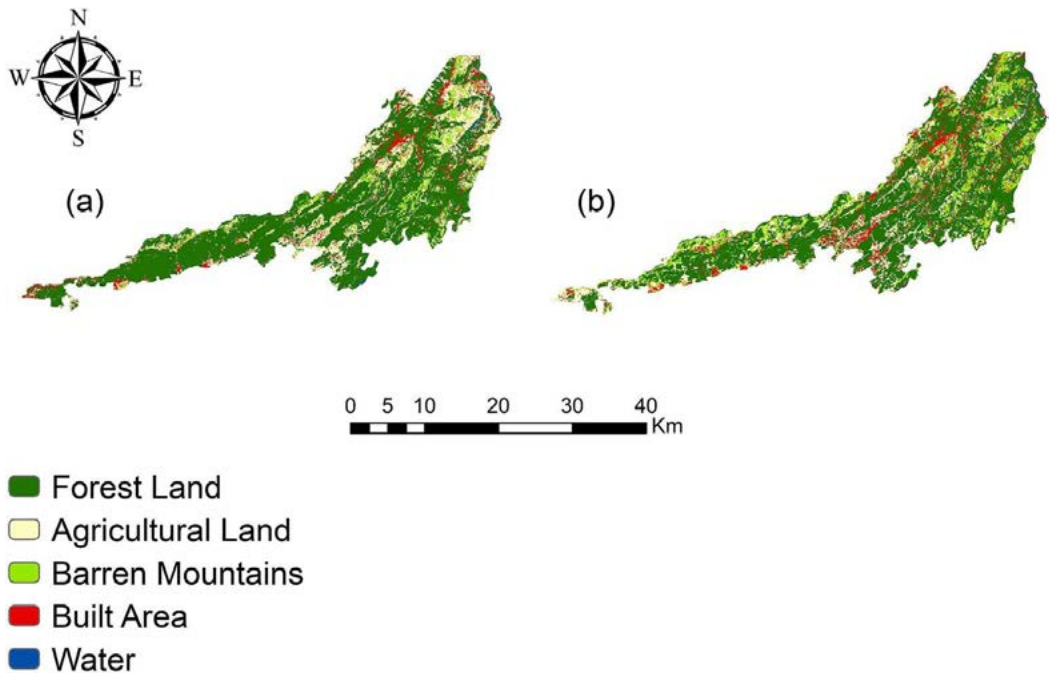

Figure 7.3 LULCC temporal projected map LULCC map (a) projected 2018 and (b) 2028 (Manan et al., 2018)

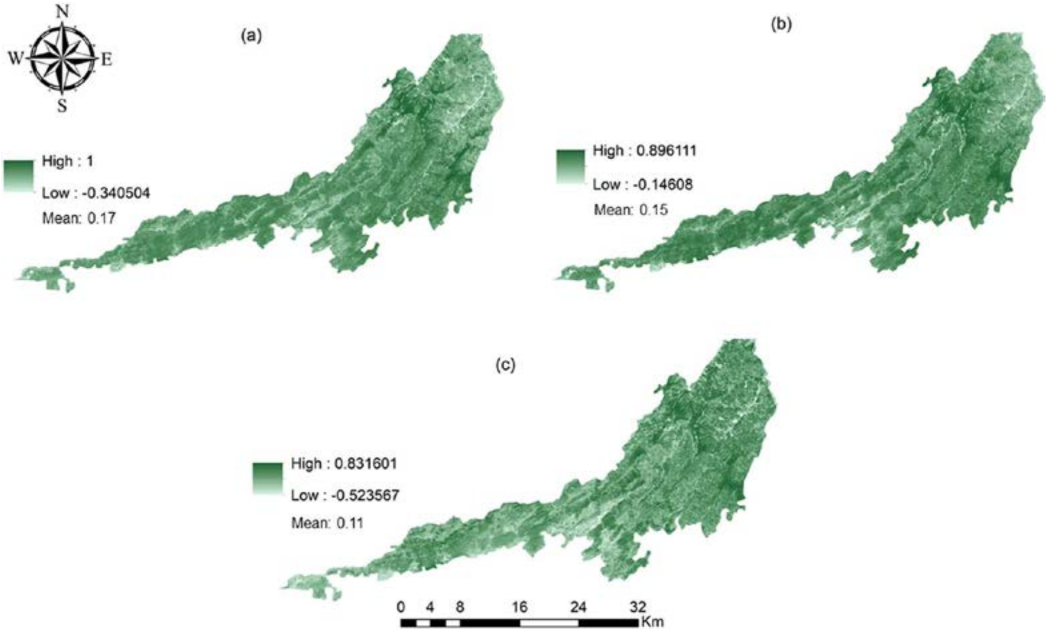

Figure 7.4 Normalized difference vegetation index (NDVI), (a) NDVI 1998, (b) NDVI 2008, (c) NDVI 2018 (Manan et al., 2018)

In a selected area of Karakoram mountains range, Raqeeb et al. (2021) found that forests have decreased from 106.589 ha in 1989 to 100.557ha in 2000. The total reduction in the area was about 6.032 ha. Grass/bushlands increased by 21.247 ha, snow cover decreased by 49.248 ha and bare ground increased by 48.916. This study revealed that in 1979-89 the total above-ground C stocks were 19.40 t ha^{-1} while these stocks showed a decreasing trend with the change in land use and reached up to 11.90 and 7.52 t ha^{-1} during the year 1990-99 and 2000-12. The mean C stocks exhibited by dominant tree species during the year 1979-89 were 9.08, 7.47, 2.55, 1.09, 8.09 t ha^{-1} respectively by *Abies pindrow* (Fir), *Picea smithiana* (spruce), *Cedrus deodara* (deodar), *Pinus gerardiana* (Chilgoza Pine) and *Pinus wallichiana* (Kail). While the total above-ground C stocks exhibited species-wise during the year 1990-99 were 7.09, 5.65, 1.99, 1.56, 5.66 t ha^{-1} respectively by *Abies pindrow* (fir), *Picea smithiana* (spruce), *Cedrus deodara* (deodar), and *Pinus gerardiana* (Chilgoza pine) (Raqeeb et al., 2021).

Major issues and challenges of mountain forests in HKH

Deforestation and forest degradation are one of the main problems in the HKH ranges of Pakistan. Region-wise deforestation varies from 0.20 to 0.8 per cent. In the Hindu Kush ranges, the annual rate of deforestation is about 0.8 per cent, while for Karakoram and Himalaya ranges, it is 0.31 and 0.20 per cent, respectively (Qamer et al., 2016; Mannan et al., 2019; Ahmad et al. 2022a). Another critical issue, particularly in the Hindu Kush range, is the exclusion of conservation and community from forest management, unstable and unsecured rights, and governments' bureaucratic interference (Ahmad et al., 2022a). Similarly, the constant conflicts between local communities and the government on ownership rights in the Hindu Kush and Karakorum ranges and the lack of technical staff, especially in the Karakoram range, are among significant problems.

The cultural attitudes of local communities, such as considering the forest as "no man's property", the traditional management of communal and private forests, illegal cutting, weak law enforcement, poor monitoring, and the socio-political scenarios under the influence of local tribal chiefs, are the other significant issues. Encroachment and the conversion of forest land to agriculture, grazing land and settlement attributed to rapid population and the migration of communities to rugged land are the other common problems within the HKH region. Livestock grazing and the over-exploitation of forest resources for fuelwood, timber and other NTFPs, beyond their carrying capacity, are also deteriorating the forests. Natural hazards like forest fires, particularly in the Himalayas (Chir pine zone) and the unplanned and massive tourist flow also affect the forests. Pollution associated with tourism and mining also drastically affects forest health.

Global climate change and its regional impacts, such as floods, GLOFs (Glacial Lake Outburst Floods), droughts, and rising temperatures, are also significant issues of concern. Global warming will cause altitudinal shifting, with the range of shifts reportedly being 8 to 14 m each year till 2080. Climate change will also affect species composition, with species like Betula shifting to alpine pastures and species from temperate forests shifting to sub-alpine forests. The phonological changes, such as the shortening of spring in the sub-alpine (18 days) and temperate zone (17 days), have been reported (Bukhari & Bajwa, 2012).

Forests in the HKH ranges are valuable carbon sinks and can play a crucial role in mitigating global climate change. However, various drivers such as deforestation, forest degradation and wood harvesting are destroying this sink. Besides, alien invasive species also disturb the natural ecosystems in different mountain regions (Chen et al., 2019). For example, in Kumrat valley of the Hindu Kush ranges, deforestation, forest degradation and wood harvest resulting a loss of 0.1 million Mg C each year (Ahmad et al., 2022a; Ali et al., 2019). Similarly, in Chitral, the annual carbon loss is about 0.5 million, while in the Himalayan ranges, the annual carbon loss is reported to be 31 Gg. (Manan et al., 2019; Ali et al., 2019; Ahmad et al., 2022a). To overcome the drivers of carbon loss and to manage forests for climate change, appropriate approaches could be the inclusion of communities in conservation, the establishment of protected areas, providing alternative energy sources, increasing agriculture production on already clear land, and growing of fodder crops and trees along the agriculture land. Furthermore, the introduction of reduced impact logging, silviculture treatment such as regeneration, extended rotation, and rehabilitation of degraded forests in the form of closure and afforestation and reforestation campaigns are some potential steps for forest conservation and carbon sequestration.

The mountain communities depend heavily on forest resources for their livelihood, timber, fuel wood, livestock rearing, and other needs. For example, in Chitral district, about 16.5 per cent of the population depends on forests for their livelihood, and 60 per cent of the people get their fuel wood from forests. Livestock rearing provides 21 per cent of local livelihood, for which 36 per cent of the population gets fodder from the forest (Ahmad et al., 2022a). Similarly, the agriculture sector shares about 26 per cent of local livelihood and communities are constantly encroaching on the forest land. For better conservation and management of forest resources, approaches such as agriculture incentives, increasing agriculture production, promotion of ecotourism, proper utilization of NTFPs, trophy hunting, fish farming, carbon trading, carbon financing and REDD+ should be implemented.

Managing mountain forests for sustained ecosystem services

For effective management of forests for the above purposes, the best way is to subdivide the forest into different units (working circles) based on productive capacity, physical condition, socio-economic condition, and ecological condition or importance. For example, well-stocked areas essentially free of rights, concessions and biotic pressures can be managed for commercial purposes and can be termed commercial working circle. Similarly, open woodlands and grazing lands can be managed for livestock and agriculture purposes, termed as grazing working circles. The areas with a potential for carbon diversity conservation and aesthetics can be declared conservation and recreational working circle. Areas with steep slopes can be declared as protection for the watershed and wildlife. In contrast, the forest areas within or near local communities may be declared community working circle, from which the local people can fulfill their needs. Similarly, the natural gap or patches within the forests or the gaps produced as a result of the group selection system can be allotted to nearby communities for agricultural purposes for 3-5 years (Blattert et al., 2017).

The HKH is one of the critical regions for biodiversity hotspots. The presence of globally significant species such as Markhor, snow leopard, musk deer, Deodar, Betula, Pine nut, Taxus, and Junipers attach greater value to this region globally. Therefore, sound management measures are required to conserve these valuable diversity hotspots, which can be best done by establishing protected areas.

One of the crucial watersheds in the country, the HKH region provides about 70 per cent of the water for the Indus basin. The regions' forests must be effectively managed as watersheds to ensure a regular water supply for our rivers and dams. In this regard, it is necessary to carry out afforestation and mountain forest rehabilitation, implement various soil and water conservation techniques, restore pasture lands, and put grazing management plans into action.

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Chapter 8

High Altitude Rangelands, their Significance and Management

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Kutwal Pastures, Haramosh, Gilgit, Pakistan © *Zafar Khan*

Introduction

Rangelands are open spaces that are unsuitable for cultivation due to physical constraints such as low precipitation, poor drainage, extreme temperatures, and rough topography; and that are used to graze wild and domestic herbivores (Stoddart, 1975). The rangeland vegetation includes grasses, forbs[1], shrubs, and scattered trees, but may also contain introduced species. Rangelands are regulated by natural ecological processes like grazing and occasionally by fires and extreme weather conditions. Worldwide, the rangelands are distributed over about 79,509,421 km^2 and make up 54 per cent of the Earth's land surface. Around the world, rangelands encompass grasslands, savannas, shrublands, deserts, tundra, alpine communities, wetlands, and meadows. Soil management practices, varying temperatures, rainfall, and other climatic factors influence the broad spectrum of rangeland floral species.

Rangelands are major areas of interest for pastoralists, hunters, gatherers, ranchers, and conservationists. Worldwide, rangelands provide food for millions of people. More than

1 An herbaceous flowering plant other than a grass (Oxford Languages)

5,000 million hectares of rangelands are maintained by 120 million pastoralists worldwide (White et al., 2000; Joshi et al., 2013a), and these rangelands serve as a substantial carbon sink since they hold up to 30 per cent of the world's soil carbon (Tennigkeit et al., 2008). Additionally, they provide habitats for indigenous fauna and flora, besides clean air, and water.

In the Hindu Kush-Karakoram-Himalayas (HKH), the rangelands are distributed over 2.29 million km^2, or 59.4 per cent of the land surface (Figure 8.1). In the HKH region of Pakistan, the rangelands cover an area of 188,118 km^2 which is 4.88 per cent of the entire land surface of the country (Joshi et al., 2013b).

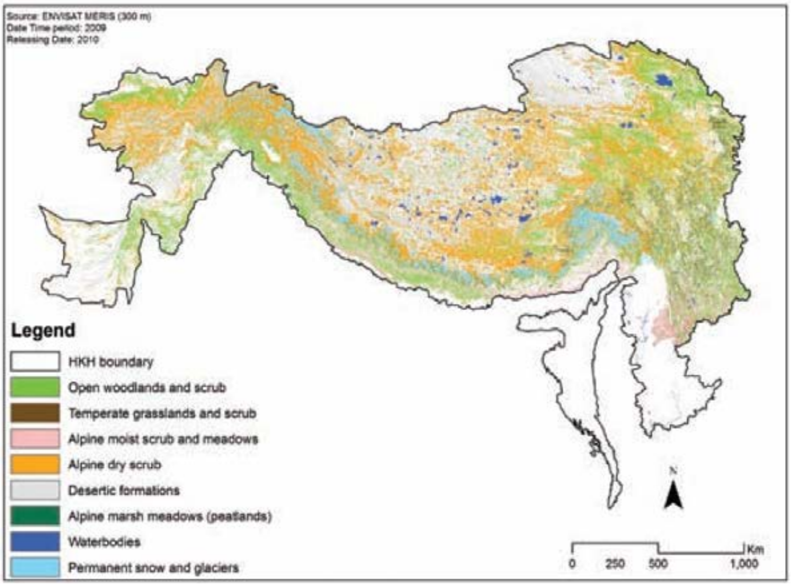

Figure 8.1 Map showing major land cover classes in the rangelands of HKH (Source: Joshi et al., 2013b).

Approximately 50.88 million ha, or more than 58 per cent of the total area of Pakistan (87.98 million ha), is covered by rangelands (Afzal et al., 2008). Within each province, rangelands cover 78.9 per cent of the land surface in Balochistan, 59.9 per cent in KPK, 55.3 per cent in Sindh, 45.1 per cent in AJK, 39.7 per cent in Punjab, and 29.8 per cent in Gilgit-Baltistan (Muhammad, 1989; Khan, 2003). These rangelands contain a variety of soils, climates, and vegetation types, ranging from Alpine pastures in the north to coastal areas in the south.

The rangeland ecosystems benefit millions of people in the HKH region. Rangelands are primary type of land use in the HKH region of Pakistan, e.g., in Gilgit-Baltistan, about one third (2.34 million hectares) of the land surface comprises of rangelands contributing from 30 to 40 per cent of household income and supporting rural livelihoods and food security (Khan et al., 2013).

In the HKH mountain ranges of Pakistan, the rangelands also produce plant biomass for household energy demands because there is a dearth of alternative energy sources. People harvest fuelwood from trees, shrubs, and bushes for cooking and heating their homes throughout the long winters. Ecotourism and mining are two other services provided by rangelands that boost economic opportunities. The breathtaking scenery and unique cultural legacy draw tourists to rangeland areas.

Types of rangelands in HKH mountains of Pakistan

Alpine pasture, trans-Himalayan rangelands, and Himalayan forests grazing lands are the three main types of rangelands in the HKH region of Pakistan (Khan, 2003).

Alpine Pasture

Most of the alpine pasture consists of snow-covered meadows for almost half the year and is accessible during the summer. They are located between 3,300 and 4,000m a.s.l above the coniferous forest tree line. They are located across all districts in Gilgit-Baltistan and areas from Hazara, Swat, Dir, and Malakand. The growing season is brief at higher elevations, lasting only three to four months in areas like the Khunjerab, Deosai, and Shandur plateaus (June to September). The subalpine scrub lies below this region. The production of forage (dry matter) differs from location to location based on altitude, slope aspect, and moisture availability. With an average of 700 kg/ha, above-ground biomass output varies from location to location, with Khunjerab National Park producing between 370 and 580 kg/ha, and Chaprote near Gilgit producing between 500 and 750 kg/ha (Khan, 2003). If properly maintained, alpine meadows include lush ground flora, giving the most significant value to grazing lands with an average stocking capacity of 5 hectares per animal unit (Khan, 2003).

The predominant plant species in alpine meadows are perennial herbs, shrubs, and grasses (Table 8.1).

Table 8.1 Common floral species in Alpine pastures (Rasool, 1998; Karki & William, 1999; Khan et al., 2013)

Type	Species
Trees and shrubs	*Berberis spp., Cotoneaster spp., Juniperus communis, Rosa webbiana*
Grasses	*Agrostis gigantea, Alopecurus gigantea, Calamagrostis pseudophragmites, Carex spp., Dactylis glomerata, Elymus dentatus, Elymus caninus, Festuca ovina, Pennisetum lanatum, Pennisetum flaccidum, Phleum alpinum, Poa spp, Trisetum spp, Oryzopsis spp.*
Forbs	*Anaphalis contorta, Astragalus spp, Fragaria nubicola, Iris hookeriana, Medicago lupulina, Nepeta spicata, Plantago ovata, Plantago major, Plantago lanceolata, Polygonum alpinum, Potentilla spp., Rumex nepalensis, Saxifraga spp, Trifolium pratense, Trifolium repens, Thymus linearis, Taraxacum officinale*
Medicinal flora	*Aconitum heterophyllum, Aconitum chasmanthum, Aconitum laeve, Podophyllum hexandrum, Rheum emodi, Saussurea lappa*

Trans-Himalayan rangelands

The northern trans-Himalayan rangelands are surrounded by the valleys of Astore, Darel, Tangir, Haramosh, Jaglote, Kargah, and Naltar in Gilgit-Baltistan. In addition, these rangelands are scattered around high mountain ranges in Hindu Kush and Pamir. The weather is characteristic of a cold desert location, with harsh winters and arid summers. Snowfall ranging from moderate to heavy is a common feature of winters, and altitude variations influence climate variation–daily and seasonal temperature variations at lower elevations and little precipitation (below 2,300 m a.s.l.). There is ample snowfall in places between 2,300 and 3,300 m a.s.l., and the climate is temperate. The growing season is brief in areas above 3,300 m a.s.l and becomes very harsh. Most areas are in the rain shadow zone outside the summer monsoon range. The precipitation that falls in the valleys yearly is between 100 and 300 mm, with the most snowfall in the winter and early spring (Khan, 2012). The area's main occupations include horticulture, agroforestry, and animal husbandry. Wheat, buckwheat, barley, and maize are the principal crops grown at lower altitudes; seed potatoes are a vital cash crop throughout the country. The destruction of grazing meadows results from excessive livestock grazing and illegally taking natural plants for fuel, and the forage production ranges from 500 to 1,500 kg/ha. Indigenous vegetation includes bushes, herbs, forbs, and trees. The common floral species that grow on these types of rangelands are listed in Table 8.2.

Table 8.2 Common floral species found in the Trans-Himalayan rangelands *(Ahmed & Qadir, 1976; Alam, 2010; Qureshi et al., 2011)*

Type	Species
Trees and shrubs	*Artemisia maritima, Artemisia sacrorum, Cedrus deodara, Caragana spp, Cotoneaster spp, Daphne oleoides, Ephedra spp, Fraxinus xanthoxyloides, Indigofera spp, Juniperus macropoda, Jasminum spp, Pinus gerardiana, Pinus wallichiana, Parrotia jacquemontiana, Quercus ilex, Salix spp, Sophora spp, Sorbaria tomentosa*
Grasses	*Aristida spp, Agrostis spp, Bromus inermis, Chrysopogon spp, Cymbopogon spp, Dactylis glomerata, Dichanthium annulatum, Eragrostis spp, Oryzopsis spp, Pennisetum orientale, Poa spp, Phacelurus speciosus, Rottboellia exaltata*
Forbs	*Iris spp, Lotus corniculatus, Lathyrus spp, Medicago spp, Nepeta spicata, Polygonum spp, Plantago lanceolata, Sambucus ebulus, Thymus linearis, Tulipa stellata, Taraxacum officinale, Viola spp.*
Medicinal flora	*Artemisia maritima, Carum bulbocastanum, Ephedra nebrodensis, Ferula, Juglans regia, Pinus gerardiana, Thymus, Zizyphus sativa*

Himalayan forests grazing lands

The Himalayan forestf are scattered with grazing areas in the Siran, Kaghan, Neelam, and Jhelum Valleys. Ecologically, these areas can be divided into humid subtropical and moist temperate zones. The moist temperate region is located between 2,000m and the timberline. This location has several Kail, Deodar, Spruce, and Fir trees. Most areas in this zone receive more than 1,000 mm of rain during the monsoon, significantly increasing soil erosion due to the steep topography and haphazard cropping. Although the summers are mild here, the winters are frigid.

The three main land uses include forestry, agriculture, and grazing. The main crops are wheat, rice, and corn. There are many acres of apple orchards. The tract is heavily forested with blue pine and Chir pine trees. Grazing is done on agricultural land, near waterways, and in woodlands. The significant flora of the Himalayan Forest grazing lands is listed in Table 8.3.

Table 8.3 Common floral species found in the Himalayan Forest grazing lands (Khan, 2003)

Type	Species
Trees	*Aesculus indica, Acer pictum, Acer caesium, Cedrus deodara, Juglans regia, Pinus wallichiana, Picea smithiana, Populus alba, Populus ciliata, Pyrus spp., Quercus incana, Quercus dilatata, Quercus semecarpifolia, Taxus baccata*
Shrubs	*Berberis lycium, Cotoneaster spp., Desmodium spp., Indigofera spp., Pistacia spp., Prunus cornuta, Rosa webbiana, Rhododendron arboreum, Rubus spp., Salix spp., Sarcococca saligna, Strobilanthes spp., Viburnum nervosum*
Grasses	*Agropyron dentatum, Alopecurus gigantea, Bromus inermis, Bothriochloa pseudo ischaemum, Chrysopogon aciculatus, Dactylis glomersata, Oryzopsis spp., Phacelurus speciosus, Pennisetum flaccidum, Poa spp. Rottboellia exaltata, Stipa sibirica, Themeda anathera*
Forbs	*Astragalus spp., Fragaria vesca, Geranium collinum, Geranium nepalense, Lotus corniculatus, Medicago spp., Plantago ovata, Plantago major, Plantago lanceolata, Polygonum aviculare, Polygonum parencoides, Phlomis bracteosa, Rumex nepalensis, Senecio spp., Trifolium repens, Trifolium pratense, Thymus serpyllum, Taraxacum officinale*
Medicinal Plants	*Atropa acuminata, Asparagus racemosus, Berberis lycium, Colchicum luteum, Dioscorea spp., Mentha piperita, Punica granatum, Skimmia laureola, Valeriana wallichii, Viola serpens, Zizyphus vulgaris*

Rangeland products and services

Rangeland is the most extensive land use system on earth. It is a valuable land resource that can offer a variety of products and services, including:

Livestock production

Raising livestock on rangelands provides a significant source of income and is a prominent way of life for mountain communities (Khan, 2012). Existing pastoral practices include transhumance and a sedentary system. Animals in the transhumant system are herded in a unique pastoral herding system that moves them across a vast mountain terrain as the seasons change, using subalpine and alpine pastures. The animals are kept in a sedentary system on the farm year-round, free to graze on moderate slopes of community lands, fallow fields, and harvested fields.

Ruminant animals are essential for producing food to sustain the world's continually rising population and leather, wool, mohair, and other animal products. They can transform the high cellulose biomass of rangeland plants into a sustainable nutritional source of animal protein and energy for human consumption due to their additional compartments in the digestive tracts. Livestock production efficiency can be increased by selecting feed-efficient animals, improving fertility, reducing livestock losses from diseases, using a flexible stocking rate strategy to adapt to seasonal forage availability and quality, and adopting environmental stresses.

Forage production

Rangelands are areas of land where the native flora is primarily made up of grasses, sedges, forbs, and shrubs. Rangelands' productivity and vegetation are influenced by various variables, including soil characteristics, plant species, overgrazing, topography, climatic attributes, climate variability, etc. In some areas like Gilgit-Baltistan, significant changes were mainly observed in the species composition, distribution, and productivity of the rangelands (Joshi et al., 2013c; Khan, 2013). The herders in northern Pakistan have witnessed climate change impacts on pastures, affecting livestock by altering the composition of the flora and lowering forage yield. In response to the transformation, they adopted a few coping strategies, such as altering their migration patterns and diversifying their income sources (Joshi et al., 2013c). Rotational grazing of animals and feeding of conserved feed on the grassland can aid in the recycling of nutrients and enhance herbage usage (Vipond and Frater, 2017). The grazing animals' dung and urine can improve soil conditions, enrich nutrients, and maximize crop yields (Franzluebbers & Stuedemann, 2008).

Wildlife habitat

Rangelands are home to various wildlife, including birds, reptiles, fish, amphibians, and mammals. This biodiversity resource gives some individuals opportunities for pleasure and spirituality while providing hunting grounds for others. Due to the growth in the human population and associated activities, many animals that inhabit rangelands are in danger. The federal government now protects some species that are at a risk of going extinct by classifying them as threatened or endangered.

Medicine

Pakistan's northern regions contain a rich medicinal flora due to the varying range of altitude, rainfall, and climatic conditions (Malcolm et al., 2002). A total of 25,000 plant species, or 10 per cent of all plant species in the world, are found in the HKH region, with 10,000 having significant medicinal value (Pei, 1992). This region has inspired many scientists to document its medicinal plants having prime importance in the local healthcare system, while enriching biodiversity (Hussain et al., 2011; Abbas et al., 2013). The flora of this area is severely threatened by the unsustainable collection and utilization of plants for various purposes. As a result, significant efforts should be undertaken to disseminate information, propagate species, and create germplasm to protect important species for future generations.

Carbon sequestration

Rangelands have a significant impact on

the carbon cycle. Numerous other ecological advantages are connected with sequestering carbon on rangelands. However, their capacity to absorb CO_2 from the atmosphere may assist in counteracting the human effect of climate change – better soil quality results from range management measures that improve the amount of carbon stored in the soil. Higher soil organic matter and vital root systems improve water infiltration and increase water holding capacity. These elements lead to improved plant productivity and higher-quality feed, which lessen rangelands' susceptibility to drought and improve their ability to support livestock and wildlife grazing during dry seasons.

Mining

Mining is a valuable rangeland attribute that can provide economic opportunities. Rangelands are often rich in mineral and fossil fuel reserves. Among the most pressing issues concerning the extraction of minerals and fossil fuels that require consideration are industrial and environmental issues. The region's well-known mining areas include Dassu, Bubin, Haramosh, Nagar, Dir and Chitral. The potential of other valleys, such as Yasin, Gupis, and Chipurson, has yet to be explored.

Food and fiber

The primary purpose of rangelands is to graze livestock for food production. Sheep and goats are now more common in food production, but they also produce fiber. Both synthetic and natural fibers from rangelands are used to make clothing. Wool and mohair are common resources from many of the world's rangelands. Numerous cottage industries now exist in developing countries across the globe that produce fibers from local plants for baskets, ropes, and other essential products. Fiber production from range plants could become more crucial if effective harvesting techniques could be developed.

Recreation

Beautiful landscapes can be found in many rangeland locations. They provide habitat for wildlife herds that attract activities such as observation or recreational hunting, and serve as the foundation for developing the tourism industry. The breathtaking scenery and unique cultural heritage draw tourists from all over the world. A few rangeland areas, such as the Deosai Plateau and Shandur Pass, which are highly known for trekking, festivals, and sports, are becoming increasingly famous as tourist attractions.

Other rangeland products

Other rangeland products include timber, water, fence posts, and other wood products. Rangelands also generate plant biomass for domestic energy needs because there are no alternative energy sources in the area. Residents collect fuel wood from trees, shrubs, and bushes during the long winters to cook and heat their homes. Water management is yet another vital function of the rangeland areas. Numerous wetlands exist at high altitudes, most of which are fed by snowmelt or runoff from surrounding glaciers, which frequently discharge small streams or rivers. These water bodies are essential to the hydrological cycle of the Indus, which besides being the foundation of the country's agro-based economy, provides water for drinking, industry, and hydropower generation.

Issues and challenges of rangelands management

The rangelands in HKH are fast diminishing due to overgrazing and trampling effects, encroachment and conversion into other land uses, drought, and climate change. The major threats and their causes are described briefly in the following.

Overgrazing

Large herds of domestic herbivores can overgraze alpine meadows and harm them by trampling on them for extended periods. Overgrazing often occurs in most rangelands in Gilgit-Baltistan (Beg, 2010; Khan et al., 2013). The two main factors that contribute to overgrazing are a lack of a grazing management system and an inappropriate land tenure system. It appears that no one is responsible for protecting grazing grounds because those are shared resources. Other concerns that require attention include administrative issues, land tenure, migratory herds, a lack of trained employees for range management practices, damaging fire regimes, invasive plant species, and a lack of research.

In 2010, 5,000 yaks, 2,000 goats, 1,900 sheep, and 500 cows were grazed with a few hundred wild herbivores, including Himalayan ibex and blue sheep, on the pasture in Shimshal Pamir. However, the 10,429 ha area could only sustain 715 yaks for six months (Khan, 2012). Similarly, 420,000 animals are grazed close to the Central Karakoram National Park (Baig, 2011), with significant year-round grazing in some lower pastures. The ecological health of pastures at higher altitudes, where the harsh climate constrains plant growth, is harmed by overgrazing. It also speeds up soil erosion and leaves little or no food for wild herbivores.

Encroachments

The lack of an efficient management system is directly related to the numerous exploitative uses of rangelands, such as agriculture, the harvest of plant biomass for fuelwood, and the rapid growth of infrastructure. Pasture and rangeland are used for crop cultivation at an alarming rate. According to the agriculture statistics from Gilgit-Baltistan, vegetables comprise more than 83 per cent (8,422 ha) of the total land area (10,080 ha), mainly because potatoes have emerged as a cash crop. The removal of the indigenous vegetation for fuelwood has caused the desertification of rangelands. Heavy vehicle traffic and off-road driving have threatened the grazing lands of Kaghan, Naran, Shandoor, Deosai, and other high-altitude tourist areas. The cultivation of peas has tremendously increased in Kaghan and Naran, up to Babusar.

Climate change

The rangelands of Gilgit-Baltistan and adjacent mountainous landscapes receive little precipitation, especially at lower elevations where rainfall rarely exceeds 200mm annually. Higher elevations (>3,500 m asl) receive heavier winter snowfall (Awan, 2002). The average temperature is -10°C in the winter and +35°C in the summer. Unlike the global trend, the region has seen significant increases in winter mean and maximum temperatures and continuous drops in summer maximum temperatures (Fowler and Archer, 2006). According to Zeidler and Steinbauer (2008), there was an increase in annual mean temperatures between 1980 and 2006. Such climatic changes have accelerated the desertification of the rangelands, especially in the arid and semi-arid zones, along with other biotic and anthropogenic processes (GoP, 2010). The Pakistan Meteorological Department's temporal data analysis also revealed a decline in vegetation cover over the country's northern half compared to 1998, which is assumed to be caused by the lack of winter rainfall (Chaudhry et al., 2010). Similar evidence has been found in Afghanistan, China, Nepal, and other regions of the world, where a decrease in precipitation has accelerated rangeland desertification. In some places, prolonged droughts have forced people to change their migratory patterns or abandon pastoralism entirely. Pastures in Misgar, Chipurson, and Central Karakoram National Park (CKNP), such as the Bagrote valleys, have suffered greatly due to droughts during the last decade (Beg, 2010).

The available data indicate that climate change is already having an adverse impact on alpine biodiversity and essential processes, such as nitrogen cycling and carbon sequestration. Many plant and animal species have lost their habitats due to the rapid glacier melt caused by climate change. Several migrating species have also disturbed their migration routes (Khan and Ali, 2011). Accordingly, the mountainous floral community is directly impacted by climate change (Xu et al., 2009). It has been noted that mountain vegetation types are moving from lower to higher altitudes due to their inability to withstand higher temperatures (Sanz-elorza et al., 2003). Treeline advancement is predicted to significantly alter diversity and function, despite our limited understanding of the underlying processes (Greenwood & Jump, 2014).

Land tenure system

The rangelands, often owned by tribes and villages, are open to all community members for grazing. Nobody cares about conservation, which causes degradation. In certain villages, *Shamilat* (common property adjacent to the villages), which can also include rangeland and wasteland, has been distributed among the group members who autonomously develop their areas, usually for cultivation. In other locations, *Shamilat* is still regarded as communal property, which the local communities manage in various ways. Where *Shamilat* are profitable, some communities forbid felling trees and grazing in the forest at specific periods and punish offenders. The local *jirga* (larger village gathering) decides on matters about forest and rangeland management, fines, obligations, and enforcement (Shah & Husain, 1998).

Gaps in customary practices

Unsustainable livestock grazing practices are degrading or reducing productivity in some areas. Regarding the carrying capacity of these lands, there are no rules in the customary norms. Since it has never been determined what these rangelands can support, excessive demands can result in degradation. The herd may become infected even though animals with illnesses are urged to stay away from the grazing areas because their water sources are shared.

Other concerns include migratory herds, invasive species, behavioral changes in grazing style, water scarcity, the grazing system, infrastructure development initiatives, land use and land conversions, conflicts, a lack of awareness and participation, a lack of resources, livestock management, range research, and a lack of a specific institutional setup for managing rangelands.

Research and monitoring techniques in rangelands studies

Researchers and managers require effective technology to track how herbivores are consuming forages. Considering the diverse challenges of rangelands, managers may employ complementary techniques to gather relevant data within manageable time frames. Rangeland monitoring systems have been created to quantify, analyze, and track plant populations, mainly where multiple-use land management strategies demand adaptive management measures. Rangeland monitoring is the systematic, continuous acquisition of ecologically primary data that identifies the properties of rangelands (Schalau, 2010). The current state of rangeland health and trends through time can be better understood by grasping rangeland attributes (Holechek et al., 2004). Additionally, rangeland monitoring data can be used to assess the efficacy of certain management techniques, track the growth of range development programs, and assess seed germination and establishment that boost plant diversity and forage production (Godínez-Alvarez et al., 2009).

Satellite image data is a potential method for identifying areas where changes in surface characteristics can be mapped and associated with some signals of changing land conditions. Now, it is possible to calculate the extent of land degradation using carefully selected criteria, which requires specialized field knowledge and is typically application dependent. Accurately mapping and monitoring changing land conditions and degradation through vegetation and land surface changes is a crucial and ongoing research topic (Vogt et al., 2011). Since 2000, the use of remote sensing and spatial modeling has grown due to the development of measures of surface properties that are then examined to assess degradation (Tewkesbury et al., 2015; Bai et al., 2008; Vicente-Serrano et al., 2015). Many remote sensing tools have been employed to assess soil conditions (Caccetta et al., 2010; Furby et al., 2010; Lobell, 2010), but satellites still need to sense soil dynamics directly. Although plant cover is now the most frequently employed indicator, invasive vegetation can occasionally confuse this indicator (Hestir et al., 2008).

Google Earth Engine (GEE), an online cloud-computing platform with a multi-petabyte collection of satellite imagery and geospatial datasets, can enable a planetary-scale analysis of remote sensing big data and presents an unprecedented chance to advance our scientific understanding of various dynamic processes connected with earth systems, particularly land change science (Donchyts et al., 2016; Hansen et al., 2013; Pekel et al., 2016). Remote sensing images allow managers to quickly sample the cover at a landscape scale, eliminating the need for time-consuming and labor-intensive field-based evaluations. Coverage measures may also be implemented in remote locations where access is often difficult.

Biomass is being utilized to a greater extent to measure the pools and fluxes of carbon from the terrestrial biosphere that are associated with variations in land use and land cover (Cairns et al., 2003). Field-based biomass assessment is believed to be more precise than remote sensing and Geographic Information System-based evaluations (Gier, 2003; Lu, 2006). Estimates of above-ground biomass are a crucial measure of feed availability in pastures, and tracking growth dynamics offers knowledge about the condition of the vegetation in pastures and rangelands (Reeves et al., 2001). In this way, the pastoral communities are informed of the state of the above-ground vegetation and its carrying capacity to graze their livestock during different seasons (Mundava et al., 2014).

A novel approach known as "virtual fencing" allows for the management and confinement of grazing cattle using sensory cues rather than physical barriers. The method uses a neckband-mounted device to provide an auditory cue whenever an animal approaches a virtual border created using a global positioning system (Campbell et al., 2019; Lomax et al., 2019; Langworthy et al., 2021). When an animal travels past the virtual barrier after hearing the trigger, the device shocks it electrically, but not if it stops or turns around. Virtual fencing in grazing management can completely change pastoral animal production. The cattle's natural habits must be considered for the successful deployment of virtual fence technology (Verdon et al., 2021).

Rangelands management interventions

Range management is the application of science to a range to achieve maximum productivity on a sustainable basis. The following actions are recommended to produce livestock and range vegetation at the best possible yields:

- Grazing management is quite essential to maintain the ecological health of rangelands. Moderate grazing and trampling can boost plant diversity by reducing the dominance of a single species. The effects of grazing on plant community diversity depend on the grazing intensity, site, and climate. Furthermore, it is recognized that if grazing is prohibited, species abundance may increase but decline later.
- Implementing rotational grazing systems or virtual fencing can be utilized in the future.
- Suitable grazing seasons should be determined by considering the growth cycles of significant range forage species and seasons of the year, avoiding grazing during extreme climatic conditions. It is a powerful tool in promoting certain species' natural reseeding and growth.
- The frequency of grazing during the season must be considered, as different grasses respond differently to grazing.
- The animal grazing pressure on rangelands can be minimized to achieve a sustainable level appropriate to the forage supply. Various methods must be explored to lessen pressure on the high alpine pastures, such as adopting rangeland grazing fees, introducing new, irrigated fodder resources close to settlement areas, providing feed supplements by utilizing available food waste resources, and by determining the carrying capacity of the range and allowing grazing accordingly.
- Uniform grazing throughout the range avoids overgrazing of specific areas and under grazing of other regions by supplementing, salting, and establishing watering points at various points.
- Periodic rest can be provided to the vegetation from grazing. Deferred grazing can be followed in some degraded areas to give plants a chance to recover. Similarly, temporary corrals can be established to convert the degraded land to vegetation cover, as manuring and urination increases the soil's organic matter and adds seeds with their dung, which can be converted to plant cover in the following seasons.
- Forage cutting on sensitive, exposed areas

rather than grazing can be utilized for hay and silage making for stall feeding during non-grazing periods.

- Animal type should be compatible with the type of vegetation. Grazing behavior, desired vegetation composition, slope, and climate should be considered when selecting suitable livestock.
- The commencement of a rangeland rehabilitation program for habitat-damaged/degraded areas.
- Enhance collaboration between the forest department's range management programs and livestock development initiatives.
- Multi-purpose trees that are suitable for local environments and provide fodder and fuel wood should be introduced to meet the demands of rural inhabitants.
- The degraded rangelands can be restored through reseeding, which requires developing range and grass reserves for seed production.
- Keep a mixed herd because it makes efficient use of varied range vegetation.
- Planting and seeding of forage and multi-purpose tree species along the sides of the water channels because aridity is one of the fundamental issues of this region.
- Establish shelter belts and ensure natural seeding.
- Local high-yielding and palatable grasses that tolerate and adapt to changing and harsh climates can be reseeded.
- Prescribed fires or control burning can be applied on a small scale. This management tool can be implemented in early spring to promote plant growth as it increases the soil temperature.
- A comprehensive program for testing, assessing, and screening forage germplasm can be established to identify promising varieties, and produce essential seeds that organized communities can replicate.

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Chapter 9

Wildlife Ecology and Conservation

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A pair of ibex males fighting probably for selective breeding in Khunjerab National Park, Pakistan, © Imtiaz/IUCN Pakistan

Introduction

Pakistan's Hindu Kush-Karakoram-Himalayan (HKH) region is a globally significant conservation landscape comprising several protected areas, encompassing the Biodiversity Hotspot, the Center for Floral Endemism, the Endemic Bird Area of Urgent Biological Importance, and the Global 200 Ecoregions. The region has a rich species diversity, particularly in large mammals primarily of Palearctic origin (Virk et al., 2003). The region is considered home to many flagship high-altitude species, including the common leopard, snow leopard, black bear, brown bear, gray wolf, flare-horned markhor, Ladakh urial, Himalayan ibex, blue sheep, Marco Polo sheep, gray goral, barking deer, golden marmot, rhesus macaque, woolly flying squirrel and a plethora of resident and migratory avifauna, herpetofauna and fishes (Mirza, 1975; Schaller, 1977; Roberts, 1997; Qureshi et al., 2011; Khan & Baig, 2020).

The HKH region in Pakistan holds the country's last remnant tracts of coniferous forests and ecologically important areas supporting local livelihoods, providing ecosystem services, creating jobs, and mitigating climate change impacts such as floods and droughts. It is also significant for non-timber forest products (NTFPs), including highly valued medicinal and aromatic plants.

Key mammalian species of the HKH region

Snow leopard (Panthera uncia)

Snow leopard cubs in Dhee area of Khunjerab National Park, Gilgit-Baltistan, © Imtiaz/IUCN Pakistan

The snow leopard is the top carnivore and a flagship species of the mountains of South and Central Asia. It is perfectly adapted to the harsh, wintry conditions of its alpine home in the HKH region. Strong survival and tremendous leaping skills, coupled with distinct body color and texture, help it camouflage into the rocky alpine slopes. Despite its elusiveness, the snow leopard has faced critical threats to its survival. Some common dangers to snow leopards across Pakistan include poaching, loss of wild prey (wild sheep and goats), retaliatory killing by shepherds, and general disturbances (including the capture of cubs). Between 3,000 and 7,500 snow leopards survive in their natural habitat across the world, which spans two million square kilometers from Russia to Nepal. Only 250 to 400 of these may still exist in Pakistan. Community-based conservation efforts have, however, helped snow leopard populations recover significantly across a large portion of the HKH region.

Distribution in HKH region: The snow leopards' range stretches across the HKH region of Pakistan. In Gilgit-Baltistan, snow leopards can be found across all ten districts. In the KPK province, they are found in Chitral, Dir, Swat and Kohistan (Khan et al., 2016), and in the Machiara and Musk Deer National Parks in Azad Jammu and Kashmir (AJK).

Conservation status: IUCN Red List – Vulnerable; Pakistan – Endangered; CITES – Appendix I; and CMS – Appendix I.

Common leopard (*Panthera pardus*)

Common leopard © Mohebullah Naveed

The common leopard is a solitary and reclusive big cat species. Once widespread across north-eastern Pakistan, its distribution and population have declined because of retributory killings over livestock depredation (Roberts, 1997; Sheikh & Molur, 2004; Akrim et al., 2021). A major threat to the leopard is the fragmentation and loss of habitat, while other threats include human-leopard conflicts, prey depletion, and poaching for body parts (Shehzad et al., 2015).

Distribution in HKH region: The common leopards have been found in the Margalla Hills, the Murree Hills, Swat, Kohistan, Dir, Chitral, Kaghan, and Abbottabad (Roberts, 1997). In AJK, common leopards have been recorded from the hill ranges of Muzaffarabad and Neelum valley (WWF-Pakistan, 2007).

Conservation status*:* IUCN Red List – Vulnerable; Pakistan – Critically Endangered; CITES – Appendix I.

Gray Wolf *(Canis lupus)*

Gray wolf © Staffan Widstrand / WWF-UK

The wolf is one of the largest species of the canid family. It is one of the most widespread terrestrial species and occurs in various habitats – from cold tundra to warm deserts. It is also found in various Protected Areas (PAs) of the country, including national parks, wildlife sanctuaries, game reserves, and community-managed conservancies in Sindh, Balochistan, Punjab, KPK, AJK, and the HKH region. In Pakistan, two subspecies of the gray wolf are present, i.e., the Tibetan wolf (*Canis lupus chanco*) and Indian wolf (*Canis lupus pallipes*), inhabiting the northern and southern region of Kashmir and the Himalayas, respectively (Lydekker & Blaine, 1907). Its habitat extends from the mountainous areas of Balochistan in the south up to the higher elevation areas of Chitral and Gilgit-Baltistan in the north (Roberts, 1997; Kabir et al., 2017).

Loss of natural prey species, human-wolf conflicts, destruction of habitats, competition and interbreeding with feral dogs, and climate change/natural hazards are the main threats to wolf survival, drastically declining the populations from all ranges of the country.

Distribution in HKH region: Gray wolf has a wide distribution across HKH region, especially in the upper reaches of Gilgit-Baltistan, Chitral, Swat Kohistan, and parts of AJK (Kabir et al., 2017).

Conservation status*:* IUCN Red List – Least Concern; Pakistan – Endangered; CITES – Appendix I.

Himalayan Lynx *(Lynx lynx isabellinus)*

Source: © Roger Leguen / WWF-Canon

The Himalayan lynx (or the Eurasian lynx) is a rare but wide-ranging predator of northern Pakistan. Although the lynx is a forest animal throughout much of its range in Pakistan and neighboring countries, this medium-sized cat is found in the subalpine and alpine regions of the high northern mountains. Habitat degradation and deforestation can harm the survival of its remnant population in its home range of the HKH region.

The lynx preys on the hare, marmot, pika, birds, and the young or sometimes adult wild sheep and goats such as ibex, markhor, and urial. It also hunts livestock – especially sheep lambs and goats' kids when natural prey species are scarce. Its thick fur enables it to live comfortably in the cold mountain climate, and wide feet help it move easily across deep snow. Livestock depredation cases are also reported and recorded in the mountains of the HKH region, including parts of KPK such as Chitral. The lynx population is declining due to commercial trapping/hunting for furs, loss of natural prey, habitat destruction, and retaliatory killings by shepherds. However, this elusive species is expected to find refuge from potential poachers in the high craggy peaks and mountains of its home range.

Distribution in HKH region: In the HKH region, the lynx have now been restricted to a few higher mountain areas of Gilgit-Baltistan and KPK. Recent studies confirmed their presence in Chitral and Gilgit-Baltistan (Din & Nawaz, 2010).

Conservation status: IUCN Red List – Near Threatened; Pakistan – Least Concern; CITES – Appendix II.

Asiatic Black Bear (*Ursus thibetanus*)

Asiatic black bear captured by infrared camera trap in Machiara National Park (Courtesy: Zahoor et al., 2021)

The Asiatic black bear, an omnivorous species that hibernates in a den during the winter, is found across northern Pakistan's conifer forest zone. This fascinating large mammal feeds on a wide variety of food items, from nuts and berries to insects and larger animals. They may climb the trees to feed on acorns and other nuts and can prey on large animals, although it mainly survives on carrion.

Habitat destruction (forest cutting) threatens the Asiatic black bear, and because they tend to raid crops, the bear is heavily persecuted. It is also hunted for commercial trade, especially for its gallbladder. Bear cubs are captured (after killing the mother) for exhibition. Retaliatory killing by shepherds and farmers threatens the Asiatic black bear leading to its disappearance from much of its range across northern Pakistan.

Distribution in HKH region: The occurrence and distribution of the bear is well known in the Kaghan Valley and AJK areas of the HKH region (Abbas et al., 2015a, Awan et al., 2016; Ali et al. 2017). However, the animals have also been recorded in Ayubia National Park (Awan et al., 2020), Astore (Bonji and Doyan), Chitral (Baranesh, Bakarabad and Ayun), Gilgit (Jaglot and Chakarkot), Diamer (Gonar Farm) and Skardu (Astak) (Abbas et al., 2015a).

Conservation status: IUCN Red List – Vulnerable; Pakistan – Endangered; CITES – Appendix I.

Himalayan Brown Bear *(Ursus arctos isabellinus)*

Brown bear in Deosai National Park, © Imtiaz/IUCN Pakistan

The Himalayan brown bear is a subspecies from the ancient lineage of the brown bear. It is omnivorous and hibernates in a den during the winter. It is found in higher terrain and alpine meadows of the Himalayas, the Karakorum, the Hindu Kush, and the Pamir, where it feeds on a wide variety of non-timber forest products, including nuts and berries, crops and fruits, marmot, pika, local fish, and other wild animals and livestock.

Its population is restricted to a few areas of northern Pakistan due to habitat degradation and fragmentation, commercial poaching/trapping for body parts and cubs, and retaliatory killings.

Distribution in HKH region*:* In Pakistan, the Himalayan brown bear population is restricted to the HKH region, where it is found in Deosai National Park, its buffer zone areas, and valleys of Astore, Hunza and Ghizer. Their presence has also been confirmed in Chitral, Kohistan and Mansehra (Abbas et al., 2015a).

Conservation status*:* IUCN Red List – Least Concern; Pakistan – Critically Endangered. CITES – Appendix I.

Flare-horned Markhor *(Capra falconeri)*

Astore Markhor (male) in Doyan, Astore, © Imtiaz/IUCN Pakistan

The flare-horned Markhor is regarded as one of the most impressive of the wild goats of Pakistan because of their massive bodies, elegantly spiraling long horns, thick fur, flowing beard, and neck ruff (Robert, 1969; Schaller, 1977). Owing to its iconic appearance and cultural significance, the markhor is the national animal of Pakistan. Markhors are the best climbers in their rocky habitats and jump up the trees to feed on foliage. They are significant for sustaining the high-altitude ecosystem by providing part of the diet of large carnivores such as snow leopards. Two subspecies of the flare-horned markhor are found in the HKH ranges of Pakistan namely, Astore Markhor (*Capra f. falconeri*) and Kashmir or Pir Panjal Markhor (*Capra f. cashmiriensis*).

Distribution in HKH region: Astore Markhor occurs in Gilgit-Baltistan's districts of Astore, Gilgit, Diamer, Skardu, and Nagar. The Kashmir Markhor are found in Chitral, Dir, Indus Kohistan of KPK, and Kaji Nag range and Neelum Valley of AJK (Roberts, 1969, 1997; Schaller, 1977; Arshad, 2011).

Conservation status*:* IUCN Red List – Near Threatened; Pakistan – Endangered; CITES – Appendix I.

Marco Polo Sheep (Ovis ammon polii)

Females of Marco Polo sheep in Karchanai nullah, KNP, © Imtiaz/IUCN Pakistan

The Marco Polo sheep is the largest of all wild sheep in the world. This subspecies of the wide-ranging argali is found primarily in the high Pamir mountains, with Pakistan being the southern edge of its range. Unfortunately, the population of Marco Polo sheep is declining across much of its range because of a combination of factors such as overhunting, competition with livestock for forage, and disturbance by humans and their livestock. Marco Polo sheep are especially sensitive to human activity, particularly the proximity of herders.

The transboundary nature of Marco Polo sheep movements makes the status of each country's animals depend on the neighboring countries' conservation situation. Few known passes enable the sheep to enter Pakistan from China. Among those, the Khunjerab Pass leads to good habitat in the Khunjerab National Park, but the presence of the Karakoram Highway and its traffic up the narrow valley to the pass, as well as a border fence partially across the valley including Kilik/Mintika at the Pakistan border, has greatly reduced the herd movements.

Distribution in HKH region*:* Presently in Pakistan, it is only found in Misgar valley and Khunjerab National Park in District Hunza in the HKH region.

Conservation status*:* IUCN Red List – Near Threatened; Pakistan – Critically Endangered; CITES – Appendix II; CMS – Appendix II.

Ladakh Urial *(Ovis vignei vignei)*

A herd of Ladakh urial in Bunji, District Astore, Pakistan © Gilgit Saeed Abbas/IUCN Pakistan

Ladakh urial or *Shapu* is a medium-sized wild sheep with large sickle-shaped horns found at lower elevations than the Argali. Once a common member of the fauna of northern Pakistan (Schaller, 1977), urial is found on rolling slopes at middle elevations, from as low as 1,500m to the tree line (Siraj-ud-Din et al., 2018). At such lower elevations, their habitat overlaps with human activities and livestock grazing, leading to illegal hunting, poaching and other disturbances that have driven the urial to the brink of extinction in Pakistan. Small and fragmented herds are still found in the HKH region. In some of the Community Managed Conservancies (CMCs) or Community-Controlled Hunting Areas (CCHAs) of Gilgit-Baltistan such as Bunji. The Parks and Wildlife Department, local community and partner organizations are actively protecting these small herds, with some populations already showing signs of recovery due to these active joint conservation efforts.

Distribution in HKH region: In Pakistan, it is only now found in Bunji and Doyan in Astore, Nanga Parbat in Diamer, Braldu in Shigar, and Kharpocho/adjacent areas of Skardu. Historically it was also reported from other areas in Gilgit and District Nagar, Diamer and Ghizer.

Conservation status: IUCN Red List – Vulnerable; Pakistan – Endangered; CITES – Appendix I.

Blue Sheep *(Psuedois nayaur)*

A herd of blue sheep in Shimshal, Hunza, © Imtiaz/IUCN Pakistan

The blue sheep or Bharal is an unusual animal that shares characteristics of both sheep and goats. It is a high-alpine specialist, living well above tree lines on steep slopes near the permanent snowpack. Pakistan is the western-most edge of blue sheep distribution, with herds found mostly in and around Shimshal and parts of Khunjerab National Park.

Here they face dangers such as poaching, disturbance and competition from livestock, and even the threat of disease from livestock, such as scabies (a skin infestation) that appears to have affected many of the animals over the past decade. blue sheep are important prey for the snow leopard, so their continued protection is also key to the survival of the snow leopard.

Distribution in HKH region: The blue sheep in Pakistan is found only in Shimshal and Khunjerab National Park and surrounding areas near the border with China.

Conservation status: IUCN Red List – Least Concern; Pakistan – Endangered.

Himalayan Ibex *(Capra ibex sibirica)*

A mix herd of Himalayan ibex (male and female) in Khunjerab National Park, Hunza, © Imtiaz/IUCN Pakistan

The Himalayan ibex is a large, muscular goat with long, scimitar-shaped horns that lives on the highest craggy peaks and alpine terrain of the mountain ranges of the Karakorum, the Pamir, the Himalaya, and the Hindu Kush. The H. ibex is essential to the mountain landscape and is considered one of the main wild prey items for large carnivores such as the snow leopard and wolf. It is believed that the ibex populations were once a source of subsistence for the local communities in its range of the country.

Despite habitat degradation, poaching, competition with livestock, and disease outbreaks, ibex distribution is believed to be widespread in most of its home ranges, and its population status is also quite satisfactory due to the protection for community-based trophy hunting program in the region.

Distribution in HKH region: The Himalayan ibex are widespread across the HKH region in Pakistan. The species is abundant in numerous valleys of Gilgit-Baltistan and Chitral, while it is also found in Dir, Kohistan, and areas of AJK such as Neelum Valley.

Conservation status: IUCN Red List – Least Concern; Pakistan – Least Concern; CITES – Appendix III [Pakistan].

Kashmir Musk Deer *(Moschus cupreus)*

A male Kashmir musk deer with distinctive fangs, ©Paras Bikram Singh

Kashmir Musk Deer (KMD) is a small forest-dwelling species of the mountain landscape of northern Pakistan. The areas fall in alpine, sub-alpine, and dry temperate mountain forests zones covered with alpine meadows, mixed coniferous, and birch forests. KMD prefers areas in sub-alpine birch forests and mixed coniferous forests and is largely confined to higher elevations. It occurs in the Himalayas from the extreme northern part of India to Pakistan, and northern Afghanistan.

The species is faced with serious population decline throughout its distribution range. In Pakistan, it was believed to be widespread at higher elevations of the HKH region, including Khyber Pakhtunkhwa (KPK) and Azad Jammu & Kashmir (AJK). However, its population has declined sharply due to habitat degradation, poaching for the musk pod, and habitat loss from deforestation. It now has a very restricted distribution, is confined only to isolated pockets, and is faced with local extinction. Field-based studies and survey results suggest that the population of the KMD is on the decline and requires immediate steps for its recovery. Otherwise, this critically endangered species will likely go extinct if the remnant populations are not protected.

Distribution in the HKH region: The Kashmir musk deer have been at higher elevations in the valleys of Astore, Diamer, and parts of Gilgit, Ghizer, and Skardu. However, field-based surveys and reports confirm that this species has now restricted distribution, and much of its population is found in Astore, especially Qamari, Minimarg, Kalasha, Maqponabad, Kalapani, and Rupal valleys of upper Astore and parts of Diamer and Gilgit. In AJK KMD have been reported from Machiara National Park and Neelum valley.

Conservation status*:* IUCN Red List – Endangered; Pakistan – Critically Endangered; CITES – Appendix I.

Barking Deer *(Muntiacus vaginalis)*

A female of barking deer in Margalla Hills National Park © Abdul Hadi/Islamabad Wildlife Management Board

The barking deer are native to South-East Asia and parts of southern China. Barking deer are associated with broad-leaved deciduous forests, feeding on grasses, herbs, ivy, thorny bushes, and low leaves (Habiba et al., 2021). They have nocturnal feeding behavior but may also feed at dusk in undisturbed areas. They face severe threats of habitat destruction, human encroachment, hunting and poaching.

Distribution in HKH: It has a narrow habitat range, restricted to Margalla Hills National Park, Murree-Kotli Sattian-Kahuta National Park, Khanpur range, Lehtrar, and in AJK, the animals have been found in parts of the southern districts of Bhimber, Kotli and Mirpur (Sheikh & Molur, 2004; Iftikhar, 2006, Zulfiqar & Minhas, 2011; Habiba et al. 2021).

Conservation status*:* IUCN Red List – Least Concern; Pakistan –Endangered.

Himalayan Gray Goral *(Naemorhedus goral bedfordi)*

Himalayan gray goral, © Mohebullah Naveed

The Himalayan goral or gray goral is endemic to the Himalayas and resembles a small antelope (Singh & Singh, 1986). It is found at elevations from 350m to 3500m. It has been reported that almost half of the global population of Himalayan gray goral exists in Pakistan (Fish and Wildlife Service, 1989; Sheikh & Molur, 2004). Significant threats to the species include habitat fragmentation, removal of plant biomass for fodder and fuelwood, and competition with domestic livestock.

Distributions: The distribution has been recorded in Abbottabad, Mansehra, Kohistan, Margalla hills, and AJK (Abbas, et al., 2015b).

Conservation Status: Pakistan – Vulnerable

Woolly Flying Squirrel *(Eupetaurus cinereus)*

Wooly flying squirrel in Diamer, Gilgit-Baltistan © Mayoor Khan/WCS Pakistan

The woolly flying squirrel is the world's largest gliding mammal and flying squirrel. It was believed to be extinct until the early 1990s when its population was rediscovered in 1994 in the Diamer district of Gilgit-Baltistan. Here it lives in cliff caves, gliding at night from its cliff home to the forests below to feed on vegetation, including pine needles – one of the few mammals in the world to have such a diet.

The prime habitat of the squirrel appears to be higher elevation conifer forests confined with cliffs and caves, which shelter it from most predators and potential poachers. In northern Pakistan, habitat destruction – clear-cutting of the high mountain pine forest ecosystem that the woolly flying squirrel depends upon for its survival – is the most immediate threat to the survival of this animal.

Distribution in HKH region*:* The woolly flying squirrel is mainly found in Diamer and southern Gilgit of HKH region.

Conservation status*:* IUCN Red List – Endangered.

Himalayan Rhesus monkey *(Macaca mulatta)*

A pair of rhesus monkeys in Nathia Gali, Pakistan © Waseem Ahmad Khan

The Rhesus monkeys are distributed throughout Afghanistan, Pakistan, and India. They are considered highly adaptable, living in diverse habitats, some on flatlands while others at altitudes as high as 3,000 m, such as the Himalayas.

Distribution in the HKH: In Pakistan, it is found in the Galiyat region (Nathia Gali, Dundagali), Kaghan, Swat, Dir, and some parts of AJK.

Status: IUCN Red List – Least Concern; Pakistan – Near Threatened.

Significance of wildlife in HKH

Maintaining ecosystem and biodiversity

The diversity of wildlife species in the HKH region helps maintain the rich biological diversity because every species relates to other species, directly or indirectly, in a balanced ecosystem. If one organism is removed or becomes extinct, it disrupts the entire food chain, resulting in declining biodiversity. In other words, diversity is an ecosystem's greatest strength. A wide variety of plants in an area means greater productivity and healthier ecosystems. In high-altitude mountainous landscapes such as the HKH, the presence of top carnivores like snow leopards and raptors (birds of prey) is considered an indicator of the ecosystem's health. The various species of wild ungulates constitute a major part of the mammalian carnivores' diet and help sustain the carnivore populations in the HKH ranges. Similarly, the carnivores prey upon the herbivores and regulate their populations; otherwise, the herbivore populations would become excessively abundant, depleting the vegetation.

Nutrition for humans

Everything we eat comes from either an animal or a plant. While most of our food comes from agriculture, all our crops and domestic animals have been derived from wild relatives. Subsistence hunting and fishing are still good sources of nutrients for local inhabitants in the HKH region of Pakistan. The water bodies in the HKH region of the country provide a variety of fish species, including 25 in Gilgit-Baltistan and 43 in AJK (Akhtar, 1991a, b).

Zoopathy: traditional use of animals in medicine

The use of animals or animal-derived materials in treating ailments is called zoopathy (Costa-Neto, 2005). Across the world, animals and their parts are used to treat a variety of human diseases. In the Himalayan region of AJK, Faiz et al. (2022) reported the ethnomedicinal uses of 62 animal species to treat 39 different diseases, including male impotency, weakness, joint pain, memory loss, paralysis, piles, poor eyesight, stomachache, whooping cough, liver problems, and kidney problems among others. Most of these animals and their products come from wildlife, including vertebrates and invertebrates.

Socio-economic importance

Sports, recreation, and research activities in the wildlife sector generate socio-economic and livelihood opportunities for local communities. Protected areas in the HKH region, such as national parks, wildlife sanctuaries, game reserves, and community-based conservation areas, contribute to economic development and societal well-being through income generation and livelihood opportunities such as tourism, trophy hunting, angling, etc. Some national parks in the region receive entry fees from visitors. Cold water fishing is another livelihood source for local people in numerous valleys of the HKH region in Pakistan. Similarly, beekeeping is another income-generating activity in many parts of the HKH in Pakistan.

Trophy hunting revenues in community-managed conservation areas across the HKH in Pakistan significantly contribute to the conservation of wildlife and the socio-economic development of local communities. The program helps to conserve and recover populations of endangered, threatened, and rare wildlife species, especially the economically important wild animals that might otherwise face extinction due to poaching and habitat degradation. Pakistan's trophy hunting program is a successful community-based conservation model, particularly in the HKH region. The trophy hunting revenue distribution ratio is considered the highest in the world, with local communities and the government receiving 80 per cent and 20 per cent, respectively. Local people are incentivized to stop poaching and sustainably manage wildlife, using these funds for conservation and local development.

Major conservation challenges

Habitat loss and fragmentation

The ever-increasing human populations and their activities have seriously impacted the natural habitats of the wild flora and fauna. High-altitude habitats are the most fragile components of natural environments. Their physical attributes, such as altitudinal gradients, seasonal severity, and micro-climatic and edaphic conditions, contribute to species richness and rarity and make them susceptible to adverse changes. The home ranges of various species have been squeezed, while the movement of other species has been restricted due to the disruption of their passage corridors. Populations of mountain ungulates have either been drastically reduced or locally extirpated due to habitat loss and fragmentation (Baig & Al-Subaiee, 2009; Arshad et al. 2012). Habitat fragmentation increases the risk of extinction by isolating small pockets of previously connected populations (Baig & Al-Subaiee, 2009). The local extinction of Ladakh urials from the areas of Nager in Gilgit-Baltistan is such an example, and presently the dwindling population of the urials is fighting for its survival at the isolated Mount Kharpocho in Skardu. Human encroachment into natural areas through cultivation, deforestation, construction, road networks and communication links, livestock grazing, tourism etc., has seriously impacted wildlife habitats.

Excessive, illegal hunting and poaching

Many birds and mammal species are subject to illegal hunting and poaching, leading to their declining populations. The major reasons for hunting are subsistence, recreation, and body parts trade. The impacts of hunting have increased manifolds with the increasing use of automatic weapons and other exploitative activities such as nets and traps. Poaching and illegal hunting are widespread in the HKH regions of Pakistan. For example, Din et al. (2022) reported 101 incidents of snow leopard poaching from 11 districts of HKH from 2005-2017, resulting in 2-4 per cent of the population loss.

Human-wildlife conflict

Human-wildlife conflict can be defined as the negative impact of humans and wildlife on each other, which includes carnivores preying on livestock, damaging crops, and causing fear in human beings, while humans respond with retaliatory shooting, poisoning, and becoming hostile to wildlife (Mishra, 1997; Suryawanshi et al., 2013). In the HKH region of Pakistan, large carnivores are involved in attacks on humans (Ali et al., 2018, Asad et al., 2019; Ali et al., 2021), livestock depredation (Awan et al., 2016; Khan et al., 2018; Khan et al., 2019; Din et al. 2022), and loss of agriculture crops (Ahmad et al., 2016; Ali et al., 2021). Human attacks on the common leopard and Asiatic black bear have also been reported. Livestock depredation for snow leopards, gray wolves, brown and black bears, jackals and sometimes foxes. Damages to trees and crops, mostly to summer crops such as maize, potatoes, and apricots, have been reported for the Asiatic black bear, jackal, and monkeys.

Another aspect of human-wildlife conflict that is often neglected is the conflict over pasture or rangeland utilization. Wild ungulates and domestic livestock rely on the same pastures, and their food preferences overlap significantly (Ashraf et al., 2014; Khan et al., 2018). Despite its significance, researchers rarely pay attention to the fact that domestic livestock outcompetes the wild ungulates, driving them to unfavorable parts of the rangelands. Furthermore, the carrying capacity of the rangelands is poorly documented. Disease transmission from livestock to wild species is another aspect of this habitat sharing (Khanyari et al., 2021). As a result, suspected carnivores are subject to retaliatory killing and retribution, especially by livestock herders and farmers who depend on the agropastoral economy.

Key conservation strategies

Effective management of Protected Areas (PAs)

The HKH region in Pakistan possesses about 80 PAs of various categories (Chaudhry et al., 2022). Ineffective and poor management are common challenges across these PAs due to a lack of resources and capacities. The government should improve the PAs management by allocating more funds and increasing human resources, while enhancing coordination among various PAs and other stakeholders. The large home ranges of mountain wildlife species require transboundary collaboration with neighboring countries. Moreover, wildlife corridors should be considered for conservation and ecological connectivity within and across borders.

Improved watch and ward mechanisms

Despite existing laws and regulations governing wildlife resources, illegal hunting and poaching have been major challenges in the HKH region. Insufficient wildlife guards in remote and inaccessible areas are another major constraint. The relevant departments managing forests and wildlife resources must hire more watchers, train and equip them with proper field gear.

Participatory or community-based conservation

Conservation efforts have not been very successful in various parts of the world without the active participation of local communities. The importance of community participation increases manifold in human-driven wildlife habitats such as Pakistan's HKH region, where local people live in proximity to wildlife and frequently harm wild animals and their habitats. Human populations in the HKH region live in less accessible narrow valleys, making it difficult for the government to place watchers everywhere; thus, community stewardship is essential. Community participation in conservation efforts has been exemplary in many parts of the HKH region, such as Gilgit-Baltistan, Chitral, and AJK (Khan & Baig, 2020; Khan & Ghaznavi, 2021).

Managing human-wildlife conflict

To mitigate human-wildlife conflict, different types of interventions are required based on the nature of the conflict, and the species involved. However, suggestions can be divided into four broad categories.

Box 9.1 Trophy hunting of wild ungulates in HKH region of Pakistan: the case of Gilgit-Baltistan (Khan & Ghaznavi, 2021)

Trophy hunting of wild ungulates in Gilgit-Baltistan (GB) was initiated in the early 1990s by motivating and involving local communities in wildlife conservation. Primarily, the program aimed to recover the depleting biodiversity with active stakeholder participation. Community-based Conservation Organizations, generally termed as Valley Conservation Committees (VCCs) were formed in valleys where participatory conservation was initiated. To provide policy support, the Government of GB declared those priority valleys as Community-controlled Hunting Areas (CCHAs). Participatory Conservation Plans were developed to with community input and endorsed by the respective District Administration. The plans outlined integrated conservation and development actions for wildlife protection and livelihood improvement. Hunters belonging to local communities were engaged as wildlife watchers by paying honorarium and training them in watch and ward mechanisms.

After few years of stringent conservation efforts when the population of wild ungulates such as markhor *(Capra falconeri)*, ibex *(Capra ibex)* and blue sheep *(Pseudois nayaur)* were recovered and improved, the Government initially allowed to harvest one trophy animal. To incentivize conservation efforts, 80 per cent of the trophy hunting revenue was allocated to the local VCCs and only 20 per cent to the government's exchequer. The community share of the trophy hunting revenues were spent on social-economic wellbeing, such as education, plantation, water supply, road construction, etc., which became an incentive for locals to be stewards of wild resources.

Hence trophy hunting became a successful conservation tool in the region. In GB, trophy hunting of wild ungulates has exponentially increased; from only four ibex in 1999-2000 to 74 ibex, 8 blue sheep and 4 markhor in 2018-19. In Gilgit-Baltistan, the ibex hunting permits have been auctioned for up to US$3,500, blue sheep US$8,000 and Astore Markhor US$100,000 per animal. According to the data compiled by GB Parks & Wildlife Department, a total of 623 ibex, 37 Astore markhor, 49 blue sheep and 2 Ladakh urial trophies have been harvested from 19 CCHAs of GB during 2000 to 2019. The total revenue earned from the trophy hunting licenses during this period was over PKR 472 million in addition to US$ 3.4 million. These revenues have been a source of financial support to continue conservation activities across GB.

Compensations: Compensation programs should be implemented to compensate for the loss of livelihood caused by livestock predation and crop damage. Such schemes are already in place in some areas of the HKH region (Kunkel et al., 2016). They are, however, limited to specific areas of Pakistan's HKH region, relying primarily on insurance funds provided by non-governmental conservation organizations and community contributions. Through the PSLEP project, the government is working to establish an insurance scheme to compensate for livestock predation in 16 valleys (MoCC, 2022). A better strategy would be to expand the scheme to all areas where livestock predation is a conservation issue with a well-thought-out governance scheme modeled after the BW-CDO pilot project (Hussain, 2000). Such an insurance scheme to compensate for livestock predation can be established at the district- or province-level based on the region's overall socio-cultural and linguistic similarity and connectivity. Resources may be pooled in from various sectors, including the trophy hunting programs, for this purpose.

Predator-proof Corrals: A substantial part of livestock losses occur when predators break into the corrals and cause mass killing (Jackson & Wangchuk, 2004). This could be prevented by strengthening the corral walls and roofs, making them predator-proof, particularly in high pastures (Din et al., 2019). Various conservation organizations have undertaken such initiatives, but the extent is limited (MoCC, 2022).

Predator-proof corrals, as well as enhanced livestock guarding and management practices, could reduce livestock losses.

Livestock health and vaccination facilities: Diseases can cause livestock mortalities and an economical cost greater than livestock predation (Din et al., 2019; Ahmad et al., 2016). Herders are often willing to tolerate occasional predation incidents to control excessive livestock mortality (Nawaz et al., 2016). Such practices exist in some parts of the HKH region. Vaccinations are also carried out against only a few viral diseases (Nawaz et al., 2016). Effective immunization needs to include a greater number of diseases, particularly against sudden outbreaks. Overhauling the existing livestock health facilities, building personnel capacity, and expanding services throughout the HKH region can help reduce disease-caused mortalities and enable co-existence with carnivores.

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Chapter 10

Medicinal and Aromatic Plants

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Himalayan bistort (*Bistorta affinis*), commonly found in alpine grass lands in HKH © Qamar Abbas

Introduction

Plants have been used in different forms as the primary solution to health problems since antiquity. The modern utilization of herbal products is based on traditional ethnobotanical wisdom. Knowledge evolves as new discoveries are made, and innovative methods are developed. Modern scientific techniques have improved traditional treatments derived from wild and domesticated plants. This has significantly contributed to the healthcare industry as well. Pakistan's climatic conditions and distinctive topography span from mighty mountain ranges in the north to the Arabian Sea in the south. As a result, Pakistan has a diverse flora with over

6,000 plant species in 1,600 genera. Some parts of the world are known as hotspots for medicinally significant plant species.

The HKH region is home to extremely rare herbs with intriguing biological properties. Almost 5,600 species of important plants are widely available in the HKH region. These plant species are used in the region for a variety of diseases like digestive disorders, bone problems, skin diseases, metabolic disorders, etc. Globally, there is a growing interest in using plants for medicinal and cosmetic purposes. Chemicals from plants are extracted and isolated, followed by purification and separation processes using chromatographic or non-chromatographic methods. Plants have served mountain-dwelling communities in multiple ways from antiquity to the modern age. However, these natural resources are at a high risk of extinction due to overexploitation and other factors. Conserving endangered plant species in areas susceptible to the destruction brought on by climate change is currently the biggest challenge. Furthermore, population growth and the associated transformations intensify the risks. Proper measures are, therefore, urgently needed to protect these important natural resources.

Historical perspective

Human beings require several complex organic and inorganic components in their diet to meet their physical, physiological, and biochemical needs. The essential constituents of diet are carbohydrates, fats, proteins, vitamins, minerals, and water. Every nutrient plays an important role, and deficiency of any one nutrient may lead to diseases or disorders (Valls et al., 2013). Other environmental pathogens like bacteria, viruses, fungi, and parasites can also affect the human body. These diseases spread from person to person and may become epidemic, endemic, or pandemic. Historically, these challenges have destroyed, devastated, and demolished nations, traditions, and customs. The emergence and advancement of medical sciences have resulted in the demise of old beliefs that diseases were caused by evil spirits or gods inhabiting the human body. Throughout history, research and development of new methods and techniques have enabled humans to combat natural and environmental calamities, disasters, and diseases (Formosa, 2007). Medicinal extracts from plant or animal sources to find remedies for various ailments have been used since antiquity. The origins of human awareness and belief in therapeutic substances derived from plants or animals are unknown. It is also believed that life originated on earth about three billion years ago, with the first oxygen-producing organisms, the archaic blue-green algae, developing approximately one billion years later (Cohan, 2007).

Scope and importance of medicinal and aromatic plants

Humans have been using medicinal and aromatic plants since times immemorial. Earlier generations relied on natural products found in their surroundings to treat a variety of illnesses and injuries. Such practices paved the way for the widespread use of traditional medicine, and today, nearly 80 per cent of the world's population relies on medicinal and aromatic plants (MAPs) to treat various diseases (Rashid et al., 2015).

Nowadays, 60 percent of the total global population and 80 per cent of the people in developing countries rely on traditional medicine for medical care (Haq et al., 2022; Kayani et al., 2015). The usage of medicinal and aromatic plants is extensive in the eastern healing systems like Ayurveda, the traditional Chinese medicine system, Unani, and Siddha. About 3,000 species of MAPs are marketed internationally, of which about 2,000 are chiefly merchandised in European countries like Germany, Switzerland, and France (Adnan et al., 2012). The worldwide business of the MAPs has increased by more than 3 per cent since 2010 and reached a volume of 673,564 tons in 2014, valued at 2,724 million US dollars. The international trade for MAPs is dominated by China, France, Germany, Italy, Japan, Spain, the UK, and the USA (Almeida & Silva, 2014).

Different plant species produce a variety of bioactive molecules with diverse chemical structures. For centuries, medicinal and aromatic plants have been used on a daily basis as cosmetics, foods, teas, and medicines. As the medical and pharmaceutical industries advance, medicinal and aromatic plants continue to be significant sources of vital compounds. A wide variety of products made from medicinal and aromatic plants are available in the market, and every fourth flowering plant is used for this purpose. Locally and internationally, there is a huge demand for MAPs. In the 1990s alone, the global import of medicinal plants averaged 40,000 tons per year, earning US$1,224 million (Lange, 2004).

Only 12 countries account for approximately 80 percent of global imports and exports of medicinal and aromatic plants, with Asian and European countries dominating the market. Japan and South Korea are the world's top buyers of medicinal plants, while China and India are the leading producers, with Hong Kong, the United States, and Germany serving as important trade hubs (Lange, 2004). The domain of essential oils, extracted from plants, has extended to a comprehensive range of applications in flavors, disinfectants, oral hygiene, cigarettes, and pharmaceuticals. Essential oils account for about 17 per cent of the worldwide flavor and perfumery market. The global production of essential oils ranges from 40,000 to 60,000 tons per year. Spice oil demand is also set at 2,000 tons per annum (Joy et al., 2001).

Significance of HKH as a habitat for MAPs

The HKH region is one of the world's 34 biodiversity hotspots and one of ten mega-centers (Sharma & Chettri, 2005). Due to specific environmental conditions, the HKH region is a hotspot for medicinally important plants (Dhar et al., 2000). The three mountain ranges collectively contain 25,000 species of plants which constitute 10 per cent of the world's flora. The HKH region has reported over 300 varieties of the 10,000 medicinally and economically important identified plant species (Salim et al., 2019).

Mountains are more abundant in medicinal plant species than the plains. Shinwari (2010) revealed that more than 80 per cent of plant diversity is endemic to the mountainous regions of Pakistan. This region offers ecosystem services i.e., food, water, and energy that sustain the livelihoods of 240 million people directly in the mountains and hills of the HKH (Rasul, 2008).

At least 70 per cent of the medicinal plants consist of wild species and 70–80 per cent of the population in these regions depends on traditional medicines (Kayani et al., 2015). Thus, this ethnobotanical knowledge is socially integrated through communal learning and intellectual exchange. The local population is well-informed about the distribution of medicinal plants as they grow at high elevation corridors or are endemic to particular localities. However, the lore varies from valley to valley in certain aspects based on health problems and other needs of a specific place. Providing details for all plant species distributed in the area is beyond the scope of this chapter, however, some of the most common medicinal plants in the mountainous landscape will be covered.

MAPs are an important source of income for local rural people in developing countries. About 15 to 30 per cent of the total income of rural households is attained by selling materials obtained from wild plants (Hamilton, 2004). The significance of medicinal plants in the Himalayan region is progressively increasing from an ecological, social, and economic point of view. Despite the importance of medicinal plants for rural communities, the diversity and abundance of forest floor medicinal plant species are disappearing by over-exploitation of the trees (Gilliam, 2007; Liira et al., 2007; Wyatt & Silman, 2010).

Native people in the mountain communities collect nearly 600 medicinal plant species to generate income and survival. Most of the plant species are fern and forest floor herbs. Among these, 500 medicinal plant species are used in different traditional practices for various health issues, and 350 are exported to the USA for foreign exchange (Adnan & Holscher, 2012). The HKH region exported 75 crude herbal drugs to the 24 leading manufacturing homeopathic companies of Greco-Arabic for making various recipes. Traditional herbal practitioners utilize more than 200 plants for making home remedies to cure various ailments (Hamayun et al., 2005).

Medicinal and aromatic plants' diversity in HKH mountain ranges

Nature has bestowed upon Pakistan a total of 1,572 genera and 5,521 species, mostly limited to the HKH region (Sheikh et al., 2013). Approximately 300-400 species are used in traditional medicines.

The most common families in the Himalayan ranges include *Rosaceae, Moraceae, Euphorbiaceae, Mimosaceae, Pinaceae, Rhamnaceae, Oleaceae, Apocynaceae, Caesalpiniaceae, Ebenaceae, Fagaceae, Lythraceae, Papilionaceae, Acanthaceae*, and *Verbenaceae*, etc., (Rashid et al., 2015). The plants of these species, prevalent in the Himalayan region, are used for gastrointestinal disorders, skin problems, respiratory disorders, urinary problems, muscle, and skeletal issues, cardiovascular problems, fertility issues, nervous disorders, and glandular problems among many more. For instance, *Juglans regia, Acacia nilotica, Phyllanthus emblica, Pinus roxburghii*, and *Punica granatum* are extensively used for the treatment of a variety of diseases. They are used as aphrodisiacs, diuretic, anti-asthma, anti-diarrhea, dyspepsia, jaundice, emollient, antiseptic, anthelmintic, diaphoretic, blood purifier, and skin cure (Adnan et al., 2012). This indicates the reliance of the local population on traditional medicines and explains their longevity.

(a) (b) (c)

Figure 10.1: Representative plants along the Himalayan region: (a) *Aconitum heterophyllum;* (b) *Anaphalis nepalensis*; (c) *Rhodiola heterodonta* © Sajjad Ali

Among the recorded plant families on the Karakoram mountains, Fabaceae, Asteraceae, Polygonaceae, Ranunculaceae, Rosaceae, Lamiaceae, Leguminosae, Apiaceae, and Zygophyllaceae have been recurrently cited. Certain plants also represent Ephedraceae from gymnosperms and Equisetaceae from Pteridophytes in the Karakoram landscape. Herbs contribute almost 69 per cent of the total flora, followed by shrubs (14 per cent), trees (13 per cent), and shrublets (4 per cent) (Abbas et al., 2017).

(a) (b) (c)

Figure 10.2 Unique plants in Karakoram region. (a) *Bergenia stracheyi;*(b) *Dephne mucronata;* (c) *Berberis orthobotrys* © Sajjad Ali

The inhabitants of the area use various formulations against a wide spectrum of diseases. The plants of these cited families are used for abdominal disorders, respiratory disorders, dermal problems, cardiovascular ailments, urinary tract disorders, pregnancy and menstrual issues, hepatic disorders, bone problems, and metabolic disorders like cancer and diabetes. For example, *Delphinium CC* is used as an effective solution to respiratory problems and gastric disorders, and *Betula utilis* is known to treat gastrointestinal problems. Similarly, *Pimpinella diversifolia, Hippophae rhamnoides, Thymus linearis*, and *Allium carolinianum* are used for the treatment of digestive problems against ringworms, vomiting, abdominal pain, etc. and these species are also exploited to treat cardiac problems, bone problems, and dermal diseases. Moreover, *Artemisia scorpia* is regarded as a highly effective antidote for diabetes in certain valleys of the Karakoram range. Further, *Pimpinella diversifolia* is the most commonly used plant for blood purification, fever, and digestive problems, and *Gentianoides tianschanica* for jaundice and fever (Bano et al., 2014). With this tremendous indigenous knowledge and rich culture of plant medication, there is an enduring threat to endemic species due to human population growth with associated transformations, urbanization, tourist outburst, and unplanned heavy constructions. Serious measures are required from relevant institutions for the conservation and sustainability of this exceedingly important natural resource.

The dominant families of the Hindu Kush Mountain range include *Lamiaceae, Leguminosae, Solanaceae, Amaryllidaceae, Euphorbiaceae, Moraceae, Rhamnaceae, Rosaceae, Amaranthaceae* and *Asteraceae* (Haq et al., 2022). The common diseases which are usually treated with plant products are gastrointestinal disorders, liver problems, respiratory disorders, cardiovascular diseases, bites, and bone problems. The locals have good knowledge about different formulations and use of plant parts. Mostly plant leaves are used for remedies followed by fruits, seeds, roots, whole plant, stem bulb latex, rhizome, flowers, and gums. Following are some examples of plants that are frequently used for common diseases.

(a) (b) (c)

Figure 10.3 Medicinal and aromatic plants of Hindukush region. (a) *Saussurea simpsoniana;* (b) *Delphinium brunonianum;* (c) *Rheum spiciformi,* © Qamar Abbas

Gastric problems are among the most common health problems in this region due to lack of access to safe drinking water. Plant species from different families are used for the treatment of abdominal problems, such as *Foeniculum vulgare, Berberis lyceum, Myrtus communis, Mentha longifolia, Zanthoxylum armatum, Vitex negundo, Morus alba, Plantago lanceolata, Ficus carica, Fragaria vesca, Rosa moschata, Ricinus communis, Eruca vesicaria*, etc. Similarly, *Zanthoxylum armatum, Olea ferruginea, Withania somnifera, Diospyros lotus, Morus alba, Morus nigra, Robinia pseudoacacia, Ranunculus muricatus, Dysphaniabotrys*, and *Salvia moorcroftiana* are used to treat respiratory diseases. Moreover, *Cannabis sa-*

tiva, Verbascum thapsus, Allium griffithianum, Marrubium vulgare, and *Nerium oleander* are considered effective remedies for cardiovascular diseases and their prevention. Metabolic disorders such as diabetes are also treated with *Cannabis sativa, Ziziphus jujuba, Ziziphus oxyphylla, Quercus baloot,* and *Dodonaea viscosa* (Ali et al., 2018; Ullah et al., 2020).

Medicinal plants vitality

Humans consume organic and inorganic nutrients to fulfill their nutritional needs. Most of these vital moieties are obtained from plants which are rich sources of all the elements essential for human beings. There is a relationship between the element content of the plant and its nutritional status. Some elements are essential for growth, structure formation, reproduction, as components of biologically active molecules, or other beneficial effects (Adnan et al., 2012).

Medicinal plants have been used as traditional treatments for numerous human diseases for thousands of years. It is an important therapeutic aid and provides the basis for traditional, conventional as well as modern therapeutic and management approaches. Early humans explored their immediate natural surroundings in search of eternal health, and remedies for pain and discomfort. The use of plants, animal products, minerals, and other substances resulted in the development of novel and potent therapeutic agents. Today, there is a renewed interest in traditional medicine and an increasing demand for more drugs from plant sources. This revival of interest in plant-derived drugs is mainly due to the current widespread belief that green medicine is safe and more dependable than costly synthetic drugs, many of which have adverse side effects (Salim et al., 2019).

Ethno-medicinal and pharmacological knowledge

The people of the area have empirical observations of nature, besides accumulating knowledge on local plant species by communicating with other people of their culture. They are thus gaining indigenous knowledge generation after generation from their ancestors (Giannenas et al., 2020). The plant and plant materials available from the nearby area is used as medicine. Similarly, local people in various villages of the area gather medicinally important weeds in different seasons of the year for personal and community use within the area. In this way, the ethnomedicinal knowledge of weedy plants is interactively linked to local culture and history (Abbas et al., 2017). Since most medicinal plants occur naturally in many countries, a plant of potential importance in one country may have been studied by scientists elsewhere. Considerable time and effort could be saved if their findings could be made available to all interested people. Pooled information is especially critical when it comes to drugs, as a value judgment on the safety or efficacy of a particular drug can rarely be based on the results of a single study. In contrast, a combination of information indicating that a specific plant has been used in a local health care system for centuries, together with efficacy and toxicity data published by several groups of scientists, can help in deciding if the plant can be used for medicinal purposes (Sofowora et al., 2013).

Traditional phytotherapies

There are millions of hidden recipes in these medicinal plants which are used by mankind for the treatment and prevention of various diseases. Natural remedies use whole herbs or herbal extracts in different forms along with some ingredients of animal or mineral origin (Ahmad et al., 2014).

According to the WHO, about 80 per cent of the world's population is taking interest in indigenous medicinal plant remedies (Rashid et al., 2015). These herbal medicines have usually been used in the form of fruits, vegetables, drugs, or extracts for the treatment of diseases and for the maintenance of health. Another report submitted by the WHO stated that 20,000 plant species are currently in use for medicinal purposes and are invaluable sources of pharmaceutical products. In Pakistan, in early 1970, an estimated 84 per cent of the population was dependent on traditional medicines while an estimated 80 per cent of the rural population still depends on traditional medicines for their primary healthcare needs. Many phytomedicines are used, registered, and recognized in different editions of European, British, and United States pharmacopoeias. In US Pharmacopoeia, more than 600 botanical substances have been recognized and registered. The global trade in MAPs is currently valued at more than US$32 billion with an estimated value of US$50 billion by 2050 (Riaz et al., 2021).

Traditional phototherapy is still practiced in many areas of developing countries and provides a base for the development of clinically effective drugs and compounds. However, this process needs exploration and screenings on scientific grounds. Phyto-investigations and research should be encouraged on national and international levels because microbial world and insects or pathological disorders are more abundant than plants; they are harmful to humans and dangerous for animals and plants as well. Similarly, aquatic and marine plants are also pharmacologically active. Bio-scientists are now diverting toward marine and phytoplankton sciences and exploring their chemistries and pharmacological activities (Kayani et al., 2015).

Medicinal plants metabolites

Plants are one of the major natural sources of drugs; rocks, animals, and microbes are the other primary sources of drugs. Sumerian Babylonians in the great Egyptian era used ocean clay as a source of treatment. The primary plant metabolites like carbohydrates, proteins, vitamins, and fats are synthesized by green plants through photosynthesis utilizing solar energy and are directly involved in the normal growth, development, and reproduction of the plants. These metabolites are then consumed by humans and other organisms for their nutritional purposes. The secondary metabolites or bioactive compounds like flavonoids, alkaloids, glycosides, terpenoids, volatile oils, phytoestrogens, carotenoids, tannins, phenols, etc., facilitate the primary metabolites and metabolisms in plants. A common role of secondary metabolites in plants is a defense mechanism which is used to fight off herbivores, pests, pathogens, etc. Research has proven that this trait is common in each plant, but it is still difficult to determine the precise role of each secondary metabolite. These secondary metabolites were used by ancient humans in different civilizations and are being used to this day. These bioactive compounds are present in barks, roots, stems, flowers, fruits, seeds, leaves, or other parts like rhizomes, bulbs, or in exudates, which may be used raw or in the form of extracts, decoctions, or infusions, etc., (Šantić, 2017).

Chemistry of Medicinal Plants

Tissues from plants or animals always contain a variety of structurally distinct types of chemicals. Each class often includes several chemicals that are structurally related to one another. The chemistry of natural products typically starts with the separation and isolation of a single pure component from a large number of closely related constituents (Xiao et al., 2013).

Organic compounds of medicinal plants

Primary metabolites are the organic substances necessary for a living body that are present in all species, including glycogen, proteins, nucleic acids, certain enzymes, and others. The additional substances that are found in a relatively small class and unique to each species of plant are referred to as secondary metabolites. Their function is currently unknown. This type of secondary metabolite is typically the target of natural product chemistry. The use of plant materials in medicine, diet, and cosmetics is becoming more and more popular. They serve as a source of active chemicals that have long been traditionally used in medicine. Plants are a potential source of natural compounds that can be used for therapeutic and other purposes (Bhat et al., 2005). Active compounds or secondary metabolites found in plant leaves, flowers, bark, seeds, fruits, roots, and other organs include steroids, alkaloids, tannins, glycosides, volatile and fixed oils, resins, phenols, and flavonoids (Dias et al., 2012). The different solubilities of the compounds in the solvent combinations are related to the extraction process of these metabolites.

Techniques used for identification, extraction,

and isolation

Separating the active components of plant tissue from their original components requires an extraction process using a suitable solvent. Solvents migrate into solid plant matter during this process, dissolving compounds of similar polarity. Traditionally, solvent extraction is the first step to isolate secondary metabolites from target plants. For example, alkaloids are extracted with acidic water, the extract is made basic and then extracted again with an organic solvent such as chloroform. The methanol extract can optionally be suspended in water and re-extracted with successively more polar solvents such as hexane and chloroform. Each extract is then separated or purified using various techniques such as chromatography. It contains many water-soluble substances such as saponins, tannins, and carbohydrates that cannot be obtained through conventional methods (Doughari, 2012). Considering this and other advances in carrier materials in chromatography, the isolation procedure was modified as follows. First, a methanol extract is prepared. After concentrating the extract, the residue is placed on a silica gel column and gradually eluted using solvents of increasing polarity, starting with hexane, and ending with chloroform-methanol. Using this technique, the range of separable substances has been extended from non-polar hydrocarbons to several water-soluble substances, including saponins. However, it remained difficult to separate highly polar molecules. Since then, many new column chromatography sorbents have been introduced, including Diaion HP-20, MCI-Gel, and Sephadex LH-20. These new materials allow more efficient and consistent fractionation of highly polar chemicals (Da Silva Sa et al., 2017). For example, using Sephadex LH-20 as a column enabled the separation of highly polar tannins.

There are several extraction techniques for plant metabolites. These techniques can be classified as traditional (long-standing) or novel. Conventional techniques use organic liquids (hexane, acetone, methanol, ethanol etc.) or water, and are generally performed at atmospheric pressure, while newer techniques use pressure and/or elevated temperatures (Zhang et al., 2018).

Selection of solvent and extraction method

Selecting an appropriate extraction method is obvious, as different methods performed on the same plant material using the same solvent result in significant differences in extraction efficiency. For future replicability, the corresponding extraction process should be as consistent as possible. Aside from the application, selecting the appropriate solvent is critical. This is because polar solvents leach polar active compounds while non-polar solvents leach non-polar active compounds (Rasul, 2018).

Solvents such as water, ethanol, chloroform, ethyl acetate, and methanol are commonly used in extraction processes, and mixtures of solvents can be used to improve extraction efficiency. Traditional solid-liquid extraction methods such as decoctions, infusions, Soxhlet extraction, maceration, and hydrodistillation are among the conventional techniques. A growing interest in plant metabolites has led researchers to explore new extraction methods that enable faster and shorter extraction times, efficient extraction, automation, and reduced consumption of organic solvents. Several new extraction methods have been developed, including ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), supercritical fluid extraction (SFE), and pressurized liquid extraction (PLE). These new methods have the potential to reduce extraction times, reduce the amount of solvents used, and increase extraction yields (El Maaiden et al., 2022).

Conventional techniques

Almost all these methods rely on the extractive power of the solvent and the combined effects of heat and/or mixing. Conventional techniques for extracting bioactive compounds from plants include decoction, infusion, Soxhlet extraction, maceration, and hydrodistillation. All these methods use solvents in combination with elevated temperatures and/or agitation (Afzal et al., 2022).

Decoction: This is a good method for extracting water-soluble components that are not degraded by heat. During the boiling process, distilled water is added to the dry extract, and the mixture is kept at 100°C for an extended period. The filtrate is then allowed to cool to room temperature before being filtered. To create an extract, the filtrate is concentrated. This method does not require additional or expensive equipment and is easy to perform (Doughari, 2012). Unfortunately, it is not recommended for the extraction of heat-sensitive ingredients.

Infusion: In this method, extraction is performed by briefly immersing solid plant powders in cold or hot water.

Soxhlet extractor: It is now used to extract valuable bioactive compounds from natural sources. Soxhlet extraction is a simple and convenient method of repeating extraction cycles indefinitely with fresh solvent until the raw material is completely depleted of solutes. The distillation process is implied when extracting with Soxhlet. It entails bringing the solution to a boil, allowing it to condense, and then returning it to the original flask. A small amount of dry material is conveniently placed in the pot. This thimble is then inserted into a distillation flask containing a specific solvent. A siphon absorbs the solvent in the hose holder and returns it to the distillation flask once at dive altitude. The extracted solutes are present in this solution. This process repeats indefinitely until the extraction is complete (Formigoni et al., 2021). A Rotavapor device is used to separate the extract from the solvent. This method does not necessitate post-extraction filtration. Soxhlet is unaffected by matrix vegetables. Since the samples are heated to high temperatures for long periods, the risk of thermal destruction of some compounds is not negligible if the plant material contains heat-labile compounds. Evaporation/concentration is limited later given the amount of solvent used.

Maceration: It is a centuries-old method of preparing medicines. It is regarded as a popular and low-cost method of extracting phytochemicals from plants. Maceration is a solid-liquid extraction method that extracts bioactive compounds (solutes) from plants by immersing the plant in a specific solvent for a predetermined amount of time. Maceration consists mainly of three steps. First, raw plant materials are ground into powder. This allows for good contact between the solvent and the material surface and proper solvent mixing. After grinding, place the solvent of choice in a sealed container. The liquid is then sieved while the solid residue from the extraction process is pressed to recover the bulk of the trapped solution (De Silva Sa et al., 2017).

Hydrodistillation: Hydrodistillation is the traditional method of extracting plant metabolites without using organic solvents. The plant material is packed into a distillation chamber, and enough water is added to bring it to a boil. Alternatively, directly inject steam into the plant sample. The main factors influencing the release of bioactive compounds from plant tissues are hot water and steam. Indirect water cooling condenses a water-oil vapor mixture. The condensed mixture flows from the condenser to a separator, where oil and bioactive compounds are automatically separated from water (Reis et al., 2019). When using high extraction temperatures, some volatile components may be lost. This disadvantage limits its application to the extraction of heat-sensitive compounds.

New extraction techniques

Green extraction refers to the discovery and design of extraction processes that reduce energy consumption while using alternative solvents and renewable natural products to ensure safe, high-quality extracts (Bubalo et al., 2018).

Ultrasound-assisted extraction (UAE): UAE is a cheap, fast, simple, energy-saving, and efficient technology. The effect of acoustic cavitation generated within the solvent by the passage of ultrasound is primarily responsible for the improved extraction. Ultrasound also destroys cell walls, allowing more solvent to penetrate the tissue and increasing the contact area between the solid and liquid phases. Second, it helps solutes diffuse rapidly from the solid phase into the solvent. The extraction process in the UAE is determined by the particle size of the plant extract, the water content, and the solvent used (Wu et al., 2018). The advantages of the UAE include shorter extraction times, lower energy consumption, and lower solvent consumption.

Microwave-assisted extraction (MAE): This is a technique for the extraction of soluble products in liquids from various materials using microwave energy (300 MHz to 300 GHz range). The principle of microwave heating is based on the direct impact on polar substances. Ionic conduction and dipole rotation mechanisms convert electromagnetic energy into heat. Microwaves can penetrate biomaterials and interact with polar molecules such as water to generate heat. The depth of microwave penetration into the plant matrix is determined by the dielectric constant, water content, temperature, and electric field frequency (Benmoussa et al., 2019).

Supercritical fluid extraction (SFE): Supercritical carbon dioxide (CO_2) extraction was introduced as an alternative to solvent extraction. SFE can be performed in a variety of solvents including hexane, pentane, butane, nitrous oxide, sulfur hexafluoride, and fluorocarbons. In SFE, carbon dioxide is the most used extraction solvent. CO_2 alone is not selective, but the use of co-solvents or modifiers can improve extractability and selectivity. Co-solvents can be easily removed after extraction. SFE works at room temperature, making it a suitable method for thermally labile compounds. SFE uses less organic solvents, and is environmentally friendly (Bubalo et al., 2018).

Identification and characterization techniques

Secondary metabolites are typically found in low concentrations and complex matrices in plant extracts. Purification methods are required to identify and characterize them. Chromatographic and non-chromatographic techniques are used to separate pure compounds from mixtures of compounds in plant extracts (McRae et al., 2007).

Chromatographic techniques

Chromatography is a technique for separating and/or identifying components of mixtures. The basic idea is that different components in a mixture have different tendencies to absorb to surfaces and dissolve in solvents. It is a powerful method used on a large scale in the industry to separate and purify intermediates and products in a variety of syntheses (Yrjönen, 2004).

Gas chromatography (GC): It is most useful for the analysis of trace amounts of organic extractable, non-polar, volatile, and slightly volatile compounds. In addition, using GC-MS in scan mode enables untargeted metabolic profiling as well as the discovery of new compounds and metabolites. The mobile phase in GC is gas. The analyzed mixture is vaporized onto the column. In columns, the stationary phase can be solid or liquid. Gas chromatography (GC) and GC-MS are widely accepted methods for analyzing volatiles due to their high specificity, sensitivity, stability, and small sample volumes. GC-MS has limitations in the analysis of highly polar compounds due to their thermolability and low volatility (Arsene, et al.,, 2011)

High-performance liquid chromatography (HPLC): HPLC is a versatile, robust, and widely used chromatographic technique for natural product separation. Biologically active entities are frequently present in extracts only as minor components, and the resolution of HPLC is ideal for the rapid processing of such multi-component samples on both analytical and preparative scales appropriate for the purpose. The choice of stationary and mobile phases primarily determines the degree of separation. The chromatograph can choose suitable conditions such as appropriate mobile phases, flow rates, detectors, and columns since each compound exhibits different peaks under specific chromatographic conditions (Zhang et al., 2018).

Thin-layer chromatography (TLC): TLC is a popular method for herbal analysis due to its simplicity, speed, and economy. A major advantage of TLC is its ability to provide optical and fluorescence images, and separate visual parameters from chromatograms. Chromatographic scans and digital processing also provide different profile levels and corresponding integral data. However, TLC analysis also has drawbacks such as low resolution, low sensitivity, and difficulty in detecting trace components (Bele & Khale, 2011).

Phytochemical screening assay: Secondary metabolites are plant components found in plants. Various chemical tests can detect them in plant extracts (phytochemical screens). Phytochemical screening assays are simple, quick, and low-cost procedures that provide researchers with quick answers to the various types of phytochemicals found in crude extracts or active fractions of plant material (Gul et al., 2017).

Issues and challenges facing MAPs

With the increasing attention to MAPs for scientific and commercial purposes, there is increasing pressure on the population of wild medicinal plants of high value being harvested from these mountain regions. Traditionally, local people in the HKH region have been using these treasures in a sustainable way, but the increasing pressure results in over-harvesting with unsustainable methods for commercial extraction that ignore the conservation aspect and long-term use. Overharvesting by middlemen and herders inhabiting these areas has placed many of the medicinal and aromatic plant species at risk of extinction (Hamilton, 2004; Manish, 2022). On the contrary, commercial exploitation has also sometimes led to traditional medicines becoming unavailable for the local people that relied on them for centuries.

Conservation

The conservation status of plants distributed in the HKH region presents a poor picture due to the pressure of urbanization and allied anthropogenic activities, such as repeated grazing, over-exploitation, construction, and increased tourism in the past few years. Consequently, the survival and adaptation of rare and endemic high-altitude plants is under pressure (Kayani et al., 2015).

At higher altitudes, the short growing season is a precarious factor for the survival of numerous plant species. The extreme environmental conditions (e.g., very low temperatures), host a range of unique and endemic plants. Seed regenerative traits of high-altitude plants may contribute to competitiveness or face danger under changing climatic conditions thereby restricting the growing period.

Excessive consumption of MAPs for commercial purposes resulted in the ruthless destruction of the natural population in most cases in South Asia (Dhar et al. 2002). The major challenges for conservation are habitat fragmentation, overharvesting, soil erosion, genetic drift, and a lack of research. Policy-related measures and strict vigilance including in-situ and ex-situ conservation and implementation by allocating grants and research facilities through R&D and academia could be a viable solution for the problems of this biome. The conservation of important plant species can be achieved by taking many practical steps, for instance, characterizing the system and defining problems, identifying potential solutions, assessing the feasibility of solutions, identifying or creating opportunities, exploring alternative sources of livelihood, and taking advantage of opportunities (Shedayi et al., 2016). No doubt globalization and increasing food demand are putting pressure on such valuable plant species in mountain areas. Several opportunities for the conservation of medicinal plants have emerged from case studies, and can easily address the dilemma of attenuation of these important resources such as raising communities' awareness regarding the importance of conserving medicinal plants, analysis by stakeholders to identify individuals and groups with special interests in medicinal plants, documentation of priority places and species requiring improved management, in placing property rights, proper plans for the management of resources while keeping community's interests in consideration, management for adaptation, defining the indicators for local monitoring, promoting cultivation following modern standards especially for commercial species, appropriate agreements between community groups and responsible agencies and proper agreements with traders and industry for the sustainable use of medicinal plants. These strategies are believed to bail out this landscape from the depletion of a major driver of the ecosystem (Hamilton, 2004; Karimi et al., 2021).

Harvesting

Simply put, Sustainable Harvesting (SH) of medicinal and aromatic plants is "a method of harvesting that provides a constant supply of wood resources throughout the landscape, with future MAP yields unaffected or improved by current harvesting methods". Over-collection or non-sustainable harvest of species poses a substantial threat to the economically important and commercially valuable wild species in these areas in addition to their habitats. In the HKH regions, particularly those areas with easy access and no restrictions by any regulatory authorities and/or local community, this threat has been more prominent for decades. IUCN reports that about 15,000 medicinal plant species may be threatened with extinction from around the globe due to overharvesting (IUCN, 2008).

Commercialization

Humans and nature have been inextricably linked with each other throughout human history. Every culture has utilized natural resources to satisfy its needs and maintain the integrity of the local ecosystem (Gilliam, 2007).

Conclusion

While there is an indigenous solution for all kinds of ailments in the HKH ranges, the biggest challenge is the conservation of endangered plant species in an area vulnerable to climate change. In addition, population growth with associated transformations is the biggest threat to flora, especially endemic and endangered flora. Ethnobotanical knowledge and folklore should be integrated and practiced with advancements in alternative healthcare systems that could improve the socio-economic status of the mountain societies. This could provoke a sense of ownership in local communities. Conventional methods are based on the solubility of solutes from plant material in solvents and require the use of large volumes of solvents to extract the desired solute even when assisted by high temperatures and mechanical agitation or shaking. Modern processes reduce solvent consumption and deliver better extractions in less time with higher yields and quality than traditional processes. The methods can further be improved by yoking the wisdom of traditional methods for the sustainable use of medicinally important plant species. These endeavors would create a healthy environment for all components of the HKH ecosystem.

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Chapter 11

Sustainable Mountain Agriculture

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A view of fields and orchards in Bagrot valley, Gilgit © Ghulam Rasool/WWF-pakistan

Introduction

Agriculture is the mainstay of Pakistan's national economy and crucial to overall economic growth, employment generation, food security, and the alleviation of poverty in both urban and rural areas. Societies benefit from agriculture in social, cultural, economic, and nutritional ways as it provides for basic human needs, i.e., food, shelter, and clothing. In Pakistan, the contribution of agriculture to the GDP is 19.2 per cent, while it employs 38.5 per cent of the labor force. Agriculture provides a living for approximately 65–70 per cent of Pakistan's population. However, shrinking cultivable lands, environmental changes, water scarcity, increasing population, the labor shift from rural to urban areas, and the escalating input costs have negatively affected agricultural growth. The government focuses on adopting new strategies to achieve maximum production of crops by introducing new varieties, advanced technology, and good management practices. Hence, it is imperative to secure food for all to reduce hunger and promote a culture of peace, harmony, and prosperity. Sustainability refers to the utilization of the production capacity of natural resources to meet the current needs of food, feed, fiber, and fuel without compromising the ability of future generations to meet their own needs. Integrating the following three objectives into the food production systems can make them sustainable: *a healthy environment*, *economic profitability*, and *socio-economic equity*. All the stakeholders are thus equally important in their roles as growers, processors, distributors, retailers, and consumers (UC Davis, 2021).

Mountain communities are of a distinctive ecological nature, depending mainly on natural resources for their sustenance. Employment opportunities, however, are somewhat limited. The habitat is vulnerable to multiple natural and anthropogenic challenges, while the resources are also fragile. The main activities are farming and rearing livestock, but the farms are usually small, and livestock mainly depends on natural pastures. Under the above circumstances, a community, as an actor within the ecosystem, must play its role with a balanced approach that does not compromise the ecological elements (soil, water, biodiversity, and environment). Sustainability thus becomes necessary for the long-term coexistence of all actors within the ecosystem. The limited resources demand the modernization and integration of activities to ensure long-term supplies of necessities.

To ensure the well-being of every living individual in the mountain ecosystem all the branches of agriculture must be made sustainable. These include, among others, agronomy (mother branch), soil science, horticulture, plant pathology, entomology, plant breeding and genetics, animal husbandry, poultry science, forestry and range management, fisheries, agribusiness management, agricultural economics, agriculture extension education, food science and technology, environmental science, agricultural engineering, veterinary science, etc.

Evolution of Agriculture: A historical perspective

Societies evolved from hunters and gatherers during the Paleolithic period to agriculture-based communities in the Neolithic period. These hunters and gatherers led nomadic lifestyles, moving their camps along the foothills and valleys of the mountains (Chandrasekaran et al., 2010). Before the adoption of agriculture, wild fruits and nuts were gathered to provide the necessary carbohydrates, oils, vitamins, and minerals, while animals and birds provided the proteins. Seeds and nuts, thrown away as waste, sprouted all over the camps. On their return to the campsites, they noticed this new growth of vegetation and plants. This phenomenon led them to appreciate the significance of the cultivation and domestication of wild plants (Ziser, 2009). Around 10 to 12,000 years ago, people began settling along water bodies and initiated subsidiary farming, which was followed by subsistence farming to fulfill their own household needs. Gradual experiences and observations led to mixed and advanced farming with various tools and implements. The expansion in populations, cultures, and new settlements, combined with advances in scientific knowledge, paved the way for improvements in agricultural techniques, plant varieties and breeds, irrigation systems, tools, and machinery. Agriculture nowadays has become a lucrative commercial activity that calls for a focus on sustainability in addition to long-term income generation.

Traditional and new farming systems

A farming system is a combination of activities like crop production, livestock, aquaculture, fruit growing, and forestry on a piece of land for family income and livelihood while preserving the resource base and maintaining environmental quality. Conventional farming generally refers to a farming system where synthetic inputs (fertilizers and pesticides) are frequently used for good yields and a better income. A general understanding of negligence in environmental protection and biodiversity conservation for sustainable farm production is attributed to the conventional farming approach and increasing demand for food. There are differing views regarding the efficient use of resources related to farming as a viable activity for sustainable benefits or family goals. However, there is an agreement on how the conventional farming approach exhausts more resources and compromises the ability of soil and the environment to support sustainable farming practices. Contrary to traditional farming, sustainable farming approaches focus on the conservation of production potential in terms of soil fertility and environmental protection for the long term through the application of more natural or green strategies. It emphasizes healthy practices through new approaches of organic, climate-smart, and integrated agriculture that minimize resource loss and ensures the future potential of farms for fair fulfillment of human needs. According to Mason (2003), currently applied new farming approaches are:

A. ***Low input farming approach*** is based on using minimum inputs (chemicals, fertilizer, and pesticides) to avoid resource loss and reduce production cost. It ensures less chance of waste residue impact and damage to the land by overworking.

B. ***Regenerative farming approaches*** consist of techniques like composting, green manuring, and recycling of residues to increase soil nutrient status after each harvest. This system is also called permaculture where a variety of different plants and animals are present on the farm without impacting the environment negatively.

C. ***Bio-dynamic approaches*** emphasize on mobilizing and harnessing the biological processes. Biological agents like microorganisms and earthworms break down the organic matter in the soil and make availability of nutrients for the crops and vegetation.

D. ***Organic farming approaches*** involve natural inputs to increase soil productivity and control diseases and insect pests. Soil production potential is maintained by crop rotation and composting. These techniques improve soil health and prevent any disease and insect to associate with the patch of land.

E. ***Conservation farming approach*** relies on the sustenance of resources on the farm that already exists. The topographical structure is not disturbed so that the slopes, creek beds, waterways, and nature strips are retained.

F. ***Hydroponic approach*** is a new development where crops are grown without soil. The required nutrients are incorporated in a solution and crops are grown in a more controlled manner. Although it is not a natural process, it enables the production of more crops in a limited area with an increased ability to control production and waste. It ensures higher returns in areas close to a market.

G. ***Land capability approach*** is the matching of enterprises with the capability of the land. It refers to situations where some sites are useful for any type of farming at any time without serious degradation. While environmental issues are encountered in the case of low fertility situations. These soils can be used for a specific crop or activity.

H. ***Genetic improvement approach*** is of great significance and involves the improvement of crop varieties and animal breeds for good production. We can select crops that are resistant to pests and diseases. Crops can be changed based on their readiness for any situation.

I. ***Polyculture or integrated approach*** deals with the knowledge of growing different crops within the same patch of land or rearing mixed breeds of animals. Monoculture generally prevails for economic benefits as the crop cultivation of one type of breed for a long time exhausts the same type of resources resulting in the underutilization of farm resources.

Concepts and approaches to sustainable agriculture

Sustainable agriculture can be described as "maintaining a regular or continuous farm production with a successful management of resources to cater to the changing human needs without negatively impacting the environment and agroecology". The overall vision of sustainability is to promote an economically and socially stable society where the food and nutritional security of all individuals are ensured without compromising the environment. The technical advisory committee of Food and Agriculture Organization (1989) defines sustainable agriculture as the "successful management of resources to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources".

According to the United Nations Brundtland Report "sustainable agriculture should be able to meet the current needs of the society without compromising the ability of future generations to meet their own needs" (WCED [World Commission on Environment and Development], 1987). FAO, (1987) defines sustainable agriculture as a "successful management of resources for agriculture to satisfy the changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources". All the definitions given above consider environmental, social, and economic factors as three pillars of agricultural sustainability. Keeping this in view, FAO (2014) has designed five principles for agricultural sustainability connected with the three pillars:

a. Improve and manage efficient use of resources
b. Conserve, protect and enhance natural ecosystems
c. Protect and improve rural livelihood and social well-being
d. Enhance the resilience of people, community, and ecosystem
e. Promote good governance of both natural and human resources

Mountains are unique in their diverse characteristics like physical, geographical, environmental, social, and cultural features. The livelihood of mountain communities is dependent on agriculture and natural resources. Hence, all the elements of sustainable agriculture must be intact to provide the expected benefits for livelihood. The components of sustainable agriculture include soil and water management, crop management, pest management, conservation of natural resources, and a healthy environment that supports maximum agricultural production.

Components of sustainable agriculture

The key components of sustainable agriculture are soil management, crop management, disease management, insect and pest management, water management, and waste management. For both conventional and sustainable farming systems, resource management is of crucial importance.

Soil management

Soil fertility is the source base for crop production. It hosts the crops and provides water and mineral nutrients for growth and sustenance. A healthy and fertile land supports healthy growth and produces quality crops that in turn provide good food for human beings and other living organisms. In conventional farming, soil fertility is maintained by running a soil fertility test and deficient nutrients are provided in the form of fertilizers, like nitrogen, phosphorus, potassium, and others to meet the nutritional needs of crops. In a sustainable farming system, soil fertility is maintained through careful agronomic practices such as crop rotation, application of green manures, green mulching, and generous amounts of compost that cover crops that are plowed back into the soil to increase organic matter. It further requires discouraging monoculture where a single crop is grown in the same soil year after year. Monocultures impair soil fertility, require more chemical fertilizer, support the spread of diseases, and make it vulnerable to soil erosion by wind and water. The pests get resistant and hence larger quantities of pesticides are required to control pest populations, degrading the environment and causing pollution.

Crop management

Crop management involves the selection of quality seeds, soil or seedbed preparation, fertilizer application, timely sowing, sowing method, irrigation, agronomic practices (hoeing, thinning, weeding, pruning, etc.), harvesting, and storage that ensure normal growth, development, and maximum yield of the crop. A good crop management approach ensures the overall quality of the farm which gives better economic returns to the farmer. The timing and sequence of farm activities depend on several factors, i.e., the season (spring, winter), type of crop, available inputs, soil, climate, and weather conditions.

Insects, pests, and disease management

Harmful insects, pests, or diseases can affect the crop yield, causing financial damage to the farmers. A proactive management strategy minimizes possible losses. Natural remediation and biological control strategies keep the farm healthy and viable for enhanced production potential. Crop rotation, green mulching, and increased organic content of soil support healthy microflora and biological control agents of disease and insect pests. The use of insecticides and chemicals should be discouraged to conserve insect biodiversity and soil microflora. Continuous use of chemicals results in the development of resistance to pathogens and pests. Therefore, diverse cropping systems and cultural practices tend to decrease the pressure of diseases and pests on the crop, while improving the soil quality and crop yield.

Water management

Irrigation and application of water according to the needs of the crop is very important to get a good yield. Efficient use of water is crucial to maintaining soil fertility and crop growth. Knowledge about the water requirements of cultivated crops and their critical growth stages is important to determine irrigation scheduling. Heavy irrigation severely impacts soil fertility by runoff or leaching of nutrients and erosion of topsoil that leaves bare land devoid of the potential to support crop growth and production (Arshad et al., 2022).

Waste management

Agricultural waste is always organic and can be converted into renewable food and energy sources, but if left unmanaged, it can cause pollution. The waste generated from farms (plant or crop debris, animal manure, bones, and inedible carcasses) has enormous value to be recycled for food, feed, fuel, fiber, and fertilizer. The waste cycle within the farm is useful for a sustainable agro-environment that supports the farm's production performance. Furthermore, waste valorization produces high value foods and chemical compounds that have multiple industrial uses. Examples are the extraction of proteins, amino acids, natural colors, antioxidants, minerals, and vitamins.

Energy and input management

Energy and inputs have a crucial role in sustainable farm production. The energy flow is the lifeline for the ecosystem. What is happening in the ecosystem is the capturing and transformation of energy. Solar energy is captured by organisms (plants, algae) through the process of photosynthesis, and converted into chemical energy and stored in the organic molecules in the form of chemical bonds. This energy is used for biological functions i.e., growth, movement, and reproduction. Most of it is converted into heat energy which is lost without any further use (Hasanuzzaman, 2019). The agricultural system uses this energy for biomass production that in turn uses it as food, feed, fuel, and fiber. The inputs, in the form of fertilizers, pesticides, weedicides, and organic residues are essential aids for maintaining fertility and soil health. The best use of these inputs ensures sustainable crop production without compromising the environment.

Agroecology of mountains

Nearly half of the world's terrestrial biodiversity hotspots and 30 per cent of all key biodiversity areas are in the mountains (Körner et al., 2011). Mountain biodiversity provides several advantages to humanity, including food, medicine, and climate and air quality control. Nevertheless, mountain biodiversity is at risk due to land use patterns, climate change, invasive species, hunting, pollution, and population shifts (Payne et al., 2020).

A framework for evaluating agroecosystem complexity is provided by agroecology, which utilizes ecological ideas and principles for the design and management of sustainable agroecosystems. Agroecology places a focus on complex agricultural systems where ecological interactions and biological component synergies serve as the mechanisms for supporting soil fertility, production, and crop protection. Agroecosystems have little reliance on large inputs of agrochemicals and energy (Bonaudo et al., 2014).

Significant evidence demonstrating the global importance of human activities on ecosystems, such as the impact of agriculture on land-cover change and the provision of ecosystem services, has been acquired through research on global change and international assessment methodologies. Important environmental problems, including regional water shortages and possibly disruptive climate change, have huge effects on agricultural output and global food security (Khiyavi et al., 2013). Consequently, local, regional, and global ecological phenomena linked with agricultural production processes and ecosystem services have a direct impact on the output.

Mountain agroecology focuses on farmers, including small farmers, indigenous people, and pastoralists. Because it makes it easier to provide ecological services, productivity, resilience, market diversification, and human diet and health promotion, diversity is a crucial component of agroecology and mountain farming (Shrestha et al., 2017). People in the Hindu Kush, Karakoram and Himalayas (HKH) region have increased their family earnings by looking for aromatic and medicinal plants and other non-timber forest products (NTFPs) (Muhammad et al., 2012). As the market for traditional high-quality mountain goods grows, it may be possible for mountain farmers, especially women, to raise their standard of living.

Agroecosystems' attributes

According to Altieri (2000) all agroecosystems have the following characteristics in common:

a. Retain vegetative cover as a positive soil and water conservation method, using no-till techniques, mulch farming, and additional acceptable methods.
b. Provide a steady supply of organic materials by incorporating organic matter.
c. Improve the recycling of nutrients using livestock systems based on legumes and similar plants.
d. Encourage pest control by the introduction and/or preservation of natural predators and competitors, which will increase the efficiency of biological control agents.

Fundamentals of mountain agroecology

In a quest to reintroduce ecological logic into agricultural production, experts and designers have overlooked a crucial element in developing self-reliant and sustainable agriculture: a deep knowledge of the characteristics of agroecosystems and the operating values that govern their operation. Resultantly, agroecology has developed as a field that offers the fundamental ecological concepts for comprehending, planning, and managing productive, resource-conserving, culturally sensitive, communally just and commercially viable agroecosystems (Bohlen & House, 2009).

Agroecology considers the ecological and social layers of coevolution, and structure, and works efficiently to move beyond a one-dimensional perspective of agroecosystems. The interconnectedness of all elements and the complicated kinetics of ecological processes should be highlighted instead of focusing on a single agroecosystem component (Ma et al., 2019). Agroecosystems are groups of plants and animals that interact with their natural ecosystems to produce products for human use and processing, such as food, fiber, and fuel. The goal of agroecological research is to better understand these ecological relationships and processes so that agroecosystems may produce more productively and sustainably with fewer negative ecological or social repercussions and fewer outside inputs (Costanzo & Bàrberi, 2014). According to Vandermeer (2009), the design of such systems incorporates the following ecological concepts:

- Increase biomass recycling while maximizing nutrient accessibility and achieving nutrient flow equilibrium.
- Enhancing soil requirements for plant development via controlling organic matter and boosting land biotic activity.
- Reducing losses from solar radiation, air, and water fluxes through managing micro-climates, collecting water, and manag-

ing soil by increasing soil cover.

- Maintaining the agroecosystem's species and genetic diversity through both time and place.
- Improve favorable biological interfaces and synergies amongst agrobiodiversity components, thus sustaining vital ecological processes and services.

These notions apply to several methods and techniques. Each variable will have various implications on the farm system's productivity, stability, and resilience based on possibilities found locally, resource limitations, and the market. The ultimate objective of an agroecological plan is to incorporate elements to increase overall biological productivity and preserve biodiversity and agroecosystem production and self-sufficiency (Altieri, 1999a). The objective is to create a mosaic of agroecosystems in the mountain landscape component, with each agroecosystem replicating the form and operation of biological ecosystems (Liebman & Schulte, 2015).

Agrobiodiversity and agroecology in hilly areas

Agroecology seeks to manage the environment while sustaining yields, naturally regulated soil fertility, and biological pest control via the formation of separate agroecosystems and the usage of low-input technology. The interactions between the different biotic and abiotic components primarily determine the most optimal behavior of agroecosystems. It is possible to create collaborations that assist agroecosystem processes by assembling functional biodiversity by offering ecological services like improving soil biology, nutrient recycling, the growth of valuable arthropods and predators, etc. (Altieri, 1999b). Restoring agricultural variety through time and place involves using methods including crop rotation, cover crops, intercropping, crop/livestock mixes, and others (Franzluebbers, 2007).

High-value crops, horticulture, livestock, and forest fauna may thrive in the mountains' diverse environment because of peculiar habitat characteristics, including height, slope, and exposure to solar radiation. This broad diversity is important from a cultural, economic, and ecological standpoint. Large portions of the most significant gene banks for agriculture and medicine are protected by the mountains. Crops crucial for food security, such as maize, tomatoes, potatoes, rice, barley, pomegranates, and apples have sustained their population or diversified in the mountains (Tulachan, 2001), with numerous animal species, including goats, yaks, Marco Polo sheep, markhor, and urial (Regmi & Huettmann, 2020). Mountain pastoralists in northern Pakistan, for example, have a highly valued livestock genetic resource pool with characteristics bred into animals such as disease resistance, cold weather endurance, and harsh environment adaptability (Rahim et al., 2013).

In mountainous landscapes, sustainable agricultural practices and the maintenance of agrobiodiversity offer food diversity and quality, produce earnings for smallholder farmers, and contribute to the preservation and restoration of ecosystems (Lemaire et al., 2018). Mountain farmers grow many of the most exotic crop species in functional biologically diverse agroecosystems. Nevertheless, the rigors of high-altitude settings and the consequences of climate change progressively drive farmers to adjust their customary practices. As shown by the near-disruption of food supply networks, food scarcities in several developing nations, and a rise in the number of people suffering from severe food insecurity, the COVID-19 pandemic has contributed to and worsened underlying issues with mountain food systems (Khan et al., 2022). Food security in the highlands has been a serious concern in recent times. According to recent statistics on food insecurity vulnerability, 50 per cent of rural mountain inhabitants in developing nations live in places where the daily supply of calories and protein is lower than the minimum amount required for healthy living (Romeo et al., 2020).

Sustainable agroecosystem design and agroecology

Most individuals engaged in sustainable agricultural development want to create a model that ensures long-term productivity. A sustainable agroecosystem design will have the following basic interactions and processes (Berthet et al., 2019):

- Integrating the numerous elements of the agriculture system, including the flora, fauna, soil, water, climate, and people, to ensure that they coexist peacefully and provide the highest number of synergistic advantages to maximize the use of locally available resources.
- Utilizing the remaining resources more wisely to reduce variable costs, and lessening the use of external, and nonrenewable inputs can harm the people or the ecosystem.
- Using a large portion of the agroecosystem's resources while supplementing outside inputs via nitrogen cycling, improved conservation, and increased utilization of regional resources.
- To preserve the long-term viability of current production levels, cropping patterns should be made more compatible with the productive capacity and environmental restrictions of climate and topography.
- Maximizing the genetic and biological capacity of many plant and animal species.
- Optimizing the use of indigenous wisdom and methods, such as cutting-edge methods that scientists still don't completely comprehend, but farmers generally embrace.

The agroecological design seeks to combine elements in a way that protects biodiversity, maximizes overall biological efficiency, and preserves agroecosystem production and self-regulation. The objective is to create an agroecosystem that is similar in composition and function to nearby natural ecosystems. High species variety, bioactive soil that supports natural pest management, nutrient recycling, and substantial soil cover are necessary to accomplish this goal.

Challenges of mountain agriculture

Mountain agriculture is unique as it is dependent on natural biodiversity and carried out mainly by women farmers. Mountain areas are remote in the geographic face of any country and food insecurity is a common phenomenon coupled with poverty, poor infrastructure, poor access to inputs, services, and the absence of an agriculture value chain. These situations hamper business activities and the timely supply of commodities to the market. As a result, postharvest losses increase, and producers get a meager amount from the farm produce. The labor force migrates to large cities for jobs and better wages and unskilled manpower is engaged in farming activities. The main challenges for mountain agriculture include:

Poverty and food security

Food security refers to a situation where all individuals have access (physical, social, and economic) to safe, nutritious, and sufficient food at all times and at all places to live a healthy and active life (FAO, 2001). The term access to food depends largely on improved income for many but in the case of agrarian societies; increased incomes depend on improved agricultural production. Human food comes from agriculture, forestry, and fisheries. All these farming sectors are capitalized by the better use of manpower, energy, and inputs. The output of the activity in the form of food production depends on soil and water resources as well as the environment along with human efforts. Thus, the agroecology, inputs, and services available in an area determine the production of food.

Low productivity and poor quality

Farm people involved in mountain agriculture usually lack the technical knowledge on better farming approaches that lead to increased production with quality. There is always a lack of quality inputs and services for sectoral growth and performance, resulting in low production and poor quality of farm commodities. Thus, the need arises to empower the farm labor with contemporary skills and knowledge along with better access to inputs and services.

Small land holdings and lack of mechanization

Land area for farming in mountains is already very limited for the cultivation of field crops. This problem is further aggravated due to the division of land from parents to offspring

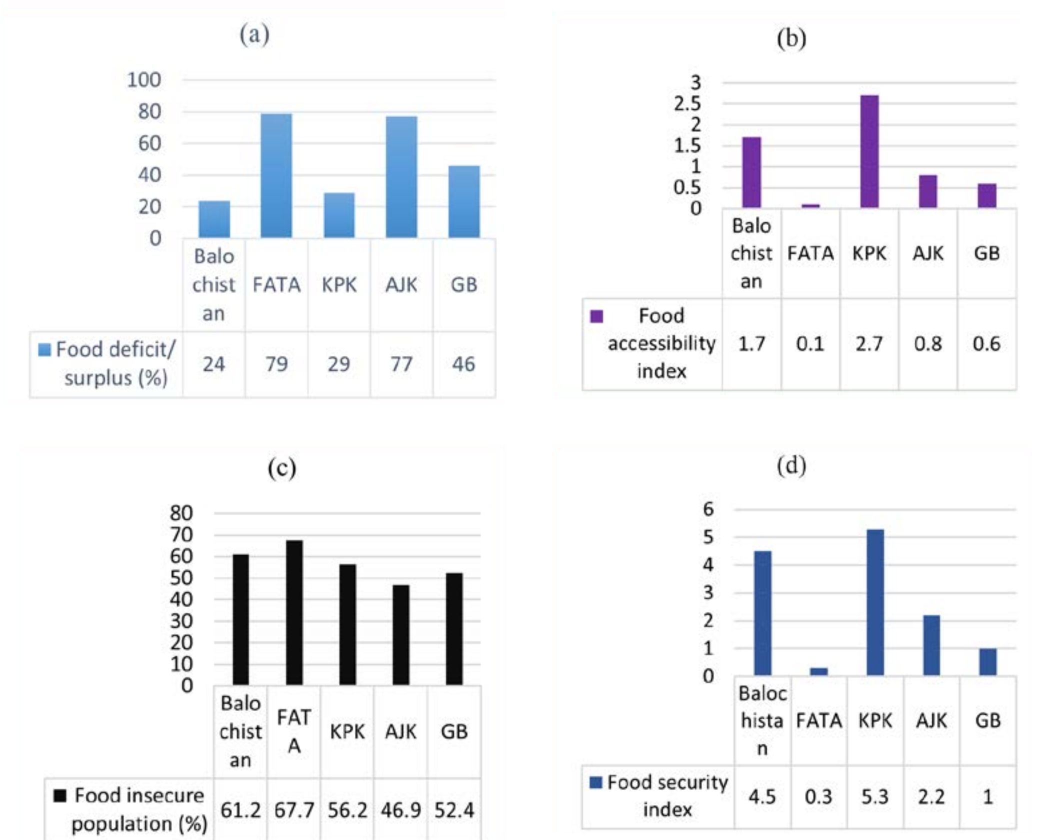

Figure 11. 1 Food security situation in the mountains of Pakistan: a. Food deficit/surplus (%); b. Food accessibility index; c. Food insecure population; d. Food security index (adapted from SDPI, 2009; Hussain, 2010; Hussain and Routray, 2012)

(inheritance fragmentation). Thus, the small landholdings do not permit the farming community to carry out any profitable farming activity. Moreover, the availability of small machinery for mountain agriculture is also scarce. Due to these reasons, it would be challenging to ensure sustainable livelihood for mountain farmers.

Poor communication infrastructure

Advances in mass communication in the current era have revolutionized all spheres of life and sectors of growth. However, proper communication facilities are lacking in the mountain areas for knowledge and information sharing related to crop production, management, protection, and marketing. It hinders the pace of growth and development of agriculture in mountain regions. Better market information enables farmers to capitalize on opportunities to market their products and obtain services to increase their productivity and profit margins.

Lack of postharvest and marketing infrastructure

Postharvest losses of fresh agricultural commodities are higher due to the non-availability of preservation and processing infrastructure at the farm level. Sun drying of agriproducts in open spaces is a common practice in mountain valleys across HKH (Figure 11.2). Besides nonexistence of marketing infrastructure at the village level and lack of connectivity with main markets contribute to postharvest losses and performance of the agriculture sector in the mountain areas.

Figure 11.2 Traditional and less efficient post-harvest techniques © Azhar Hussain & Sartaj Ali

Migration of farm communities and lack of trained labor force

Migration of farming communities to cities and industrially developed areas for better jobs, wages, and services is a serious challenge for rural and mountain agriculture. They find better returns for their time and effort in off-farm jobs as compared to agricultural income. Menfolk, especially male youth, find no attraction in agriculture and female members of the family carry out farming activities while lacking the skills and knowledge to make farming a more rewarding job.

Absence of or weak agriculture value chain

The agricultural value chain in mountain regions is weak and, in most cases, absent in the HKH region. Lack of postharvest technologies, communication, infrastructure, and value-addition skills leave no option for better farm incomes. The raw produce without marketing and value chain fetches meager returns to the farmers for their sustainable livelihood.

Climate change and natural disasters

Global warming and changing precipitation patterns have seriously affected crop productivity. Multiple challenges in the form of disease infestation, insect pest attacks, and variation in cropping seasons have drastically reduced agricultural performance. As a result of climate change, unpredictable natural disasters in the form of glacial lake outburst floods (GLOF), landslides, and soil degradation have put agriculture at more risk. Under the circumstances, the rehabilitation of farms and the sustainability of livelihood are becoming more challenging.

Loss of agrobiodiversity and degradation of landscape

Increasing anthropogenic activities and unplanned constructional developments of housing, roads, and building infrastructure seriously threatened the small agricultural landholdings and mountain landscapes. Conservation of natural habitats, agro-biodiversity, and the natural landscape becomes imperative to sustain farm production and livelihood sources in the mountains.

Opportunities in mountain agriculture

Despite various challenges, mountain agriculture offers tremendous opportunities that can be availed to improve the socio-economic condition of mountain people. The unique mountain agroecology favors many diverse species and crops that are highly nutritious and have numerous health benefits. The isolated valleys, water resources, forest, and high-altitude pastures provide many business avenues related to agritourism, organic agriculture, aquaculture, medicinal and nutritional herbs, wild fruits, and animal breeds (Yaks, sheep, goats). The potential opportunities can be summarized as under:

1. Production of specialized crops under the diverse agroecological zones
2. Agro-tourism
3. Terrace farming
4. Aquaculture or fish farming
5. High value seed production
6. Organic agriculture
7. Nutraceutical and medicinal herbs farming
8. Mushroom cultivation
9. Rearing rare animal breeds
10. Economizing seasonal advantages for marketing of food commodities

Increasing land use efficiency and productivity through intercropping: a case study

Background

Gilgit-Baltistan, a mountainous area, has a scarcity of agricultural land where the agriculture sector serves as the main source of food and income for the inhabitants. Intercropping can increase land use efficiency and productivity at different elevations in a mountainous region to augment land productivity to ensure food security. Increasing food production in this area to ensure self-sufficiency is a bigger challenge compared to non-mountainous areas. This research was conducted as one of the approaches used to optimize resources and increase land use efficiency through an intercropping approach as a replacement of existing monocropping systems.

Rationale

Crop diversity through intercropping increases land productivity and ensures the sustainability of production systems (Arshad, 2021). Intensive and extensive cultivation of monocultures is an inherent threat to agrobiodiversity and soil resources. This is because monocropping gives a tough time to a variety of biological populations by restricting their access to diverse opportunities for survival. Sequentially grown exhaustive crops (cereals) overexploit soil resources and reduce the sustainability potential of futuristic agroecosystems in different agroecological zones. Thus, establishing or expediting the flow of natural dynamic resources among soil, plant and atmospheric systems helps ensure the sustainability of underlying agroecosystems. When grown in intercropping, legume plants bring multiple benefits. In addition to serving as a staple food (pulses), legumes help to diversify the farm produce for benefits in terms of income and in the case of major crops (like cereals), reduce the chances of failure due to natural calamities. Additionally, due to the presence of root nodules, legumes add nitrogen to the soil profile through biological fixation. Thus, to exploit the benefits of legumes, their inclusion in cropping patterns is imperative.

Description

Research experiments were performed in the summer season at three different locations namely Danyore (Gilgit), Gitch (Ghizer), and Thole (Nagar), having elevations of 1,500m (135.9202o N, 74.3080o E), 1,800m (361025o N, 73.4600o E) and 2,200m (36.3167o N, 74.6500o E), average temperature 16°C, 14°C and 10°C, respectively. The locations have different climatic conditions owing to their different altitudes from the mean sea level (MSL). Three cropping systems (sole cropping of traditionally grown maize, sole cropping of introduced maize, and intercropping of maize and mung bean) with three nitrogen *(N)* levels (28, 56, 113 kg N ha^{-1}) were established. Land at experimental locations was prepared by means of a disc harrow and a cultivator and leveled using a plank. Recommended varieties of maize [Azam (introduced) and Pahari (traditional)] and mung bean (NM– 2006) were used (Figure 11.3). Simultaneous sowing of crops in prepared plots was done on three different elevation sites. Experimental plots were irrigated weekly during the growing season following the germination. Nitrogenous fertilizers were applied according to the treatment level in two splits as basal dose and at the booting stage of maize whereas the recommended dose of phosphorus was applied entirely as basal dose at the time of sowing for both intercropping and sole cropping treatments of maize and mung bean using *Nitrophos* as the source of phosphorus. Thinning to optimum plant density and weeding were done manually for the experimental crops. Plant samples of maize and mung bean and their parts were taken at maturity. Plant parts were separated. Pods of mung bean and ears of maize were threshed, and grains were collected. The plant parts and grains were dried in an electric oven in the laboratory. The dried samples were weighed on a digital balance and their weights were recorded for analysis. Thereafter, the average yield per plant was calculated while grain production per hectare was computed. The contents of total carbohydrates, protein, fat, and digestible energy in grains of maize and mung bean were determined for both sole and intercropping systems, considering the published information. The land equivalent ratio (LER) was computed using yield information from sole and intercropped maize and mung bean.

Figure 11.3 Maize-mung bean intercropping system in Gilgit-Baltistan (Source: Pakistan Science Foundation Project # 478)

Outcomes

Maize, cv. Pahari is grown on most of the agricultural land in the study area because of its early maturity. But it is characterized by short stature, lower biomass, and lesser grain yield compared to another recommended and high-yielding variety of maize, i.e., cv. Azam. The new maize variety was tested through research experiments conducted at different elevations for its sole cropping and intercropping with mung bean. Experimental sites have different climatic conditions due to variations in elevation. Plant height, grain yield, and associated nutritional parameters were greater in the case of Azam variety compared to the Pahari variety. This could be due to the different genetic potentials of varieties. Maize and mung bean responded differently to different elevation conditions as indicated for growth and yield parameters. Selected elevations have different lengths of suitable weather conditions for the experimental crops which influenced their growth and yield, thereby affecting the land equivalent ratio and associated production levels of carbohydrates, protein, fat, and digestible energy contents. To some extent, environmental conditions of 1,500m and 1,800m elevations are in proximity though significant variation in growth and yield components of the crops was not reflected. Growth and yield of intercropped maize and mung bean were lower compared to their sole stands owing to competition in intercropping for above- and below-ground resources i.e., light, nutrients, water, etc. Nitrogen is the most important major nutrient for plant growth and grain production. Increasing the quantity of nitrogen application increases production to a certain level, but further increase is not noticeable thereafter. Sometimes excessive application of nitrogen leads to lodging and disease attacks for crops. Maize with respect to its grain yield responded positively to increasing application of nitrogen, however, other parameters remained unaffected.

This research explored the merits of growing improved maize cv. Azam over the traditionally grown cv. Pahari and investigated advantages of intercropping maize with mung bean over its sole cropping and the appropriate dose of nitrogen fertilizer to be adopted. Maize cv. Azam exhibited superior genetic potential by virtue of its better growth, yield and nutritional parameters compared to the traditionally grown Pahari variety. In mountainous areas, lower elevations provide more conducive conditions for greater grain production of both maize and mung bean. This study also revealed that in between the rows of maize, rows of mung bean can be grown as intercrop to increase diversity, cropping intensity and land productivity. Moreover, application of nitrogen fertilizer to maize in split doses enhances its grain yield and associated nutritional and economic benefits.

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GOVERNANCE, MARKETS, AND COMMON GOODS IN MOUNTAINS

Chapter 12

Sustainable Mountain Tourism

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A view of K2 from Concordia, Baltistan, Pakistan © Christof Hahn

Introduction

With the beginning of the last century and the founding of the first national park in the Alps – the Swiss National Park in Engadin, Switzerland – Protected Areas' tourism in the Alpine countries has become a tradition where self-sustaining ecologies, societies, and economies are central to the preservation and development of cultures and landscapes. Being a catalyst for the economy, tourism may be the only source of primary income whose significance for economic development will increase in the future. The quality of the natural world affects tourism. Governments and the corresponding tourism industries are, thus, obligated to protect the environment. This leads to the concept of "sustainable tourism" as a management strategy. In mountainous areas, planning and shaping tourism policies that consider the effects on local communities, the built and natural environment, as well as the economic implications, can be difficult.

The requirements of mountain regions vary in terms of sustainability and tourism. Most importantly, it is believed that the socio-economic and socio-cultural aspects of such places generate adequate and long-lasting added value. The ability of an area to develop while adapting to new challenges is the dynamic perspective on sustainable regional development where the collaboration of actors leads to learning. Tourism as a system integrates various economic sectors relevant to the industry. While most tourism related activities such as stays, departures, and others are viewed from an industry perspective, changes to the landscape caused by these activities, such as ski slopes, golf courses, etc., constitute issues related to environmental sustainability. Gas exhaust, biotope destruction, garbage removal, sewage treatment, and water supply for snowmaking equipment all harm natural environments. Important infrastructure projects like schools, water pipes and treatment facilities, roads and other community development initiatives can potentially have unfavorable outcomes for the environment as well.

To manage these and other possible negative effects on the environment and natural beauty of the mountains, sustainable development policies and practices need to be studied and implemented. The chapter covers theoretical and practical concepts of sustainable mountain tourism, eco-tourism, and best practices.

Concept and approaches of sustainable tourism

The concept of sustainable tourism emerged to ensure that activities related to tourism would not affect the areas where it was being promoted, and over time has become a significant source of livelihood for the local communities. In mountain regions, this means that the threat to the inherently fragile environment and marginal communities is prevented or mitigated. The term sustainable tourism in many cases does not have any standard definition or conception and is often argued to be context-specific; its application is to be decided on a case-to-case basis (Manning, 1999). According to the United Nations World Tourism Organization (UNWTO), sustainable tourism can be defined as *"tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment, and host communities"* (UNEP and UNWTO, 2005).

Box 12.1 According to WTO, sustainable tourism should:

"Make optimal use of environmental resources that constitute a key element in tourism development, maintaining essential ecological processes and helping to conserve natural heritage and biodiversity."

"Respect the socio-cultural authenticity of host communities, conserve their built and living cultural heritage and traditional values, and contribute to inter-cultural understanding and tolerance."

"Ensure viable, long-term economic operations, providing socio-economic benefits to all stakeholders that are fairly distributed, including stable employment and income-earning opportunities and social services to host communities, and contributing to poverty alleviation."

Among these approaches to sustainable tourism, the concept of 'sustainable' is attributed to the Brundtland Commission report (WCED, 1987). Sustainable development is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." The triple bottom line (TBL), one of the main approaches to sustainable tourism, is commonly used to conceptualize the idea of sustainable development. It encompasses the economic, social, and environmental accountability of tourism-related activities (Stoddard et al., 2012).

Triple bottom line: environmental, economic, and socio-cultural impacts

The concept of the Triple Bottom Line (TBL) approach originates from the conceptions of sustainability and sustainable development, especially pertinent to ecological or environmental sustainability, which was mainly discussed in the Brundtland report. Later, some important contributions are discussed in important conventions and Agendas such as Agenda 21 (Stoddard et. Al., 2012). Although the TBL approach was frequently used as a framework to consider economic, environmental, and social performance, it was not exclusively applied to the study of sustainability (Slaper & Hall, 2011). The TBL moves beyond the simpler economic evaluation and adds the ecological and social components to the assessment, which may be more difficult to measure and assess. Consequently, measuring the TBL concept rather than defining it presents the greatest challenge (Slaper & Hall, 2011). Table 12.1 identifies some common indicators which are used to assess the three major areas of the TBL.

Table 12.1 Common Sustainability Measures in each area of the TBL (Slaper & Hall, 2011)

Economic Measures	Environmental Measures	Social Measures
Job growth Employment distribution by sector Percentage of firms in each sector Revenue by sector contributing to gross state product Personal income	Electricity consumption Fossil fuel consumption Solid waste management Hazardous waste management Change in land use/land cover Resource depletion	Unemployment rate Female labor force participation rate Median household income Relative poverty Percentage of population with a post-secondary degree or certificate Violent crimes per capita Health-adjusted life expectancy

Tourism can have both positive and negative impacts in general. However, regarding the TBL, these impacts can be assessed in terms of the impacts on the environment, on the economy as well as the socio-cultural aspects of the region in which such activities take place. This is particularly important when talking about tourism and its impacts on mountain regions and nature-based destinations, due to the fragile environments and marginal communities (Belsky, 1999). Thus, to assess the sustainability of tourism activities in mountain regions, the impacts on the environment, the sociocultural aspects, and the economy must be assessed in the region. The assessment mechanism is always useful to establish quality control protocols to mitigate the negative impacts of tourism activity on society or the environment.

Although tourism is considered to be a cleaner economic sector in comparison to many others, there are several environmental impacts of tourism that need to be considered. These are especially important in rural areas or in places where nature-based tourism is common. For instance, in mountainous areas-where, the pristine environment may be the source of attraction but may also be vulnerable to slight disturbances, such as the extensive use of resources (Silva et. al., 2013; Vaccaro & Beltran, 2007). Tourism activities are now known to have direct impacts on the air, land, and water (Wong, 2004). For instance, tourists traveling to various destinations are involved in the careless use of the resources, disturbing biodiversity and causing pollution. National parks and protected areas, being an important part and tourist attraction of many mountainous destinations (such as Deosai National Park, Shandur National Park, and Ayubia National Park), may be affected by the pollution and waste produced, and may also lead to disturbances for the local biodiversity (Buckley, 2011).

In areas of mass tourism, tourists are known to continue their practice of high consumption, which leads to undue pressure on scarce local resources as well as an increased generation of waste and pollution (Neto, 2003). Waste generation and accumulation in the mountain regions can be a huge problem, with severe environmental implications (Andereck et al., 2005). Tourism and related activities are also the major contributors to the emission of carbon dioxide (Saqib et al., 2019), mostly because of increased transportation, housing, and lodging in mountain areas. Additionally, an increase in the flow of tourists or related activities has raised the energy demand, subsequently adding a burden on the local resources (Gössling, 2002), especially where energy needs are often unmet. The economic impacts of tourism as an economic sector are now widely recognized. The tourism sector contributes to employment, foreign exchange, and national income in many regions of the world (Neto, 2003). In the case of Pakistan, the tourism sector contributes to around 2.8 per cent of the GDP, to the tune of around USD 2 million (Karim et al., 2021).

The socio-cultural impacts of tourism and related activities are an important aspect of the sustainability of tourism. Unlike the economic challenges, the environmental impacts of tourism, particularly on the sociocultural domains, are often irreversible and may only be visible over longer periods (Mathieson & Wall, 1982; Swarbrooke, 1999). Tourism may also create several localized problems such as increased traffic and overcrowded spaces (Lindberg & Johnson, 1997).

Mountain tourism

In the biosphere, mountains of different altitudes, with a great variety of shapes with climates, and specific combinations of ecosystems are found. Since antiquity, mountains have been of great importance to the humans living on them, while supporting agriculture and livestock raising, transport, and trade of goods. In today's world, most of the mountains have been devalued because less investment is being made in them. Due to overuse, resources have been depleted, although tourism raises some hope.

Promoting mountain tourism is one of the means to get benefits from the mountains. Mountain tourism is a type of tourism that takes place in a specific geographical range such as hills or mountains with distinguishing characteristics and features limited to that specific landscape, topography, climate, biodiversity, and the local community. A broad spectrum of outdoor activities and types of sports, ranging from the mainstream to the extreme, are possible in the mountains (Nepal and Chipeniuk, 2005).

Sustainable mountain tourism

Mountain tourism will only be sustainable if it meets the needs of today and creates opportunities for future generations. The fundamentals of sustainable tourism development are composed of environmental, economic, and socio-cultural aspects. Balance among these aspects must be established for sustainable mountain tourism (Samy & El-Barmelgy, 2005). Ignoring environmental and socio-economic aspects might result in more degradation of the mountain biodiversity which is the case in many developing countries. Khadka Nepal (2010) have rightly mentioned that in developing countries the unplanned influx of tourism-related activities to remote mountain regions potentially threatened the sustainability of mountain communities. This includes high energy demand and consumption, land use, and negative impacts on the conservation of protected areas.

Strategies for sustainable mountain tourism

Some strategies for sustainable mountain tourism are presented here:

Funding for integrated development in the mountains

To promote sustainable tourism in the mountain regions, financing mechanisms in sectors like climate change, biodiversity conservation, and Sustainable Development Goals must be integrated. Financial institutions must be engaged to develop tourism related products by putting sustainable initiatives as loan condition. All borrowers must be bound to incorporate pro-environment initiatives in their business plans. e.g., climate changes awareness programs, conservation activities and green product development. All government and private sector projects must be bound to keep 3-5% budget for conservation initiatives under their corporate social responsibility.

Collaboration between the mountain regions

A cohesive strategy is needed to determine the current and future development of the region's mountains. National and regional institutions must be involved to facilitate economic and knowledge exchange, transboundary cooperation, and capacity building. Even the involvement of outside institutions at the expense of the exclusion of local and regional communities will not bear proper fruit in sustainability.

Scientific approach and research on mountains

To sustain mountain tourism, it is important to devise a mountain policy framework and its implementation plan for the region. The research contributions are a significant source to design input for policy frameworks, especially the evidence-based findings that are key to responding to the changing nature of technological advancement and modernization processes. Efforts to integrate scientific knowledge with local communities' engagement and experience need to be strengthened. Burns & Novelli (2008) are of the view that more specific research in this field can have some feasible and suitable recommendations for sustainability in mountain tourism.

Education and awareness of mountain ecosystems

The local community plays a leading role in the sustainability of mountain tourism. This requires educating the local communities as important stakeholders, and sensitization mechanisms may help to mitigate the disruptive effects of the mass flow of tourism and evolve into responsible tourism. Research recommendations or local community's help for sustainable mountain tourism cannot be useful until and unless major policy reforms are not introduced at the national level. The leadership of any area plays a vital role in sustainable mountain tourism by highlighting the contextual needs and demands of the region at the regional and national levels.

Responsible tourism depends on civic awareness, which values the plantations as a sustainable source of green vegetation and carbon sequestration. The benefits of a green landscape attract people to such spots. Developing countries lack a national focus on an eco-friendly tourism policy for the mountains, which is necessary for the country's environmental, economic, and social well-being. Mountains are home to a variety of wildlife, which is one of the main sources of attraction for tourism. The downside is that massive movements in mountains may also be a source of wildlife extinction and pollution.

Biodiversity conservation

Biodiversity conservation is a need of the modern world and its growing population. Local communities are more benefited by wildlife. Ashe (2005) reported that "tourism is linked with biodiversity and forests and has a direct relationship between the growth of international tourism and the growth of economic output as measured in GDP. For example, in years when world economic growth exceeds 4%, the growth of tourism volume tends to be higher, and when GDP growth falls below 2%, tourism growth tends to be even lower".

Nowadays, uncontrolled visits to nature adversely affect the population of wildlife. Some species of plants and animals are going to be extinct, while others are endangered or even critically endangered. Global environmental changes can considerably cause the extinction of wildlife in the future (Sala et al., 2000). With such drastic climatic change patterns, reportedly 15-37 per cent of the species of plants and the animal kingdom are expected to be extinct by 2050 (Thomas et al., 2004). The estimates may vary in the climate change scenario and assumptions concerning adaptation in species. Many species may not be able to survive in new habitats and niches (Thomas et al., 2004).

National mountain development policies

Stakeholders in developing nations may create goals and implementation strategies that will help address some of the most important problems involving the mountains. Mountain management decisions and activities that are pertinent to mountain environments require national mountain policies that contain guiding concepts. To promote the well-being, prosperity, and security of both the present and future generations, they should make sure that the mountains and the downstream lands that surround them are robust, secure and productive, and well-understood.

Ecotourism as a tool of sustainable tourism

Ecotourism is defined as a "responsible tour for conservation of nature and its components for the welfa*re of local people".* A responsible tour of nature helps in achieving the conservation objectives as well as the sustainability of habitats for social well-being (Blangy and Wood, 1993). The principle of ecotourism is to overcome the negative impact on nature and culture, bring cultural awareness, ensure a positive experience for tourists and local communities, empower the local people and also ensure funds for conservation. It explores the natural resources, which maintain ecological sustainability. It also highlights the various means of consumption of natural resources for the future (Voltaire et al. 2017; Pascoe 2019).

Eco-tourism involves planned visits to nature to learn, explore or participate in such activities that do not bring negative impacts or damage to the environment, and focuses on the protection and socio-economic empowerment of the local community (Christian et. al., 1996). The goal of ecotourism is to create opportunities for local communities, considering their requirements and living standards, by protecting and conserving their local natural resources (Bansal and Kumar, 2013).

Opportunities for mountain tourism in northern Pakistan

The northern areas of Pakistan have huge tourism potential, yet the overall contribution of this sector is only 5.7 per cent of the Gross Domestic Product (The Friday Times, 2022). The tourism destinations in Pakistan are known for their captivating natural beauty, a high degree of hospitality offered by the residents to the tourists, and cultural diversity. Apart from this, another huge advantage of the northern areas of Pakistan is that it includes three of the world-famous mountain ranges: the Hindu Kush, Himalayas, and the Karakoram. Despite these attractive features, the tourism sector has not fully capitalized on the available opportunities. Below, we discuss a few of the unique opportunities for mountain tourism in Pakistan.

Mountain tourism is the upcoming frontier

Mountains are very attractive destinations for visitors across the world. The key features of mountains are the scenic views, adventure sports attractions, low cost, and cultural diversity. Each year thousands of tourists, including hikers, climbers, and trekkers visit the mountains, making mountains a mass tourist destination. The popularity of mountain tourism is further increased by the recent crisis caused by COVID-19 pandemic. People are looking for less crowded places. The HKH region is one such region that offers a pool of tourism attractions in one basket. So far,very few places in the HKH region are known to both local and foreign tourists. For example, there are some popular tourist destinations in Gilgit Baltistan, a few areas of KPK and Kashmir. The majority of tourists visit these places for scenic views. However, these places have huge potential for tourism development. The following list of potential places and types of tourism that can be promoted for a sustainable mountain eco-tourism.

Skiing

Europe and North America are famous for skiing. These countries arrange different sports events related to skiing in the mountains. Every year, thousands of professionals as well as amateur skiers visit these places. There is huge potential for skiing in the HKH region. Until recently, skiing was not seriously considered a sport by the government authorities. The HKH region has a lot of potential for the development of ski resorts. However, due to several constraints, e.g., infrastructure, transport, sports logistics, and awareness, the authorities have developed only a few resorts, which include Malam Jabba Ski Resort; Naltar Valley Ski Resort; Nathiagali Ski Resort; Astore Valley Ski Resort; Fairy Meadows Ski Resort; and Shimshal Ski Resort.

Tourism development authorities must collaborate with local communities to identify and develop Ski resorts in the HKH region. This will help Pakistan to attract local as well as foreign tourists. It will also help Pakistan to arrange and compete in the winter games.

Development of Hiking Trails

Hiking and trailing are one of the oldest activities in the world. It provides an opportunity to feel the land and experience its beauty. Hiking is also considered very beneficial for health. Due to its importance and attractiveness, many countries have developed hiking trails. These trails are now an integral part of the tourism industry.

Some of the key areas that need special attention for the development of mountain tourism through hiking trails include: designing, building, and maintaining sustainable trails; trail maintenance; trail safety; '*leave no trace*'; and family hiking trips.

Table 12.2 Some of the famous tracks in HKH region of Pakistan (https://www.wikiloc.com/trails/hiking/pakistan)

Name of the track	Location
Dagri Bungalow Trek	Near Moji Dhara, Khyber Pakhtunkhwa (Pakistan)
Nunga Parbat	Fairy Meadows to Rakhiot base camp, Pakistan
Mankial Pass via Jagbanal and Chokail Banda	Near Narai Banda, Khyber Pakhtunkhwa (Pakistan)
Banjeer Baba	Narai Banda, Khyber Pakhtunkhwa (Pakistan)
Dhadriyaal Pass	Ushū Sar, Khyber Pakhtunkhwa (Pakistan)
Fairy Meadows, Pakistan	Near Jail, Gilgit-Baltistan (Pakistan)
Passu glacier and Passu lake, Pakistan	Near Barut, Gilgit-Baltistan (Pakistan)
Musa ka Musallah	Kagan valley
Dwa Saray trek	Near Bikrai, Khyber Pakhtunkhwa (Pakistan)

Box 12.2 Winter Tourism (Ice-Hockey organized by SCARF at Hunza)

Gilgit-Baltistan is a winter wonderland, and there's much attraction for tourists. Local communities also continue to generate revenues and attain tourism sustainability. The Altit SCARF (Sports Club Rising Federation) a nonprofit organization in Hunza initiated ice hockey to promote winter tourism in Gilgit-Baltistan, particularly in Hunza. SCARF creates an opportunity to engage the local community, educational institutions, and industry through community-supported winter sports tournaments, particularly ice-hockey tournaments, and training programs for the youth of various schools, colleges, and university students at Hunza.

Source: https://www.24newshd.tv/21-Jan-2022/canadian-envoy-promotes-winter-sports-in-hunza

Culture tourism

The HKH region is home to a diverse group of cultures. Each culture represents different traits, traditions, and colors. These cultures originate from the KPK, Kashmir, Chitral, and Gilgit-Baltistan. Each culture has its subculture with its unique dresses, languages, and festivals. Such rich diversity is an open opportunity for the promotion of cultural tourism. Below, we discuss the different languages, events, and games that are part of these cultures and can play a vital role in the promotion of tourism.

Some of the most dominant languages in the HKH region are listed below in Table 12.3. The table also shows the geographical location where the language is spoken. These languages have a rich history and their folk music.

Table 12.3 Region-wise classification of languages in the HKH region

Region	Languages
Gilgit-Baltistan	Shina, Burushaski, Wakhi, Khowar and Balti
Chitral	Khowar, Kalasha, Dameli, Kirghiz, Madaglashti
Dir (Upper)	Pushto, Kohistani Gawri
Kashmir	Kashmiri, Dogri, Urdu
Swat region	Pushto, Kohistani Gawri

The diverse cultures in the HKH region also have their unique festivals (Table 12.4). These festivals are indigenous and can be experienced only in the HKH region. It is also an opportunity for the tourism industry to promote cultural tourism. Some of the well-known local festivals are listed below:

Table 12.4 Key Festivals in the HKH region

Festival	
Chitral	Joshi Spring Festival, Uchal Festival, Phool Festival, Chaumas, Festival
Dir	Aman Gala
Dir Upper	Jashn e Kumrat
Gilgit-Baltistan	Babosar Polo Festival, Novroz Festival, Bo Fao, Tagham
Gilgit-Baltistan/ Chitral	Shandoor Polo Festival
Azad Jammu & Kashmir	Pahari Mushaira

Sport tourism

Another means of attracting both domestic and foreign tourists is sports. It provides entertainment and a social environment. Sports also portray the beauty of local culture. In the

Box 12.3 Cultural Tourism (Kalash Festival)

In recent years, Kalash has become an increasingly popular tourist destination for its rich ancient culture and scenic beauty. It is known for its unique traditions (ancient Hinduism), language, and cultural heritage. Cultural tourism is flourishing in the region, due to domestic and national travelers. The Kalash festival is part of cultural tourism, which is celebrated by the Kalasha tribe each year. Kalash is a major attraction for national and international tourists due to its ancient culture and festivals like Chilam Joshi, Uchal, and Choimus Festivals. Visitors from around the globe travel to Kalash to attend these festivals which are celebrated in the spring, summer, and winter seasons. They are fascinated by the traditional attire, dances, rituals, religion, and marital practices. These factors have drawn tourists and significantly boosted the local economy. The Kalash Valley has tremendous potential to develop into a prime tourist travel destination. By investing in winter tourism, sustainability in the travel industry may be realized. To achieve long-term financial success, the government and commercial groups must collaborate with the local communities to promote winter tourism and create and execute policies to uphold their traditions.

Source: https://theblindside.pk/blog/the-tale-of-colorful-chilam-joshi-festival-of-kalash/

HKH region, the local community participates in many traditional sports. Some of these sports are famous throughout the world, e.g., Polo. Other culturally specific sports are popular only in the communities that know how to play them. This is also an area that needs attention from government bodies. Through proper documentation and marketing strategy, these sports events can help boost tourism in the HKH region.

Box 12.4 Sport Tourism (Shandur Polo Festival)

Shandur Top is a major tourist attraction surrounded by the majestic mountains of the Hindu Kush, Pamirs, and Karakoram Ranges. The Shandur Pass remains snow-covered in winters, and it is a popular summer destination, partly due to the Polo festival. Sport tourism is gaining popularity and is highly influenced by developmental and promotional programs. Every year, the GB and KPK governments organize the "Shandur Polo Festival." It lasts for three weeks, and is enjoyed by Polo fans, authors, photographers, mountain bikers, and local and foreign visitors.

Source: https://indyguide.com/tours/shandur-polo-festival-tour

Challenges of and from mountain tourism

Though mountains are popular tourism destinations, they also face several challenges from increased human activity. It is important to consider the culture and ground realities of mountain regions in northern Pakistan. Local communities must closely monitor the quality of the natural environment to reduce the negative effect of tourism. Some of the most critical challenges are listed below.

Tourism harms the natural environment of mountains if not managed properly. Specifically, tourism is considered a threat to protected areas. Most of the HKH region is not explored by tourists. Therefore, the ecosystem of these unexplored regions is in pure form. However, with the increasing development of the tourism industry, tourists will get access to these locations. It can have a drastic effect on the ecosystem of the HKH region.

Pollution

Mountain tourism is also a root cause of increasing pollution in the HKH region. The major sources of pollution include:

Transportation: Most tourists travel by their land vehicles, which increases traffic in the HKH region.

Biowaste: It is mostly related to food materials left behind by tourists, such as fruits, vegetables, seeds, and other biowaste.

Other waste: another major source of pollution is plastic. Most of the food items are covered in plastic wrap. The tourists leave behind plastic bags after consuming edibles.

The absence of proper governance and sustainable tourism policies is further increasing pollution in the HKH region and it is negatively affecting the overall ecosystem of the mountain regions. For example, the effect on the life of local communities specifically, children and old age people, disturbance to native wildlife, and effect on the biological process of plants.

Prone to natural disasters

The geophysical and geomorphological features of the HKH area closely resemble the regions located on the boundaries of the tectonic plates. This makes the HKH region extremely vulnerable to natural disasters. The risk of natural calamities and casualties is further heightened by the global warming issue. For example, in recent years we have noticed a significant increase in the melting rate of the glaciers in the HKH region. This can create a serious challenge to the development of mountain tourism. In the absence of proper facilities, it can also cause casualties.

Provision of basic facilities in HKH region

Another enormous challenge to the promotion of mountain tourism is the availability of basic facilities in high altitude regions. These facilities include transport, health, and boarding facilities. The geographical location of the HKH region is the main reason for the lack of facilities. In addition, the cost of providing basic facilities is also a huge hindrance to the development of these regions.

Lack of government policies and security issues are the key reasons that the hospitality sector remains undeveloped as compared to international standards. For example, the majority of the hotels in the HKH region do not implement adequate certification standards. That is why most of the services of these hotels are below standards. Another major reason is the lack of human resource development. This sector in Pakistan is running short of trained human resources.

Depleted infrastructure

Underdeveloped infrastructure is a common issue in Pakistan. It is affecting almost all sectors, including the tourism sector. However, this issue is severe in the HKH region and plays a vital role in the less developed mountain tourism industry in the region. This industry is facing severe challenges due to poor quality of roads, a lack of air transport facilities, a lack of railway tracks, underdeveloped hospitality facilities, a lack of proper tracking infrastructure, and first aid centers in mountains. To overcome these challenges, the government must work on promoting infrastructure, including airports, proper roads, proper railway tracks, and restaurants.

Conclusion

Tourism development has been seen at a faster pace which has got excellent prospects for the promotion of rapid economic development. However, the sustainability aspect has never been a considerable part of tourism policies and strategies of developing nations, resulting in straining nature beyond its carrying capacity and adversely affecting its ecological balance. Additionally, the culture and traditions as well as the interests of local people have been compromised to extract benefits from tourists securing their interests only. Hence, the need for the adoption of eco-tourism and environment-friendly strategies arise in their true letter and spirit, rather than the compliance with regulatory stipulations or norms with concerted action on behalf of all concerned, nurturing sustainable tourism development.

In countries like Bhutan, tourism has been expertly managed to protect people's land and resources while also ensuring the protection of their cultural sensitivities. If the government, relevant departments, and stakeholders work collaboratively to develop effective policies that are modeled on successful countries, a better model of tourism will prevail. The mountain regions will gain from changing those tourism strategies and adapting their policies on numerous levels. Remodeling the tourism models of those countries and reproducing their policies will benefit the mountain regions on multiple fronts. Hence, the incorporation of policies and integration of such models will make HKH mountain areas a quality tourism and travel destination in the years to come.

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Chapter 13

Socio-Economic Transformations in High Asia

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The Gilgit-Skardu Road passing along the River Indus near Gilgit, Pakistan © *Zafar Khan*

The economic transitions in mountain societies

Mountains are biological and cultural hotspots of regional and global significance. They have a diverse range of eco-regions rich in species and habitats. A community's livelihood in the lowlands or the highlands is mutually dependent. The well-being of communities in the lowlands also relies on mountains and hills for natural resources and ecosystem services. In contrast, villages in the highlands rely primarily on those in the lowlands for connectivity, trade, transit, and transportation (Rasul et al., 2018). The volume of these resource outflows has dramatically increased because of the introduction of new technologies, population growth, and development pressures (Pratt & Preston, 1998). In this exchange process, mountainous communities remain vulnerable to various transitory phases.

People are increasingly exposed to livelihood stresses brought on by both climatic and non-climatic conditions. Communities become vulnerable when they cannot manage, recover from, or maintain livelihoods and well-being under such strains (Adger & Kelly, 1999).

According to Wang et al. (2019), rapid demographic and economic growth in most parts of the mountainous region increases the demand for natural resources. In many cases, this results in overexploitation, inefficient land use and land cover change, habitat fragmentation, and unsustainable socio-economic activities. Consequently, traditional downstream beneficiaries are affected as they no longer receive the benefits of indirect environmental services (Pratt & Preston, 1998).

Mountainous regions' pastoral and economic structures can add value to small-scale, diverse production. Despite the vulnerability of the mountain ecosystems, they can still provide services for large-scale commercialization. However, the use of mountain resources may irreversibly undermine the inherent capability of the production base, affecting living standards (Byers, 1995). In recent years, mountain resource merchandizing for "mass" tourism, including recreational and sports activities, has become the primary driving factor behind mountain economies. As a result, there has been a rise in tourist numbers, shorter and more frequent stays, denser and more diverse leisure activities, and increased utilization of mountain resources. It can provide local community employment associated with the community's socio-economic development. This frenzy is also causing increased noise and discontent in previously quiet places and increasing garbage generation and traffic congestion (Marclay, 2018).

The development process must take the environmental and social implications seriously in these mountainous regions. There is mounting evidence that large-scale commercial development and high-investment projects have exacerbated the resource crisis (Pradhan & Rankin, 1990). For instance, extensive road construction and infrastructure development are significant causes of environmental degradation and the marginalization of mountain people. The abandonment of local forest protection systems near newly built roadways is a regularly documented scenario. Locals sense alienation from their land base and participate in short-term profiteering, knowing that outsiders are unlikely to honor old informal agreements (Byers, 1995).

Livelihood diversification in mountain societies

Livelihood is how people satisfy their needs or sustain their lives under any given condition (Chambers & Conway, 1992). Community residents' livelihoods in rural areas depend entirely on natural resources (Ellis, 2000). Most mountain-dwelling households survive on a relatively traditional and diverse range of sources, from subsistence farming to wild edible plants. However, some households achieve livelihood primarily through fewer yet more agro-based productive activities (Chambers, 1989). A livelihood consists of capabilities, assets, and activities required for a living (Islam & Ryan, 2016). The concept revolves around resources such as land, knowledge, crops, food, finances, and social relationships and their interrelated connection with a community's political, economic, and sociocultural characteristics.

The mountainous regions' traditional way of life shares several socio-ecological values with other highland cultures worldwide. Sati (2015) has described very distinct characteristics: (a) a combination of activities, including farming, pastoralism, and seasonal processing of forest products to support the family economy; (b) seasonal transhumance involving pastoral nomads, with several combinations such as using favorable seasonal conditions at different altitudes to maximize the resources needed for the family economy. Agricultural production and animal husbandry traditionally form the foundation of the rural economy, which is made up of a variety of activities. Similarly, utilizing non-timber forest products gives the market economy its foundation with locally famous marketable goods (Sati, 2015). Adding to the utilization of natural resources, such as forests, grasslands, freshwater, and other resources, as well as biomass-based production, is crucial to livelihood. For centuries, these areas predominantly relied on agricultural practices, primarily on small, terraced fields, and are distinguished by the predominance of essential survival cereal cultivation, which is the primary job of the locals. The main cereal crops are rice, wheat, barley, millets, oilseeds, and pulses, but their economic viability is insufficient even for meeting daily needs (Sati, 2015).

In mountainous regions, communities engage in various livelihood activities using the resources at their disposal. Regarding changes in land use, cropping practices, and market accessibility, mountainous regions such as the HKH, have undergone a significant transformation in recent decades. Farmers in the area have been gradually converting from low-value agriculture to high-value cash crop products (Singh et al., 2011). Various factors have influenced this shift, including the growing awareness of markets for high-value crops like vegetables, fruits, and fresh spices like ginger, turmeric, and cardamom (J. Adhikari, 2014; Chand et al., 2008). Other factors that have aided the shift to high-value crops include improved road networks that provide market access to previously isolated communities through increased remittance inflows, cooperative expansion, growth in the number of NGOs, and targeted government activities (Khattri, 2012). For instance, in Pakistan's Gilgit-Baltistan (GB) region, cash crops such as potatoes and fruits (such as almonds, apricots, apples, grapes, and cherries) have been gradually introduced since the 1980s. Along with cash crops and increased road connectivity, the construction of the Karakoram Highway has greatly improved trade and income in the region (Kreutzman, 2008; Gioli et al., 2014). Similar trends have been observed in other mountainous regions, such as Tibet, where farmers with access to roads report growing a more significant proportion of cash crops and a smaller proportion of food crops for survival (Salick et al., 2005).

The mountain communities are changing. Over the past three decades, a significant transition has occurred from an agropastoral to a combined subsistence-labor system. Mountain households no longer depend entirely on their land, though they still need it to sustain the ecosystem. The livelihoods of mountain households are becoming more and more dependent on non-agricultural activities like wage labor, circular labor migration, and tourism services (Gioli et al., 2019).

Some mountain societies have discovered livelihood possibilities in the recreation and tourism sectors as part of a broader search for options for livelihood diversification. Institutionally, the allure of outdoor recreation in the mountains has long been acknowledged, as seen in the designation of national parks. Mountain communities all over the world have been transformed by tourism, which has helped to diversify local economies, create job opportunities, and advance these societies (Gioli et al., 2019).

In the mountainous communities of the HKH, there is a significant macroeconomic shift from agriculture to the services industry (Gioli et al., 2019). There are various reasons for this shift from traditional crop rotations and pastoral practices to more livelihood options because of ongoing social changes, such as rapid urbanization, predominantly male outmigration, and growing populations (Yi et al., 2008).

Socio-economic transformation and challenges

Mountain areas are ecologically significant, aesthetically pleasing, and socioeconomically beneficial to locals, visitors, and those living in the lowlands (Sharma et al., 2019). Traditional mountainous rural communities have extensively managed their land, resulting in land use patterns that provide essential ecosystem services to rural and urban areas. These communities' economic structures, population sizes, and land use have all changed dramatically in recent decades (Vidal-Legaz et al., 2013). Sharma et al. (2019) argue that in addition to direct human intervention, a number of change drivers cause challenges, such as globalization, infrastructure development, climate change, armed conflicts, tourism, migration, and urbanization. However, the result of the interaction of these intricate forces has significant global and regional effects. For example, road infrastructure makes mountainous communities less remote and more reachable, but they frequently have serious adverse effects in the steep upper watersheds due to improper setting, construction, and maintenance (Hamilton & Bruijnzeel, 1997).

Similarly, poor quality road construction on mountains makes soil erosion more likely and is among the most significant human-caused factors that cause landslides. The drainage patterns for both surface and groundwater are changed by these mountain roads, increasing the risk of instability (Sati, 2015). In most parts of the HKH region, rapid population growth and economic expansion have enhanced the demand for natural resources, often leading to overexploitation. Rapid economic expansion has altered infrastructure investment, consumption levels, and patterns. For instance, constructing dams for irrigation may increase food production efficiency and create opportunities to export food. In contrast, hydropower in dams may improve local livelihoods by providing electricity and energy for export. The dividend of such initiatives could transform agricultural communities by diversifying livelihood opportunities such as tourism.

However, large-scale investments improve the quality and convenience of social services like education, health care, and waste management. However, they have a slew of unexpected consequences, some of which are critical, such as social and environmental consequences. Similarly, demographic shifts, as people become more concentrated in towns and cities, are expected to create future environmental problems with significantly higher demands for energy and food (Wang et al., 2019).

Many rural societies in the region, though not all, are now moving from subsistence farming to even more market-based non-agricultural use of land, a decline in traditional practices (Wang et al., 2019). For example, the HKH region has a significant amount of potential for mountain tourism, which could offer local communities alternative economic opportunities. However, most of the region's tourism development is poorly planned, sometimes even unplanned, and the construction of infrastructures like recreation centers, guest houses, campgrounds, and restaurants frequently have negative effects on the mountain environment (Dorji, 2001). Tourism also contributes significantly to the deterioration of the ecological system through uncontrolled solid waste disposal, soil and vegetation trampling, and locally intensive resource extraction. The infrastructure necessary to maintain tourism can also negatively influence the local aesthetic and cultural assets, lowering their significance and future tourism income potential (Oli & Zomer, 2011).

The HKH region's economy suffers from skill shortages, a diminishing labor force due to emigration, inadequate infrastructure, and limited market access. Countries in this region have recognized that entrepreneurship and enterprise development could be a vehicle for economic growth and the community's livelihood (Shrestha, 2019). The advancement of technological innovations has significantly gained global importance, including in mountainous regions. This has changed local and indigenous socio-cultural practices by developing various opportunities in remote mountain areas. There is a dire need for the mountainous inhabitants to be empowered by using innovative technologies for the livelihood improvement of the mountainous communities.

Eco-entrepreneurship in the mountains

Eco-entrepreneurship, an emerging trend in business, has been emphasized in many studies (Schaper, 2010; Yasser Arafat et al., 2019). This new concept promotes integrated approaches such as the business's economic, social, and environmental aspects. When it comes to the socioeconomic development of the mountainous region, the core concept is "eco-entrepreneurship," which focuses on business activities that are less harmful to the environment. Preserving cultural assets is at the core of this concept.

Entrepreneur is a French word meaning "someone who embarks on an adventure." Entrepreneurs pool resources that tie together innovations, capital, and business expertise to convert breakthroughs into commercially viable products. In reaction to a perceived opportunity or necessity, an entrepreneur creates a new organization or takes a step toward rejuvenating a mature organization. Creating a new business is the most obvious example of entrepreneurship (Saleem & Abideen, 2011), which requires a problem-solving mindset and creativity and imagination (Yasser Arafat et al., 2019). However, "entrepreneurship" typically refers to a single person or organization that can also be categorized as entrepreneurial in how they do business and seek to expand (Schaper, 2010).

Eco-entrepreneurship refers to business practices that consider the sensitivity and importance of the environment and provide the impetus for conscious entrepreneurship (Yasser Arafat et al., 2019). Alternatively, there are several other terms used in the literature to refer to a similar field of study, such as *green entrepreneurship*, *ecopreneurship*, and *environmental entrepreneurship* (Saari & Joensuu-Salo, 2019). The value creation logic distinguishes conventional entrepreneurship from eco-entrepreneurship. Traditional entrepreneurship helps to drive economic growth and regional development (Saari & Joensuu-Salo, 2019). In traditional entrepreneurship, the primary and often sole driver is creating economic value. In eco-entrepreneurship, the economic aspect is viewed as a means to achieve other values on the environmental and social levels (Vuorio et al., 2017).

Moreover, conventional business owners are increasingly responding to consumer demand for environmentally friendlier products and being sensitized about sustainability standards through environmental legislation and regimes. As a result, current evolving economic trends and financial performance equally value the inclusion of an environmental component in their core business strategy and their willingness to seize business opportunities to minimize environmental damage (Cohen & Winn, 2007). Furthermore, eco-entrepreneurship aims to enhance the business environments in which companies operate and to foster changes in business practices that have less harmful affect on the social and natural environment (Gast et al., 2017).

Eco-entrepreneurship: An emerging economic outlook in the mountainous region

Mountains supply globally significant goods and services such as water, hydroelectricity, timber, biodiversity and niche products, mineral resources, recreation, and flood management (Molden & Sharma, 2013). Approximately half of the population's livelihood depends on mountain resources, mainly water. Mountains contain 25 per cent of the world's terrestrial biodiversity and nearly half of the world's biodiversity hotspots. Approximately six of the 20 plant species that provide 80 per cent of the world's food originated in mountains, including potatoes, tomatoes, apples, maize, and sorghum (Fleury, 1999).

Mountainous topography generates geographical limitations, but there is a potential for its development in a sustainable fashion. A lack of skilled workers, a declining labor force due to emigration, insufficient infrastructure, and restricted market access hampers the mountain economy in the highlands. The communities dwelling in the mountainous regions have realized that enterprise growth through eco-entrepreneurship may be a tool for enhancing livelihoods and socio-economic development (Steurer, 2013). There are various potential investment opportunities in the mountainous region. For instance, utilizing the benefits of local food systems, promoting the local breed of livestock, high-value mountain crops, sustainability of natural resources, opportunities for non-farm income: (tourism, handicrafts, and others), improving food transportation through regional connectivity, remittance productivity, and mountain food and nutrition security (Rasul et al., 2019). Mountainous regions have the potential for new ventures, yet several traditional economic trades in the mountainous region are required to sync with newer ideas. One of the most common industries in the mountainous region is tourism.

Tourism is considered the most viable industry in the mountainous region. Its full potential has yet to be realized because of the lack of knowledge and innovative techniques. Other industries associated with tourism are likely to develop and grow together with the progress of tourism, especially the businesses related to hotels and restaurants. Enterprises established by incorporating indigenous fruits and vegetables in the restaurant menu may enhance their importance (L. Adhikari et al., 2017). Moreover, numerous business opportunities associated with tourism have significant potential for the local cottage industry, including handicraft and traditional souvenirs, wood carvings, blankets, shawls, embroidery, carpets, baskets, gemstones, and many more (Rasul et al., 2019).

Economic growth equally relies on advanced production vis-à-vis distribution mechanisms. Mountain regions rely heavily on better connectivity infrastructures for an effective distribution procedure. To increase farmers' access to market information, they need the application of ICTs such as e-information systems, mobile phones, and local FM radio, as well as enhancing processing, storage, and distribution systems to reduce post-harvest food losses (Rasul et al., 2019). They could help identify new commercial ventures.

Moreover, mountain areas are geographically very challenging, impacting transportation and access. This is further complicated due to forces of nature – snow, torrential rains, and floods – that occasionally disrupt communications and distribution of goods, while posing high risks of being cut off from market supplies. Improvements in communication and connectivity are crucial. Enterprising individuals also need to turn their idea into commercial reality by providing a food storage facility as a community food bank. It can also open avenues for export competitiveness by strengthening technical support and making financial aid available to improve the production of high-demand organic products, processing, packaging, marketing, etc. (Rasul et al., 2019).

Historically, the mountain regions relied on traditional cross-border trade due to geographic location and infrastructural conditionalities. Largely lacking an effective communication system and industrial zones, the peripheral valleys of the highlands continue to follow the old way of making cross-border trade. An innovative system for both internal and cross-border food trade should be developed. The border communities are at the forefront of encountering cross-border food trade problems during winters and require an enterprise to solve the problem (Rasul et al., 2019). A similar nature of enterprises may be established in mountainous regions. Entrepreneurship is not limited to any industry, country, or group of people. Enterprising conduct can be found in all communities and economic situations (Schaper, 2010). Thus, there are many entrepreneurial opportunities for investment that can be used for the socio-economic development of the mountainous regions. Converting these enterprises into investment opportunities only serves the purpose of protecting the ecosystem of the mountains. Creating resilience in the ecosystem of the mountains through the introduction of eco-enterprises is one of the viable solutions to attain sustainable development goals in the long run.

Why is eco-entrepreneurship important in mountains?

The mountainous regions are facing various challenges, as environmental, sociocultural, and economic changes have a dynamic impact on livelihoods, environmental conditions, and, ultimately, the sustainability of the community (Wang et al., 2019). A wide range of underlying socio-economic reasons – varying levels of activity in tourism, minerals, agriculture, forestry – are typically associated with mountain societies in some form of small business, or a higher share of employment in the public sector. The association of people with small businesses indicates that there are few opportunities due to location disadvantages and geographical challenges to build large industries that have replaced traditional small-scale business opportunities in agriculture, forestry, mineral, and agriculture sector (Wang et al., 2019). Studies found that human activities in the past 500 years have caused the extinction of 844 species due to habitat destruction, overexploitation, pollution, disease, invasion of alien species, and global climate change (Schipper et al., 2008). However, it is indisputable that all businesses affect the social and natural environments (Will, 2008). Small businesses may individually have little environmental impact, but cumulatively they exert a considerable impact not only on the economy but also on the social and natural environment of the country (Lawrence et al., 2006). This sparks a new discussion on sustainability in the economic literature. There cannot, however, be a "one size fits all" strategy for the socio-economic sustainability of the mountainous regions. However, eco-entrepreneurs are crucial change agents in all mountainous regions who work to tackle sustainability issues. They are pioneers and leaders of sustainability in a world with limited resources and a focus on markets because they set an example for the business community by utilizing eco-entrepreneurship methods (Schaper, 2010).

Eco-entrepreneurs promote the widespread adoption of environmental best practices and assist in bringing about and sustaining social transformation. The aim is to be self-sustaining while converting environmental externalities into profit-generating business models, and they are long-term problem solvers. Their success is self-sustaining and does not rely on ongoing outside funding (Carter, 2010). A case mentioned in this chapter define initiatives as eco-entrepreneurial. The eco-entrepreneurial case studies involve a single eco 'hero' who drives the enterprise – a person with a distinctive concept to address the sustainability crisis by establishing an eco-enterprise. This may encourage others to take more coordinated action to promote eco-entrepreneurship in the area, aiding aspiring eco-entrepreneurs in starting their own companies or transforming existing ones into more eco-friendly enterprises. In both situations, the person and the project will advance eco-entrepreneurship. To summarize, eco-entrepreneurs employ a business strategy considering strong ethical and environmental issues that are a part of their business plan and were the main forces behind starting their organization.

BOX 13.1 The Success Story of SheDev (A women-led tech company in Gilgit)

The theme of eco-entrepreneurship discussed earlier paints a sobering scenario. However, it is advocated that many environmental problems can be addressed smartly by employing digital technologies and related innovative business models (George et al., 2021). Particularly in the mountain communities, the start-ups leveraging digital connectivity are effectively stirring eco-friendlier economic activities with little or no environmental effect. One of these start-ups working in Gilgit is SheDev.

SheDev is the first-ever women-led tech company in Gilgit-Baltistan (GB). The idea initiated by TechScape, originated in the Business Incubation Center (BIC) at KIU, when the Special Communication Organization (SCO) in collaboration with the Pakistan Software Export Board (PSEB) and Ministry of Information Technology and Telecommunication, established the SCO Software Technology Park at KIU, Gilgit. It provided a remarkable opportunity for women to utilize tech start-ups in the vicinity to flourish. The digital era offers opportunities without considering borders, and it is revamping the traditional job market. This transformative scenario is a source of empowerment for marginalized women from remote and geographically isolated areas like GB, where entrepreneurship has found traction among younger female generations despite the contextual barriers for women commonly found in mountainous terrains of developing societies. SheDev was among the pioneering women start-ups that primarily focused on leveraging the female workforce to start a tech company. Given the socio-cultural milieu of GB, there was a need to create a safe and secure working environment for women to reach their full potential in both personal and professional terms. Thus, the SheDev initiative was taken by TechScape, already established at the Technology Park, and dedicated to developing the female segment. Gradually, it progressed as a platform that digitally empowers women and provides them with opportunities to enhance and monetize their digital skills. The aim was to connect women to the digital, technologically advanced world, thus providing them with financial stability via atypical methods of learning and earning.

Moreover, it surfaced as a place for women to break stereotypes and excel in technology. SheDev is playing a role in contributing to society. Keeping the socio-cultural provisions, the company offers women a diverse and secure working environment while providing them opportunities to earn from the comfort of their homes. Over the years, the SheDev initiative grew into a successful venture, where a team of 15 original members cohort trained more than

500 underprevileged women and provided employment to some 28 others. SheDev works across various digital platforms, including but not limited to Digital Marketing, Website Development, UX/UI Designing, Graphic Designing, Content Writing, Mobile App Development, and Full-stack web development. She said, "I always felt women should come forward and become a part of the tech world. I took the responsibility to give back to society, utilize my skills and knowledge, and help inspire and motivate women back home. I am a top-rated freelancer on Upwork and a C-Atrax Certified Cyber Security Expert. Zahra Noureen, the CEO and co-founder of SheDev, has worked in Microsoft Technologies for three years. She is a Microsoft Office Specialist and is also skilled in SEO, Web Development & Graphic Designing.

Some of the critical achievements of SheDev include:

1. Recognized among Extra Ordinary Freelancers of Pakistan, 2021, by the Pakistan Software Export Board and the Ministry of IT and Telecommunication.
2. Featured in BBC Urdu and 92 News
3. Awarded by "Ba-kamal- logun sy Rawan Hy Pakistan" by the Government of Gilgit Baltistan, Youth Affairs Department.
4. Best start-up of National Expansion Plan of NICs GB Chapter Cycle ONE.

The story of SheDev points towards those eco-entrepreneurial initiatives employing digital technologies in mountain settings. These interventions are considered to help tackle critical social sustainability challenges. Although not much technological innovation is involved, they have developed business models that infuse innovations with new purposes. These start-ups help advance the sustainable development goals in mountain regions. The digital nature of these activities enables them to be less harmful to the fragile contexts of mountain ecology. More importantly, SheDev has gone beyond geographical limitations, and the scale of working is rendering services to national and international clients. In addition, these start-ups are creating socio-ecological value as an integral part of an economic proposition, thereby disarming the trade-off between profit and purpose.

It is very challenging to encourage eco-entrepreneurship in a mountain region. Entrepreneurs face daily hurdles due to a lack of resources, restricted access, and technical services. Despite these obstacles, several young entrepreneurs, including SheDev have developed novel concepts and established prosperous eco-enterprises by utilizing mountain goods and services. To achieve success, one must be dedicated, focused, and willing to take chances. It is more challenging in the mountains than in the lowlands, where access to roads and business development services is easy. As a result, it is critical to provide an enabling environment for entrepreneurs to thrive.

Conclusion

This chapter discussed that socioeconomic changes in the mountainous region are influenced by a web of interactions between various forces. These forces are creating both constraints and new opportunities for socio-economic development. However, some of these channels are global, for instance, climate change, globalization, and scientific and technological advancement. Some components are specific to each location and related to specific mountain ecosystems landscapes.

In this context, several challenges to socioeconomic conditions in the mountainous region are related to the increasing exploitation of natural resources, which leads to further environmental degradation, uncontrolled urbanization, and the loss of traditional culture. Endogenous economic growth and global demand for tangible and intangible mountain products are both driving up the consumption of mountain resources. The result is the sustainability of the mountainous community. Similarly, increased inter-regional trade further enhances transport flows that introduce challenges for the local administration through waste management, sewage, and social issues. They are also destroying the traditional value chains of local agricultural products and crafts.

However, there are various opportunities to improve connectivity, such as communication and transportation, collaborations, and easy market access. Accessibility is currently being expanded through road network development, and national investment in forestry and farming in remote locations is driving new trends in rural economic growth. Income growth and science and technology progress have enabled health and education improvement. Furthermore, a growing list of local urban centers may help to spread new well-being to rural residents, as the advancement of urban mountain areas may help to increase the power and influence of such regions within national states. The mountainous regions have been identified as undergoing an overall transition of mountain socioeconomic systems. Growing global awareness about the environment and society has signaled further changes in the region's response to resource governance and institutional reform.

However, poverty and vulnerability in the highlands can be reduced through coordinated, contextualized, and mountain-specific initiatives. Entrepreneurship has been recognized as an essential component that contributes to a country's long-term development. Mountains are typically less competitive than remote regions in fertile lowlands near cities. Maintaining eco entrepreneurship in these areas entails fostering the development of substantial competitive advantages that allow mountainous enterprises to expand beyond the confines of local or even national markets. There is a need to develop a method to improve the skill, knowledge, and awareness of eco-entrepreneurship among mountain people. Advanced techniques and technologies may enable traditional practices to become more sustainable and make mountain communities more resilient.

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Chapter 14

Governing the Commons in the Highlands: Understanding the Mountain Society Resource Management System

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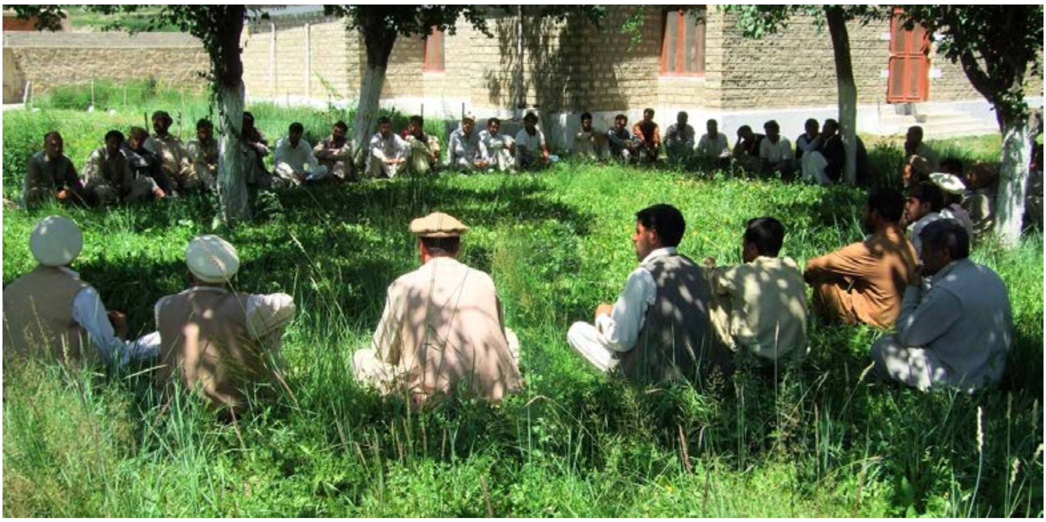

A view of community meeting at Hoper, Nagir, Pakistan © WWF Pakistan

Introduction

This chapter will highlight mountain societies' resources and governance structures and describe the richness and diversity of mountain culture, knowledge, and livelihoods. The way mountain societies conceptualize and govern their "commons" is also discussed. The chapter presents a few case studies on governing the commons.

Mountain resources in retrospect

Nearly half of the global mountain population resides in Asia. The mountains of Gilgit-Baltistan, Azad Jammu and Kashmir, and the vast majority of Khyber Pakhtunkhwa in Pakistan possess a rich diversity of mountain societies. Mountains serve as hubs for bio-cultural variety (Spehn et al., 2006) while providing a rich habitat for the people and attracting tourists from around the world. In many cultures, mountains have spiritual and religious significance. For example, Mount Fuji and Mount Kailash are sacred to millions of Buddhists and Hindus (Price et al., 2013). From a historical perspective, mountain people first domesticated many of the world's staple foods, like potatoes, wheat, and corn. Based on altitudes and ecological zones, mountain societies have developed distinct agricultural production systems (Grötzbach & Stadel, 1997). Mountain communities have specialized indigenous knowledge of local flora, fauna, and medicinal plants (Daniggelis, 1997). Mountain people, resources, cultural diversity, ecosystem services, and their potential opportunities and challenges, are still being studied.

The mountain societies are susceptible to earthquakes, GLOF, snow avalanches, flash floods, drought, extreme weather, and landslides, particularly those in the Hindu Kush-Karakoram-Himalaya (HKH) region. Pakistan's mountain slopes, being a relatively new mountain system, are particularly fragile due to slope instability. Threats to communities are exacerbated further by inadequate infrastructure, communication channels, and underutilized natural resources. The already susceptible livelihoods of mountain people are at high risk. Well-planned mitigation measures at the government level and resilience-building efforts at the community level to absorb the shocks of disasters and cope with uncertain means of livelihood are the need of the time.

Mountain societies often rely on scarce and dwindling resources related to livestock and agriculture, forested areas, and mining. Since there are often fewer employment opportunities, people often migrate to the lowlands for labor and jobs. This trend is common in Pakistan. Most of the young men from these communities migrate to the country's more developed cities for better education, healthcare, and employment opportunities. One of the significant sources of income in mountain societies comes from these young people.

Additionally, some of the poorest and most marginalized individuals reside in mountain communities (Huddleston et al., 2003). They are often underrepresented in decision-making and have relatively limited access to health, education, and employment opportunities. Notwithstanding these challenges, they are often innovative and adaptive to harsh climatic and geographic conditions.

Interestingly, societies living in mountainous areas, like those in Pakistan, have typically had modest means of subsistence. However, people and society possess a wealth of cultural and social capital, which they employ to mutually profit for survival (Price et al., 2013). This solid social network and livelihood make life in the mountains bearable in the harsh climatic and topographic conditions prone to hazards and natural disasters.

Mountain Resources

Mountain societies share a quarter of the planet's land. The socio-ecological system of the mountains is well integrated. It aligns with the sustainability of livelihoods and export of resources to the highland economies vis-à-vis the lowland economies. In retrospect, natural resource endowments have always remained lucrative to the lowlands and the national economy through hydropower, water, forests, minerals, and wildlife. The cultural and environmental landscape of these highlands also acts as a trampoline for the economic growth of communities. Throughout history, mountain regions have been net exporters of resources to the plains. Natural resources like minerals, forests, water, and recreational opportunities are crucial national or regional assets.

Notwithstanding their importance, not much consideration has been given to the rights of the mountain communities (Byers, 1995). The transition to more modern production and distribution systems has come with its own set of challenges. Mountain habitats are adversely affected by the extractive industries' production practices (Byers, 1995). Communities here are vulnerable to societal or ecological change because of such difficulties. However, the management of mountain ecosystem services and the preservation of natural resources receive little to no attention.

The primary cause of this is the emergence of new sociopolitical institutions that are meant to replace traditional resource-governing structures. In retrospect, community-based resource management remained a dominant practice under customary laws, despite the fact that new statutory laws are being implemented for the protection and conservation of common natural resources (Khan, et al 2021; Khan, et al 2022). As modern regulatory authorities gradually encroach on the traditional domain, the traditional aspects of the socio-ecological structure are ultimately disturbed. In order to view and manage mountains, lowland perspectives are still used. The powerful lowland urban centers make decisions on mountain resources, e.g., water, glaciers, minerals, forests, and all other ecosystem services. There is an urgent need for a mountain area conservation strategy for better management of natural resources and their sustainable utilization for the benefit of the local people.

In response to the global transformative order, a rapidly expanding "jungle of concrete" gives mountain societies a quasi-urban outlook rather than green development and a resource management conservation plan. The mountain chain and its resource management systems have been affected by this unsustainable form of development. Mountains are believed to be the first to be affected by ecological changes, and risks always loom for the indigenous communities dwelling in these ecosystems. Rapid urban structures are turning into a destructive force, transforming the mountain chain, its watershed, and social and natural resources that used to be governed under a 'mountain social-ecological system' (MtSES) (Tucker et al., 2021). There is a conflict between the modern and conventional ways of adapting to the change impact, which is also vivid through an ambiguous relationship between the highland and lowland populations. For instance, by and large, the highland areas are under-represented in the inclusive decision-making process, particularly regarding the resources of mountain areas, their management, and defining governance structures for sustainable mountain development (Klein et al., 2019).

Conceptualizing the governing commons in mountains

Here, efforts are made to highlight the importance of the mountain chain in the ecosystem of mountain sustainability and indigenous governance patterns as a culture of collectivism to safeguard the mountain ecology. The core arguments are built upon the importance of local socio-ecological knowledge as a base for understanding the theoretical perspective on 'bio-cultural diversity,' which further helps understand the related governing patterns, procedures, and norms (Klein, 2014). Local systems' efficiency in addressing the environmental and social challenges faced by the communities can also be gauged (Crosetti & Joye, 2021). To understand the alterations in relationships in the social world, where socio-political, cultural, and environmental changes do not only happen but also have a significant effect on what is around, the transformation of another supplement the evolution of one of these entities. The local indigenous knowledge and practices of conservation, resource utilization, and social networks for governing the commons, e.g., pastures and grazing lands, forests, and water channels, need proper understanding and documentation in the mountain region of Pakistan. Otherwise, the centuries-old conservation and livelihood practices will diminish with time.

Why is it essential for mountain communities to continue consulting indigenous knowledge? Firstly, indigenous knowledge, according to Nakashima & Roue (2002), develops after an interplay between society and environment in a system that encompasses "complex arrays of knowledge, know-how, practices, and representations that guide human societies in their innumerable interactions with the natural milieu: agriculture and animal husbandry; hunting; fishing and gathering; struggles against disease and injury; naming and explaining natural phenomena; and strategies for coping with changing environments." Local knowledge helps with coping strategies and acts as a cognitive filter to respond to various issues in human life caused by distinctive socio-cultural and environmental settings.

The socio-political ecology of each highland is distinctive in its own right. Instead of being limited to a high-altitude landscape alone, MtSES provides ecosystem services (ES) to a significant portion of the world's population (Klein et al., 2019). Therefore, mountain landscapes are locally unique with their indigenous governance frameworks. These governance practices evolve from norms, values, and binding principles, formal and informal, that shape or define the actions of a society.

The formal governance mechanisms are codified institutional structures for "organizing society and producing collective goods and services through authoritative rules." In contrast, informal governance protocols are non-codified institutional systems that "operate through unwritten rules, webs of power and relationships, and decision-making processes that operate outside official channels" (Tucker et al., 2021). For example, in northern Pakistan's Himalaya-Karakoram-Hindu Kush (KHK) region, the *Jastero* or *Jirga* System refers to traditional village councils or village republics that operate under customary laws and collectively manage the shared common resources (Stellrecht, 1998). Village councils provide an open forum for democratic consultation while empowering communities to use this network and collective wisdom as a source of social capital for collective action.

Communities in the mountain landscape actively rely on social capital that facilitates engagement and mobilizes the society. A wide scale of preparedness and community-driven adaptability rules are required to manage the commons, like pastoral management, watersheds, trophy hunting, or the socio-cultural engagement of the traditional network of village councils. Community networks are increasingly becoming required for developing a "bottom-up" approach to sustainable development and framing long-term sustainable adaptation mechanisms to offset ecological vulnerabilities. The tragic nature of climate-induced vulnerabilities results from the selfish nature of human behavior, where the 'tragedy of the commons' could be resolved with responsible collective actions to govern the commons sustainably (Collier, 2011; Hardin, 1968; Ostrom, 2009).

In terms of global climatic changes, the last decade has been one of the hottest in the recorded history, with a negative impact on the state of the land, atmosphere, and oceans. Policymakers and practitioners worldwide agree that empowered and active community engagement is pivotal in influencing lasting behavioral change. The United States, as an advanced and developed nation, values the significance of social capital in the development of, and civic participation for, the 'collective efficacy' of society, which is also endorsed in the congressional report "*What We Do Together: The State of Associational Life in America*" (U.S. Congress, 2017).

Theory and practice show that "transformative changes were fostered by the local perception of environmental change, shared narratives, sustained scientific monitoring programs, and the interaction between knowledge systems, facilitated by a bridging organization within a broader process of governance transformation" (Gianelli et al., 2021). The mountain societies in Pakistan have great potential for governing the commons. They have a centuries-old tradition of working together, deciding, and governing using collective wisdom. The revolution in ICT and access to 3G and 4G technology, along with relatively better transportation systems, can contribute to good networking, participatory planning, and collective decisions on the "commons".

Harmonizing new days with old ways in the HKH region

It is generally noticed that environmental imbalance and unsustainable use occur faster and more prominently in fragile mountain ecosystems than in comparatively resilient lowland environments (Jodha, 1990), which creates a vulnerability for the mountainous community. However, mountain societies have been essential for centuries in ensuring a steady flow of resources from the mountains to the lowlands. The size of these resource outflows has dramatically increased due to the introduction of new technologies, population growth, and development pressures. However, downstream recipients have made little contribution to investing in resource renewal or compensating traditional custodians of these resources (Pratt & Preston, 1998).

The life of a mountainous community is inextricably linked to specific mountain characteristics that exacerbate the vulnerability of the dwellers. At the same time, nature endowed the mountain society's natural resources. The inherent disadvantages of the region are manifested by the ways in which available resources have continued to be grossly underused and under-valued, causing poverty, malnutrition, and a lack of food (Sati, 2015). Infrastructure and services are generally deficient, particularly in education, health, and agricultural extension. Transportation costs are high, markets are far away, and the value-added cost of goods and services significantly restricts product flow in and out of mountain areas. High investment costs constrain infrastructure and economic development even further. Rural electrification in the mountains can be prohibitively expensive, even with substantial hydropower resources. However, the potential of small-scale and decentralized power generation must be explored and harvested.

Mountains are politically and economically marginalized compared to neighboring lowland communities and regional power centers. Mountain peoples have little or no say in national matters, even concerning issues affecting their resources and towns. External market access is frequently provided only on unequal and unfavorable trading terms. The relative and absolute poverty of mountain peoples is noticeable worldwide (Byers, 1995). Here, the case of Gilgit-Baltistan is interesting to refer to as a critical HKH region, which remained in seclusion for centuries until the Karakoram Highway (KKH) opened in the late 1970s (Stellrecht, 1998). This helped in connecting this mountainous region with the external world, and "exposed the local inhabitants to the full impact of modern Western Civilization… today's situation is inevitable between … an age-old, inward-looking mountain society (whose feudal traditions lasted until 1974) and modern civilization with the combined impacts of its secular governance systems, industrial products, capitalist economy, and powerful, omnipresent communication tools" (Bianca, 2006, p. 12).

Despite improvements in communications and orientation to new modes of institutional and governance patterns, the marginalization of highland communities continued in decision-making processes. This is why the marginalization of many mountain communities and the lack of a voice of support for mountain ecosystems are essential factors leading to the downward flow of net resource benefits. Also, the Highlanders frequently face unstable rights to ownership, access, and use and minimal influence over the resources they administer. They have been excluded from mainstream economic and political activity throughout history, and they feel powerless to influence decisions that affect their lives. Because of their isolation, they have little access to information, or to decision-making authorities within their national governments; often, participation in foreign markets is predicated on uneven and unfavorable trade terms (Byers, 1995).

The recent new days have prompted the highland communities to diversify their economies for their well-being and to sustain livelihoods, yet they feel obliged to protect the mountain ecosystem. For instance, 21st-century modernization projects under the China-Pakistan Economic Corridor (CPEC) have their own social and environmental challenges in the Gilgit-Baltistan region that may be mitigated through local solutions (Beg et al., 2018). Therefore, in similar situations elsewhere, it is crucial to create harmony between traditional wisdom and the modernization process to ensure sustainable green development. This may include carefully nurturing traditional social capital and governance practices to manage resources, while designing responsible tourism is also essential to economic diversification.

The earlier discussion emphasized local knowledge as a way forward to understanding governance practices and the culture of collectivism as a core normative value to sustain mountain societies' socio-cultural, political, economic, and ecological landscape. According to Nakashima and Roué (2002), local, indigenous, or traditional knowledge systems bridge the gap between biological and cultural diversities. These complex and dynamic arrays of knowledge, know-how, practices, and representations guide human societies in their innumerable interactions with the natural milieu. The following discussion introduces some of the local practices on resource management or the governing of commons in the mountainous HKH region of Pakistan.

Pastoral rangeland management

According to the latest statistics, the herbivorous livestock in Gilgit-Baltistan increased from 1.92 to 2.62 million from 2006 to 2019 (Government of Gilgit-Baltistan, 2020). During the vegetation period, approximately 80 percent of the domesticated animals in the GB graze in mountainous pastures (Kreutzmann, 2015; Khan et al., 2016). The figures reported by the Government of GB (2020) illustrate that 2.8 percent of livestock are entirely dependent on the rangelands for grazing. This puts enormous grazing pressure on the rangelands. However, there are reported disparities in the regional differences in livestock populations across various districts of GB (Gura, 2006; Rahman et al., 2008).

The maintenance, composition, movement, and grazing options of herds depend on mountainous environmental conditions and environmental adaptation strategies adopted by shepherds (Khan et al., 2013). Animal husbandry is one of the fundamental components of the mountain agriculture system and off-farm income generation. Local pasture and livestock management are deeply rooted in the social, economic, and cultural structures of the community, as evidenced by labor availability, market demand for livestock products, and household cooperation within and between households for herding (Schmidt, 2000; Ali & Butz, 2003; Omer et al., 2006; Rahman et al., 2008; Kreutzmann, 2015).

Box 14.1 Nomads, animal husbandry and pastures

The nomadic tribes in mountain regions typically rely on animal husbandry. Some nomads also collect gold along the river bank on the tributaries of the Indus River. Most of the nomads in this region are mostly found in the pastures, where they breed sheep and goats, cattle, and yaks for livestock production and use camels, horses, donkeys, and mules for transportation. During seasonal migrations, nomadic groups travel a long distance from the lowlands to the highlands in search of better pastures. The nomadic tribes have strong cultural values and social relations. These groups regularly move to and fro and deal in livestock proprietorship and management. Nomads access pasture lands under customary laws; however, the taxes are paid to private individuals or the government. In remote valleys, business relations between nomads and farmers are run on traditional barter trade. The farmers are paid in grains or other goods in exchange for animal grazing. Other than livestock management, mountain nomads are engaged in other commercial activities like transport and business; however, crop cultivation is never practiced in their communities. Since nomadic communities are always mobile, their movable property includes tents that shelter them on the grazing grounds. In the last two decades, the changing socio-economic and political dimensions of the world posed severe impacts on nomadic communities, ultimately changing their survival tactics. Some of the influential factors that limit migration patterns and periods are the introduction of confined camping sites, agrarian reforms, and general changes in the socio-economic features of the societies. In addition, the extension of cultivable land, the commercialization of land cover, the reduction of available space, and the increased involvement of bureaucracy in land management have strained the access of pastoral lands to nomadic tribes immensely (Kreutzmann, 2012).

Irrigation channel as water resource management

Water resources have gradually dwindled due to anthropogenic activities. Changes in water regimes and other societal costs are some of the implications. Sustainable water governance is advocated for the long-term viability of irrigation mechanisms and efficient water resource management (Renner, 2013). Gilgit can be an intriguing example to understand the irrigation and water resource management systems in the HKH region. Irrigation system development in Gilgit and Chitral is an old but well-established process carried out over several centuries of collective efforts among farmers. Their livelihood is dependent on Kuhl systems for irrigation. The Kuhl system depends primarily on a suitable location near a spring or glacial meltwater source. The development of the channel is carried out by a small group of farmers from the community using locally available resources (Bryan & Helmi, 1996).

Historically, the chiefs in the areas, the Mirs (Tham) or Raja (Ra'a), mobilized the local population in their respective territories for the construction, maintenance, and rehabilitation of old systems and the development of new land for agriculture and the construction of new Kuhls in challenging locations. Therefore, through the engagement of several generations of farmers with the dynamic biophysical environment, irrigation water is distributed to the fields through sophisticated channel networks (Sökefeld, 2012). According to a survey of the Water and Power Development Authority in Gilgit, it is reported that there are 221 Kuhls supplying irrigation water to developed agricultural lands in the sub-basin of the Gilgit

River in 25 localities and the sub-basin of the Hunza-Hispar River in 34 localities. The water source for the Kuhl system is a combination of glacial melt, springs, and snowmelt. Most Kuhls had continuous flows with seasonal variations between high and low flows (Government of Gilgit-Baltistan, 2020).

Box 14.2 A brief case study of Village Sikanderabad in Nagar Valley, GB

Sikanderabad village, which is both *Burushaski* and *Shina*-speaking, is located at the bottom of Rakaposhi (the 27th highest mountain in the world). The villagers show a degree of homogeneity in their natural resource utilization for their sustenance and livelihood security. Animal husbandry and irrigated agriculture are the main economic activities. Indigenous irrigation practices can be traced back to hundreds of years. The irrigation infrastructure is regarded as common property. Each clan or household is in charge of a particular section of the channel, and the upkeep is divided among them.

Sikanderabad's irrigation channel construction combines modern engineering technology with local engineering know-how from community members. Village elders are frequently consulted for advice on past glacial movements, avalanche and mudflow paths, and glacial and snowmelt or spring stream flows.

In the mountainous environment, physical conditions vary greatly within short distances, or from one season to another; therefore, the construction and maintenance of irrigation systems are not possible without community ownership and participation.

The Chowkidar (the Watchman or *Yatqu'een*)

The chowkidar is a traditional figure with detailed knowledge of the workings of the Kuhl system. Usually, a chowkidar is employed by the local farmers to monitor the water channels and identify issues, if any. Currently, Skindarabad has two parallel monitoring systems in place: the chowkidars, who keep an eye on the older systems, and the village organization, which is in charge of collectively deciding on the designs and sites for the development of new water channels.

The *Warabandi* system (water distribution system)

Under the *warabandi* system, each household takes its irrigation turn every fourteen days. However, farmers can trade their turns depending on their needs and demands for water. Generally, vegetables are prioritized in the Warabandi system over fodder crops like alfalfa, and trees. The trees and shrubs are irrigated mostly at night, whereas the vegetables, wheat, and fodder are watered during the day.

***Rajaki*: Irrigation management**

Irrigation channels are common property, and they require collective management in terms of maintenance and upscaling. Traditionally, for the maintenance of the irrigation channel, the local farmers contributed in the form of labor or produce. The principle continues to live on, however, cash contributions are also acceptable as contributions. Normally, annual maintenance starts in the spring before the first irrigation for the new crop year, and when water flows are low or nonexistent. On channels where silt loads are heavy, all farmers may also participate in a one- or two-day mid-season desilting operation.

Some villages employ a chowkidar or watchman during the maintenance season to patrol the channel to adjust and clear debris from the channel intake, plug leaks, repair small breaches, and otherwise monitor water supply conditions. In systems where chowkidars are not employed, farmers take regular turns patrolling and maintaining the common channel, usually at the time of their irrigation turn. Whenever a major breach or other maintenance emergency occurs, all farmers participate in its repair.

Disputes Resolution Mechanism

Not many conflicts occur between the irrigators. In a few instances, there have been disputes between the irrigators at the tail end, and those at the middle and upper portions, but these are regularly settled by the community based organizations. If the disputes are not settled by a community based organization, then settlement is done by the supreme council, consisting of community elders.

Cooperation rather than conflict is the basic norm within irrigation management. For efficient functioning, working together for survival in a challenging and ever changing environment is the key. Responsibility for water allocation, reconciliation of village disputes, and maintenance of irrigation channels gradually evolved into functional institutions. For this purpose, The Supreme Council - a body of village elders, acts as the highest civil authority for irrigation management and dispute resolution in villages. In cases of water theft or misuse, the crooks are fined in cash.

Conclusion

Mountain society, culture, and resources are rich and unique. Like mountain people and resources, their institutions and local governance systems are wealthy and at par with the conservation of the commons. Due to rapid growth in population, exposure, the ICT revolution, and the influence of lowland dwellers, the traditional mountain resources, ecosystem services, institutions, and their governance system are endangered. There is a need for investment in mountain societies for the protection and diversification of their livelihood opportunities. A mountain conservation strategy and green development initiatives for the benefit of the mountain society should be launched in Pakistan.

The concepts and processes of change need to be understood, managed and directed. Change should not erode the positive values and constructive aspects of indigenous cultures. Change is an unavoidable and irreversible global phenomenon that must be accepted while remaining compatible with other prevalent norms. The normative order of collective management is a cultural value of governance that communities have been engaged in for extended periods. Moreover, it is built upon the values of local wisdom and knowledge. It is well-researched and observed how 'bottom-up strategies' to help communities and societies successfully govern and manage their environmental resources for centuries (Ostrom, 2009).

The increase in quasi-urban centers in the fragile ecology of mountain regions is now a reality, which bifurcates the quasi-urban and rural systems in mountain societies. Nevertheless, the local response and adaptability strategies are pivotal in the resource management of the mountain chain.

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MOUNTAIN STUDIES

UNDERSTANDING AND MANAGING MOUNTAINS FOR PEOPLE AND NATURE

This book is intended for those with an academic, scientific, and practical interest in mountains, particularly the Hindu Kush-Karakoram-Himalaya (HKH) region of Pakistan. Primarily, it serves as a resource book for those engaged in teaching and learning about mountains and associated resources. It provides an overview of the key aspects or resources of mountains from a background information to, classification and current status. It also highlights the likely challenges and future directions for conservation of mountain resources.

The book will be a useful resource for teaching as a core course in the mountain universities of Pakistan's HKH region or in similar geographical settings elsewhere, where possible, or by integrating it partially into existing curricula of relevant subjects.

Following an introduction to the HKH region of Pakistan, this book contains 14 chapters, arranged under three broader thematic areas:

- *Physical landscapes and associated challenges* – covering mountain geography, glaciology, land use land cover changes, mountain hazards and climate change;
- *Life and resources* – describing mountain ecosystem services, mountain forests, rangelands, wildlife, medicinal and aromatic plants and agroecology; and
- *Governance, markets, and common goods* – sustainable mountain tourism, socioeconomic transformation, governing the commons and resource management systems in the highlands

Sixty co-authors representing numerous disciplines from the six partner universities in the HKH region of Pakistan contributed to the chapters. A considerable number of images have been used across all chapters to portray important elements. More than 650 references provide the reader with an invaluable resource to gain first-hand knowledge of mountains in the Asian highlands.

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