CLIMATE CHANGE RISK PROFILE OF THE MOUNTAIN REGION IN SRI LANKA

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ASIAN DEVELOPMENT BANK

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On the cover: Sri Lanka's mountain region has a climate ideal for forest growth and rich biodiversity and is an important base for tea production. However, this mountain ecosystem is highly vulnerable and at risk due to the impacts of climate change (photo by R.H.S. Suranjan Fernando).

Cover design by Editha Creus

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Foreword

Sri Lanka, a small island nation in the Indian Ocean, is highly vulnerable to extreme climate events, which adversely affect all sectors. Climate change impacts are seen in agriculture, in communities, and its economies. The mountain region in Sri Lanka covers an area of 9,942 square kilometers, or 15.2% of the island's total land area, and has a climate ideal for forest growth. The region is rich in biodiversity. It serves as the headwaters of many major rivers, including the Mahaweli River, and is the most important base for the country's tea production. However, the region is prone to flash floods and landslides. Soil erosion and land degradation occur at an alarming rate and have been worsening due to the increasing frequency of extreme rainfall events and intensity of human activities, particularly changes in land use and poor land management practices. The integrity and functionality of the fragile mountain ecosystem are anticipated to further degrade with climate change.

This technical study establishes a definition and a resource profile for the "mountain region" in Sri Lanka that will form the basis for conducting climate change vulnerability assessments. Given the vulnerability, it is critical to comprehensively understand the impacts and risks of climate change on the area to facilitate adaptation while minimizing any negative effects. This will assist national institutions such as Sri Lanka's Climate Change Secretariat (CCS) in applying a comprehensive approach to address climate change challenges, recognized as environmental cum developmental issues for the country.

Sri Lanka is ranked 106 out of 182 countries in the most recent Notre Dame-Global Adaptation Index (ND-GAIN) Country Index for 2019, which summarizes a country's vulnerability to climate change and other global challenges combined with its readiness to improve resilience. An understanding of a country's topography and climate will aid decision-makers such as the CCS in finding appropriate climate change adaptation and mitigation solutions and in formulating and implementing them through country policies and development planning.

The *Climate Change Risk Profile of the Mountain Region in Sri Lanka* is an updated and abridged version of a more comprehensive climate change vulnerability assessment of the country's mountain region. The comprehensive assessment is an output of the project "Updating Climate Change Vulnerability Assessment and Piloting Mainstreaming Climate Change Adaptation into National Development Activities in Sri Lanka," which was implemented by Sri Lanka's Climate Change Secretariat in 2016–2018 under the regional knowledge and support (capacity development) technical assistance Action on Climate Change in South Asia (TA8572-REG, 2013–2018) of the Asian Development Bank (ADB).

Since its establishment in 1966, ADB has been committing loans, grants, and technical assistance to Sri Lanka. ADB remains as Sri Lanka's largest multilateral development financier, with $745 million disbursed to the country in 2020—the highest ever annual disbursement. In 2021, ADB established the Serendipity Knowledge Program (SKOP), a dedicated knowledge program for the country. These investments and knowledge work will continue to strengthen the country's drivers of growth and further development assistance addressing climate change risks.

ADB is committed to implementing climate change adaptation and disaster resilience through projects as outlined in ADB's Strategy 2030 Operational Priority 3, which focuses on tackling climate change, building climate and disaster resilience, and enhancing environmental sustainability. ADB recognizes the value of easy-to-use technical resources that promote country capacity for climate risk assessment and adaptation and mitigation planning.

This technical study is a publication under the SKOP, a platform dedicated to identifying knowledge solutions for Sri Lanka's development challenges. Serendib is one of Sri Lanka's ancient names and serendipity refers to a fortunate finding, which is a common occurrence throughout the history of product invention and scientific discovery. ADB established this new knowledge program in 2021 in line with its vision as a knowledge solutions bank. It can benefit institutions and stakeholders having current or planned development activities and research in Sri Lanka, including public and private sector agencies, nongovernment organizations, academia, and development partners. It aims to promote the sustainable development of the mountain region in Sri Lanka by enhancing the awareness of stakeholders and enjoining them to address climate and disaster risks.

The *Climate Change Risk Profile of the Mountain Region in Sri Lanka* can also be used for a wide range of practical purposes. It can be a useful resource for assessing future investments in terms of risks associated with climate and geophysical hazards, urban and rural planning with disaster-proofing, and guiding decision-makers toward better project outcomes and development impacts for Sri Lanka.

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This technical study was prepared under the guidance of Kenichi Yokoyama, Director General, South Asia Department (SARD), ADB, with the team led by Liping Zheng, Advisor, Office of the Director General, SARD, in close coordination with the Sri Lanka Resident Mission (SLRM) headed by Chen Chen, Country Director.

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Abbreviations

AVRF	average annual rainfall
DEM	digital elevation model
DOM	Department of Meteorology
DSD	Divisional Secretariat Division
FIM	first inter-monsoon
GIS	geographical information system
GND	Grama Niladhari Division
ha	hectare
km^2	square kilometers
m	meter
m^3	cubic meters
MCM	million cubic meters
NASA	National Aeronautics and Space Administration
NEM	northeast monsoon
RCP	representative concentration pathway
SEA	Sustainable Energy Authority
SIM	second inter-monsoon
SRTM	Shuttle Radar Topography Mission
SWM	southwest monsoon
TA	technical assistance
USGS	United States Geological Survey

Executive Summary

Mountains of the world occupy about 24% of the global land surface (Sayre et al. 2018) and significantly influence the regulation of environmental services and sustainability of livelihoods in most parts of the world. Mountain ecosystems are also considered highly vulnerable to current climatic conditions and projected climate scenarios. The mountainous region in the central part of Sri Lanka impacts the surrounding lowland areas. Yet, the country has no broadly relevant definition or boundary for the mountain region apart from a few subject-specific definitions.

This study developed a definition of the mountain region in Sri Lanka. The definition considers the physical, environmental, and socioeconomic factors unique to the mountain region. The present definition is not restricted to a specific discipline but is widely applicable to diverse disciplines, such as for developing legal policies or multidisciplinary tasks. The study compiled a basic resource profile for the mountain region by using available information on geographical and geological features. Rainfall, hydrology, and land use with major agricultural activities were also incorporated.

The climate change risk assessment was conducted by using multi-ensemble rainfall projections developed by the Department of Meteorology (DOM) in Sri Lanka. The study used RCP 8.5 for the period 2040–2060 as the climate change projection emission scenario with reference to the baseline period 1975–2005.

The projected data shows a marked change of annual average rainfall, with significantly high rainfall seasonality and considerable reduction during the first inter-monsoon (FIM) and northeast monsoon (NEM).

The analysis of landslide triggers due to excessive rainfall for the period 2040–2060 shows high risk in the Grama Niladhari Divisions (GNDs) in Ratnapura, Kegalle, and Nuwara Eliya Districts. Kandy District shows a high number of GNDs having high- and low-risk landslide potential, while Badulla District shows a higher number of GNDs with low-risk landslide potential.

Due to fluctuations in projected extreme seasonal rainfall, the river basins of Attanagalu Oya to Nilwala Ganga may be prone to heavy seasonal floods. Maha Oya, Walawe Ganga, and Kirama Ara river basins may experience moderate floods during the southwest monsoon and second inter-monsoon. The significant reduction of rainfall during the FIM and NEM in most river basins in the north, east, and southeast parts of the mountain region will cause severe water shortages affecting a large extent of the Mahaweli River.

Incorporating other climate parameters such as temperature and atmospheric water vapor would facilitate a more complete analysis. Using the newly developed shared socioeconomic pathway projections is expected to provide a more comparable analysis.

The findings of the study are beneficial for crucial resource identification, effective resource administration and management, and policy development in the mountain region in Sri Lanka.

I Introduction

As a small island nation, Sri Lanka is highly vulnerable to the impacts of climate change, ranking 30th in 2019 (and 23 in 2000–2019) among 180 countries affected by climate change based on the Climate Risk Index for 2021 (Eckstein et al. 2021). Natural hazards affecting Sri Lanka include floods, landslides, cyclones, droughts, coastal erosion, forest fires, tsunamis, minor earthquakes, lightning strikes, sea surges, and high winds, among which landslides, droughts, and floods dominate. Except for tsunamis and earthquakes, all other natural hazards are hydrometeorological in nature.

In response to a request from the Government of Sri Lanka, ADB implemented a technical assistance (TA) project in 2009–2011 to help increase the country's resilience to climate change impacts while pursuing sustainable economic development and natural environment conservation.[1] The TA outputs included a National Climate Change Adaptation Strategy for Sri Lanka and sector vulnerability profiles on urban development, human settlements and economic infrastructure, agriculture and fisheries, water, health, and biodiversity and ecosystem services. The vulnerability mapping and assessment work was groundbreaking, being the first vulnerability assessment ever conducted in the country and providing the government with very useful information for national planning.

However, previous island-wide climate change risk profiles in Sri Lanka were developed without sufficient attention to the mountain region. The importance of the mountain region merits developing a separate climate change risk profile.

At present, there is no specific definition or compendium of information or resource profile for the mountain region in Sri Lanka. Therefore, the initial part of this report establishes a working definition of "mountain region" and builds a resource profile, which is necessary for conducting a climate change vulnerability assessment. This report, an abridged version of a full and longer technical study, looks at a few significant resources that could be exposed and at risk to climate changes and associated hazards.

1 ADB. 2009. *Technical Assistance to Sri Lanka for Strengthening Capacity for Climate Change Adaptation*. Manila.

II

Defining the Mountain Region in Sri Lanka

Global Definitions of Mountain Region

Mountains are generally recognized by their significant height. However, elevation alone cannot accurately describe the unique nature of mountains. In some areas, large plains and plateaus are high in elevation but do not show typical mountain characteristics (e.g., undulating geography and associated environmental features) (Körner et al. 2011). Some typical high mountains show a distinct tree line, nival zone, and cryosphere (Kapos et al. 2000). Ruggedness or steepness is another characteristic used to define mountain environments. Most mountain habitats comprise a combination of ruggedness and elevation. Considering all these features are not found in all mountains of the world, it is a challenging task to provide a generalized definition for mountains.

Numerous authors define and classify the world's mountain regions using a combination of the abovementioned features. The development of remote sensing and analysis using geographical information systems (GIS) has allowed the enumeration of mountain regions using the above criteria. Among these, three widely used classification systems are:

- Kapos et al. (2000) defined "mountain area" based on multiple factors, such as principal elevation, slope, and relative relief. They categorized mountains into seven elevation ranges (>4,500 meters [m], 3,500–4,499 m, 2,500–3,499 m, 1,500–2,499 m, 1,000–1,499 m, 300–999 m, and 0–299 m). The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) uses these categories.
- The Körner et al. (2011) mountain definition refrains from any truncation by low elevation thresholds and defines the world's mountains by a common ruggedness threshold (200-m difference in elevation within a 2.50′ cell, 0.50′ resolution). Seven climate-defined life zones in mountains facilitate large-scale (global)

comparisons of biodiversity information as used in the new electronic Mountain Biodiversity Portal of the Global Mountain Biodiversity Assessment.[2] These seven climate-defined life zones or thermal belts are:

1. Nival (<3.5°C, growing season (GS) mean temperature < 10 days)
2. Upper alpine (<3.5°C, 10 days < GS < 54 days)
3. Lower alpine (<6.4°C, GS < 94 days)
4. Upper montane (>6.4 ≤ 10°C)
5. Lower montane (>10 ≤ 15°C)
6. Remaining mountain area with frost (>15°C)
7. Remaining mountain area without frost (>15°C)

- Karagülle et al. (2017) followed the global Hammond (1964) landform classification with slope, local relief, and profile type as the essential parameters for classifying and mapping regional landform classes. It defines mountain regions with four landform categories: plains, hills, low mountains, and high mountains.

Mountain Region Definition for Sri Lanka

This study adopts the following definition for mountain region in Sri Lanka, selecting a 500-meter mean sea level contour as the baseline.

(i) The area above the 500-m contour was invariably included in the mountain region and the slope of the same ridge was considered as the lower boundary of the mountain region.

(ii) If the peak is an isolated hilltop or hill range equal to or higher than 500 m, the whole mountain mass encompassing the peak is considered part of the mountain region.

(iii) Deep valleys lower than the 500-m contour line located between two large mountain ranges or surrounding the area influenced by the mountains are also considered as part of the mountain region (Map 1).

The above-defined mountain region was then characterized using the Grama Niladhari Divisions (GNDs)[3] that lie within the mountain region as suitable administrative units. Using districts or divisional secretariats (DSDs) was unsuitable because they are too large and have extensive non-mountainous areas.

Justification for the Definition

Defining a mountain is a difficult task. The criteria needed to differentiate a small rock outcrop or hill which may not have distinct environs between the surrounding lowlands and specific mountain habitats are difficult to interpret. Many international criteria (Kapos et al. 2000; Körner et al. 2017; Karagülle et al. 2017) fail to distinguish these finer, yet locally important conditions. The characteristics of mountain environments vary among countries (e.g., surrounding conditions, distribution of biodiversity, and traditional livelihoods that can be supported).

International definitions of mountains have focused mainly on ruggedness. This assessment considered biotic characteristics as a better indicator in defining the mountain region of Sri Lanka. Two main criteria were considered in identifying the lowest level of the mountain area:

(i) The lowest elevation where the typical mountain forest environment was recorded. It supports a high percentage of epiphytic flora on tree trunks or branches and has a frequently high diversity of perennial non-graminoid herbaceous plant species.

(ii) The lowest elevation area where the mist envelope is frequently found. The hill tops in the wet and intermediate zones show this characteristic above the 500-m elevation.

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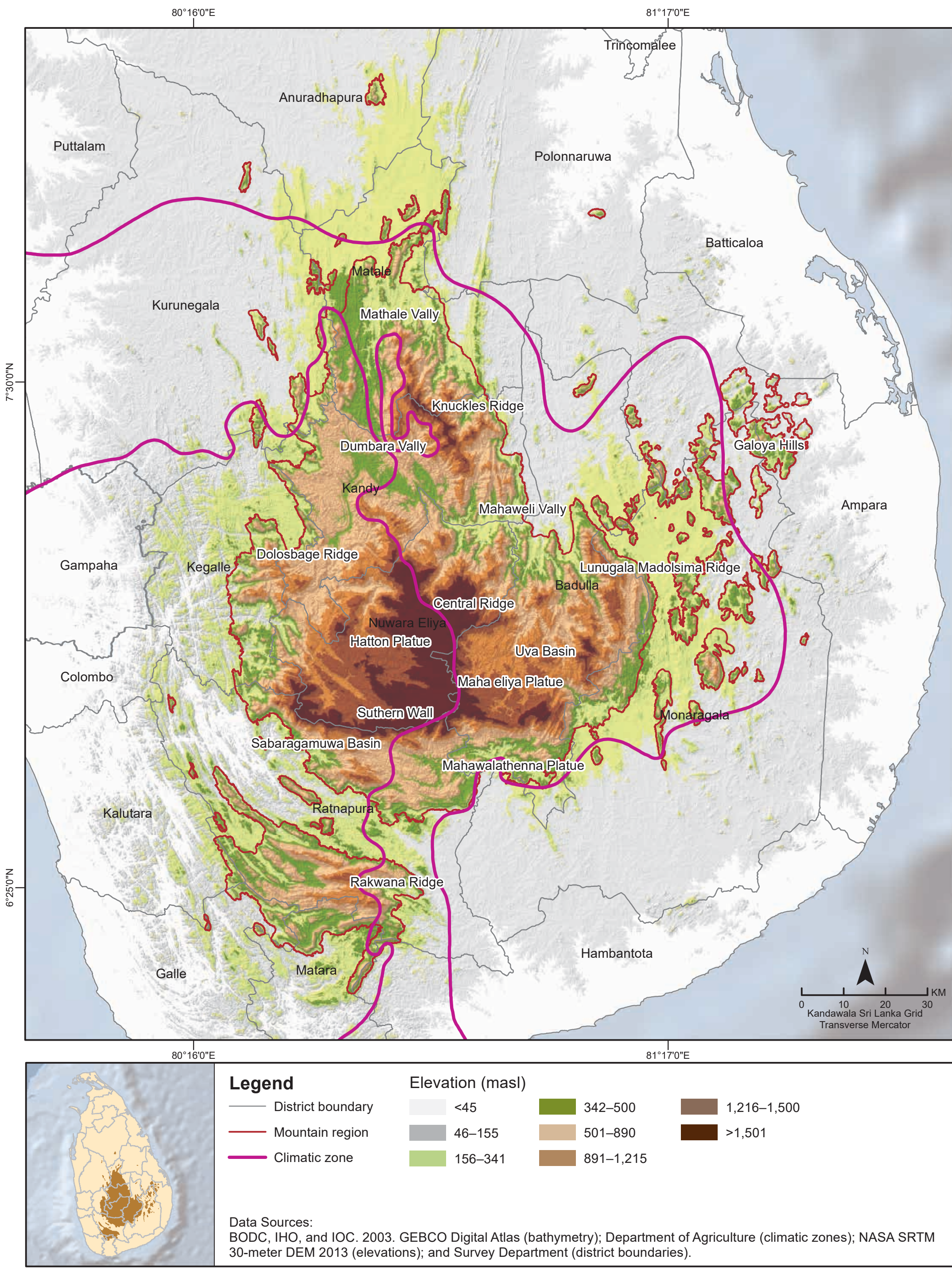
2 The Global Mountain Biodiversity Assessment (GMBA, http://www.mountainbiodiversity.org) is a platform for international and cross-disciplinary collaboration on the assessment, conservation, and sustainable management of mountain biodiversity.

3 Grama Niladhari Division (GND), a subunit of a divisional secretariat, is the lowest level administrative division in Sri Lanka. There are currently 14,022 GNDs in Sri Lanka.

Map 1: Geographical Features of the Mountain Region of Sri Lanka



Based on these two criteria, this assessment used the 500-m contour line as the baseline for identifying the mountain region of Sri Lanka.

Mountain habitats are mostly characterized by relief features (high slopes, deep valleys, waterfalls, etc.) which are distributed along mountain slopes. In high mountains, some slopes have micro-environments that can be recognized below the 500-m elevation threshold. Where the base of the 500-m contour ridge was considered the boundary for specific locations but too difficult to determine, the base of the ridge or a distance of 1 kilometer from the ridge area was considered the mountain boundary. However, some areas of this region have ecological characteristics which are transitional between lowlands and mountains.

When considering isolated hills or relatively small, isolated hill clusters, the 500-m elevation cutoff limit represents an area at the topmost part of the mountain mass not significant enough to be considered part of the mountain zone. Hence, selecting the whole isolated hill as part of the mountain zone from the surrounding plain is more reasonable.

Where there are clusters of isolated hills separated from narrow valleys, the valley areas are also considered part of the mountain zone. Similarly, if one hill cluster is slightly below the 500-m cutoff point, it is still considered part of the mountain zone.

The present mountain zone boundary is 70%–90% compatible with three international mountain region definitions (Kapos et al. 2000; Körner et al. 2017; Karagülle et al. 2017).

Extent of the Mountain Region of Sri Lanka

Using the definition in this study, Sri Lanka's mountain region covers an area of 9,940 square kilometers (km^2) or 15.1% of the island's total land area. The mountain area spreads over into all provinces except the Northern Province. Sixteen of the country's 25 districts are also associated with the mountain area (Table 1). The mountain region covers 111 DSDs and 3,409 GNDs.

Table 1: Mountain Area by District, Sri Lanka

District	Total Area of the District (km^2)	Mountain Area in the District (km^2)	Mountain Area as Proportion of District Area (%)
Nuwara Eliya	1,745.35	1,745.35	100.0
Kandy	1,924.03	1,742.72	90.6
Badulla	2,871.96	1,807.34	62.9
Matale	2,057.82	1,043.07	50.7
Ratnapura	3,288.70	1,511.57	46.0
Kegalle	1,661.26	493.43	29.7
Moneragala	5,752.25	829.19	14.4
Matara	1,309.94	181.60	13.9
Ampara	4,485.03	237.37	5.3

continued on next page

Table 1 continued

District	Total Area of the District (km^2)	Mountain Area in the District (km^2)	Mountain Area as Proportion of District Area (%)
Galle	1,615.66	82.32	5.1
Kurunegala	4,904.48	183.89	3.7
Kalutara	1,646.45	25.35	1.5
Hambantota	2,623.59	19.46	0.7
Polonnaruwa	3,446.32	15.72	0.5
Anuradhapura	7,212.23	20.47	0.3
Batticaloa	2,489.19	1.12	0.04

km^2 = square kilometers.
Note: Calculated using the 2017 district boundary layer of the Survey Department and mountain boundary map layers developed in 2018 under the country activities of ADB's regional TA Action on Climate Change in South Asia.

Sri Lanka has three geologically defined peneplains differentiated by elevation (Adams 1929; Wadia 1945; Cooray 1984).[4] The first peneplain or lowland is from sea level to 120 m, the second from 300 m to 760 m, and the third is 910 m upwards. The most prominent mountain top areas in Sri Lanka are in the third peneplain. Some authors (e.g., Cooray 1998) set 910 m upwards (third peneplain) as the mountain region. This report includes as "mountain region" the upper part of the second peneplain (above 500 m) and the third peneplain.

The mountain region of Sri Lanka can be divided into four geographical categories, the Central Highlands, the Knuckles Range, the Rakwana Range, and the isolated hills in the lowland peneplain (Map 1).

The Central Highlands

The Central Highlands comprise the largest mountain mass in Sri Lanka. The main mountain ridges are distributed in an anchor shape. The north–south directed "stem" or central mountain ridge peaks on Mount Pidurutalagala, the highest mountain in Sri Lanka (2,524 m) and Nuwara Eliya, a famous holiday destination town. The base of the anchor is a large plateau, Mahaeliya (2,100 m approximately), where the country's second and third highest mountains are located (Kirigalpotta, 2,395 m and Totapola, 2,359 m). The base arm curves slightly in an east–west direction from its center in Mahaeliya (the Horton Plains). The arch-shaped western arm extends up to the Laxapana area, which is significant as the northwestern part of the central mountain ridge. This rugged steep arm called Adams' Peak Range contains the famous Sri Pada Peak (2,243 m).

The Hatton Plateau is in the western half of the mountain region, partially encircled by the northeastern slope of Adams' Peak ridge and the western slope of the middle mountain ridge. There is a relatively broad variedly eroded plateau with an elevation of 1,000–1,200 m. Several rivers cut deep valleys between southeast–northwest-oriented parallel hill ranges in the area. Several waterfalls are formed in the escarpment of the Hatton Plateau. The northernmost portion gradually descends and merges with the wide Kandy Valley. An important network of hydroelectric reservoirs is in this area (Maskeliya, Castelreigh, Norton Bridge, Canyon, and Upper Kotmale).

4 A peneplain is a gently undulating, almost featureless plain that, in principle, would be produced by erosion that would, in the course of geologic time, reduce the land almost to base level, leaving so little gradient that essentially no more erosion could occur. The areas in between peneplains are referred to as slopes or inclines.

The Dolosbage Hills are a scattered range in the western end of the Central Highlands, which is separated from the Hatton Plateau from the Nawalapitya area by the Mahaweli River. The hill cluster stands at 1,000 m to 1,200 m. The western part of the hill range steeply descends to the first peneplain and is bounded by Kitulgala, Yatiyantota, and Bulathkohupitiya.

The eastern arm of the anchor ridge runs from the eastern flank of the Maha Eliya Plateau. The narrow steep mountain ridge is aligned in an east to northeast direction. The highest peak of this narrow mountain range is Namunukula (2,005 m). Two significant gaps in the ridge, Haputale and Ella, offer panoramic views of the lower peneplain.

The Madolsima and Lunugala mountain range areas run in a north–south direction. These mountains run as two long and steep parallel ridges separated by deep valleys. The range marks the eastern margin of the Central Highlands.

The Uva Basin is encircled by the middle mountain arm and the eastern part of the anchor ridge with the Lunugala–Madolsima mountain range. The basin is a relatively flatter area with a lower elevation than Hatton Plateau (900–1,200 m). The Uma Oya, Badulu Oya, and Loggal Oya river basins, running relatively parallel in a north–south direction, dissect the eastern part of the Uva Basin. This area lies in a rain shadow during the southwest monsoon (SWM) and experiences a dry, cooler climate due to the central mountain ridge.

The southern slope of the anchor-shaped mountain rim is a generally steep escarpment descending from 2,000 m on the upper peneplain to 300 m on the lower peneplain. This area is considered the southern mountain wall.

The relatively broad Mahawalatenna Plateau, about 500–600 m, is in the lower part of the southern escarpment. The main branches (Belihul Oya, Weli Oya) of the Walawe River flow through this plateau.

The undulating Kandyan terrain and the Dumbara Valley lying in the northern part of the Central Highlands consists of mosaics of tapering hill ridges covered with Kandyan Home Gardens and shallow valleys with paddy fields. These are separated from the Knuckles Mountain mass to the north and east. Elevations vary between 450 m and 700 m.

The Matale valley is a narrow north–south valley that lies between Knuckles Ridge and the ridges of the Matale Hills. This valley has microclimate conditions suitable for growing several valuable spices.

The Knuckles Mountain Range

The Knuckles Range is located north of the Central Highlands and is separated from the Central Highlands by the valley of the Mahaweli River in Kandy. It runs northwest to southeast, and altitudes vary from 1,400 m to 1,800 m. The Knuckles Range lies within Kandy and Matale Districts. The rivers originating from the Knuckles Mountain massif feed into the northern part of the Mahaweli River. Protected areas in the Knuckles Mountain are part of the Central Highlands World Heritage Site, along with the Peak Wilderness and Horton Plains.

The Rakwana Mountain Range

The Rakwana Range, sometimes referred to as the Sabaragamuwa Hills (Erb 1984), is in the southwestern part of Sri Lanka and is separated from the Central Highlands. It runs in a southeast to northwest direction with a general elevation of 1,000–1,300 m, which includes the highest peak (Gonagala Hill 1,320 m) and two distinct plateaus (Handapan Ella Plains at 1,200 m ca and Thangamale Plains at 1,000 m ca). Most areas here are covered with forests. The hill range is partially connected to the Sinharaja World Heritage Site. Despite its small size, the Rakwana Range is significant because it is the catchment for the Kalu, Gin, Nilwala, and part of the Walawe Rivers, which flow into Ratnapura, Galle, and Matara Districts.

The Rammale Range is a parallel low-lying (500–700 m) range running in a northeast–southwest direction from the southern end of the Rakwana Range. The Matara–Hambantota District border lies along the Rammale Range, part of which forms the border of the wet and intermediate zones. This hill range is an important watershed for many rivers, including part of the Nilwala Ganga, Kirama Oya, and Urubokka Aara, which border the intermediate and wet zone boundary.

The Isolated Hills in the Lower Peneplain

Many isolated hills with a height of about 500 m or higher are present in the lower peneplain. Table 2 shows prominent isolated hills which may be considered erosional remnants (Cooray 1984). Many of these isolated hills show the Massenerhebung Effect (Grubb 1971).[5] There are many scattered isolated hills in the northern and eastern plains of the country. The latter hill cluster is sometimes called Gal Oya Hills or Bintenna Hills. The peaks of isolated hills typically have rugged, exposed rock-dominated steep terrain. Some of the taller hills show a hilltop environment with a frequent mist cap. However, there are few studies on the ecology of these hills (e.g., Lewis 1907, 1908; Willis 1906, 1908), which are locally and regionally important for various ecosystem services, especially water conservation, which is critical when the isolated hills lie within the intermediate or dry zones (Table 2).

Table 2: Significant Isolated Hills in the Lower Peneplain by Climate Zone, Sri Lanka

Climate Zone and District	Name of Hill	Hill Height (meters)
Wet Zone		
Kegalle	Batalegala	798
Ratnapura	Kukulugala	704
Galle	Hinidumkanda (Haycock)	661
Intermediate Zone		
Monaragala	Maragala	1,100
Badulla	Bintanna	729
Ampara	Kokagala	687
Monaragala	Unukirigala	660
Ampara	Walibehela (Friar's Hood)	658
Kurunegala	Doluwakanda	620
Monaragala	Govindahela (Westminster Abbey)	558
Polonnaruwa	Dimbulagala (Gunner's Quoin or Gunner's Rock)	534
Ampara	Nuwaragala	400
Dry Zone		
Anuradhapura	Ritigala	766

Source: Fernando, R.H.S.S. 2011. Biodiversity of Ecological Communities and the Biogeography of their Species in Three Isolated Hills in Sri Lanka. Unpublished PhD dissertation, Postgraduate Institute of Sciences, University of Peradeniya, Sri Lanka.

5 The Massenerhebung Effect (German for "mountain mass elevation") describes variation in the tree line based on mountain size and location. In general, mountains surrounded by large ranges will tend to have higher tree lines than more isolated mountains due to heat retention and wind shadowing (Grubb 1971).

Geology

The geological formation of Sri Lanka dates to the pre-Cambrian age (1,000–2,500 million years) and is mainly comprised of metamorphic rocks of a crystalline and foliated nature. The Highland Series, the main subformation, represents the mountain region and runs northeast to southwest as a broad strip through the middle of the country. The Kadugannawa Complex is a relatively small geological formation around the Kandy–Matale area (Cooray 1984).

Soil

There are several distinct soil groups in the mountain region. Variants of red-yellow podzolic soils cover about 60% of the area. The higher plains in the mountain chains have red-yellow podzolic soils with a prominent A1 horizon. Both red-yellow podzolic soils and mountain regosols are found around the main mountain chains. Along the mountain slopes, red-yellow podzolic soils are common in steeply dissected, hilly, and rolling terrain. In the northwestern part of the mountain region, reddish-brown latosolic soils are found in dissected, hilly, and rolling terrain.

III

Main Features and Characteristics of Sri Lanka's Mountain Region

Climate

The climate in the mountain region varies significantly from the lowland peneplain. The main climate drivers of the mountain region are orographic monsoonal rains that create comparatively drier and wetter conditions and temperature lapse rates along contour lines.[6]

Key Climate Variables

The main climate variables in the mountain region are rainfall, temperature, wind velocity, and relative humidity. While sufficient data on rainfall in Sri Lanka weather stations are available, only a few stations have temperature records in the mountain zone.

Rainfall

The influence of two monsoons and two inter-monsoons are highly varied within the mountain zone. The western and southwestern slopes of the mountain zone show high annual rainfall compared to the southeast and northern parts. This is observed on the southern slope of the Central Highlands and Rakwana Range, which receives 4,000–4,500 mm during all three rainfall seasons, except the northeast monsoon (NEM). The isolated hills on the far northern side of the mountain region receive the lowest annual rainfall of approximately 1,300–1,450 mm, mainly during the second inter-monsoon (SIM) and NEM (Map 2).

The first inter-monsoon (FIM) lasts from mid-March to the first half of May and typically delivers 600–630 mm of rainfall, which accounts for roughly 14% of the total annual rainfall. It strongly influences the southwest parts of the mountain region, particularly the upper areas of the Kelani and Kalu Basins. FIM gradually decreases towards the eastern side of the mountain region and is the lowest at 150–170 mm in the isolated hills of the eastern parts.

6 The temperature lapse rate in an atmosphere is the rate of decrease of temperature with height.

The southwest monsoon (SWM) lasts from May to July and delivers between 2,500 mm and 2,700 mm or 30% of the annual total rainfall in the southwest part of Sri Lanka. This has a high impact on the southwest part of the mountain region, including the southern slopes of the Central Highlands in the Kalu, Kelani, and Mahaweli Basins (Kotmala Oya, Puna Oya, Agra Oya). The influence of the SWM is lower at 220–240 mm in the eastern and northern parts of the mountain region.

The SIM in September to November delivers 30% (850–900 mm) of the annual total rainfall for the whole island, significantly affecting the whole mountain region. The SIM influence is lowest at 430–450 mm in the northern part of the region.

The NEM occurs from December to January and delivers 800–900 mm of rainfall, mainly affecting the drier northern and eastern parts of the mountain region. These monsoons bring less rainfall (approximately 250–300 mm) to the wetter western and southwestern parts of the mountain region, with Nuwara Eliya and Ambagamuwa receiving the least (Map 2).

Temperature

There are significant temperature gradients in the mountain region. Because of elevation, low temperatures have been recorded in the higher areas, such as Nuwara Eliya (10°C–15°C). Lower mountain areas record higher temperatures (30°C–31°C). This is common to both the maximum and minimum temperatures.

Wind

Temporal variations of wind velocity and humidity are important factors influencing the mountain climate. However, long term data on wind velocity and seasonality in the mountain region are scarce.

The annual wind pattern varies with season and location within the mountain region. During the SWM period, the rain shadow side of the northern and eastern parts of the mountain region have strong winds due to orographic precipitation and the Foehn Effect.[7] These dry winds, occurring usually from June to September, are one of the main climate drivers that influence most of the environmental and socioeconomic conditions in the area. The wind results in high desiccation of groundwater and crop damage and contributes to the spread of forest fires. The locals call this "Ill Hulan" or "Kachan Wind" (Punyawardhana 2008).

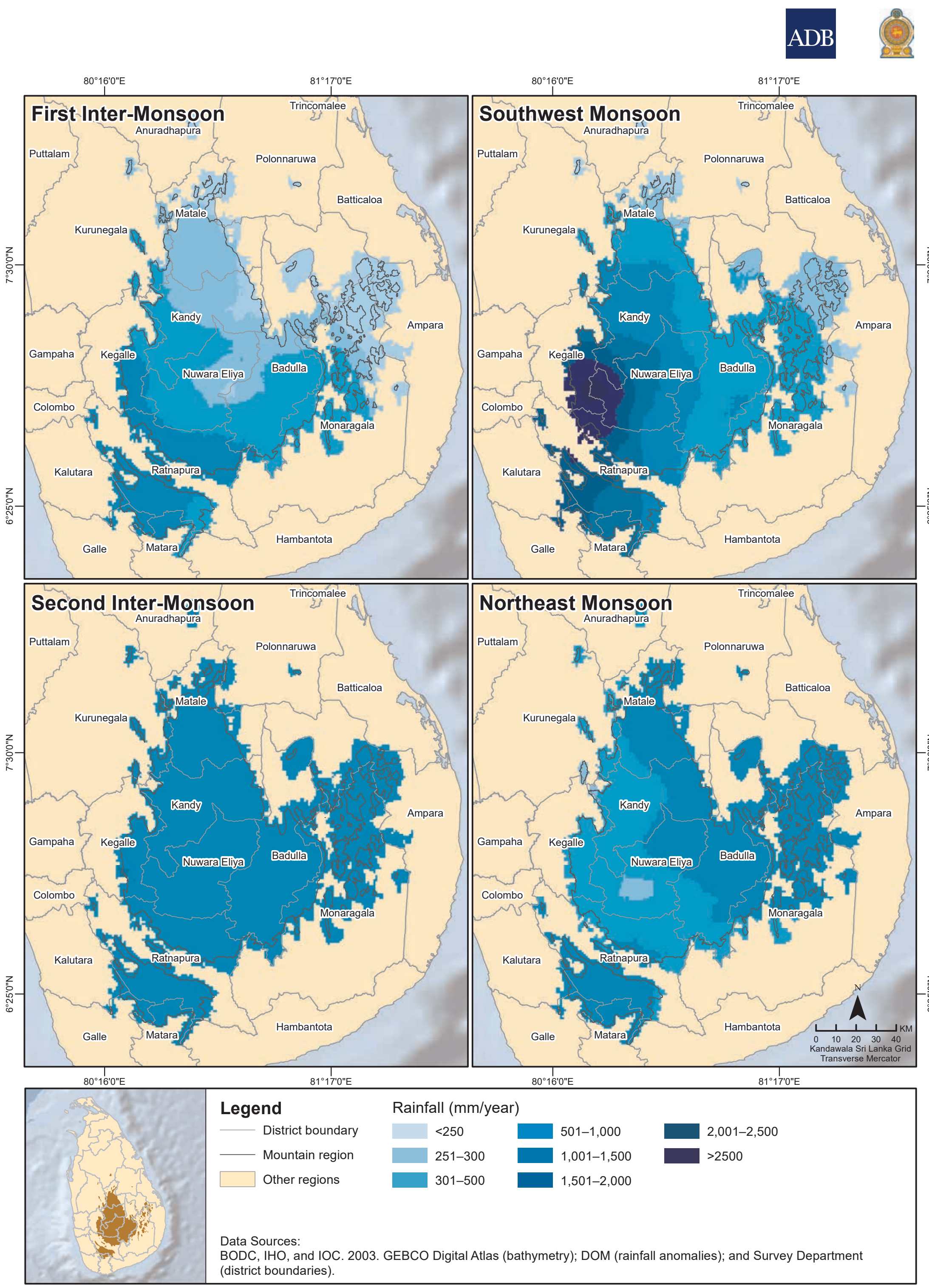
According to the wind map, the highest velocity of about 10 m/second (m/s) was recorded along the steepest mountain ridges of the northern flank of the central mountain ridge and in the Knuckles Range.[8] The valley bottom areas on either side of the Central Highlands, Deraniyagala, and Badulla show the lowest speed of about 3.0–3.5 m/s.

The southern slopes of the mountain region (Godakawela, Balangoda, and Haputale) show moderately high annual winds of about 5–6 m/s. The northern parts of the mountain region (Kandy, Knuckles, and Elahara) show relatively high wind conditions, ranging at 5–9 m/s. All isolated hilltops in the dry and intermediate zones show moderate to high winds of about 6–9 m/s.

7 The Foehn wind effect is a dry, warm, down-slope wind that occurs in the lee (downwind side) of a mountain range. Source: NetworkMeteorology. n.d. *What is the foehn effect*? https://www.meteorologiaenred.com/en/foehn-effect.html.

8 Additional information is available at UL Wind Map. https://aws-dewi.ul.com/knowledge-center/maps/.

Map 2: Observed Seasonal Rainfall in the Mountain Region, Sri Lanka



Data Sources:
BODC, IHO, and IOC. 2003. GEBCO Digital Atlas (bathymetry); DOM (rainfall anomalies); and Survey Department (district boundaries).

Climate Zones

Due to the variability of altitude and climate drivers, different areas of the mountain region experience different climate conditions. The distribution of natural resources, modes of human intervention, and the occurrence of potential impacts of climate change also vary in these areas. Map 3 and Table 3 show the subclimate zones based on altitude and rainfall gradients.

Map 3: Climate Zones in the Mountain Region, Sri Lanka

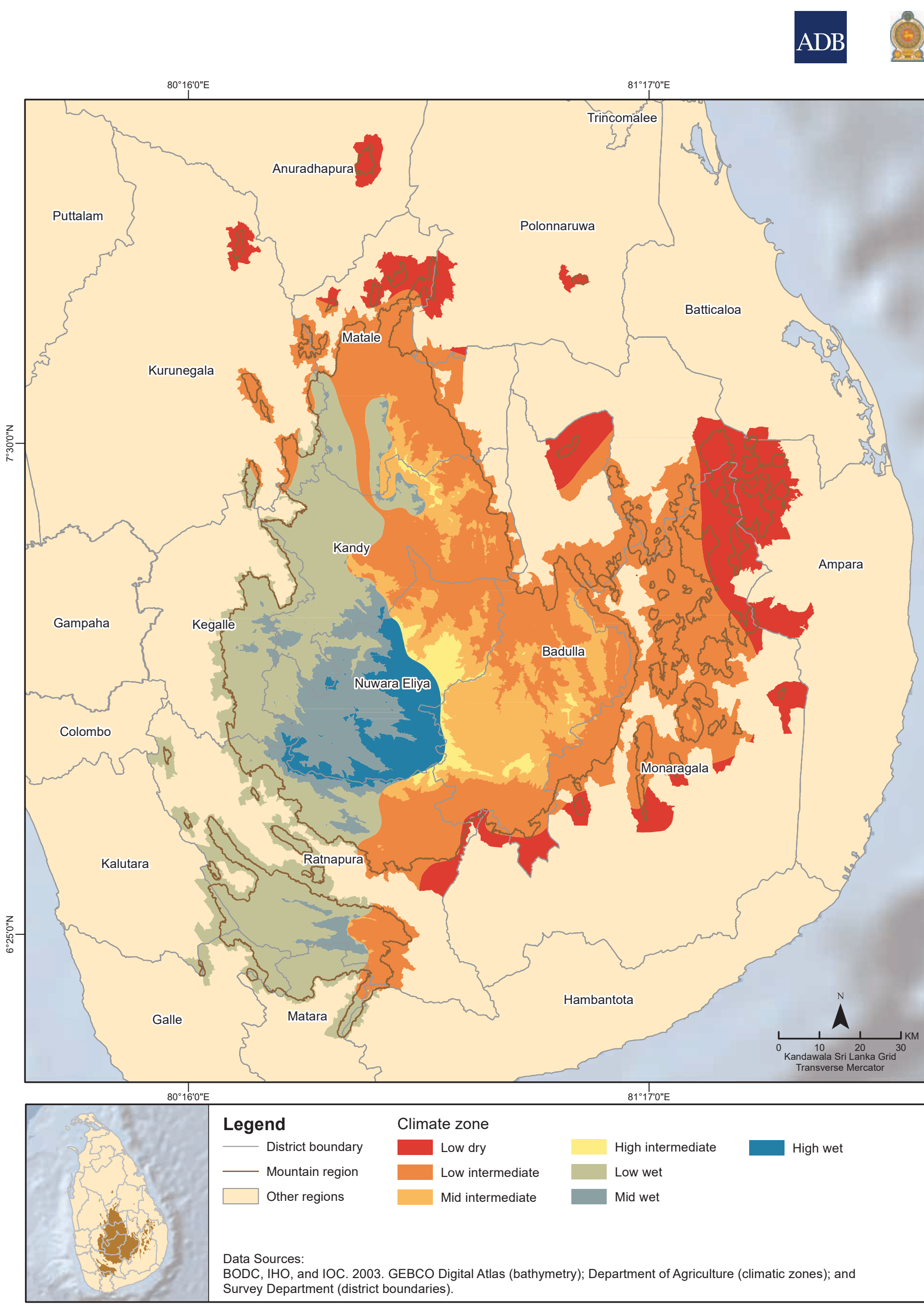


Table 3: Climate Zones in the Mountain Region, Sri Lanka

Climate Zone and Rainfall Gradient	Elevation Zone		
	Lower Mountain Region (<900 m)	Mid-Mountain Region (900–1,500 m)	Upper Mountain Region (>1,500 m)
Wet zone Rainfall >2,500 mm	Lower mountain wet zone = southwest part of the lower elevation region and its isolated hills (1,628 GNDs)	Mid-mountain wet zone (428 GNDs)	Upper mountain wet zone (155 GNDs)
Intermediate zone Rainfall 2,500–1,750 mm	Lower mountain intermediate zone = eastern part of the intermediate zone with mountain lower slopes and isolated hills (1,520 GNDs)	Mid-mountain intermediate zone (845 GNDs)	Upper mountain intermediate zone (168 GNDs)
Dry zone Rainfall<1,750 mm	Lower mountain dry zone (92 GNDs)		

GND = Grama Niladhari Division, m = meter, mm = millimeter.
Note: This table was developed under the country activities of ADB regional TA Action on Climate Change in South Asia using climate zone layer (Department of Agriculture 1960), elevation data (NASA and USGS SRTM 30-meter digital elevation model [DEM]), and GND boundaries (Survey Department 2017).
Source: ADB. 2018. *Climate Change Vulnerability in the Mountain Region of Sri Lanka*. Draft Consultant's Report (unpublished). Manila (TA 8572-REG).

Watersheds and Drainage Basins

Mountains provide important watershed protection and water provision to areas far from the mountainous zone. Mountains induce high precipitation levels, store and distribute water to the lowlands (Viviroli and Weingartner 2004), and capture mist from clouds (Bubb et al. 2004). Sri Lanka's mountain region reflects these functions significantly.

The geography of the mountains influences the capacity to receive water by orographic precipitation and water accumulation by fog interception in higher altitudes. Within the mountain mass, numerous cracks and openings of various sizes and depths in different altitudes act as massive aquifers, which store water temporarily or permanently. These aquifers are in high altitudes and water is continuously released to river systems by gravity throughout the year. Mountains are therefore regarded as the nation's water towers. In Sri Lanka, the mountain region is the main water accumulation and distribution center.

Drainage Basins

Drainage basins in Sri Lanka are distributed in a radial pattern from the mountain region. Of the country's 103 river basins, 23 directly originate from the mountain region as defined in this study. These river basins capture 77% of the island's total rainfall (Senaratne 2007).

The Mahaweli Basin occupies the largest area (10,327 km^2) of over 50% of the mountain region, including the whole Knuckles Range, and receives the highest rainfall volume (20,101 million cubic meters [MCM]). The basin expands to the wetter and intermediate climate zones of the mountain region and the river flows to the dry lowland area in the northeast direction. Another nine river basins originate in the Central Highlands. Among them, Gal Oya, Menik Ganga, and Kubukkan Oya flow from the east to the southeast. Maha Oya, Deduru Oya, and Kala Oya flow northwest. These nine rivers flow through dry and intermediate parts of the country. The Kelani River basin occupies 8% of the mountain region, flows through a high rainfall zone, and has an annual flow volume of 7,865 MCM (Senaratne 2007).

The Kalu and Walawe Basins occupy the Central Highlands and Rakwana Range. Kalu has a mountain catchment area of 10%, while Walawe covers 9%. The Kalu River has the second-highest rainfall rate in the basin (9,690 MCM).

The Gin and Nilwala Rivers originate from the Rakwana Range while the Bentara River originates in the foothills of the Rakwana Range. These three rivers flow to the wetter southwest part of Sri Lanka. The Urubokka Oya starts from the Rammale Hills, a subregion of the Rakwana Range, and is important for distributing water to the country's Southern Intermediate Zone (Table 4).

Table 4: Areas and Volumes of Main River Basins in the Mountain Region

River Basin	Area of the River Basin			Area Covered by a portion of the River Basin (%)	Volume of Rainfall (MCM)	Volume of Discharge (MCM)	Discharge as Volume of Rainfall (%)
	Total Area (km^2)	Area within Mountain Region (km^2)	Area within Mountain Region (%)				
Mahaweli Ganga	10,327	4,604	44.6	46.30	20,101	4,009	19.9
Walawe Ganga	2,442	846	34.6	8.50	4,333	350	8.1
Kalu Ganga	2,688	834	31.0	8.39	9,690	4,032	41.6
Kelani Ganga	2,278	746	32.7	7.50	7,865	3,417	43.4
Gal Oya	1,792	273	15.2	2.74	3,641	237	6.5
Maha Oya	1,510	225	14.9	2.26	4,109	1,746	42.5
Gin Ganga	922	220	23.9	2.21	2,662	1,268	47.6
Kirindi Oya	1,165	209	17.9	2.10	1,885	74	3.9
Deduru Oya	2,616	184	7.0	1.85	4,522	1,608	35.6
Kumbukkan Oya	1,218	175	14.4	1.76	1,976	472	23.9
Menik Ganga	1,272	165	13.0	1.66	2,124	347	16.3
Nilwala Ganga	960	97	10.1	0.98	2,337	1,152	49.3
Mundeni Aru (Maha Oya)	1,280	81	6.3	0.81	2,240	757	33.8
Kala Oya	2,772	81	2.9	0.81	3,304	386	11.7
Heda Oya	604	45	7.5	0.45	1,012	394	38.9
Maduru Oya	1,541	31	2.0	0.31	2,697	226	8.4
Andella Oya	522	22	4.2	0.22	783	278	35.5
Magalavatavan Aru (Unnichchi Aru)	346	22	6.4	0.22	536	195	36.4
Malwathu Oya (Aruvi Aru)	3,246	16	0.5	0.16	4,324	192	4.4
Urubokka Oya	348	15	4.3	0.15	499	86	17.2
Mi Oya	1,516	4	0.3	0.04	1,846	40	2.2
Karanda Oya	422	2	0.5	0.02	633	253	40.0
Wila Oya	484	0.17	0.04	0.00	707	254	35.9

km^2 = square kilometers, MCM = million cubic meters.
Source: Adapted from Senaratne, P.C. 2007. Surface Water. In *National Atlas of Sri Lanka*, 2nd Edition, Survey Department of Sri Lanka. pp. 60–62.

Scattered isolated hills also make significant contributions to most river flows. Examples are parts of Kala Oya and Daduru Oya, which originate from the hills in the Matale Pallepola area. Ritigala is a significant watershed for the Malwathu Oya and Yaan Oya Rivers. The Gal Oya Mountains are scattered in the eastern part and feed into at least nine rivers, which all flow from the eastern to the southeast dry lowlands. Most of these rivers are seasonal (Map 4).

River and Stream Network

River and stream networks are distributed across the whole area of the mountain region with a higher density of streams near the main rivers.

Reservoirs and Water Bodies

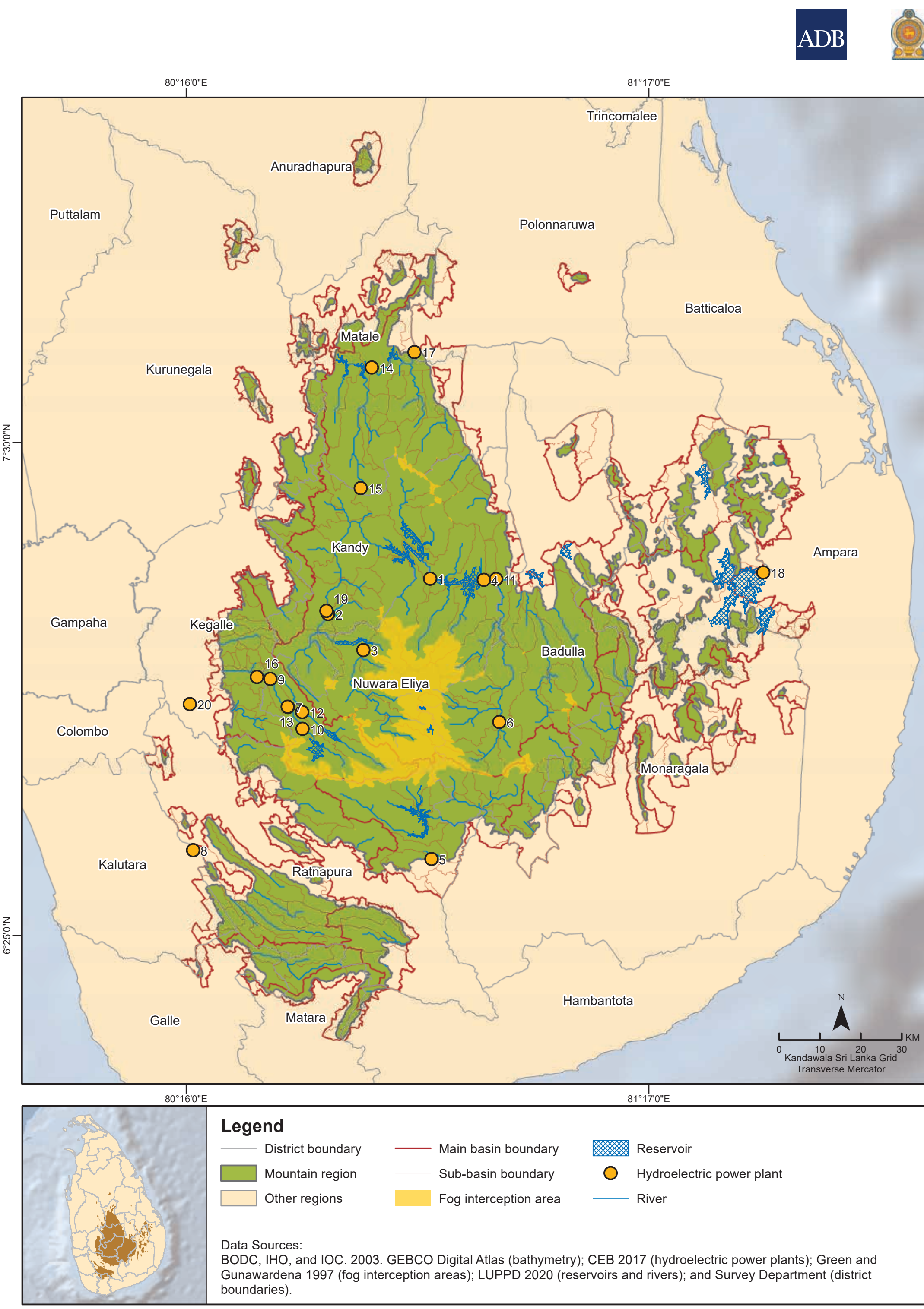
There are two types of water bodies associated with the mountain region: (i) water bodies within the mountain region and (ii) water bodies outside the mountain region but directly fed by the water sources originating from the mountain region. These water bodies range from those that extend over a large area to smaller ones (Map 4). Approximately 1,285 water bodies are associated with the mountain region. Of these, 532 are within the mountain region. Table 5 shows a list of major reservoirs fed from the mountain region.

Table 5: Major Reservoirs in and Associated with the Mountain Region

Name of Reservoir	Area (hectares)	Name of Reservoir	Area (hectares)
Alikandura Reservoir	234.2	Maduru Oya Reservoir	6,381.7
Ambewela Reservoir	24.8	Mahakandiya Tank or Degha Wewa	486.3
Balalu Wewa	706.7	Maussakele Reservoir	780.2
Batalagoda Wewa	255.2	Minneriya Wewa	2,251.6
Bopathtalawa	13.2	Moragahakanda Reservoir	4,172.9
Canyon Reservoir	10.9	Muruthawela Wewa	493.6
Castlereigh Reservoir	361.9	Muthukandiya Tank	1,780.4
Chandrika Wewa	505.7	Nachchaduwa Wewa	1,646.2
Deduru Oya Reservoir	1,295.8	Nagolle Dee Kodiunne Wewa	591.1
Divulana Tank	534.2	Nanu Oya Reservoir	47.7
Diyabanaoya Reservoir	147.4	Pannelagama Reservoir	473.2
Dyaraba Reservoir	16.1	Parakrama Samudra	2,576.7
Ekgal Aru Reservoir	405.8	Pimburattewa Wewa	878.2
Halmillapilawa Kandiya Wewa	59.5	Puhul Pola Reservoir (Uma Oya)	7.6
Handapangala Wewa	225.9	Rabukkan Oya	473.2
Hurulu Wewa	1,292.6	Rajangana Tank	1,760.6
Ibbankotuwa Reservoir	322.1	Randenigala Reservoir	2,384.4
Kala Wewa	1,495.8	Rantabe Reservoir	119.8
Kalu Ganga Reservoir	837.6	Ratkinda Oya Reservoir	838.4
Kandalama Tank	606.4	Samanala Wewa	801.4
Kande Ela Reservoir	50.5	Senanayaka Smudraya	7,937.7
Kaudulla Wewa	2,359.8	Senasuma Wewa	20.8
Kirama Wewa	30.9	Udawalawe Reservoir	2,979.8
Kiridi Oya Reservoir	56.1	Ulhitiya Oya Reservoir	1,677.5
Kotmale Reservoir	633.6	Upper Kotmale Reservoir	22.6
Kukule Ganga	33.8	Victoria Reservoir	2,321.8
Loggaloya Reservoir	532.8		

Source: Extracted from 2017 digital data (GIS) layers from Land Use Policy Planning Department.

Map 4: Hydrological Features in the Mountain Region, Sri Lanka



Data Sources:
BODC, IHO, and IOC. 2003. GEBCO Digital Atlas (bathymetry); CEB 2017 (hydroelectric power plants); Green and Gunawardena 1997 (fog interception areas); LUPPD 2020 (reservoirs and rivers); and Survey Department (district boundaries).

Fog Interception Activity

Fog interception or water collection from mist is an important hydrological function in mountain forests. The combination of a cool climate and high altitude turns air humidity into tiny water droplets which form mist or fog. When mist or fog contacts a cooler surface, it accumulates as large water drops and flows to the ground. This is often called horizontal precipitation—an important function when the area has heavy mist and a long period of low rainfall (Villegas et al. 2008).

The complex structure of tropical mountain rainforests, with its architecture and high presence of epiphytic plants, increases the canopy surface and persistency and maximizes fog interception (Holder 2004). Such forests frequently covered by mist are often called cloud forests. Fog interception by artificial structures such as buildings and most types of plantations and cultivated landscapes is not effective.

In Sri Lanka, an area higher than 1,500 m is regarded as suitable for fog interception (Map 4) (Green and Gunawardena 1997). The fog interception area is restricted to a small part of the Central Highlands and the highest ridge of the Knuckles Range. All the other areas in the mountain region do not contribute to fog interception according to the published literature (Green and Gunawardena 1997). However, some hills at lower elevations, like those in Rakwana, Monaragala, and Ritigala, exhibit the Massenerhebung Effect and demonstrate similar cloud forest characteristics, possibly generating some water from fog interception. This topic needs further research.

The largest fog interception area in Sri Lanka is along the Central Highlands arm of the highland region, which is in the Kotmale, Haguranketha, Nuwara Eliya, and Walimada Divisional Secretariat Divisions (DSDs). The continuing forest extends to the Peak Wilderness Nature Reserve and forms a single large cloud forest area that encompasses the Ambagamuwa, Deraniyagala, Ratnapura, and Imbulpe DSDs. The smallest cloud forest area is in the eastern arm of the Central Highlands. The Welimada, Haldummulla, Haputale, Badulla, and Passara DSDs have marginal cloud forest areas. Several potential areas in the upper mountain intermediate zone can be brought under cloud forest cover that may improve the watershed quality.

The total area capable of effectively intercepting fog is about 776.8 km^2 or 7.8% of the total mountain area in Sri Lanka. Fog interception by the natural cloud forests above 1,500 m is estimated at 730 MCM per year on average (Green and Gunawardena 1997). The highest amount of fog interception was recorded in the Peak Wilderness Nature Reserve at about 240.6 MCM, followed by those in the Knuckles and Pidurutalagala conservation forests, which are within the headwaters of the Kelani, Kalu, Walawe, and Mahaweli Rivers. The Horton Plains National Park recorded the highest amount of fog intercepted per unit area at 1,426.4 MCM/km^2, while the Knuckles Conservation Forest recorded the least amount (280 MCM/km^2) (Table 6). On average, Sri Lanka's mountain cloud forests capture 760 MCM/km^2 of water per year (Table 6) (Green and Gunawardena 1997).

Table 6: Fog Interception in the Main Mountain Forests

Forest Name by Protection Status	Area (km²)	Area Above 1,500 m (km²)	Volume ('000 m³)	Volume per Unit Area ('000 m³/km²)
Conservation Forests				
Knuckles	300.00	19.91	84,277	280.9
Pidurutalagala	76.13	75.14	75,611	1,119.0
Kadapola Sitha Eliya	26.16	26.16	23,924	914.5
Mahakudugala	16.39	14.80	15,678	956.6
Welegama	6.39	3.40	6,105	955.3
Namunukula	2.79	2.79	2,123	760.9
National Park				
Horton Plains	31.60	30.46	45,075	1,426.4
Nature Reserve				
Peak Wilderness	280.45	79.51	240,581	857.8
Proposed Reserves				
Agra-Bopats	69.34	49.70	67,591	974.8
Kikiliyamana	45.81	39.00	51,629	1,127.0
Bogawanthalawa	42.90	23.60	47,665	1,111.1
Ohiya	17.69	16.80	16,706	944.4
Pattipola-Ambewela	14.80	14.80	15,470	1,045.3
Conical Hill	7.08	7.08	7,399	1,045.1
Meepilimana	7.72	7.72	7,169	928.6
Nanu Oya	4.16	4.16	4,547	1,093.0
Harasbadda	3.64	3.64	3,384	929.7
Ragala	2.68	2.68	2,738	1,021.6
Sanctuary				
Tangamalei	1.32	1.32	998	756.1
Strict Nature Reserve				
Hakgala	11.42	11.49	10,982	961.7
Total	**959.91**	**439.80**	**729,652**	**760.1**

km^2 = square kilometers, m^3 = cubic meters.
Source: Adapted from Green, M.J.B. and E.R.N. Gunawardena. 1997. Designing an Optimum Protected Areas System for Sri Lanka's Natural Forests. Unpublished. A project of the Forest Department, Ministry of Agriculture, Lands and Forestry. Prepared by IUCN-The World Conservation Union and the World Conservation Monitoring Centre for the FAO of the United Nations. p. 201.

Hydropower

GIS analysis of data from the Sustainable Energy Authority (SEA) showed there are 22 large-scale and 264 mini-hydropower stations in Sri Lanka—most are in the mountain region. Nineteen hydropower stations in the mountain region collectively generate 1,609.2 megawatts (MW) (Table 7 and Map 4) and 200 mini-hydropower facilities provide a total of 504 MW.

Table 7: Main Hydropower Stations in the Mountain Region by Status, Sri Lanka

Number Code Location in Map 4	Main Hydropower Station	Capacity (megawatts)	Number Code Location in Map 4	Main Hydropower Station	Capacity (megawatts)
	Operational			**Under Construction**	
1	Victoria	210	6	Uma Oya	120
2	Kotmale	201	16	Broadlands	35
3	Upper Kotmale	150	17	Moragahakanda	25
4	Randenigala	126	19	Moragolla	30
5	Samanala	124	20	Sithawaka Ganga	30
7	New Laxapana	100			
8	Kukule Ganga	80			
9	Polpitiya	75			
10	Canyon	60			
11	Rantembe	52			
12	Wimalasurendra	50			
13	Old Laxapana	50			
14	Bowatenna	40			
15	Ukuwela	40			
18	Inginiyagala	11			

Source: Extracted from 2017 digital data (GIS) layers from Sustainable Energy Authority.

Crop Agriculture

The mountain area encompasses 15.1% of the total land area of Sri Lanka. GIS analysis of data from the Land Use Policy Planning Department showed that most of the mountain region is used for agriculture (267,925.6 hectares [ha] or 27%).

Agroecological Zones

Agroecological zones (see Box 1 for the classification codes) in Sri Lanka are based on three agriculturally important physical variables, i.e., 75% of expected monthly rainfall, altitude, and soil types (Punyawardhana 2008). Based on these variables, the mountain region represents 38 out of 46 agroecological zones in the country: 5 of 11 subzones in the dry zone, all 20 subzones in the intermediate zone, and 13 of 15 subzones in the wet zone (Table 8). There is a high number of agriculturally important areas in the mountain region. IL2a and WM1a are the largest agroecological zones in the mountain region, while Zone WM3b has the most GNDs, a factor critical for making decisions concerning agriculture (Table 8). Punyawardhana (2008) provides detailed descriptions of these agroecological zones.

Box 1: Character Codes of Sri Lanka's Agroecological Zones

Three major rainfall zones are indicated by the first upper case letter of the code: W=wet, I=intermediate, and D=dry.

Three categories of elevation are noted by the second upper case letter of the code: L=low, M=middle, and U=upper.

The numerical character in the third position represents the degree of wetness on a scale of 1 to 5, where 1 represents the most favorable condition.

The lowercase letter in the fourth position indicates a subregion as determined by rainfall and other physical environmental factors. The degree of wetness decreases from a to f.

Source: Dharmasena, P.B. 2019. Lesson 9: Climate and Soils of Sri Lanka. Lecture delivered under the course Poverty and Environment, Faculty of Social Sciences and Humanities, Rajarata University of Sri Lanka. https://www.slideshare.net/DharmasenaPb/9-climate-and-soils-of-sri-lanka.

Table 8: Agroecological Zones in the Mountain Region, Sri Lanka

Agroecological Zone Code (refer to Box 1)	Area (km^2)	Area of Mountain Region (%)	No. of GNDs	Agroecological Zone Code (refer to Box 1)	Area (km^2)	Area of Mountain Region (%)	No. of GNDs
DL1a	36.3	0.4	22	IU2	410.8	4.1	207
DL1b	63.5	0.6	34	IU3a	57.4	0.6	33
DL1c	31.9	0.3	11	IU3b	122.9	1.2	40
DL2a	283.2	2.8	20	IU3c	303.0	3.0	148
DL2b	5.9	0.1	2	IU3d	65.2	0.7	30
IL1a	70.8	0.7	87	IU3e	209.0	2.1	152
IL1b	12.8	0.1	13	WL1a	208.4	2.1	132
IL1c	202.0	2.0	94	WL2a	48.2	0.5	59
IL2	628.8	6.3	167	WL2b	20.8	0.2	22
IL3	28.4	0.3	40	WM1a	949.1	9.5	228
IM1a	499.6	5.0	316	WM1b	342.3	3.4	122
IM1b	498.3	5.0	130	WM2a	183.9	1.8	134
IM1c	275.2	2.8	95	WM2b	323.9	3.3	382
IM2a	331.6	3.3	140	WM3a	97.2	1.0	138
IM2b	738.0	7.4	183	WM3b	620.0	6.2	699
IM3a	124.1	1.2	178	WU1	484.8	4.9	123
IM3b	201.2	2.0	140	WU2a	336.0	3.4	86
IM3c	261.7	2.6	212	WU2b	253.5	2.6	93
IU1	328.4	3.3	129	WU3	282.2	2.8	56

GND = Grama Niladhari Division, km^2 = square kilometers.
Note: Percent area of the mountain region was calculated using the Department of Agriculture's 2003 agroecological zones, Survey Department's 2017 GND boundaries, and mountain boundaries as defined in this study.

Main Crops

Tea

Tea is the most significant and extensive plantation crop in the mountain region. Tea is grown on 151,419 ha or 83% of the total area. The country produced 278,900 metric tons of tea in 2020 (Central Bank of Sri Lanka 2021). Tea production is highly dependent on rainfall and temperature and production areas are categorized into three regions based on altitude. Low-grown tea is found at altitudes below 600 m, covering 33,591 ha. Mid-grown tea is planted in areas at 600–1,200 m, covering 58,013 ha. High-grown tea is found in areas above 1,200 m, covering 59,815 ha (Table 9).

Table 9: Tea Cultivation in the Mountain Region, Sri Lanka

Tea Region	Altitude (meters)	Cultivated Area (hectares)	Abandoned Area[a] (hectares)	Total Area (hectares)
Low-grown	<600	33,381.0	209.8	33,590.8
Mid-grown	600–1,200	54,106.8	3,906.1	58,012.9
High-grown	>1,200	58,275.0	1,540.3	59,815.3
Grand Total		**145,762.8**	**5,656.2**	**151,419.0**

[a] Abandoned tea areas are either temporary or permanent. Temporary abandoned areas are (a) fields that have old tea plants removed and enriched by grasses for the next tea planting cycle, or (b) areas where tea planting is resumed after some years due to initial financial restrictions. The cultivated and abandoned tea areas in Sri Lanka can be considered dynamic states.

Note: Calculated using 2016 land-use layer from Land Use Policy Planning Department and elevation data (NASA and USGS SRTM 30-meter DEM).

Based on rainfall variability, temperature fluctuations, and altitudinal zones, Sri Lanka has specific tea districts, each producing tea with a unique taste.[9]

- Nuwara Eliya Tea District: A high plateau 1,868 m above sea level in a cool climate with a prevalent wet condition with moderate rainfall. This region has the highest average elevation. Combined with low temperatures, this area produces the most refined and sought-after tea varieties such as whole leaf Orange Pekoe and Broken Pekoe.
- Dimbula Tea District: An area on the outskirts of Nuwara Eliya and Horton Plains, at 1,100–1,600 m. This area lies in and around the Hatton Plateau and has southwestern rainfall and cool weather. Dimbula Region is further subdivided into eight subdistricts, i.e., Hatton–Dickoya, Upcot–Maskeliya, Bogawanthalawa, Pathana–Kotagala, Lindula–Nanuoya–Thalawakele, Agrapathana, Pundalu Oya, and Ramboda. Due to their high geographical variation and microclimates, a range of flavors are produced with a predominant golden-orange hue.
- Kandy Tea District: Mid-grown tea is cultivated at an elevation of 650–1,300 m, although the major portion of this area is below 1,200 m. The district receives its main rainfall from the southwest monsoon. Most estates lie on the western slopes of the hillside and produce the best tea in the first quarter of the year when cool, dry weather sets in. Pusselawa–Hewaheta and Matale are the main subdistricts.
- Uda Pusselawa Tea District: Tea is grown at mid to high elevations of 950–1,600 m in a wedge between Nuwara Eliya and Uva areas, i.e., the eastern side of the Central Highlands. The main rainfall is from the northeast monsoon from November to January. Frequent misty conditions are prevalent in the region

9 The information on tea districts is scarce and not precise. This information has been acquired through discussions with planters' personal experience and information from the Sri Lanka Tea Board. http://www.srilankateaboard.lk/index.php/features/the-importance-of-origin.

and dry, cool, windy conditions are experienced during the southwest monsoon. The two subdistricts are Mathurata and Ragala-Halgran Oya.

- Uva Tea District: Characterized by mid to high elevations from 914 m to 1,524 m with intermediate climate conditions. The main rainfall is received during the northeast monsoon with a dry spell after May. The eastern boundary of Sri Lanka's tea-growing area is in this region. This tea, produced after a long dry spell, has a distinctly different taste from other Ceylon teas. The flavor and aroma are influenced by the reception of both northeast monsoon and southwest monsoon winds, which when traversing through the gulley and mountain slopes, shed their moisture on the lower slopes and carry dry winds to the higher elevations. The tea produced in this region is widely used for blends. The subdistricts in this region are Malwatte–Welimada, Demodara–Haliela–Badulla, Passara–Lunugala–Madolsima, Ella–Namunukula, Bandarawela–Punagala, Haputale, and Koslanda–Haldummulla.
- Sabaragamuwa Tea District: Low-country tea is grown at an elevation of around 800 m, mostly by smallholders. Fast-growing bushes with long leaves are cultivated in this region. It has a warm climate with high rainfall and fertile soils. This region produces a large quantity of tea although only a small area falls within the mountain region.
- Ruhuna Tea District: Low-country tea grown at elevations below 600 m, mainly in the southern lowland region of Sri Lanka. As in the case of Sabaragamuwa tea, a long leafed fast-growing bush is cultivated. The tea is a full-flavored black tea with a strong aroma, distinct to the regions of Deniyaya, Matara, and Galle.

Export Agriculture Crops in Home Gardens

Export crops are of great value due to their high market value. Among these export crops, cardamom, cloves, nutmeg, vanilla, coffee, cocoa, and pepper are grown mainly in the mountain region, with pepper, cinnamon, and coffee cultivated in small-scale plantations. Arecanut, betel, cinnamon, turmeric, and ginger are grown mainly in traditional home gardens in the mountain region known as Kandyan Home Gardens.

The Kandyan Home Garden is a traditional sustainable agricultural production system that is both ecologically and economically viable. It has a multi-strata vegetation structure and well-functioning ecological interactions, which conserve soil moisture, prevent erosion, and enhance pest control. The system contributes to household livelihoods (Pushpakumara et al. 2016). Kandyan Home Gardens are usually found in Kandy, Kegalle, Kurunegala, Matale, Nuwara Eliya, Badulla, and Ratnapura, which are within the historic Kandyan Kingdom. As of 1995, Kandyan Home Gardens covered an area of approximately 858,100 ha.

The essential characteristics and distribution of the main minor export crops in the mountain region are outlined below.

Cardamom

Cardamom is a highland crop grown above an elevation of 600 m. It is cultivated in the Knuckles Region in Kandy and Matale Districts, the Dolosbage Hills of Kegalle District, the eastern side of the Pedro Hill Range in Nuwara Eliya District, and the foothills of Peak Wilderness of the Ratnapura District. It is also cultivated in the hilly areas of the wet zone and on a small-scale in the Rakwana Range. Three varieties of cardamom are grown in Sri Lanka: Malabar is grown in the lower elevations, while Mysore and Vazhukka are grown at elevations above 800 m. Cardamom is a shade-loving plant grown under canopy cover and requires well-drained loamy soil with high organic matter. A well-drained annual rainfall of 1,500–2,500 mm and temperatures between 10°C and 25°C are most favorable for growth.

Nutmeg

Nutmeg flourishes in cooler climates and the mid-country areas of Sri Lanka are ideal for its growth. Sri Lanka grows nutmeg on 924 ha, 80% of which is within Kandy District. Kegalle and Matale Districts are the other major areas for nutmeg cultivation.

Nutmeg production requires a well-distributed annual rainfall of 1,500–2,500 mm and an average annual temperature between 20°C and 30°C. Nutmeg can grow at altitudes up to 1,500 m. Shade is an important factor during the first 2 years of growth, followed by exposure to light. A humid microclimate is also required for its establishment and fruit set. Persistent strong winds are harmful but sheltered valleys and leeward slopes are ideal for growing nutmeg.

Cloves

Cloves are cultivated on a total of 7,618 ha, mainly in Sri Lanka's mid-country wet zone and in Kandy, Matale, and Kegalle Districts. Deep, rich, well-drained loamy soil rich in humus are most suitable for growth. Cloves grow in a humid tropical climate up to 1,000-m elevation. The annual rainfall should be between 1,750 mm and 2,500 mm. However, flowering requires a dry period, which alternates with a moist one. The annual average temperature should be between 20°C and 30°C with less seasonal and diurnal variation.

Cocoa

Cocoa grows mainly in mid-elevation mountain areas in Matale, Kandy, Badulla, and Monaragala Districts. Grown below an elevation of 600 m, cocoa is typically cultivated as a mixed crop in Kandyan Home Gardens or as an understory in rubber plantations. Well-drained soil with rich organic matter is important for cocoa. The ideal temperature range is from 21°C to 32°C with an annual rainfall of 1,150–2,500 mm. This crop prefers high levels of shade, humid conditions, and less windy conditions as humidity drops.

Pepper

Pepper grows in well-drained loamy soils rich in organic matter at an altitude ranging from sea level to 800 m. Annual rainfall should not be less than 1,750 mm. Prolonged droughts have a deleterious effect on pepper unless supplementary irrigation is provided. A clear dry spell, sufficient rainfall, and temperatures between 15°C and 35°C are required for flowering and pollination. Strong winds are harmful. Pepper is mainly cultivated in the drier parts of the mountain region, including Matale, Kandy, Ratnapura, and Badulla Districts.

Other Crops Cultivated

Paddy

Paddy is cultivated on about 39,535 ha and is not a dominant crop in the mountain region. Significant areas are planted in Kandy (10,666 ha), Matale (5,436 ha), and Uva basins (10,893 ha). Terrace cultivation is the common method for growing paddy rice. In the Uva region, most paddy fields are planted with a variety of vegetables during the dry season.

Rubber

Rubber is generally a lowland crop but has also been grown in the peripheral areas of the mountain region at lower altitudes of the wet and intermediate zones. The land conditions vary from entirely flat to undulating steep terrain. In the mountain region, rubber is cultivated along hill slopes at lower elevations on a total of 20,835 ha. Rubber is most productive on well-drained, steep to moderately undulating hilly areas, with an ideal annual rainfall between 1,650 mm and 3,000 mm distributed evenly throughout the year. Annual rainfall of less than 1,250 mm is highly unfavorable (Tillekeratne et al. 2002). Rubber productivity severely declines if rainfall is less than 500 mm and is unevenly distributed over 6 months. Rainfall should occur ideally in the late evening, ceasing before the morning tapping. The ideal temperature should be between 23°C and 28°C. Temperatures below 20°C for more than a few weeks is unfavorable.

Coconut

Coconut is an invaluable resource cultivated on 20% of Sri Lanka's arable land, of which 20% are large-scale plantations and the rest owned by smallholders. Coconut is essentially a rainfed crop that does not require irrigation but needs well-distributed rainfall throughout the year. The ideal conditions for coconut cultivation include sand-mixed soils in the lowlands, with soil moisture retained throughout the dry period (Mahindapala and Pinto 1991). Coconut cultivation in the mountain region is restricted to the lower elevations in the wet and intermediate zones and is estimated at 5,952 ha total.

IV

Key Climate Change Risks and Impacts in the Mountain Region

Risk Assessment Framework and Methodology

Risk is assessed as a function of hazards, exposure, and vulnerability (i.e., susceptibility or proneness to be affected). The hazards used in the assessment are changes in temperature and rainfall within the mountain regions and associated hazards such as rainfall-induced landslides. Exposed elements consist of (i) hydropower stations; (ii) river basins; and (iii) water reservoir, agroclimatic zones, and crop cultivation (tea plantations, cash crops such as cardamom and nutmeg). Vulnerability is treated as the potentially affected physical areas exposed to hazards. For example, landslide vulnerability maps indicate areas where the potential for landslides is high.

Climate Projections

According to climate scenario RCP 8.5 in the 2040–2060 time period, these general changes with reference to the mean observed for the baseline period 1975–2005 can be expected. Climate change induced impacts are forecast by using the evidence of change between the baseline climatological period 1975–2005 and the projected climate patterns according to climate scenario RCP 8.5 in 2040–2060. Box 2 gives a more detailed account of climate projections based on a multi-assembled model developed by Sri Lanka's Department of Meteorology (DOM) as given in Jayawardhana et al. (2017).

The projections show the following climate trends (Table 10):

- The average annual rainfall in the whole mountain range (Figure 1) will increase.
- The northern and eastern parts of the mountain region will show small rainfall increments.
- The western and southwestern parts will show a markedly high rainfall increment.
- The highest rainfall trend will be experienced in the western arm of the Sri Pada Range and the foothills of the Central Highlands and the Rakwana Range.

- The Knuckles Range and isolated hills in the north and east together with the Lunugala–Madulsima Range will experience a marginal increase in annual rainfall.
- The Piduruthalagala Range towards the eastern arm of the high mountains will experience a moderate increase in annual rainfall.

Box 2: Climate Projections for Seasonal Rainfall, Annual Rainfall, and Annual Temperature for Sri Lanka

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset (Thrasher and Nemani 2015) is comprised of downscaled climate scenarios for the globe. It is derived from General Circulation Model (GCM) runs conducted under CMIP5 (Taylor et al. 2012) and across two of the four greenhouse gas emission scenarios of the Representative Concentration Pathways, i.e., RCP 4.5 and RCP 8.5. NEX-GDDP data for six GCM climate models (25-kilometer [km] grid resolution) were used to develop climate projections, as shown in the table.

The RCP 8.5 and RCP 4.5 scenarios from the IPCC Fifth Assessment Report (AR5) 2013, representing futures under high emission and moderate emission, respectively, were adopted, with three time periods, 2030s, 2050s, and 2080s. To address this source of uncertainty, single climate projections from climate models mentioned in table below are used to generate a multi-model ensemble.

The risk assessment used rainfall and temperature future scenarios downscaled by the Department of Meteorology, Sri Lanka. To define the hazard, the assessment developed multi-ensembled raster map series for each climate scenario model (average annual rainfall, average seasonal rainfall, average annual minimal temperature, and average annual maximum temperature) for the years 2030 and 2050 (for the RCP 8.5) using GIS and the Kriging interpolation technique and raster calculations in GIS spatial analysis.

CMIP5 Models Used to Develop Climate Projections for Sri Lanka

CanESM2	Second Generation Coupled Global Climate Model Canadian Centre for Climate Modelling and Analysis (2.8*2.8)
CNRM-CM5	National Centre for Meteorological Research, Meteo-France (1.4*1.4)
CSIRO-MK3-6-0	Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Queensland Climate Change Centre of Excellence (QCCCE) (1.895*1.875)
GFDL-CM3	Geophysical Fluid Dynamic Laboratory NOAA, USA Coupled Climate Model (2*2.5)
MRI-CGCM3	Global Climate Model of the Meteorological Research Institute, Japan (1.132*1.125)
NCAR-CCSM4	National Center for Atmospheric Research, USA Coupled Climate Model (0.942*1.25)

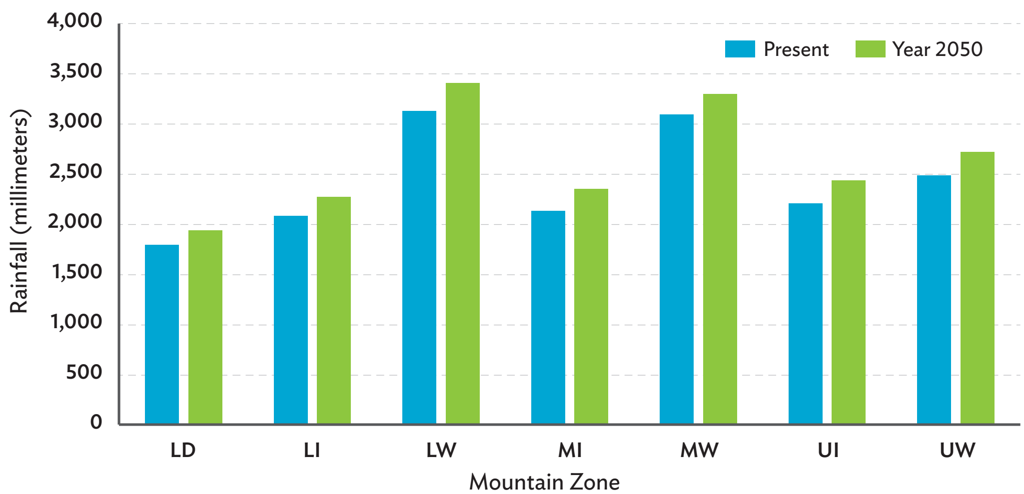
Source: Personal communication in January 2017 with M.S.P. Jayawardena, H.M. Roshan, C. Herath, and K.H.M.S. Premalal, Department of Meteorology, Sri Lanka.

Table 10: Schematic Diagram of Projected Rainfall Trends in the Mountain Region under RCP 8.5 2040–2060 with Reference to Baseline Period 1975–2005

Rainfall Season	Amount of Rainfall Received as % of Annual Total	Rainfall Trends in the Mountain Zones by Rainfall Regime and Elevation						
		Wet Zone (> 2,500 mm)			Intermediate Zone (1,750 mm–2,500 mm)			Dry Zone (< 1,750 mm)
		Lower (< 900 m)	Mid (900–1,500 m)	Upper (> 1,500 m)	Lower (< 900 m)	Mid (900–1,500 m)	Upper (> 1,500 m)	Lower (< 900 m)
First inter-monsoon	14	⬇	⬇	⬇	↓	↓	↓	↓
Southwest monsoon	30	⬆⬆	⬆↑	⬆	↑	↑	↑	↑
Second inter-monsoon	30	⬆⬆	⬆↑	⬆	↑	⬆	⬆	↑
Northeast monsoon	26	↓	↓	⬇	⬇	⬇	⬇↓	⬇↓
Annual average rainfall		⬆↑	⬆	⬆	↑	↑	↑	↑

Notes: Zones are according to Map 5. Size of arrows indicates the intensity of rainfall (bigger arrows, more intense; smaller arrows, less intense) and direction of the rainfall trend (up indicates increasing trend; down indicates decreasing trend).
Source of data: Government of Sri Lanka, Department of Meteorology. 2017.

Figure 1: Comparison of Present and Projected Annual Average Rainfall in the Seven Mountain Zones in Sri Lanka



LD – lower mountain dry zone
LI – lower mountain intermediate zone
LW – lower mountain wet zone
MI – mid-mountain intermediate zone
MW – mid-mountain wet zone
UI – upper mountain intermediate zone
UW – upper mountain wet zone

Source of data: Government of Sri Lanka, Department of Meteorology. 2017.

Projected Seasonal Rainfall and Temperature Anomalies

Seasonal Rainfall Anomalies

The FIM, which mainly covers the wet zone areas, contributes 14% of the annual rainfall across Sri Lanka. This rainfall mostly affects the south and southwestern parts of the mountain region which comprise the western slopes of the Sri Pada Hills and the Rakwana Range. Based on the projected climate scenario, the FIM will be considerably reduced in the whole mountain range. The reduction will be marginal in the eastern and southeastern parts and significant in the western and southwestern parts of the mountain region, which is currently receiving the highest FIM rainfall in the country. Projections indicate that the FIM will decline significantly.

The SWM is the main rainfall event in the wet zone, contributing 30% of the annual rainfall. Projections show that the SWM will strongly influence the whole mountain region. Rainfall intensity will be much higher in the western and southwestern slopes of the mountain region (Map 5).

The SIM, which also contributes to 30% of the total rainfall, is presently experienced by the whole mountain region and provides high rainfall to the western and southwestern parts of the mountain region. The projections show that the SIM will be much stronger in the whole mountain region, particularly in the southwestern flank and in the Rakwana Range.

The 1975–2005 climatology indicates that the NEM is the main source of rain for the northern and eastern parts of the mountain region from November to February. The NEM contributes 26% of the total annual rainfall in the country. However, the projected climate scenario indicates a reduction in rainfall. In the mountain region, the western and southwestern parts show a lower intensity in rainfall reduction, while the northern and eastern parts show a significant rainfall reduction. This projected precipitation pattern must be considered seriously as this is currently the main rainfall event in the drier parts of the mountain region.

Temperature Anomalies

The selected future scenario (RCP 8.5 in 2040–2060) indicates increasing temperatures throughout the whole mountain region in line with global trends. A higher increase of annual diurnal temperature (Tmax) can be seen in areas less than 900-m elevation in the northern and eastern parts of the mountain region. The temperature increase is projected to be lower in the higher parts of the mountains.

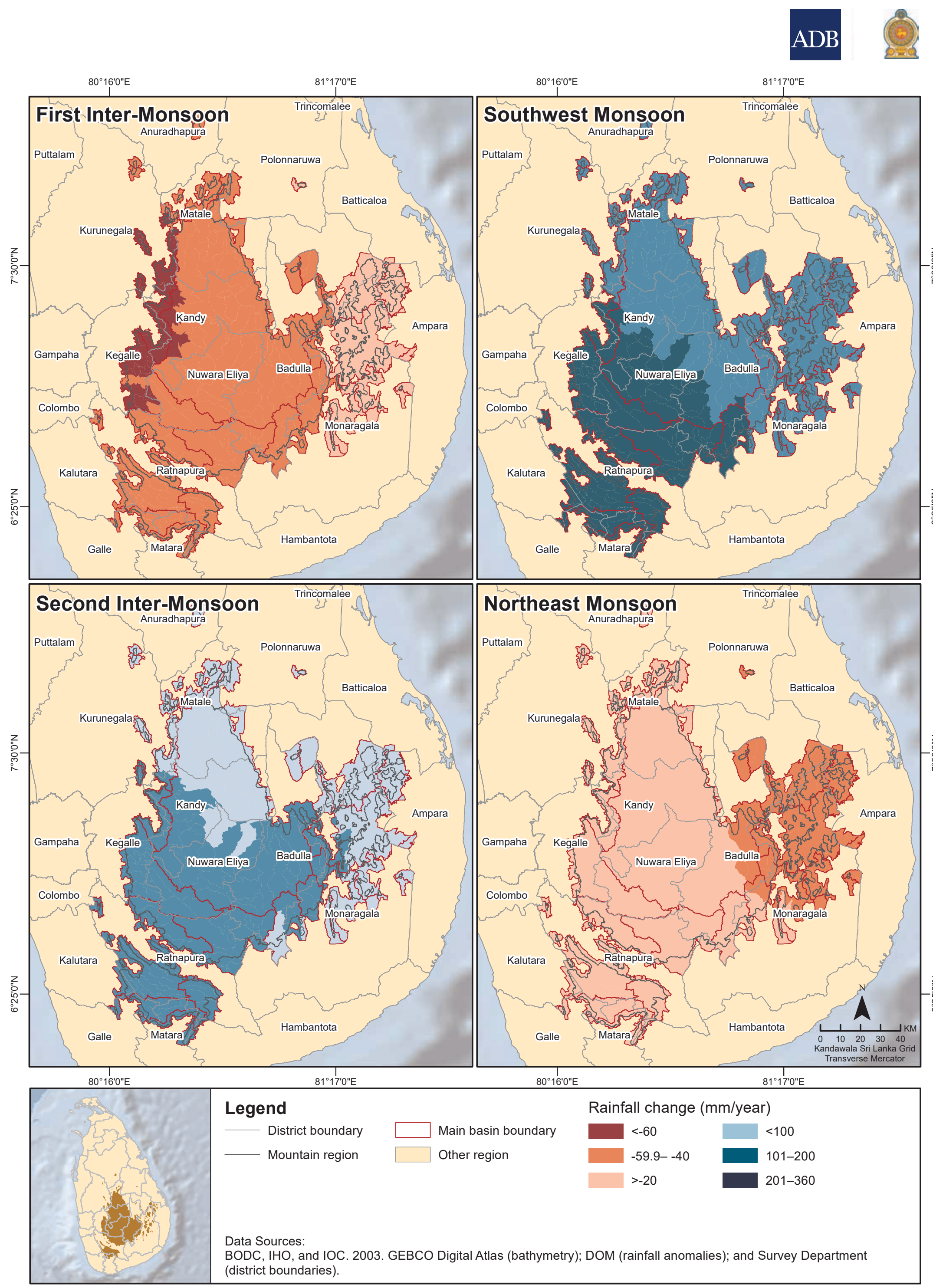
The change in the annual night temperature (Tmin) will be smaller in the southwestern part of the mountain region, while a higher temperature increase will be observed in the north and eastern parts. A moderate increase in nighttime temperatures is expected in the higher elevation areas of the mountain region.

Based on this analysis, some seasonal climate change impacts that may occur in and around Sri Lanka's mountain region can be summarized as follows:

Rainfall

- Significant climate seasonality can be observed along with a reduction of the NEM and the FIM. Prolonged drought can be experienced during the November to April period and in the rest of the year, heavy rains can be expected.
- Total annual rainfall will increase but will be received within a shorter period.
- The decrease in rainfall during the northeast monsoon will cause a potential drought in the intermediate and the dry zones of the mountain region.

Map 5: Projected Seasonal Rainfall Change in the Mountain Region under RCP 8.5 2040–2060 with Reference to Baseline Period 1975–2005



Data Sources:
BODC, IHO, and IOC. 2003. GEBCO Digital Atlas (bathymetry); DOM (rainfall anomalies); and Survey Department (district boundaries).

- The inter-seasonal change in rainfall over the southwestern part of the mountain region is likely to result in a significant loss of native and endemic biota. A seasonal climate with 0–1.9 continuous months with less than 100 mm rainfall in southwest Sri Lanka will also be included (Ashton 2014).
- In the southwest part of the country, increasing rains may increase the probability of floods with landslides occurring.

Temperature

- Projected day and night temperatures higher than today's levels will contribute to higher evaporation.
- The reduction of the gap between day and night temperatures will significantly affect the life cycle of some plants (e.g., potatoes) and some animal species (e.g., amphibians, insects) and affect production.
- Strong dry winds can be expected in the northeastern parts of the mountain region during the southwest monsoon period. This region has intensive annual vegetable cultivation that can cause disturbances to soil structure and a decline in soil water retention capacity and fertility. Expected prolonged droughts may make the soil susceptible to wind erosion. This could result in the development of dust storms in the lower mountain intermediate zone, mid-mountain intermediate zone, and lower mountain dry zone, which can cause health hazards such as asthma and other airborne illnesses.
- Drier soil conditions may emerge in many areas currently under cultivation. These will either require more irrigation or lead to the abandonment of agricultural land.
- Potential wildfires in the drier areas could increase during the SWM period due to the Foehn wind effect.

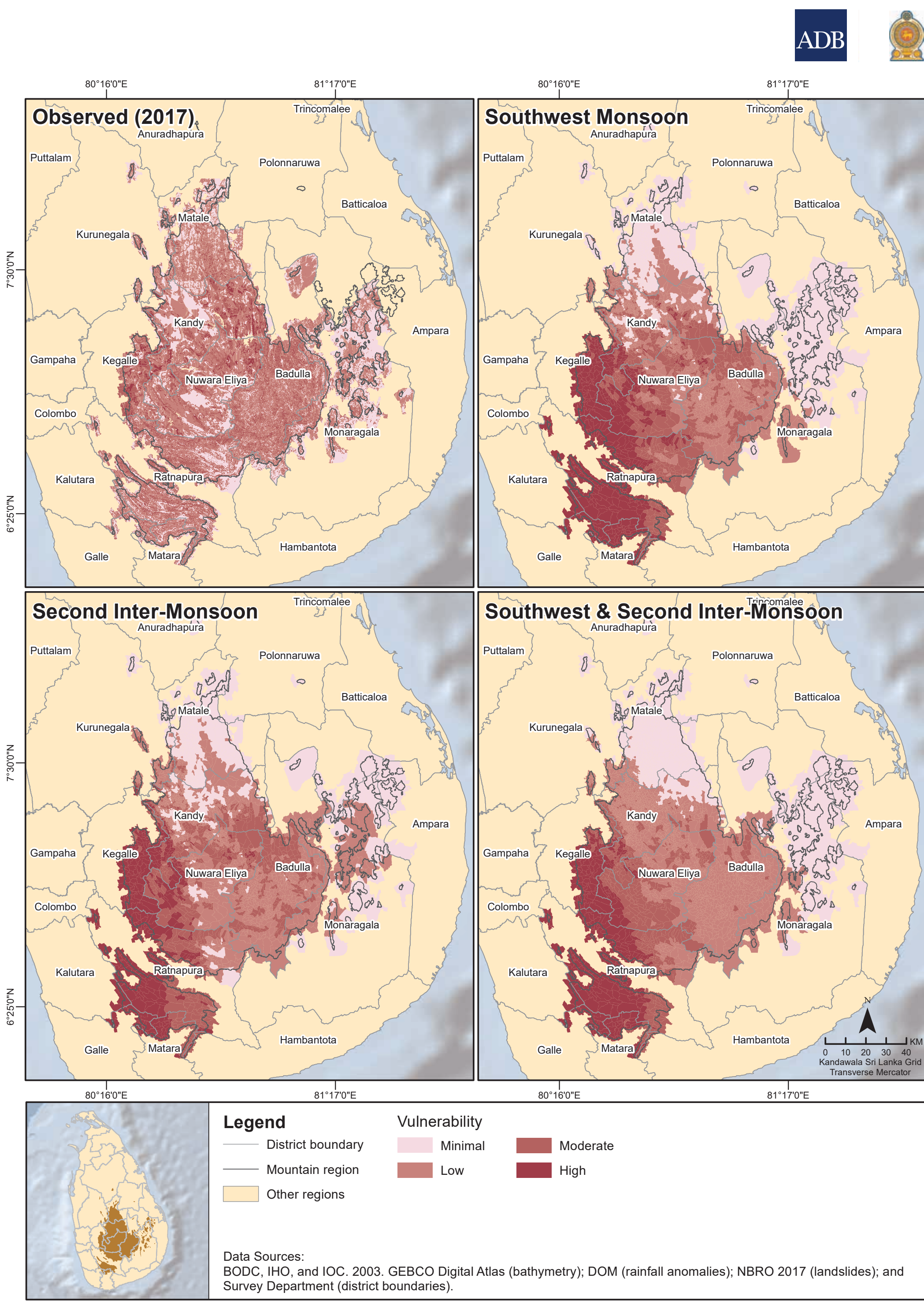
Landslide Potential Due to Projected Monsoon Seasons and Their Distribution

The potential disaster situations associated with climate change are of great concern to the general public. When considering the mountain region, several types of disasters triggered by climate change events are envisaged. However, no disaster is caused solely by climate change but results from a combination of multiple factors (Map 6).

Among those factors, heavy rainfall within a short period is the main trigger for landslides (Larsen and Simon 1993). The potential rainfall during the SWM and the SIM in 2040–2060 is projected to be higher than at present. Map 6 on susceptibilities to rainfall-induced landslides was constructed using landslide potential areas developed in 2017 by the National Building Research Organization and future rainfall anomalies under RCP 8.5 2040–2060, with reference to baseline period 1975–2005, for the SWM and SIM.

Map 5 shows the probability of receiving high rainfall in the southwestern part of the mountain region within the Sabaragamuwa Hills from Kegalle to the Hiniduma–Deniyaya areas. Moderately high rainfall is expected in the Kandy, Walapane, Nuwara Eliya, and Balangoda areas. Badulla, Haputale, and Mahiyangana areas show a relatively low rainfall pattern. The total annual rainfall in the mountain region is expected to increase and the major contributors will be the SWM and the SIM.

Map 6: Landslide Vulnerability in the Mountain Region under RCP 8.5 2040–2060 with Reference to Baseline Period 1975–2005



Map 6 and Table 11 show the number of GNDs by potential vulnerability to landslides during the SWM and SIM. Twelve districts show vulnerability to rainfall-induced landslides. Among these districts, Kandy, Kegalle, Nuwara Eliya, and Ratnaputra have GNDs with low, medium, or high vulnerability. The southwestern flank of the mountain range and the Sabaragamuwa Basin are more vulnerable to rainfall-triggered landslides during both the SWM and the SIM. During the SWM, 451 GNDs and 677 GNDs show high and medium vulnerability to landslides, respectively. Among those with high vulnerability, the most affected GNDs are Ratnapura, Nuwara Eliya, and Kegalle (in this order). Medium vulnerability can be seen in Nuwara Eliya, Kandy, Ratnapura, and Badulla Districts. Ratnapura and Kegalle Districts show high vulnerability to landslides for both SWM and SIM.

Table 11: Number of Grama Niladhari Divisions Vulnerable to Landslides by District and Season under RCP 8.5 2040–2060 with Reference to Baseline Period 1975–2005

District	High Vulnerability			Moderate Vulnerability			Low Vulnerability		
	SWM	SIM	SWM and SIM	SWM	SIM	SWM and SIM	SWM	SIM	SWM and SIM
Ampara	0	0	**0**	0	0	**0**	0	0	**0**
Anuradhapura	0	0	**0**	0	0	**0**	0	0	**0**
Badulla	1	0	**0**	103	67	**17**	371	396	**479**
Batticaloa	0	0	**0**	0	0	**0**	0	0	**0**
Galle	22	22	**22**	0	0	**0**	0	0	**0**
Hambantota	3	1	**2**	16	18	**19**	2	2	**0**
Kalutara	4	4	**4**	0	0	**0**	0	0	**0**
Kandy	47	43	**16**	183	168	**123**	510	494	**892**
Kegalle	86	95	**75**	31	40	**61**	22	4	**3**
Kurunegala	0	1	**0**	5	10	**3**	63	75	**79**
Matale	0	0	**0**	0	5	**0**	55	49	**46**
Matara	43	21	**37**	10	29	**16**	0	3	**0**
Monaragala	0	0	**0**	3	0	**0**	58	72	**77**
Nuwara Eliya	89	38	**20**	203	172	**190**	181	230	**281**
Polonnaruwa	0	0	**0**	0	0	**0**	0	0	**0**
Ratnapura	156	99	**141**	123	120	**114**	22	52	**46**
Total	**451**	**324**	**317**	**677**	**629**	**543**	**1,284**	**1,377**	**1,903**

SIM = second inter-monsoon, SWM = southwest monsoon.
Note: Calculated using climate projections in 2017 from the Department of Meteorology and 2017 Grama Niladhari Division boundary layers from the Survey Department.

Impacts of Climate Anomaly on Watersheds

Impacts on Surface Water Availability

The projected impacts of climate anomalies under RCP 8.5 by 2040–2060 show that the four rainfall seasons have different effects across watersheds. When mapped over the watershed areas, the anomalies expected due to changing rainfall patterns clearly demarcate spatial and temporal differences (Map 7).

Under RCP 8.5 scenario (2040–2060), the western and southwestern flanks of the mountains will receive higher rainfall, which may lead to excessive erosion and heavy floods (Map 7). However, a distinct dry season will also occur due to the failure of the FIM. The river basins of Attanagalu Oya, Kalani, Kalu, Bentara, Gin, and Nilwala can be affected by heavy seasonal floods. Maha Oya, Walawe Ganga, and Kirama Ara may experience moderate floods.

With the failure of the NEM, the eastern and northern parts of the mountain region will receive low rainfall, which could lead to prolonged dry periods. The river basins fed from the drier parts of the mountain region will suffer severe water shortages. Most subbasins of the Mahaweli River, particularly the Uma Oya, Mathatilla Oya, Sudu Ganga, and Amban Ganga areas will receive significantly lower rainfall from December to April. Due to the decrease in rainfall in the upper areas of the mountain region such as in Nuwara Eliya, potential water scarcity may increase. Hence, a sustainable water management system will be required to meet the demands of agriculture and human consumption.

Twelve of the 19 hydropower plants which are fed by these subbasins are in the high-risk category due to the weakening of FIM rainfall. These 12 hydropower plants have a current total capacity of 831 MW. All power plants except two have a moderate to high risk level and face potential extended drought periods (Table 12 and Map 8).

Table 12: Projected Impact on Hydroelectricity Generation of Insufficient Rainfall for Each Subbasin

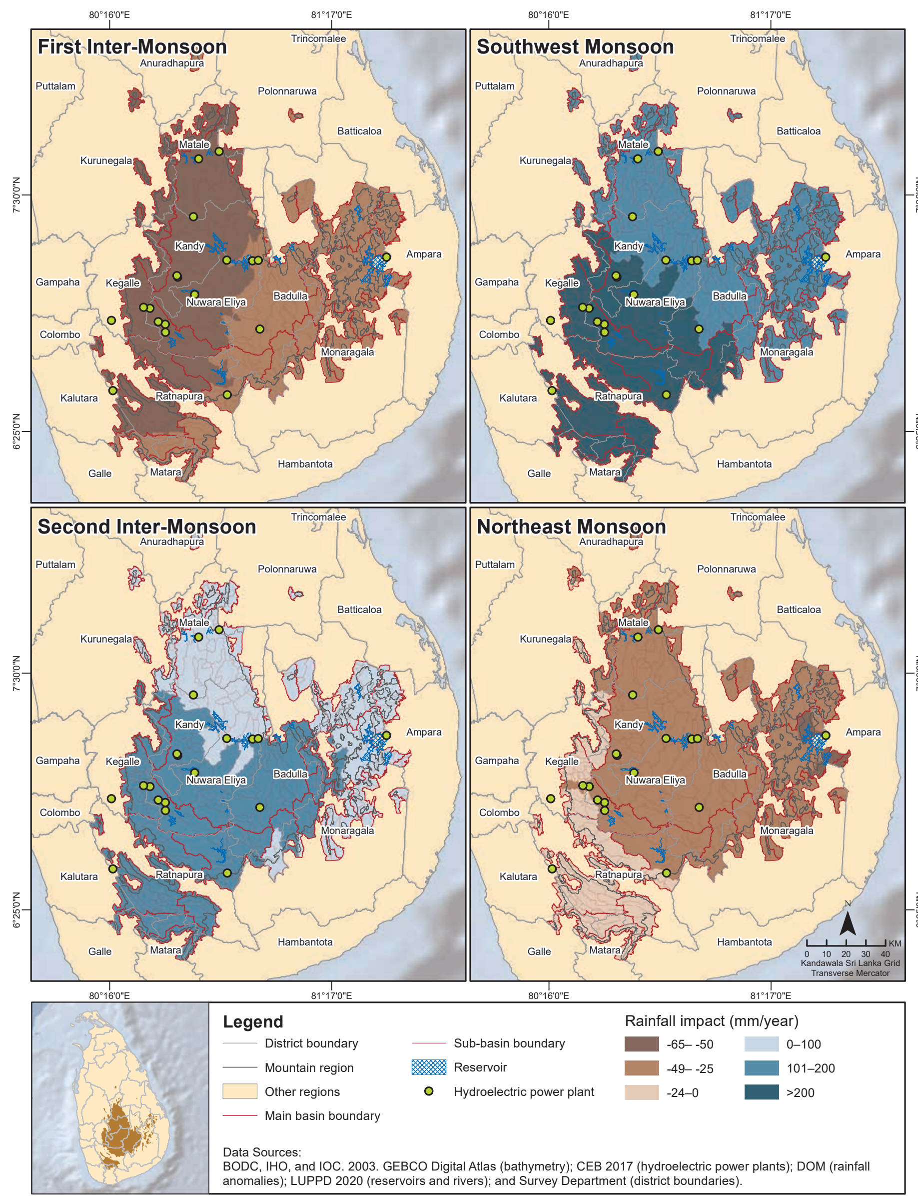
ID	Station	Subbasin	Low Rainfall / Drought in FIM	Low Rainfall / Drought in NEM	Extended Drought
1	Victoria	Mahaweli Ganga	Moderate	Moderate	Moderate
2	Kotmale	Mahaweli Ganga	High	Low	Moderate
3	Upper Kotmale	Kotmale Oya	High	Low	Moderate
4	Randenigala	Heppola Oya	Moderate	Moderate	Moderate
5	Samanala	Katupa Oya	Low	Low	Low
6	Uma Oya	Uma Oya	Low	Moderate	Low
7	New Laxapana	Maskeli Oya	High	Low	Moderate
9	Polpitiya	Maskeli Oya	High	Low	Moderate
10	Canyon	Maskeli Oya	High	Low	Moderate
11	Rantembe	Heppola Oya	Moderate	Moderate	Moderate
12	Wimalasurendra	Kelani Ganga	High	Low	Moderate
13	Old Laxapana	Maskeli Oya	High	Low	Moderate
14	Bowatenna	Amban Ganga	High	Moderate	High
15	Ukuwela	Sudu Ganga	High	Low	Moderate
16	Broadlands	Kelani Ganga	High	Low	Moderate
17	Moragahakanda		Moderate	Moderate	Moderate
19	Moragolla	Mahaweli Ganga	High	Low	Moderate

FIM = first inter-monsoon, NEM = northeast monsoon.
Source: ADB. 2018. *Climate Change Vulnerability in the Mountain Region of Sri Lanka*. Draft Consultant's Report (unpublished). Manila (TA 8572-REG).

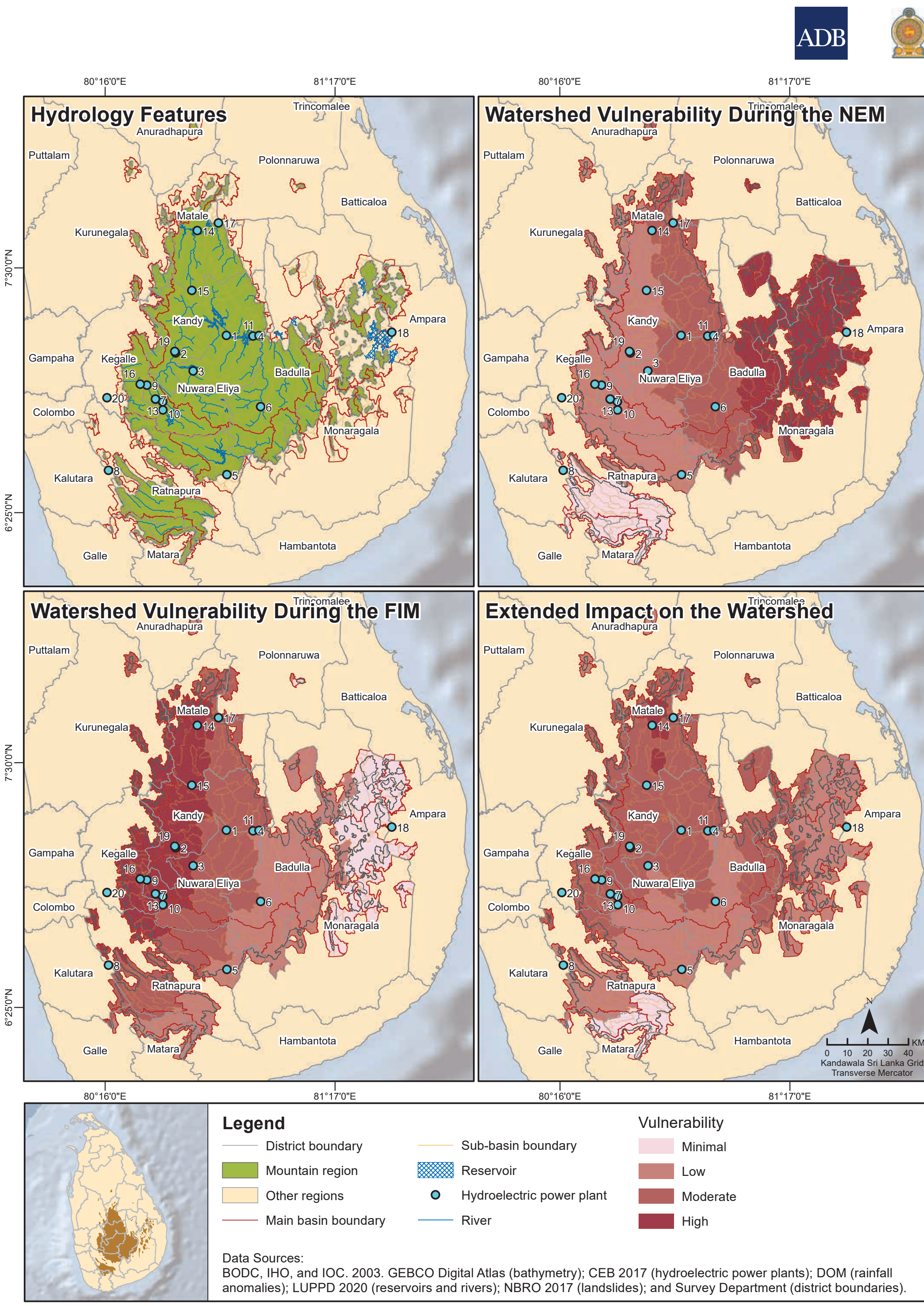
Impact on Fog Interception

Due to insufficient research and knowledge on the factors affecting the fog interception capacity of different types of vegetation, it is difficult to project the potential climate change impacts on this important hydrological phenomenon. However, increases in day and nighttime temperatures could negatively affect the current fog interception activities.

Map 7: Impact of Projected Seasonal Rainfall on River Basins in the Mountain Region under RCP 8.5 2040–2060 with Reference to Baseline Period 1975–2005



Map 8: Impact of Projected Drought Vulnerability on Hydropower Stations in the Mountain Region under RCP 8.5 2040–2060 with Reference to Baseline Period 1975–2005



V

Summary and Conclusions

This study developed a basic profile of resources in the mountain region of Sri Lanka and developed a widely applicable definition of the region. Although occupying only 15% of Sri Lanka's total landmass, the mountain region plays an important role in providing island-wide water supply. The physical, biological, and social features of the mountain region are unique on a global and local scale. A comprehensive description and visualization of this distinct region is required for its valuation. The mountain region's resource profile can be further enhanced, observed, and monitored with additional data and the region's definition incorporated into national government policies and resource management programs.

This assessment was conducted using a downscaled six-model ensemble suitable to Sri Lanka. This enabled the identification of site-specific changes in rainfall patterns in different parts of the country's mountain region. The combination of these data with land use and other resource maps through GIS allowed future climate-related impacts to be identified. This will help create pathways for addressing climate change impacts such as developing appropriate and sustainable adaptive strategies.

The projected scenarios highlight three significant trends, which should be considered in developing climate change mitigation and adaptation strategies for implementation:

- An increase in the average annual rainfall in the whole mountain region.
- A prolonged and distinct dry season (compared to the current season), followed by excessive rain in a seasonal climate pattern.
- A distinct increase in ambient temperature.

The study findings indicate potential disasters in the western and southwestern parts of the Central Highlands due to high rainfall conditions. In contrast, drought-related issues are projected in the north, east, and southeastern parts.

The only widely available climate data for the mountain region is rainfall. Temperature data is only available from a few stations, whereas wind speed, solar radiation, and atmospheric water vapor—although essential data—are scarce. Thus, more substantial and accurate sources of climate data would facilitate a more comprehensive analysis of climate risks and impacts.

Basic data for developing the resource profile was also insufficient, outdated, or in a format incompatible with GIS analysis. For instance, updated data on export agriculture crop distribution is unavailable. Consistent data for analytical purposes are lacking, particularly socioeconomic data. It would help if the data in various government institutes (for example, GND) could be maintained in a simple, common format and the spatial data collection unit is a common unit applicable to all.

This study used RCP scenario climate projections according to the Intergovernmental Panel for Climate Change Fifth Assessment Report (IPCC AR5). However, the recent Sixth Assessment Report (AR6) introduced projections based on Shared Socioeconomic Pathways. If the most recent downscaled climate data is obtained, a more comparable analysis can be done. The inclusion of more data such as temperature, wind speed, and water vapor would facilitate a more refined analysis and better decision making concerning the impact of climate trends in different locations of the mountain region.

Overall, the findings of this study will prove crucial for designing projects, programs, and policies for sustainable development, appropriate management, and systematic administration of sectors in the mountain region. It is vital that these findings are applied and their implications considered in planning and development decisions for Sri Lanka's mountain region.

Map Data Sources

Government Ministries and Departments in Sri Lanka

Ceylon Electricity Board

- Hydroelectric power plants

Department of Meteorology

- Annual average rainfall
- Seasonal average rainfall
- Projected climate change

Land Use Policy Planning Department

- Agricultural areas
- Land use
- Reservoirs and rivers

National Building Research Organization

- Landslide vulnerable areas

Survey Department

- Administrative boundaries

International Institution

National Aeronautics and Space Administration (NASA) Shuttle Radar Topography Mission (SRTM) 2013. Shuttle Radar Topography Mission (SRTM) Global 30-meter digital elevation model (DEM). Distributed by OpenTopography. https://doi.org/10.5069/G9445JDF and https://earthexplorer.usgs.gov.

- Elevations
- Main and sub-river basins

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Climate Change Risk Profile of the Mountain Region in Sri Lanka

This publication studies the potential impact of climate change on Sri Lanka's vulnerable mountain ecosystem in order to help guide sustainable adaptation strategies. It uses a mix of geographic information system mapping combined with average and projected rainfall figures to show how the mountains that make up 15% of Sri Lanka could be affected. Including a series of maps, the publication illustrates how the area faces rising drought alongside increasingly severe monsoons that could cause more floods and landslides. By showing the potential impact of climate change, it aims to help assess both future investments and strategies to cut disaster risk and enhance environmental sustainability in the biodiverse area.

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