

COMPENDIUM OF **ENVIRONMENT STATISTICS**

NEPAL 2026



Government Of Nepal
Office of the Prime Minister and Council of Ministers
National Statistics Office

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Government of Nepal
Office of the Prime Minister and Council of Ministers
National Statistics Office



Phone

4245946
4245947
4245948
4245848
4241801
4228406

Ref. No.

Fax: 977-14227720
Post Box No: 11031
Thapathali, Kathmandu

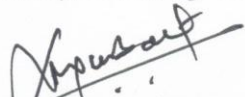
Message from the Chief Statistician

Nepal's environment is an essential foundation for sustainable development, supporting livelihoods, economic activities, public health, and the well-being of present and future generations. At the same time, increasing pressures from climate change, population growth, urbanization, resource use, and environmental degradation underscore the need for reliable, comprehensive, and timely environmental statistics. The Compendium of Environment Statistics 2026, the fourth edition of this publication, responds to this need by bringing together important statistical information and analytical perspectives on Nepal's environment.

This Compendium presents a comprehensive collection of environment-related statistics covering key areas such as land, forests, biodiversity, water resources, energy, climate change, waste, pollution, and other dimensions of the environment. A distinctive feature of this fourth edition is the inclusion of analytical papers contributed by experts in environment and related fields. These papers provide deeper insights into emerging environmental issues, complement the statistical information presented in the Compendium, and help readers understand the broader context and implications of environmental changes in Nepal. I believe that the Compendium of Environment Statistics 2026 will serve not only as an important statistical reference but also as a useful source of knowledge for researchers and students undertaking studies on the environment, climate change, natural resources, and sustainable development. It is our hope that this publication will encourage further research, informed discussion, and evidence-based policy and planning for the sustainable management of Nepal's natural environment.

On behalf of the National Statistics Office, I sincerely appreciate the Deputy Chief Statistician for overall guidance in bringing this publication. I would like to express my gratitude to all authors who have contributed chapters to this compendium. Special thanks to Director of the Environment Statistics Section for hard work in ensuring the timely publication of this report. Statistics Officers and the Statistics Assistant of the Environment Statistics Section also deserve thanks for their sincere involvement in this publication.

Lastly, I encourage constructive feedback from our users to improve future editions of the compendium.


Laxmi Kumari Basnet
Chief Statistician
National Statistics Office (NSO)



Government of Nepal
Office of the Prime Minister and Council of Ministers
National Statistics Office



Phone

4245946
4245947
4245948
4245848
4241801
4228406

Fax: 977-14227720

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Preface

Environmental data and statistics play an important role in monitoring environmental conditions and understanding environmental trends across different themes and sectors. Reliable environmental data provide the basis for generating environmental statistics and information, which support the assessment of emerging issues, research, policy formulation, planning, and informed decision-making for sustainable development. In this context, the National Statistics Office (NSO) is pleased to present the Compendium of Environment Statistics 2026, the fourth edition of this publication. The Compendium is a compilation of statistical information and articles covering a wide range of environmental themes, including forests and biodiversity, land, water resources, climate change, energy, waste, pollution, and other important aspects of Nepal's environment. It brings together relevant statistics and information from various sources in a structured and accessible form, providing a useful reference for understanding environmental conditions and trends and supporting evidence-based analysis, planning, and decision-making.

An important feature of this edition is the inclusion of expert analytical papers on selected environment-related topics. These contributions add analytical depth to the statistical information and provide perspectives on important environmental issues facing Nepal. The combination of statistical information and expert analysis is expected to make this Compendium a useful resource not only for government agencies and policymakers but also for researchers, academicians, students, development partners, and other users interested in environmental and climate-related issues.

I would like to express my sincere appreciation to all the authors and experts who contributed analytical papers and chapters to this Compendium. Their knowledge, experience, and analytical perspectives have significantly enriched the publication. I also acknowledge the valuable contribution of the Director of the Environment Statistics Section for providing leadership and coordinating the preparation of the Compendium, as well as the dedicated efforts of the officers and staff involved in data collection, compilation, analysis, review, editing, and publication. In particular, I appreciate the sincere efforts of the Statistics Officers and Statistics Assistant of the Environment Statistics Section, whose continuous involvement and teamwork contributed to bringing this publication to completion. The collective efforts of all those involved have made it possible to prepare the fourth edition of the Compendium in a systematic and timely manner.

I hope that the Compendium of Environment Statistics 2026 will serve as a valuable reference for understanding Nepal's environmental situation and as a useful source of information for research, teaching, academic studies, policy analysis, and programme planning. I also hope that the publication will encourage further research and discussion on environmental and climate-related issues and contribute to the continued development of Nepal's environmental statistical system.

Finally, I would like to acknowledge the contribution of everyone who directly or indirectly supported the preparation of this Compendium. The National Statistics Office remains committed to strengthening environmental statistics and making reliable statistical information increasingly accessible to all users.

Dhundi Raj Lamichhane
Deputy Chief Statistician
National Statistics Office (NSO)

Members of the Core Team Associated with the Publication

Mr. Dhundi Raj Lamichhane, Deputy Chief Statistician

Mr. Gangaram Bhattarai, Director

Mr. Bhim Bahadur Shakha, Statistics Officer

Mr. Prakash Bista, Statistics Officer

Mrs. Kamala Nath, Statistics Assistant

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Abbreviation

ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
APF	Armed Police Force
BCN	Bird Conservation Nepal
CBD	Convention on Biodiversity
CBS	Central Bureau of Statistics
CDAF	Central Disaster Aid Fund
CDRC	Central Disaster Relief Committee
CEA	Classifications of Environmental Activities
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CPC	Central Product Classification
DDC	District Development Committee
DDRC	District Disaster Relief Committees
DHM	Department of Hydrology and Meteorology
DNPWC	Department of National Parks and Wildlife Conservation
DoF	Department of Forest
DPSRF	Driving-Force-Pressure-State-Response Framework
DRR	Disaster Risk Reduction
EIA	Environmental Impact Assessment
ENPHO	Environment & Public Health Organization
FAO	Food and Agriculture Organization of the United Nations
FY	Fiscal Year
GDP	Gross Domestic Product
GER	Gross Enrollment Ratio
GHG	Green House Gas
GLOF	Glacial Lake Outburst Flood
GON	Government of Nepal
GTF	Global Tiger Forum
HFA	Hyogo Framework for Action
ICD	International Classification of Diseases
ICIMOD	International Centre for Integrated Mountain Development
IDNDR	International Decade for Natural Disaster Reduction
IEE	Initial Environmental Examination
IPCC	Inter-governmental Panel on Climate Change
ISIC	International Standard Industrial Classification Of All Activities
ITTA	International Tropical Timber Agreement
IUCN	International Union for the Conservation of Nature
LAPA	Local Adaptation Programme of Action
LCCS	Land Cover Classification System
LDMC	Local Disaster Management Committee
LDRC	Local Disaster Relief Committee
LRMP	Land Resource Mapping Project
MDGs	Millennium Development Goals
MEAS	Multilateral Environment Agreements
MFA	Material Flow Accounts

MoEST	Ministry of Environments Science and Technology
MoF	Ministry of Finance
MoHa	Ministry of Home Affairs
MoWR	Ministry of Water Resources
NA	Not Available / Nepal Army
NAPA	National Adaptation Programme of Action
NAPDM	National Action Plan on Disaster Management
NARC	National Agriculture Research Council
NCDM	National Centre for Disaster Management
NCIDNDR	National Committee for the International Decade for Natural Disaster Reduction
NCP	Nepal Civil Police
NCRA	Natural Calamity Relief Act
NDMC	National Disaster Management Council
NEOC	National Emergency Operation Centre
NER	Net Enrollment Ratio
NGOs	Non-Governmental Organizations
NPC	National Planning Commission
NPWC	National Park and Wildlife Conservation
NSDRMN	National Strategy for Disaster Risk Management in Nepal
NSO	National Statistical Office
NTNC	National Trust for Nature Conservation
NWP	National Water Plan
OECD	Organization for Economic Co-operation and Development
PMNCAF	Prime Minister Natural Calamity Aid Fund
PSRF	Pressure-State-Response Framework
RDRRC	Regional Disaster Relief Committee
SAARC	South Asian Association for Regional Cooperation
SAM	Social Accounting Matrix
SDGS	Sustainable Development Goals
SEEA	System of Economic and Environment Accounting
SNA	System of National Accounts
SSDS	System of Social and Demographic Statistics
SWM	Solid Waste Management
SWMRMC	Solid Waste Management and Resource Mobilization Center
TYP	Three Year Plans
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and Pacific
UNFDES	United Nations Framework for the Development of Environment Statistics
UNSD	United Nations Statistics Division
VDC	Village Development Committee
WECS	Water and Energy Commission Secretariat
WHO	World Health Organization
WRS	Water Resource Strategy
WTO	World Trade Organization
WUAs	Water Users Associations

CHAPTER: I

Historical Overview of Compendium of Environment Statistics in Nepal

Dhundi Raj Lamichhane¹, Ganga Ram Bhattarai¹

¹ National Statistics Office, Thapathali, Kathmandu

Email: dhundiraj@gmail.com, gaganbhattarai9@gmail.com

Summary

Nepal faces complex environmental challenges, including land degradation, deforestation, biodiversity loss, pollution, waste management, and the impacts of climate change. This paper traces the evolution of the Compendium of Environment Statistics, from its first edition in 1994 to the latest publications, highlighting its contribution to documenting environmental trends and strengthening the evidence base for policymaking. It further reviews the integration of environmental priorities into Nepal's periodic development plans, illustrating the transition from resource conservation to climate-resilient and sustainable development. Drawing on the Framework for the Development of Environment Statistics (FDES) and related international frameworks, the paper demonstrates how the systematic development of environmental statistics has enhanced environmental governance, policy formulation, and progress toward sustainable development.

Keywords: Climate change; Compendium of Environment Statistics; FDES; Period Plans; Policy response

1. Environmental Context and Rationale for an Environmental Compendium in Nepal

1.1. Environmental Context

Nepal is endowed with exceptional environmental diversity, encompassing ecosystems that range from the High Himalayas to the Terai plains. Although occupying only about 0.1 percent of the world's land area, Nepal supports approximately 3.2 percent of the world's known flora and 1.1 percent of the world's fauna, reflecting its remarkable ecological richness and altitudinal variation (MoFE, 2018). According to the latest National Land Cover Monitoring System (2022), forests cover 43.38 percent of the country's land area, while forest and other wooded land together account for 46.08 percent of the total area, providing critical ecosystem services including freshwater regulation, soil conservation, carbon sequestration, biodiversity conservation, and livelihood support for millions of people. These natural resources form the foundation for agriculture, tourism, hydropower development, and the well-being of Nepalese society.

Despite this rich natural capital, Nepal is experiencing increasing environmental pressures arising from rapid population growth, urbanization, changing consumption patterns, infrastructure expansion, climate change, and unsustainable exploitation of natural resources. These pressures have contributed to land degradation, biodiversity loss, air and water pollution, increasing waste generation, and greater vulnerability to climate-induced disasters such as floods, landslides, droughts, and glacial lake outburst floods (Government of Nepal, 2019; World Bank, 2022; IPCC, 2023). As environmental challenges become more complex and interconnected, the demand for reliable, integrated, and policy-relevant environmental information has increased to support evidence-based planning, monitoring, and decision-making at national and sub-national levels.

Environmental issues in Nepal are inherently multidimensional, extending beyond ecological degradation to include economic, social, institutional, technological, and ethical dimensions. Environmental degradation affects economic productivity, public health, food security, disaster resilience, and social equity, while

governance quality, technological advancement, and environmental awareness influence the effectiveness of environmental management. Recognizing these interrelationships, international frameworks such as the Framework for the Development of Environment Statistics (FDES, 2013) developed by the United Nations Statistics Division and the System of Environmental Economic Accounting (SEEA) emphasize the integration of environmental, economic, and social information within a comprehensive statistical framework. Consequently, environmental information cannot be generated or interpreted in isolation but requires coordinated data collection and integration across multiple sectors and institutions to provide a holistic understanding of environmental conditions and support sustainable development.

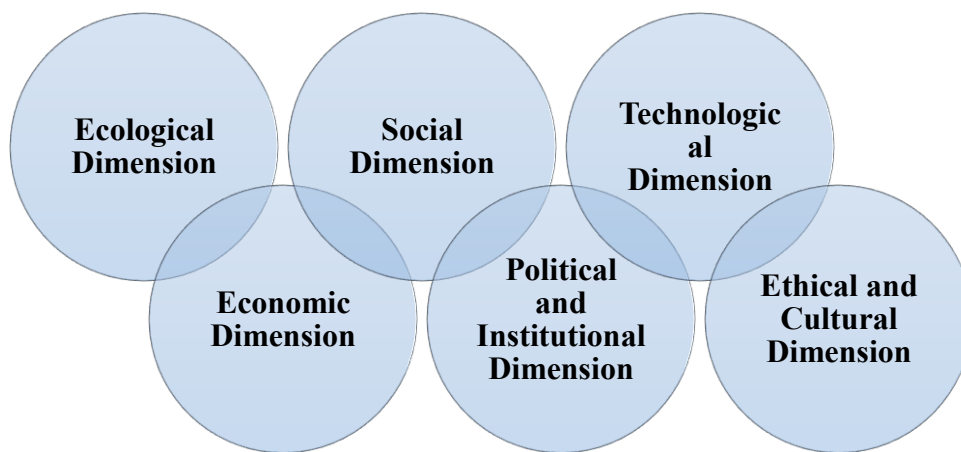


Figure 1: Multidimensional Nature of Environmental Issues Source: Author's compilation based on UNEP (2019) and IPCC (2023)

1.1.1 Ecological Dimension

The ecological dimension of environmental issues in Nepal is reflected in land degradation, deforestation, biodiversity loss, declining water quality, air pollution, and the impacts of climate change. Nepal's fragile mountain ecosystems are increasingly threatened by soil erosion, habitat degradation, invasive alien species, and glacier retreat, reducing ecosystem services such as watershed protection, carbon sequestration, and biodiversity conservation (MoFE, 2021; World Bank, 2022).

1.1.2. Economic Dimension

Environmental degradation imposes significant economic costs on Nepal through reduced agricultural productivity, infrastructure damage from floods and landslides, declining tourism potential, and increasing health expenditures associated with pollution. Unsustainable extraction of forest products and riverbed materials, together with inefficient waste management, threatens natural capital and long-term sustainable economic development (Government of Nepal, 2019; World Bank, 2022).

1.1.3. Social Dimension

In Nepal, environmental degradation directly affects public health, livelihoods, and food security. Air pollution, unsafe drinking water, floods, landslides, and climate change disproportionately affect poor and vulnerable communities, particularly those dependent on agriculture and natural resources. Improving environmental quality is therefore essential for achieving sustainable and inclusive development (United Nations, 2015; Government of Nepal, 2020; MoFE, 2021).

1.1.4. Political and Institutional Dimension

Nepal has strengthened environmental governance through the Constitution of Nepal (2015), the Environment Protection Act, 2019, and the National Climate Change Policy, 2019. Environmental responsibilities are shared among federal, provincial, and local governments; however, weak enforcement, limited institutional capacity, and coordination challenges continue to hinder effective environmental management (Government of Nepal, 2019; MoFE, 2019; UNEP, 2019).

1.1.5. Technological Dimension

Technological development in Nepal has contributed to both environmental challenges and solutions. Increasing urbanization, transportation, and industrial activities have intensified pollution and waste generation, while hydropower, solar energy, biogas, electric vehicles, and GIS-based environmental monitoring support low-carbon and climate-resilient development (MoFE, 2021; IPCC, 2022; AEPC, 2023). Effective waste management, emission control technologies, and the adoption of green and energy-efficient technologies are essential for reducing environmental damage.

1.1.6. Ethical and Cultural Dimension

Nepal's religious traditions, indigenous knowledge, and community-based natural resource management have significantly contributed to environmental conservation. Community forestry, sacred forests, and traditional conservation practices demonstrate the country's strong ethical and cultural commitment to protecting biodiversity and natural resources for future generations (UNEP, 2016; MoFE, 2018; FAO, 2020).

1.2. Rationale for Environment Compendium in Nepal

The environment is a cross-cutting component of sustainable development that influences ecological integrity, economic growth, public health, and social well-being. As environmental issues become increasingly complex and interconnected, there is a growing need for comprehensive, credible, and evidence-based information to support informed decision-making, policy formulation, research, and public awareness. Although a considerable body of environmental knowledge exists in Nepal, it is often scattered across government reports, research publications, policy documents, statistical reports, and institutional databases, making it difficult for users to access and interpret information in a holistic manner.

This Environmental Compendium has been prepared to address this gap by bringing together a collection of evidence-based articles that present the status, trends, challenges, and responses related to Nepal's environment. The articles are developed using verified environmental statistics, scientific research, administrative records, policy documents, and information from authoritative national and international sources. By synthesizing evidence from diverse sectors, the compendium provides a comprehensive and balanced understanding of environmental issues while ensuring that the information is reliable, current, and relevant.

The compendium serves as a single reference source for policymakers, planners, researchers, academics, students, development partners, civil society organizations, and the general public. It facilitates access to consolidated environmental knowledge, promotes evidence-based policymaking and research, supports environmental education and awareness, and contributes to informed public discourse on environmental sustainability. Furthermore, by documenting key environmental themes and emerging issues in a systematic

manner, the compendium supports national development planning and Nepal's commitments to sustainable development and international environmental agreements.

2. Evolution of Compendium of Environment Statistics in Nepal

The development of environmental statistics in Nepal is closely associated with the efforts of the National Statistics Office (formerly the Central Bureau of Statistics Nepal). Environmental statistics began to receive formal attention in the early 1990s, as Nepal increasingly recognized the importance of balancing poverty reduction with environmental sustainability within the broader framework of sustainable development. At that time, the statistical documentation of environmental information was still at a preliminary stage, and environmental data were scattered across different institutions. To address this gap, the Central Bureau of Statistics published the Compendium of Environment Statistics, 1994 Nepal, which provided a structured compilation along with explanatory descriptions of available environmental information. This was followed by the Compendium of Environment Statistics, 1998 Nepal, which included broader thematic coverage and additional interpretation of environmental trends and issues, although the overall environmental database remained limited. Later, the Compendium of Environment Statistics Nepal 2015 further expanded the scope by integrating data from multiple sectors and presenting environmental information with descriptive analysis and contextual discussion.

In addition to the compendium reports, the Central Bureau of Statistics began publishing the Environment Statistics of Nepal from 2002 onward to systematically compile environmental data. Unlike the compendium reports, these publications primarily present tabular compilations of environmental indicators collected from various secondary sources such as government agencies and administrative records. Subsequent editions were published in 2003, 2004, 2005, 2006, 2008, 2011, 2013 and 2019, providing updated statistical tables across different environmental sectors. The most recent publication, Environment Statistics of Nepal 2024, continues this approach by presenting updated environmental statistics and indicators, thereby supporting data availability for environmental monitoring, research, and policy use.

1. First Compendium (1994) – Initiation Phase	2. Second Compendium (1998) – Analytical Expansion Phase	3. Third Compendium (2015) – Institutional Strengthening and Framework-Based Phase
• Nature: Descriptive and compilation-based Focus: Consolidation of available environmental data	• Nature: Compilation with analytical interpretation Focus: Updated data with sectoral analysis	• Nature: Comprehensive, analytical, and framework-based Focus: Integrated environmental statistics aligned with international standards(FDES)

Figure 2: Compendium of Environment Statistics

2.1. First Compendium of Environment Statistics (1994)

The Compendium of Environment Statistics, Nepal 1994 was the first official publication on environmental statistics prepared by the Central Bureau of Statistics under the Government of Nepal, then His Majesty’s Government of Nepal (HMG/N). This landmark publication consolidated scattered environmental

information into a single statistical reference, marking an important step toward the systematic development of environmental statistics in the country (Government of Nepal, 1994/2000).

At the time, the compendium was highly significant because environmental information in Nepal was scattered, incomplete, and largely inaccessible. There was an urgent need for data to support sustainable development, resource management, and national policy decisions. By compiling available information in one place, the compendium provided policymakers, planners, and researchers with a comprehensive overview of the country's environmental situation, raising awareness about the importance of environmental statistics for planning and decision-making.

The compendium included following major themes:

Land and Soil: Land use patterns, agricultural land, forest cover, and soil resources.

- Forests and Biodiversity: Forest types, area coverage, species diversity, and forest resource utilization.
- Water Resources: Surface and groundwater availability, water use for irrigation, drinking, and industrial purposes, and water quality indicators where available.
- Energy Resources: Traditional and commercial energy consumption, fuelwood, and hydropower potential.
- Population and Environment: Demographic pressures, urbanization trends, human–environment interactions, and environmental impacts of population growth.
- Natural Resource Management: Utilization of minerals, forests, and other renewable and non-renewable resources, along with basic indicators of environmental stress.

The compendium primarily relied on secondary data collection, compiling statistics from existing government records, surveys, and reports of various ministries, departments, and research institutions. No primary surveys were conducted specifically for the compendium. Data were organized according to environmental domains, presented in tabular and descriptive formats, and structured to provide comparability across sectors. The publication followed basic statistical compilation guidelines, including verification of sources, cross-checking with multiple institutions, and standardization of units, but it did not apply advanced analytical or modeling techniques, reflecting the early stage of environmental statistics development in Nepal. The compendium's scope was to provide a structured statistical overview of the country's environment, raise awareness of environmental issues, and lay the foundation for future systematic environmental monitoring and statistical reporting in Nepal.

2.2. Second Compendium of Environment Statistics (1998)

The Second Compendium of Environment Statistics, Nepal 1998 was published by the Central Bureau of Statistics under the then His Majesty's Government of Nepal (HMG/N). This publication represented a major advancement in the development of environmental statistics in Nepal compared to the first edition of 1994 (Government of Nepal, 1998/2000). Unlike the 1994 compendium, which primarily focused on descriptive compilation of available data, the 1998 edition incorporated analytical components alongside updated statistical information, providing broader insights into environmental trends, patterns, and challenges across the country.

At the time, the 1998 compendium was highly important because it reflected a growing national awareness of environmental issues and the need for evidence-based planning and policy formulation. By updating and expanding the previous edition, it enabled policymakers, planners, and researchers to access not only

compiled environmental data but also interpretive analyses that could support sustainable development, resource management, and decision-making.

The 1998 compendium expanded and deepened the thematic scope of the first edition, including:

- Land Use and Soil Conditions: Updated statistics on land utilization, soil quality, agricultural land patterns, and erosion indicators.
- Forest and Biological Resources: Forest cover, biodiversity indicators, species distribution, and forest resource management.
- Water Resources: Surface and groundwater availability, quality indicators, and usage for domestic, agricultural, and industrial purposes.
- Population–Environment Linkages: Impacts of population growth, urbanization, and human activities on environmental quality.
- Environmental Degradation and Resource Management: Indicators of deforestation, soil erosion, water pollution, and strategies for sustainable management of natural resources.

The methodology and guidelines are similar to the 1994 edition. The second compendium relied on secondary data collection from government departments, agencies, and research institutions. However, it also incorporated analytical interpretation, using trends, comparisons over time, and cross-sectoral analysis to provide insights into environmental conditions and policy implications. Data were verified, standardized, and presented in both tabular and descriptive formats, allowing sectoral and temporal comparisons that were not possible in the first edition.

The scope of the 1998 compendium was to update and expand the 1994 data, strengthen coverage of environmental indicators, introduce basic analytical perspectives, and support evidence-based environmental planning. The 1998 edition included analytical components, interpreting trends, relationships, and patterns in environmental indicators. Coverage was broader and more detailed, with additional focus on environmental degradation, resource management, and population–environment linkages.

2.3. Third Compendium of Environment Statistics (2015)

The Third Compendium of Environment Statistics, Nepal 2015 represents a major milestone in the development of environmental statistics in the country. This is the third series of Environmental Compendium published by the Central Bureau of Statistics (CBS) in January 2016. Following a long gap after the first (1994) and second (1998) editions, this publication addressed the growing significance of environmental concerns in Nepal, including climate change, urbanization, waste management, biodiversity loss, and disaster risks. At the same time, there was increasing international emphasis on sustainable development and the importance of environmental monitoring, which the compendium sought to address by updating environmental data and strengthening analytical content.

A key distinguishing feature of the 2015 edition is its adoption of the Framework for the Development of Environment Statistics (FDES) developed by the United Nations (United Nations Statistics Division, 2014). By aligning with this international framework, the compendium improved the structure, organization, and comparability of environmental statistics, ensuring a systematic classification of environmental themes and integration of environmental, social, and economic dimensions. Additionally, the compendium aligned with global reporting requirements, including the Sustainable Development Goals (SDGs).

Compared to previous editions, the third compendium was more comprehensive and analytical. It included updated environmental data from multiple sectors, detailed analytical articles contributed by environmental

experts, and a thematic organization covering social and demographic issues, climatic extremities, land and soil, water resources, biological resources, solid waste management, human settlements, and disaster management systems. By combining systematic data collection with analytical interpretation, the 2015 compendium established a robust foundation for evidence-based environmental planning and policymaking in Nepal (Government of Nepal, Central Bureau of Statistics, 2016).

3. Framework for Compendium of Environment Statistics Preparation (FDES)

3.1. Overview of the FDES and Its Objectives

The Framework for the Development of Environment Statistics (FDES) was initiated following the 1972 Stockholm Conference to standardize environmental statistics. The first FDES was published by the United Nations in 1984. It was comprehensively revised and endorsed by the United Nations Statistical Commission in 2013 to address emerging environmental issues. FDES provides a comprehensive conceptual structure for organizing environmental data and strengthening national environmental information systems. It enables countries to compile reliable and comparable environmental statistics that support policy formulation, environmental management, and sustainable development monitoring. The FDES links environmental conditions with human activities and socio-economic development, offering a structured approach for national statistical offices and other institutions to identify, collect, and integrate environmental data across sectors. It also supports international reporting and analytical frameworks, including the System of Environmental-Economic Accounting, the System of National Accounts, the Driving Force-Pressure-State-Impact-Response (DPSIR) framework, and monitoring progress toward the Sustainable Development Goals.

The primary objectives of the FDES are to:

- Define environmental statistics scope and human–environment interactions.
- Identify data needs and gaps for better data collection.
- Develop structured environmental databases for analysis and reporting.
- Promote coordination among institutions producing environmental data.
- Support environmental monitoring and sustainability reporting (e.g., Sustainable Development Goals).

The objectives of the Framework for the Development of Environment Statistics (FDES) are based on the understanding that ecosystems and the services they provide are essential for human life and economic activities. Ecosystems are systems where plants, animals, microorganisms, and the physical environment interact with each other. Ecosystem services are usually grouped into four main types i.e. provisioning services, regulating services, supporting services and cultural services. Provisioning services provide resources such as food, timber, freshwater, and raw materials. Regulating services help control environmental conditions through processes like climate regulation, flood control, and water purification. Supporting services include basic natural processes such as nutrient cycling, soil formation, and photosynthesis that support all life. Cultural services provide non-material benefits such as recreation, spiritual value, natural beauty, and cultural heritage.

The FDES aims to organize and compile environmental statistics that help measure these ecosystem conditions, services, and their changes over time. By collecting data on natural resources, environmental processes, and human activities, the framework helps countries understand how ecosystems support human well-being and how environmental pressures affect them. In addition, the environment also contains abiotic resources such as minerals, fossil fuels, and renewable energy sources like solar and wind. Although these

are not ecosystem services, their extraction and use can influence ecosystems and environmental quality. Therefore, the FDES framework emphasizes understanding the relationships between ecosystems, natural resources, and human activities to support better environmental monitoring, policy making, and sustainable development.

3.2 Structure of the FDES

The Framework for the Development of Environment Statistics (FDES) developed by the United Nations Statistics Division(UNSD). This structure enables countries to compile environmental data in a coherent and consistent manner. The framework is organized into four hierarchical levels. At the highest level are the components, which represent broad domains of environmental statistics. Each component is further divided into subcomponents, which group related thematic areas within the domain. These subcomponents contain statistical topics, representing specific aspects of the environment that can be measured and analyzed. Finally, each topic is represented by individual statistics, which are the actual data collected at the national or local level. Within this hierarchical framework, the FDES is structured around six major components that collectively capture the interactions between the environment, human activities, and socio-economic systems.

Table 1: Environmental indicator components and their relationships with the DPSIR framework and SEEA environmental accounting system

Component	Focus	Data Types	DPSIR / SEEA Relation
Environmental Conditions & Quality	Ecosystem and environmental conditions	Geospatial, Physical, Qualitative	State & Impact; Experimental ecosystem accounts
Environmental Resources & Use	Resource quantities and use	Physical, Geospatial	Driving force, Pressure, State; Asset & flow accounts
Residuals	Waste and pollutant generation	Physical	Pressure & Response; Physical flow accounts
Extreme Events & Disasters	Natural & technological disasters	Physical, Monetary, Geospatial, Qualitative	Pressure, Impact & Response; Asset accounts
Human Settlements & Health	Built environment, population, health	Geospatial, Physical	Driving force, Pressure & Impact
Protection, Management & Engagement	Environmental management and societal engagement	Monetary, Qualitative	Response; Environmental activity & flows

3.2.1. Environmental Conditions and Quality

The first component, Environmental Conditions and Quality, focuses on the overall state of the natural environment. It includes statistics on climate, atmosphere, air quality, water quality, land, soil, and ecosystems. These statistics help assess environmental conditions and monitor changes in environmental quality over time. This component describes the overall state of the environment, including physical environmental conditions, ecosystems, biodiversity, and environmental quality indicators such as air, water, and soil quality.

3.2.2. Environmental Resources and Their Use

The second component, Environmental Resources and Their Use, deals with natural resources and the ways in which human activities utilize them. It includes statistics related to water resources, forests, land

resources, energy resources, fisheries, and biodiversity. These data help assess the availability, distribution, and sustainable use of natural resources. This component focuses on natural resources and how they are utilized by human activities. It includes statistics related to minerals, energy resources, land, soil, water resources, and biological resources such as forests and fisheries.

3.2.3. Residuals

The third component, Residuals, covers waste and emissions generated by economic and human activities. It includes statistics on air emissions, greenhouse gases, solid waste, wastewater, and hazardous waste. These statistics help measure environmental pressures caused by production, consumption, and industrial activities. This component captures the by-products of human production and consumption processes that are released into the environment. It includes emissions to air, wastewater discharges, solid waste generation, and the release of chemicals and pollutants.

3.2.4. Extreme Events and Disasters

The fourth component, Extreme Events and Disasters, focuses on statistics related to natural hazards and environmental disasters such as floods, droughts, landslides, earthquakes, and storms. It also includes information on the impacts of these events on people, infrastructure, and ecosystems. This component covers both natural and technological disasters and their environmental, social, and economic impacts. Examples include floods, landslides, earthquakes, droughts, and industrial accidents.

3.2.5. Human Settlements and Environmental Health

The fifth component, Human Settlements and Environmental Health, addresses the relationship between environmental conditions and human well-being. It includes statistics on housing conditions, access to safe drinking water, sanitation, waste management, and environmental risks affecting human health. This component examines the interaction between environmental conditions and human well-being. It includes statistics related to housing conditions, access to safe water and sanitation, exposure to environmental risks, and health outcomes associated with environmental factors.

3.2.6. Environmental Protection, Management, and Engagement

The sixth component, Environmental Protection, Management and Engagement, includes statistics on societal responses to environmental challenges. It covers environmental governance, environmental expenditure, environmental policies, protected areas, environmental education, and public participation in environmental conservation activities. This component focuses on societal responses to environmental challenges. It includes environmental governance, policy measures, environmental protection expenditures, public awareness initiatives, and disaster preparedness and management activities.

2.6 Relationship with Other Frameworks.

3.3 FDES and SEEA

The Framework for the Development of Environment Statistics (FDES) provides a structure to organize environmental statistics. It helps countries collect, arrange, and present environmental data in a systematic way. The framework also connects with other international statistical systems that help analyze the relationship between the environment and the economy. One important related system is the System of Environmental-Economic Accounting (SEEA). The SEEA links environmental data with economic information. It shows how natural resources such as water, energy, forests, and minerals support economic production and human activities. The SEEA mainly focuses on economic activities carried out by residents within the economy. In contrast, the FDES focuses on environmental conditions within a country's territory, including all environmental impacts that occur inside the country. Many types of environmental data collected through the FDES are useful for the SEEA. For example, data on natural resources, their use, emissions, waste, and environmental protection activities are important inputs for environmental-economic accounts. These data help prepare accounts such as water accounts, energy accounts, and material flow accounts. In this way, the FDES provides the basic statistics, while the SEEA uses these statistics to create environmental-economic accounts.

The FDES also relates to the Driving Force–Pressure–State–Impact–Response (DPSIR) framework. The DPSIR framework explains how human activities affect the environment. For example, economic activities act as driving forces. These activities create pressures such as pollution or resource use. These pressures change the state of the environment. These changes create impacts on ecosystems and human well-being. Society then responds through policies, environmental management, or conservation actions. Although the FDES does not directly use the DPSIR structure, many environmental statistics collected under FDES can be interpreted using this cause and effect model.

In practice, the FDES is very useful for preparing environmental statistics compendiums and reports. It helps statistical agencies organize environmental data in a clear and systematic way. The framework covers many environmental sectors such as water resources, energy use, forests, biodiversity, climate change, waste management, and environmental governance. By following this structure, countries can present environmental data more clearly and consistently. The FDES also helps identify missing information and data gaps. It encourages cooperation among different government institutions that produce environmental data. This improves the quality, consistency, and comparability of environmental statistics across sectors and over time.

4. Environmental Management through Nepal's Periodic Plans

Nepal's environmental governance has evolved through its Five-Year Periodic Plans. Over time, the country has moved from ignoring ecological issues to taking a leading role in climate action. This report

systematically details how environmental issues emerged, were addressed, and ultimately became central to national development strategy, with particular focus on the critical integration of Nepal's enhanced climate commitments i.e. NDCs into planning frameworks.

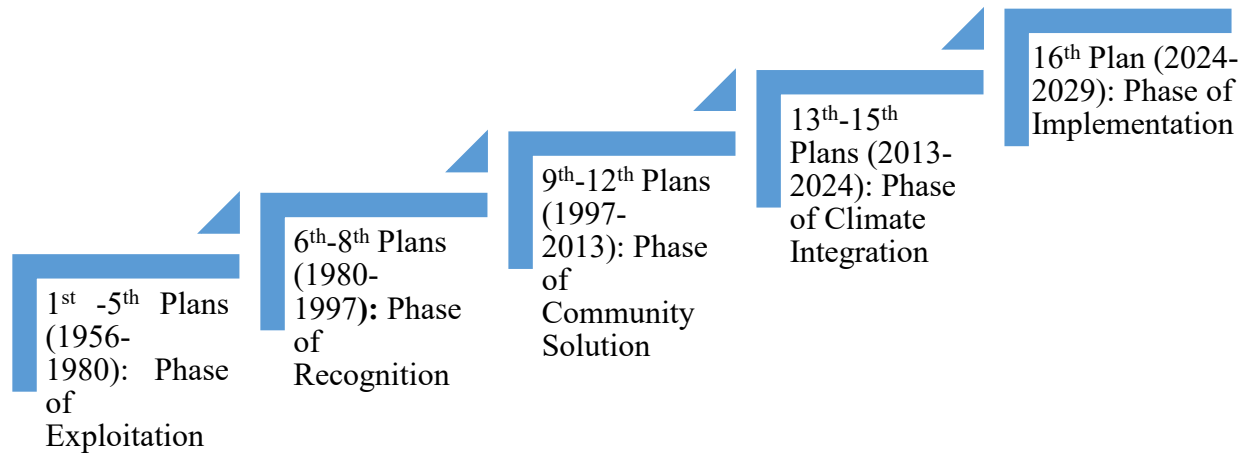


Figure 3: Figure 2. Development Phases of Environmental Management in Nepal

4.1. The Phase of Exploitation (1st to 5th Plans: 1956-1980)

During Nepal's early planning period, development was pursued through a largely extractive approach, where nature was treated as a resource to be exploited rather than sustained. This phase was marked by a significant "planning blind spot," in which forest clearance was promoted for agricultural expansion and infrastructure development without considering environmental consequences. As a result, large-scale resettlement programs led to deforestation in the Terai, causing ecological displacement and long-term alterations in hydrological systems.

At the same time, infrastructure development and rapid urbanization further intensified environmental degradation. Projects such as the East–West Highway, implemented without proper environmental safeguards, triggered landslides and increased sedimentation, affecting downstream agriculture. In urban areas, particularly the Kathmandu Valley, unplanned growth turned rivers like the Bagmati into major sewage channels. Additionally, heavy reliance on fuelwood as the primary energy source accelerated deforestation due to the absence of sustainable forest management practices.

4.2. The Phase of Recognition (6th to 8th Plans: 1980-1997)

By the early 1980s, the environmental crises resulting from earlier development practices had become too significant to ignore. This period marked a major transition from passive neglect to the recognition of environmental conservation as a national priority. Policymakers began to understand that economic development was closely linked with ecological stability. During the Sixth Plan, this realization led to the formal inclusion of environmental conservation as a key objective, with particular emphasis on watershed management in critical areas such as Phewa Tal to reduce flooding, soil erosion, and environmental degradation.

The subsequent plans focused on strengthening institutional and legal frameworks for environmental management. During the Seventh Plan, the government introduced Environmental Impact Assessment (EIA) guidelines in 1987 to regulate the environmental effects of development projects and established the Environment Protection Council to oversee environmental matters. This progress culminated in the Eighth Plan with the enactment of the Environment Protection Act (1996) and the Nepal Environmental Policy and

Action Plan (NEPAP), which transformed environmental management into a legally enforceable system with defined standards for pollution control and conservation.

4.3. The Phase of Community Solution (9th to 12th Plans: 1997-2013)

During this phase, Nepal shifted from a centralized, top-down approach to a more decentralized and community-based model of environmental management. It was increasingly recognized that sustainable conservation could not be achieved without the active participation of local communities, whose livelihoods are directly dependent on natural resources. As a result, planning emphasized local stewardship, transforming citizens from passive beneficiaries into active stakeholders in environmental protection and resource management.

This shift was reflected in key policy initiatives during the period. The Ninth Plan promoted community forestry by transferring management rights of large forest areas to Community Forest User Groups (CFUGs), empowering local communities to manage and conserve forest resources effectively. In the Tenth Plan, the link between environment and poverty was formally recognized through the integration of environmental concerns into the Poverty Reduction Strategy Paper (PRSP). This approach promoted soil conservation, sustainable resource use, and alternative energy sources such as biogas, which helped reduce pressure on forests while also improving rural livelihoods and reducing the workload, particularly for women.

4.4. The Phase of Climate Integration (13th to 15th Plans: 2013-2024)

In the current era, Nepal has transitioned from localized conservation to a global leadership role in climate action. This period marks the complete integration of environmental health into national economic strategy, responding to the dual pressures of global climate vulnerability and acute urban environmental crises. Climate adaptation, mitigation, and disaster risk reduction have become cross-cutting priorities, aligning national development with sustainable and resilient growth pathways (Government of Nepal, 2020a).

During the 13th and 14th Plans (2013–2019), Nepal shifted toward a green economy framework, aligning national development priorities with the UN Sustainable Development Goals (SDGs). This period also marked the submission of Nepal's first Nationally Determined Contribution (NDC 1.0) in 2016, which established a conditional, time-bound target of maintaining at least 45% forest cover by 2020, with 96–97% of its mitigation and adaptation commitments contingent on international financial, technological, and capacity-building support. On the ground, these commitments were complemented by initiatives such as the Brick Kiln Improvement Program to reduce air pollution and the piloting of Local Adaptation Plans of Action (LAPAs) to strengthen climate resilience in vulnerable districts (Government of Nepal, 2020b).

The Fifteenth Plan (2019–2024) served as the principal implementation framework for Nepal's climate and environmental agenda during the plan period and coincided with the submission of Nepal's Second Nationally Determined Contribution (NDC 2.0) in 2020 under the Paris Agreement. For the first time, environmental protection, climate change adaptation, and disaster risk reduction were recognized as one of the four cross-cutting pillars of the national development strategy, reflecting the government's commitment to mainstreaming environmental sustainability across sectors. The plan emphasized the expansion of renewable energy, promotion of clean and sustainable transport, conservation of forests and biodiversity, climate-resilient infrastructure, and strengthened disaster risk management. It also adopted the Green, Resilient, and Inclusive Development (GRID) framework to align post-pandemic recovery with long-term sustainable and climate-resilient development. Recognizing the increasing environmental pressures

associated with urbanization, the plan promoted interventions such as the expansion of ambient air quality monitoring, stricter vehicle emission control measures, implementation of the Clean Bagmati Campaign, improved solid waste management through waste segregation and material recovery, and the promotion of circular economy practices (Government of Nepal, 2020a, 2020b).

4.5. The Phase of Implementation (16th Plan: 2024-2029)

As Nepal transitions into the 16th Five-Year Development Plan (2024/25–2028/29), the country's environmental governance enters a results-oriented implementation phase. Unlike earlier plans that emphasized broad visions, this phase prioritizes quantifiable climate targets, systematic execution, and measurable outcomes. The foundation of this implementation is Nepal's Third Nationally Determined Contribution (NDC 3.0) under the Paris Agreement, which guides climate policy toward specific, sectoral commitments beyond general goals (UNFCCC, 2025). The 16th Plan serves as the primary delivery mechanism for integrating climate priorities into national development investments and policies, aligning development pathways with climate mitigation and adaptation objectives through five strategies:

4.5.1 Strengthening Sector-Wise Mitigation Targets

Nepal's NDC 3.0 sets quantified greenhouse gas (GHG) reduction targets across key sectors including energy, agriculture, transport, waste, and forestry, moving from generalized intentions to concrete, trackable actions. The economy-wide target is to reduce net GHG emissions by 17.12 % by 2030 and 26.79 % by 2035 compared to a business-as-usual scenario, with most reductions dependent on international support (MoFE, 2025).

4.5.2 Enhancing Climate Resilience and Adaptation

The Plan integrates climate adaptation into national strategies, emphasizing resilient infrastructure, early warning systems, watershed management, and disaster risk reduction, including responses to climate-induced hazards such as Glacial Lake Outburst Floods (GLOFs). Adaptation priorities are costed and embedded in planning frameworks, reflecting Nepal's high vulnerability despite its low global emissions.

4.5.3 Quantified Targets for Key Sectors

Energy and Transport:

The NDC 3.0 targets a major transition to renewable energy and clean transport technologies. Electricity generation capacity is projected to grow from 3,500 MW to 14,031 MW by 2030, and further to 28,500 MW by 2035, including solar, wind, and micro-hydro sources. Transport electrification targets aim to increase Battery Electric Vehicle (BEV) adoption, potentially achieving 60 % of new private vehicle sales by 2030 and 90 % by 2035, reducing road transport emissions and improving urban air quality. (MoFE, 2025)

Agriculture and Livestock:

The NDC establishes mitigation measures for emissions from agriculture, including methane reduction from livestock. The AFOLU sector is expected to achieve 1,566.49 GgCO₂-eq reductions by 2030 and 2,472.94 GgCO₂-eq by 2035 through low-emission agricultural practices, marking the first quantified agricultural mitigation commitment in Nepal's climate policy (UNFCCC, 2025).

Forestry and Ecosystems:

The Plan aims to sustain and enhance forest cover, maintaining it above 46 % of the total land area, while integrating ecosystem-based adaptation to support both mitigation and local livelihoods. Forest management strategies also contribute to biodiversity conservation and strengthen Nepal's carbon sink capacity.

4.5.4 Institutional and Governance Strengthening

To implement these targets, the Plan emphasizes robust institutional coordination, monitoring, evaluation systems, and accountability across federal, provincial, and local governments. These structures are designed to track performance against climate targets and integrate climate considerations into budgeting and policy decisions.

4.5.5 Climate Finance and Just Transition

The 16th Plan highlights climate finance, targeting an increased climate-responsive portion of the national budget and facilitating international fund access to address loss and damage in vulnerable communities. Complementing finance mechanisms, the Just Transition Framework aims to retrain workers from high-emission industries and create jobs in green sectors, including renewable energy, ecosystem restoration, recycling, and circular economy ventures.

Local governments are empowered to monitor environmental quality (air, water) in real time and enforce standards through Extended Producer Responsibility (EPR) frameworks. This enables a transition from “throw-away” practices to circular economy approaches. Measurement, Reporting, and Verification (MRV) systems are embedded into government processes to track progress toward climate targets and ensure accountability. The Plan also emphasizes co-benefits of climate action, improved energy security, reduced air pollution, and enhanced ecosystem services, demonstrating the integration of mitigation and adaptation into broader national development outcomes (Climate Policy Database, 2025).

5. Overview of the Compendium of Environment Statistics 2026

The Compendium of Environment Statistics 2026 is organized into a set of thematic chapters that collectively present the status, trends, and challenges of the environment in Nepal. The structure of the compendium follows a systematic approach to environmental statistics and is broadly consistent with international statistical frameworks such as the Framework for the Development of Environment Statistics (FDES) developed by the United Nations Statistics Division. The chapters are designed to provide an integrated understanding of environmental conditions, resource use, environmental pressures, and institutional responses.

The first chapter, Historical Overview of the Compendium of Environment Statistics 2026, provides the conceptual and institutional context for the report. It introduces the importance of environmental statistics for monitoring environmental change and supporting evidence-based policymaking. The chapter also explains the background and evolution of environmental statistics compilation, the framework used in preparing the compendium, and the relationship between environmental information and national development planning. In addition, it offers an overview of the structure and contents of the compendium. The second chapter, Air Pollution and Human Health, examines the status of air quality and the major sources of air pollution in Nepal. It highlights the environmental and public health implications of deteriorating air quality and discusses air pollution monitoring systems and related policy responses. This

chapter emphasizes the importance of environmental statistics for assessing pollution trends and their impacts on human health.

The third chapter, Water Resources and Degradation, focuses on the availability, distribution, and quality of water resources in Nepal. It discusses issues such as water pollution, water scarcity, and the pressures on freshwater ecosystems arising from urbanization, industrialization, and agricultural activities. The chapter also highlights the importance of sustainable water resource management and conservation efforts.

The fourth chapter, Land Use and Land Cover Change, presents information on the patterns and trends of land use and land cover in Nepal. It examines the major drivers of land use change, including population growth, infrastructure development, agricultural expansion, and urbanization. The chapter also discusses land management practices and the implications of land degradation for ecosystems and livelihoods.

The fifth chapter, Forest and Biodiversity, provides an overview of the status of forests and biodiversity resources in Nepal. It highlights the ecological importance of forests, the diversity of species and ecosystems, and the major threats to biodiversity such as habitat loss and environmental degradation. The chapter also outlines conservation initiatives and policies aimed at protecting Nepal's rich natural heritage.

The sixth chapter, Solid Waste Management, examines the generation, composition, and management of solid waste in Nepal. It addresses challenges related to urban waste management, hazardous waste handling, and the environmental impacts of improper waste disposal. The chapter also highlights policy initiatives and practices aimed at improving waste management systems.

The seventh chapter, Energy and Environment, discusses patterns of energy consumption in Nepal, including both renewable and non-renewable sources. It explores the environmental implications of energy production and use, including emissions and resource pressures. The chapter also considers the development of energy accounts and the role of cleaner energy systems in promoting environmental sustainability.

The eighth chapter, Environmental Assessment Practices in Nepal, focuses on environmental impact assessment mechanisms used to evaluate the environmental consequences of development projects. It describes different forms of environmental assessment, such as environmental impact assessments, initial environmental examinations, and strategic environmental assessments. The chapter also discusses the importance of these tools in promoting environmentally responsible development and the challenges associated with their implementation.

The ninth chapter, Climate Change and Disaster Risk Reduction, highlights the growing risks associated with climate change and natural disasters in Nepal. It presents information on greenhouse gas emissions, climate trends, and the frequency of climate-related hazards. The chapter also discusses the impacts of climate change on ecosystems, livelihoods, and infrastructure, as well as national efforts in climate change adaptation, mitigation, and disaster risk management.

The final chapter, Environmental Governance and Institutions, examines the legal, policy, and institutional frameworks that guide environmental management in Nepal. It outlines environmental legislation, regulatory standards, and the roles of different government institutions and stakeholders in environmental protection. The chapter also highlights coordination mechanisms and governance challenges related to environmental management.

Together, these chapters provide a comprehensive overview of key environmental issues in Nepal. By presenting statistical evidence and analytical insights across different environmental domains, the Compendium of Environment Statistics 2026 serves as an important reference for policymakers, researchers, and other stakeholders engaged in environmental management and sustainable development.

6. Conclusion

Nepal faces complex and interconnected environmental challenges, ranging from land degradation, deforestation, and biodiversity loss to water and air pollution, climate change impacts, and urban environmental pressures. These issues are multidimensional, spanning ecological, economic, social, political, technological, and ethical dimensions. The development of the Compendium of Environment Statistics has played a critical role in systematically documenting environmental conditions, trends, and pressures over time, providing policymakers, researchers, and stakeholders with a robust foundation for evidence-based decision-making.

From its first edition in 1994 to the latest publications aligned with the Framework for the Development of Environment Statistics (FDES), the compendium has evolved to include analytical insights, cross-sectoral integration, and alignment with global sustainability goals. Coupled with Nepal's progressive approach to environmental management through periodic plans from extractive development to community-based conservation, and now to climate-integrated planning these efforts illustrate the country's gradual but steady commitment to sustainable development.

Moving forward, effective environmental governance in Nepal will depend on continued integration of robust data, strengthened institutional coordination, targeted policy interventions, and community engagement. By combining systematic statistical monitoring with proactive management strategies, Nepal can better address environmental pressures, safeguard its ecosystems, and achieve sustainable and resilient development.

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CHAPTER: II

Air Pollution and Human Health

Indira Parajuli

Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal

Email: indira.parajuli@cdes.tu.edu.np

Summary

Air pollution is a pervasive environmental and public health crisis. Elevated Air Quality Index (AQI) values consistently reflect deteriorated air quality, corresponding to a greater likelihood of severe adverse health effects. Currently, air pollution stands as the leading environmental risk factor for morbidity and mortality in the country. Every year, it is responsible for approximately 41,300 deaths, accounting for about 23% of total national mortality. Furthermore, continuous exposure reduces the average lifespan in Nepal by 3.4 to 4.1 years. The severity of this pollution is driven by a complex interplay of topographical, meteorological, and emission-related factors. In Kathmandu Valley, the bowl shaped terrain and seasonal thermal inversions trap local emissions like vehicular exhaust and construction dust nearby ground, formulating persistent smog. Conversely, in the Terai region, where the average lifespan is reduced by over 7.5 years, air quality is heavily degraded by local sources like agricultural burning and forest fires, compounded by transboundary pollution. Research indicates that during peak pollution periods, over 60% of the particulate pollutant load in the Terai originates from cross border atmospheric transport. Fine particulate matter (PM_{2.5}) is the primary driver of these health impacts, as it is strongly linked to severe cardiopulmonary diseases. In Nepal, PM_{2.5} exposure accounts for 75 % of Chronic Obstructive Pulmonary Disease (COPD) cases and nearly half of all strokes. Children, whose developing immune and respiratory systems make them exceptionally vulnerable, bear a significant burden. Air pollution is responsible for 21 % of mortality in children under five. Beyond human health, PM_{2.5}, black carbon, and other pollutants trouble the regional radiation balance. This accelerates the melting of Himalayan glaciers, threatening the long term water security of the entire region. The economic toll of this crisis is substantial, costing Nepal an estimated 6 % of its Gross Domestic Product (GDP) annually. Addressing this multifaceted challenge requires coordinated national and international interventions. Establishing robust local emission controls and mitigating cross-border pollution are essential to meet the National and World Health Organization (WHO) air quality guidelines. Ultimately, ensuring clean air is not only a constitutional right but a fundamental prerequisite for safeguarding public health and strengthening national economic and environmental resilience.

Keywords: Planetary Health; PM_{2.5}; Public Health Crisis; Short-Lived Climate Pollutants (SLCPs); Thermal Inversion

1. Introduction

Air pollution is the biggest threat to public health in most of the world in the 21st century. It comes from a complicated mix of natural events and anthropogenic activities, such as burning of fossil fuels, running factories, driving cars, and burning biomass. These activities release powerful combination of harmful chemicals into the air. PM_{2.5} is the most clinically important among other pollutants. Because PM_{2.5} is so tiny, it can enter through the natural filters in the upper respiratory tract and into the alveolar regions. From there, it enters to bloodstream causing inflammation in different organs (WHO, 2021).

The global burden of disease caused by air pollution around the world is shocking. Both ambient air and indoor air pollutants cause millions of early deaths every year, mostly from non-communicable diseases. Air quality has improved in some wealthy areas, but in developing countries, rapid urbanization, uncontrolled industrialization, and rising energy needs have made the air much worse. In places like Nepal, this crisis is made worse due to the widespread use solid biomass fuels, rapid pace of urbanization, and inadequate policy guidance and weak enforcement of environmental standards (Health Effects Institute (HEI) & Institute for Health Metrics and Evaluation (IHME) (HEI & IHME, 2023; WHO, 2021). As a result, air pollution is now one of the main causes of early death, along with major metabolic risk factors like smoking and malnutrition.

Contemporary epidemiological evidence indicates that the health threshold for PM_{2.5} is significantly lower than previously estimated. Exposure even at levels once considered "safe" is now robustly linked to adverse birth outcomes, metabolic disorders, impaired cognitive development, and increased all-cause mortality (HEI & IHME, 2023). Despite these findings, over 90 % of the global population resides in areas exceeding the 2021 WHO Air Quality Guidelines (5µg/m³), with the highest concentrations disproportionately concentrated in low- and middle-income countries (WHO, 2026a; WHO, 2026b).

The worldwide epicenter of this crisis is now South Asia. PM_{2.5} concentrations in Nepal, particularly in the topographically constrained Kathmandu Valley, have historically continued to be significantly higher than both national and international safety standards. This result in a loss of 3.4 to 4.6 years of life expectancy for the average citizen, and the national economy bears a burden equal to almost 6% of GDP (HEI & IHME, 2024). As a direct result of this ongoing air pollution, Nepal has the highest age-standardized death rate in the region from COPD.

Understanding the dynamics of air pollution is now essential for public health as well as the environment due to these important stakes. The sources of pollutants, exposure routes, and the particular socio-environmental elements causing the air quality issue in Nepal and South Asia are thoroughly examined in this chapter.

1.1 Regulatory Frameworks and Air Quality Standards

To evaluate the severity of the air quality crisis in Nepal, it is essential to establish the benchmarks defined by both international and national authorities. These standards represent the threshold between "acceptable" risk and significant public health endangerment. Nepal has adopted various strategic frameworks, including statutory provisions over time, to strengthen air quality governance (Table1).

Table 1: Hierarchical Mapping of Nepal’s Statutory and Strategic Framework for Air Quality Governance

Category	Policy	Key Description & Provisions
General / Constitutional	Constitution of Nepal 2015 (Government of Nepal [GoN], 2015)	Article 30 (Part 3): Establishes the "Right to a clean and healthy environment" as a fundamental right for every citizen.
	16th Plan 2024/25–2028/29 (National Planning Commission [NPC], 2024)	The Sixteenth Periodic Plan of Nepal (2024/25–2028/29) recognizes air pollution as a critical environmental and public health challenge and emphasizes strengthening air quality monitoring systems, promoting electric mobility, reducing emissions from transport and industry, improving urban environmental management, and advancing climate-resilient and green development pathways. The plan integrates air quality improvement within broader objectives of environmental

Category	Policy	Key Description & Provisions
		sustainability, public health protection, and low-carbon economic growth.
Environment & Climate	National Environment Policy 2019 (Ministry of Forests and Environment [MoFE], 2019a)	Aims to control pollution and manage waste to ensure constitutional rights. Objective is to minimize and control all pollution sources.
	National Climate Change Policy 2019 (MoFE, 2019b)	Promotes a green economy by reducing carbon emissions across themes like industry, transport, and urban settlements.
	Kathmandu Valley Air Quality Management Action Plan (KVAQMAP) 2020 (GoN, 2020b)	Focuses on the Kathmandu Valley with 135 actions. Includes provisions to declare a Public Health Emergency if the AQI exceeds 300.
	Second Nationally Determined Contributions 2020 (GoN, 2020c)	Targets for electric mobility: 90% private and 60% public EVs by 2030; 25% of households to use electric cook stoves as primary mode by 2030.
	Nepal CAP Project 2026 (World Bank, 2026)	A \$52 million (Rs. 7.7 billion) World Bank-supported initiative targeting industrial emissions. It provides financing for 400 enterprises to adopt electric or modern biomass boilers and advanced emission control technologies.
	National Air Quality Management Action Plan (NAQMAP) 2025 (GoN, 2025)	Initiated in late 2025 as an expansion of the Kathmandu Valley plan. It aims to establish a nationwide monitoring network and prioritize regional investments to manage transboundary pollution "hotspots" in the Terai.
	Pollution Tax /Finance Act, 2066 (GoN, 2009)	Government collects Rs. 1.50 per litre of diesel and petrol sold, though funds remain largely unutilized.
Health	National Health Policy 2019 (Ministry of Health and Population [MoHP], 2019)	Calls for a Multi-sectoral Action Plan. Envisions an Integrated Urban Health System with regular air quality monitoring and health assessments.
	Urban Health Policy 2015 (MoHP, 2015)	Visions safety from adverse health factors in urban areas but lacks specific air pollution control programs.
	Health National Adaptation Strategy & Action Plan (HNAP) 2024 (MoHP, 2024)	The first major strategy to explicitly link air pollution, climate change, and public health. It aims to develop technologies to minimize "mixed pollutants" like black carbon and PM2.5 to reduce the rising burden of respiratory and cardiovascular diseases.
	COP28 Declaration on Climate and Health 2024 (COP28 Presidency, 2023)	Nepal endorsed this global commitment to integrate health into its Third Nationally Determined Contributions (NDC), ensuring that future climate targets are measured by lives saved and healthcare costs reduced.
Transportation	National Transport Policy 2007 (Department of Roads [DoR], 2001)	Aims for safe, sustainable transport; focuses on gas and electric mobility solutions and effective public transport.
	Transport Management Act (1991) / Rules (1996) (GoN, 1991)	Authorizes DoTM to regulate standards. Restricts vehicle modifications, preventing conversion of petroleum vehicles to electric.
	Nepal Vehicle Mass Emission Standard 2082 (MoFE, 2025a)	Sets Euro 5-equivalent emission standards for motorcycles, three-wheelers, and light vehicles and Euro 6-equivalent standards for heavier four-wheeled vehicles, including cars, buses, and trucks.

Category	Policy	Key Description & Provisions
	Environment Friendly Vehicle & Transport Policy (2014 (Ministry of Physical Infrastructure and Transport [MoPIT], 2014)	Targeted a 20 % share of "environment friendly vehicles" by 2020. Encourages private investment in EV infrastructure.
	Five Year Strategic Plan 2073-2078 (MoPIT, 2014)	Discourages private vehicles; promotes mass transit, pedestrian-friendly roads, and cycle lanes in urban areas.
	National Action Plan for Electric Mobility 2018 (MoPIT, 2018)	Priority actions: Establish an electric mobility unit, a national program, and a financing mechanism for EVs.
Waste Management	Solid Waste Management Act (2011) / Rules (2013) (GoN, 2011a)	Mandates source separation and promotes recycling. Notably does not explicitly prohibit open waste burning.
Industries	Industrial Policy 2011 (GoN, 2011b)	Calls for the promotion of environment-friendly production processes. Mandates financial and technical support for industries adopting energy-saving and green technologies.
	Industrial Enterprises Act 2020 (GoN, 2020a)	Makes industries legally responsible for pollution control. Requires mandatory EIA procedures before licensing and empowers the Industrial Promotion Board to restrict industry registration in urban areas like the Kathmandu Valley.
Household Energy	Biomass Energy Strategy 2017 (Ministry of Population and Environment [MoPE], 2017a)	Aimed to eliminate indoor air pollution by 2022 through clean cooking. Sets a 2030 goal to ensure all biomass-dependent households have access to modern clean energy.
	Ministry of Energy, Water Resources and Irrigation (MoEWRI) White Paper 2018 (Ministry of Energy, Water Resources and Irrigation [MoEWRI], 2018)	Establishes the "Electric Stove in Every House" program. Sets a target for 50% of all imported vehicles to be electric within five years and mandates a national work plan for EV charging infrastructure.
	Nepal Renewable Energy Programme (NREP) Completion, 2025 (Winrock International, 2025)	Concluded in March 2025, having successfully established over 50 EV charging stations and assisted 45,000 families in switching to electric cooking, setting the technical blueprint for the MoEWRI's next phase of electrification.
	Electric Cooking /NDC Quantified Targets 2025 (MoFE, 2025b)	Updated implementation goals under the NDC aim to transition 2.1 million households to electric cookstoves by 2035. Recent 2025 pilot projects in districts like Pyuthan are subsidizing induction stoves to eliminate indoor biomass smoke.
Regulatory Standards	Nepal National Ambient Air Quality Standards (NAAQS), 2026 (GoN, 2026)	Nepal's domestic regulatory limit is currently set at 40 µg/m ³ for an annual average
	WHO Air Quality Guidelines (AQG), 2021 (WHO, 2021)	WHO drastically revised its annual PM _{2.5} guideline from 10 µg/m ³ to 5 µg/m ³

The NAAQS serves as a pragmatic policy target, which remains 4-5 times higher than the WHO's health-based recommendation (Table 2) for individual pollutants listed in terms of annual averaging time. WHO

(2021) guidelines reflecting updated epidemiological evidence that health damage occurs at much lower concentrations than previously thought (Table 2).

Table 2: Comparative Analysis of NAAQS, 2012 and WHO, 2021 Air Quality Guidelines. (Source: Government of Nepal, 2026, WHO, 2021)

Pollutant	Nepal NAAQS (2026)		WHO Guidelines (2021)	
	24- hour averaging time	Annual averaging time	24- hour averaging time	Annual averaging time
PM _{2.5}	40 µg/m ³	25 µg/m ³	15µg/m ³	5 µg/m ³
PM ₁₀	120 µg/m ³	70 µg/m ³	45 µg/m ³	15 µg/m ³
NO ₂	80 µg/m ³	40 µg/m ³	25 µg/m ³	10 µg/m ³
SO ₂	70 µg/m ³	50 µg/m ³	40 µg/m ³	-

The current legal thresholds in Nepal remain significantly more permissive than the WHO's 2021 evidence-based guidelines, particularly for PM_{2.5} and NO₂, which are the primary drivers of respiratory morbidity in urban cohorts

1.2 Institutional Framework for Air Quality Management

Under the federal structure, air quality management is distributed across three tiers of government, each with specific roles and responsibilities (Table 3).

Table 3: Institutional Architecture and Functional Jurisdictions for Air Quality Management in Nepal		
Tier	Authority	Primary Responsibilities
Federal	Ministry of Forests and Environment (MoFE)	Formulation of national standards, international treaty compliance, and transboundary pollution diplomacy.
	Department of Environment (DoE)	Managing the national real-time monitoring network, data reporting, and enforcement of emission standards.
	National Planning Commission (NPC)	Integrating clean air targets into the national budget and long-term development frameworks.
Provincial	Ministry of Industry, Tourism, Forest & Environment	Regional air quality monitoring and overseeing industrial emission compliance within provincial borders.
Local	Municipalities	Management of solid waste (preventing open burning), control of local construction dust, and urban greening.
Supportive	Department of Transport Management (DoTM)	Enforcement of vehicle "green stickers" and road-side emission testing.

1.3 Types of Air Pollution

Air pollution is broadly categorized into ambient and indoor air pollution.

1.3.1 Ambient Air Pollution

Ambient air pollution refers to the contamination of the outdoor atmosphere by both anthropogenic activities and natural sources (WHO, 2024b). It is a critical environmental and public health issue hence contributing substantially to the global burden of disease (HEI, 2024; WHO, 2024a). It arises from a combination of natural and anthropogenic sources, including transportation, industrial activities, energy production, agricultural practices, and biomass burning and natural processes like dust storms and wildfires (United Nations Environment Programme [UNEP], 2021b). Exposure to elevated concentrations of ambient air pollutants, PM_{2.5}, has been linked to numerous adverse health outcomes, including respiratory and cardiovascular diseases, lung cancer, and premature mortality (WHO, 2021; HEI, 2024). Consequently,

improving ambient air quality has become a priority within global sustainable development, climate action, and public health agendas (WHO, 2024a; UNFCCC, 2024). Major contributors include vehicular emissions, which release nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), and particulate matter (European Environment Agency [EEA], 2023). Likewise, industrial processes, including manufacturing and fossil fuel-based power generation, emit sulfur dioxide (SO₂), NO_x, PM, and other hazardous pollutants (UNEP, 2021a). Similarly, construction activities, which generate significant quantities of dust and PM through excavation, demolition, and transportation of construction materials (WHO, 2021). The vital contribution from agricultural activities, including crop residue burning and ammonia emissions from fertilizer application and livestock production, which contribute to secondary particulate matter formation (UNEP, 2021a). In a same way, the solid waste management practices; particularly open waste burning and landfill emissions, which release particulate matter, methane, and toxic air pollutants into the atmosphere (UNEP, 2021b).

1.3.2 Indoor Air Pollution

The use of fuels like wood, coal, dung and crop residues for cooking and heating is a big problem (WHO, 2023). 2.1 Billion People around the world use these polluting fuels (WHO, 2023). The inefficient combustion of these fuels, particularly in poorly ventilated indoor environments, generates high concentrations of harmful air pollutants, leading to household air pollution (WHO, 2023). This polluted air causes about 3.2 million people to die early every year (WHO, 2023). In a country like Nepal, the people who are affected the most are women and children who live in areas and spend a lot of time near the cooking fires (Kurmi et al., 2012; Devakumar et al., 2014). The continued dependence on solid biomass fuels in rural households poses significant health risks, including respiratory and cardiovascular diseases, particularly among vulnerable populations (WHO, 2023; Clean Cooking Alliance, 2024).

1.4 Major Air Pollutants

Pollutants derived from fossil fuels (like those used in cars and factories) burning release directly into atmosphere (WHO, 2024b). We also get air pollution from sources such as cars and trucks driving around and from people burning wood or other biomass fuels (UNEP, 2021b). These pollutants in the air can be divided into two groups: those that pose threats to public health and those that act as environmental stressors (WHO, 2021). Table 4 shows the types of air pollution and what makes each one unique. Air pollution is a major environmental problem, and it adversely affects human health (HEI, 2024; WHO, 2024b).

Table 4: Various air pollutants and their characteristics

Pollutant	Key Characteristics and Sources
Particulate Matter (PM _{2.5})	Particles $\leq 2.5\mu\text{m}$; dangerous as they penetrate the bloodstream and deep lung tissue.
Nitrogen Dioxide (NO ₂)	Produced from vehicle exhaust; contributes to respiratory inflammation and smog.
Sulfur Dioxide (SO ₂)	Emitted from burning coal and oil; causes respiratory irritation and acid rain.
Carbon Monoxide (CO)	Result of incomplete combustion; reduces oxygen regulation in the body.
Ozone (O ₃)	Ground-level secondary pollutant; causes acute respiratory distress.
Black Carbon	Systemic toxicity, climate-health link; absorbs solar energy; carries carcinogens into the lungs.

1.4.1 Primary Pollutants

In Nepal, the main health problem creator is PM_{2.5} (WHO, 2021; HEI, 2024). This is because PM_{2.5} is so small that it can enter the natural filtering system of the upper respiratory tract and penetrate deep into the lungs, reaching the alveolar region where oxygen exchange occurs (Pope & Dockery, 2006; WHO, 2021). When PM_{2.5} enters the bloodstream, it can cause a variety of adverse health effects throughout the body (Brook et al., 2010). PM_{2.5} triggers inflammation in different organs and tissues, causes oxidative stress that can damage cells, and may even result in DNA damage (Brook et al., 2010; WHO, 2021).

1.4.2 Short-Lived Climate Pollutants (SLCPs)

SLCPs are primarily classified according to their relatively short atmospheric lifetimes and strong radiative forcing effects rather than their toxicological properties. However, several SLCPs, particularly black carbon, are also posing serious risks to both human and environmental health. As a major component of fine PM_{2.5}, black carbon contributes to adverse health effects while simultaneously absorbing solar radiation and warming the atmosphere (UNEP & WMO, 2011; Bond et al., 2013). In addition to its atmospheric warming effects, black carbon is transported over long distances and deposited on snow and ice surfaces, including the Himalayan glaciers, where it reduces surface reflectivity (albedo) and increases the absorption of solar radiation (Ramanathan & Carmichael, 2008; Bond et al., 2013). This process accelerates glacier melting, disrupts the cryosphere, and threatens regional water security by altering the timing and availability of freshwater resources for millions of people dependent on glacier-fed river systems (UNEP & WMO, 2011; Intergovernmental Panel on Climate Change [IPCC], 2021). Therefore, the impacts of black carbon and other SLCPs extend well beyond human health, affecting climate systems, ecosystems, biodiversity, and the overall health of the planet. These multiple and interconnected impacts underscore the importance of mitigating SLCP emissions as a key strategy for achieving both climate change mitigation and sustainable environmental management.

2. Major Sources of Air Pollution

In Nepal, air pollution levels show a strong seasonality that peaks during the dry winter and pre-monsoon months (December to May) (International Centre for Integrated Mountain Development [ICIMOD], 2019; WHO, 2021). As of early 2026, Kathmandu and the Terai region continue to rank among the most polluted areas globally, with AQI levels frequently crossing the "unhealthy" threshold of 150–200 and occasionally hitting "hazardous" levels above 300 (WHO, 2021; World Bank, 2024). The major sources of air pollution in context of Nepal are associated with various activities like vehicular emissions, industrial production, brick kiln operations, household combustion of biomass and fossil fuels for cooking and heating, open

burning of solid waste, construction and road dust, agricultural residue burning, diesel generator use, quarrying and mining activities, forest fires, and transboundary transport of air pollutants (ICIMOD, 2019).

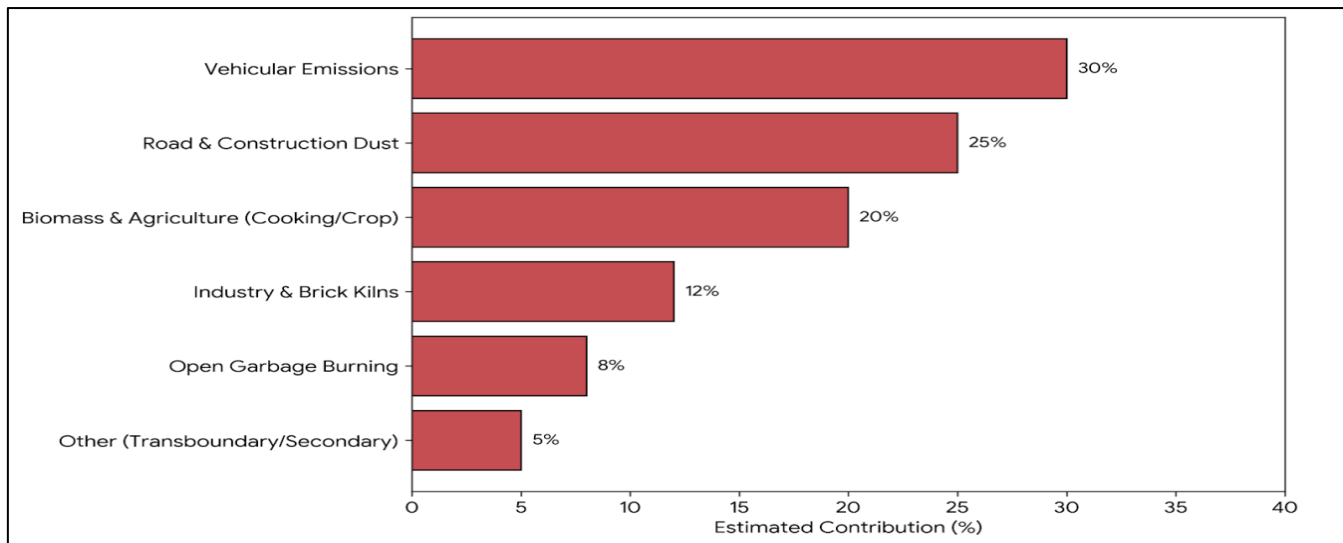


Figure 4: Major sources of PM_{2.5} pollution in Kathmandu Valley (Source: Sadavarte et al., 2019)

Studies indicate that vehicular emissions are the largest single contributor to particulate air pollution in the Kathmandu Valley, accounting for about 30 % of total PM_{2.5} emissions (Figure 1) (Sadavarte et al., 2019). This high share is attributed to the rapid growth of vehicles in the valley's terrain and narrow street traps polluted air. Most of them are old and poorly maintained along with heavy diesel trucks and a large number of two-wheelers (Sadavarte et al., 2019).

The road and construction sector is a part of the problem when it comes to pollution that contributes to fine and course particles. It is responsible for 25 % of the particulate pollution (Sadavarte et al., 2019). The resuspension of dust is exacerbated by heavy traffic (World Bank, 2023a). Similarly, burning waste and biomass is also a big contributor to pollution. It contributes around 20 percent of the pollutants. Seasonal agricultural burning by farmers, combined with regional forest fires during the spring, transports large plumes of smoke into urban areas of the valley, worsening air quality (Sadavarte et al., 2019).

Brick kilns located around the valley account for nearly 12 % of particulate. Brick kilns operate seasonally in the winter, coinciding with temperature inversions that trap soot and sulfur near the ground (Sadavarte et al., 2019). In addition, open waste burning contributes about 8 % of particulate emissions, as municipal solid waste and biomass materials are often burned in open spaces, releasing harmful pollutants like toxic dioxin into the atmosphere (World Bank, 2023e). Particulates transported by wind from IGP and other regional sources contribute 5 % of particulates in the valley (GoN, 2020b).

2.1 Local Sources in Urban Areas

Vehicular Emissions are the dominant source in the urban centers like Kathmandu Valley (MoFE, 2022). High densities of older, poorly maintained diesel and petrol vehicles release significant amounts of NO_x and PM_{2.5} (World Bank, 2023a). Similarly, construction dust release from massive infrastructure projects and unregulated roadwork contribute to high levels of coarse PM (ICIMOD, 2020). Moreover, the brick kilns around the valley and in the Terai, hundreds of brick kilns use low-grade coal and biomass, releasing SO₂ and black carbon (Clean Air Network Nepal, 2021). Likewise, open Waste Burning: Inadequate waste management leads to the frequent burning of household and municipal trash, releasing toxic dioxins and furans (UNEP, 2021b).

2.2 Regional and Trans-Boundary Sources

During winter, a thick layer of haze from northern India and Pakistan (The IDP) drifts into the Terai and is funneled into mid-hills (ICIMOD, 2019). Research indicates that over 60 % of PM_{2.5} in the Terai during peak episodes originates from across the border (World Bank, 2022b). In another way, the agricultural residue burning, the seasonal stubble burning in neighboring Indian states (Punjab, Haryana, Uttar Pradesh), and increasingly in southern Nepal significantly spikes regional pollution concentrations (WHO, 2022; NASA, 2022a).

2.3 Seasonal and Natural Factors

Forest Fires peaking between March and May. Wildfires across the mid-hills are a primary source of seasonal haze, often grounding flights and causing widespread respiratory distress (DoF, 2023). Valley's unique geography, the bowl shaped topography, traps pollutants. During winter, thermal inversions occur where a layer of warm air sits above cool air, preventing smoke and dust from dispersing (ICIMOD, 2019; World Bank, 2023a).

3. Health effects of air pollution

The health effects of air pollution are now known to be the biggest risk factor of death worldwide as of 2026 after high blood pressure (HEI, 2024; WHO, 2024a). It even surpasses tobacco use in some regions (HEI, 2024). According to data from *State of Global Air 2024/2025* and WHO updates, almost everyone globally breathes air that is not safe (HEI, 2024; WHO, 2024a). This leads to around 8.1 million deaths every year (HEI, 2024). Air pollution impacts all parts of the human body (WHO, 2024a). It is a risk factor for non-communicable diseases (NCDs), which are a major global health concern (WHO, 2024a). The air we breathe is not safe, and air pollution affects our health in multiple ways (WHO, 2024a).

Multi-Organ Impacts

Modern research has shifted from seeing air pollution as solely a respiratory issue to understanding it as a systemic toxicant (WHO, 2021; HEI, 2024) (Figure 2).

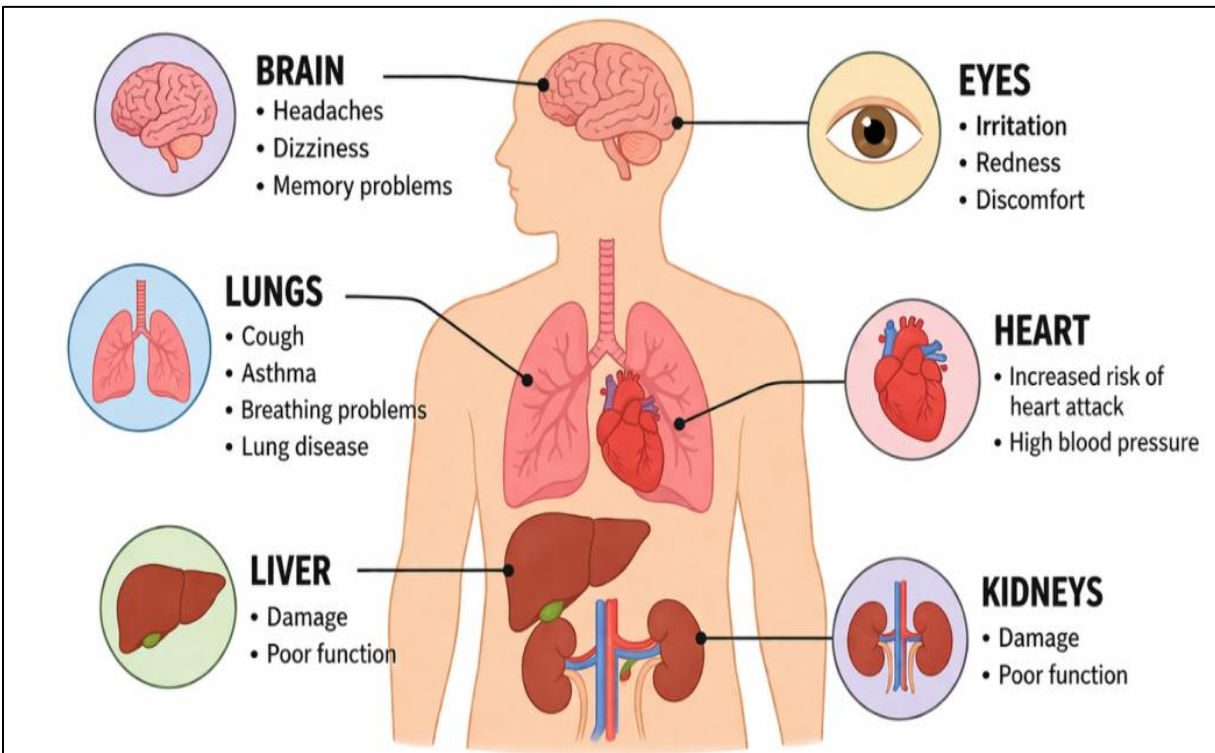


Figure 2: Air pollution impacts on human organs (Source: HEI, 2024)

Air pollutants impact on respiratory System causing asthma, COPD, and lung cancer (HEI, 2024; WHO, 2024a). Breathing in PM_{2.5} over time can cause arteries to harden and become inflamed (Brook et al., 2010; WHO, 2024a) effecting on cardiovascular System. This is a reason for heart disease and strokes, which make up a large proportion of deaths caused by air pollution (HEI, 2024; WHO, 2024a). Likewise, Fine particles can enter the brain via the bloodstream and cause inflammation (Block & Calderón-Garcidueñas, 2009) effecting neurological health. This is connected to mental decline, a higher risk of Alzheimer's and Parkinson's disease, and also affects children's intelligence and emotional development (Block & Calderón-Garcidueñas, 2009; WHO, 2024a). Additionally, research shows a link between long-term exposure to pollutants and type 2 Diabetes and obesity (Rajagopalan & Brook, 2012; WHO, 2024a) causing metabolic disorders. This happens because pollutants interfere with insulin sensitivity and metabolic pathways (Rajagopalan & Brook, 2012).

Vulnerable Populations

The health burden is not shared equally; the biological impact is most severe at the "bookends" of life (HEI, 2024; WHO, 2024a). Children breathe faster and their organs are still growing (Table 5). They are more likely to have impaired lung development and severe asthma due to air pollution exposure (WHO, 2024a). Every year, around 700,000 children under five die in world due to pneumonia linked to air pollution (UNICEF, 2023; WHO, 2024a). Children have higher minute ventilation per unit of body mass compared to adults (EPA, 2019; WHO, 2024a). This means they inhale a proportionally larger volume of air and thus more PM_{2.5} relative to their size (EPA, 2019). It effects on maternal and neonatal health too. When pregnant women are exposed to air pollution, it can cause babies to be born preterm or with low birth weight (HEI, 2024; WHO, 2024a). As of recent research, up to 34 % of all preterm births are linked to air pollution exposure in highly polluted regions (Chawanpaiboon et al., 2019; HEI, 2024). The elderly section of people

are also affected by air pollution. Older people are more likely to die from cardiovascular and respiratory diseases that are worsened by air pollution exposure (Brook et al., 2010; WHO, 2024a).

Table 5: Age-specific respiratory physiological reference values used for inhalation and minute ventilation modeling
(Source: American Heart Association (AHA), 2020)

Age Group	Normal Range (Breaths /min)	Average Tidal Volume (VT)	Average Minute Ventilation (VE)
Newborn to one month	30 – 60	15–30 mL	0.5–1.0 L/min
One month to one year	26 – 60		
1-10 years of age	14 – 50	150–200 mL	3.5–5.0 L/min
11-18 years of age	12 – 22	300-400 mL	4.0 – 6.0 L/min
Adult (ages 18 and older)	10 – 20	400–500 mL (Female)	5.0–7.0 L/min
		500–600 mL (Male)	6.0–8.0 L/min

Moreover, females usually breathe (12 to 16 breaths/minute) a bit faster when they are not doing anything compared to males primarily due to smaller lung size and airway capacity (Table 5) (West, 2012; Guyton & Hall, 2021). Females and males usually breathe between 12 and 20 times per minute when they are resting; females exhibit higher work of breathing during exercise due to these anatomical differences (West, 2012; American Thoracic Society, 2023). The higher the breathing rate, the higher would be the probability of particles gets entered into the lungs.

3.1 Exposure Pathways and Vulnerability

Human exposure to air pollutants occurs primarily through inhalation, although minor exposure pathways include dermal absorption and the ingestion of contaminated food and water (WHO, 2024a). Susceptibility to the adverse effects of air pollution varies according to age, physiological condition, and overall health status (WHO, 2021). Vulnerable populations include: (1) Children’s lungs and immune systems are still developing, making them particularly sensitive to air pollution exposure (UNICEF, 2019; WHO, 2021). (2) Many elderly individuals have pre-existing cardiovascular and respiratory conditions, increasing their vulnerability to the adverse health effects of air pollution (WHO, 2021; HEI, 2024). (3) Women expose to air pollutants during pregnancy has been associated with adverse birth outcomes, including low birth weight, preterm birth, and impaired fetal development (Bekkar et al., 2020; WHO, 2021). (4) Low-income communities often have limited access to clean energy sources and are more likely to reside near industrial facilities, major roads, or other sources of air pollution, resulting in higher exposure levels (UNEP, 2021a; WHO, 2024).

4. Air Pollution and Human Health

4.1 Air Pollution and Human Health in South Asian Context

In the South Asian context, air pollution surpasses standard guidelines for safe health, manifesting as a pervasive determinant of morbidity and mortality that fundamentally shapes the lived experience of millions. Communities are subjected to an atmospheric burden driven by vehicular exhaust, industrial emissions, and agricultural residue burning pollutants that disperse freely across regional airsheds, ignoring geopolitical boundaries (World Bank, 2022a). Concurrently, a severe, localized threat persists within domestic environments. In rural and Himalayan households, the socioeconomic necessity of relying on solid biomass fuels for cooking and heating exposes families to hazardous concentrations of indoor pollutants daily (Ullah, 2020). Chronic inhalation of PM2.5 bypasses respiratory defenses and infiltrates the systemic

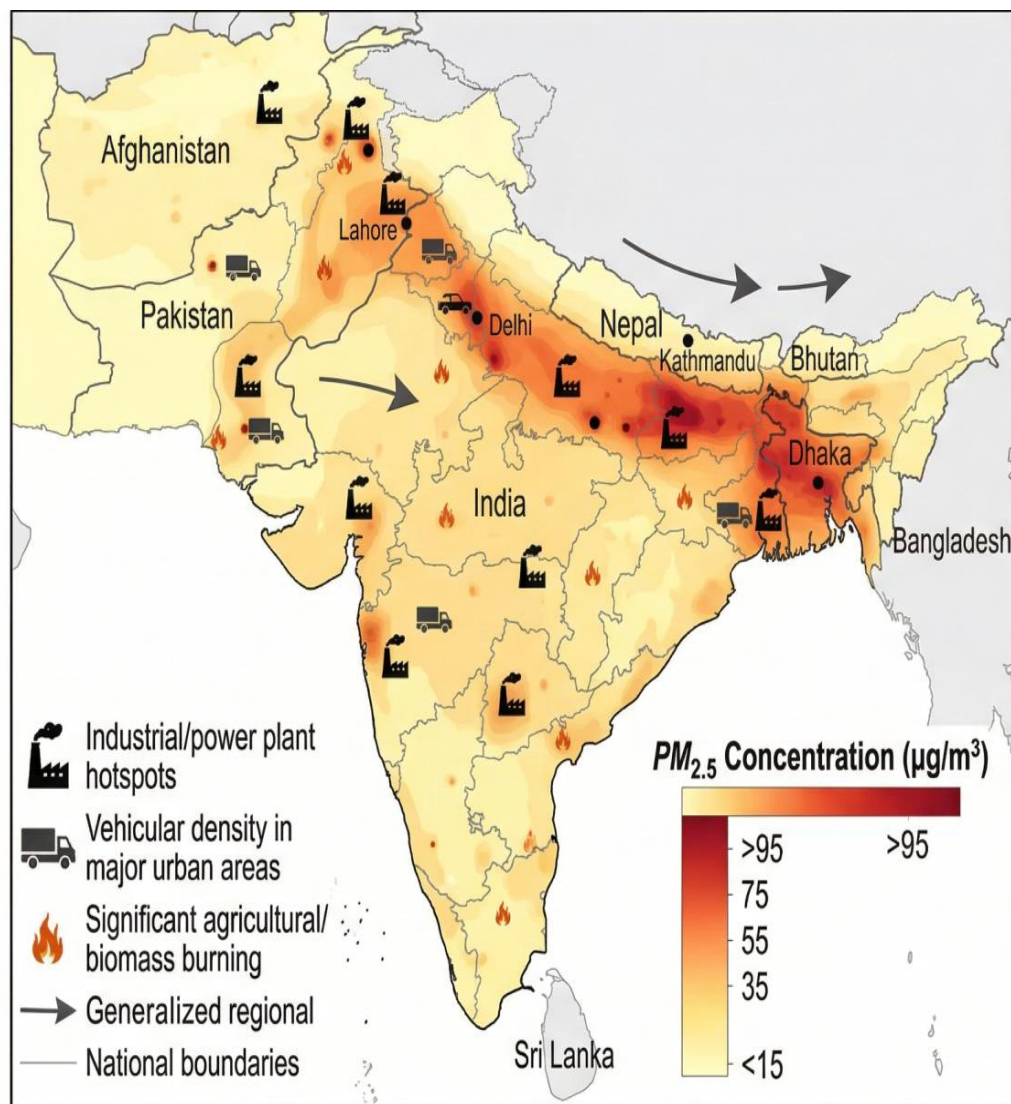
circulation, initiating widespread oxidative stress and placing a silent but profound physiological burden on the human body (HEI, 2024). Over time, this cumulative exposure becomes a primary catalyst for severe, chronic pathologies, including asthma, ischemic heart disease, and cerebrovascular events (Elaprolu, 2024). Crucially, this environmental hazard exacts an intimate and devastating toll on maternal and fetal health, precipitating alarming rates of low birth weight and pregnancy loss (Xue et al., 2021). Mitigating this public health crisis necessitates a paradigm shift: policymakers must implement collaborative, cross-border airshed management strategies while simultaneously prioritizing equitable access to clean energy transitions for the region's most vulnerable populations (Krishna et al., 2017).

4.1.1 Analysis of Regional Pollution Drivers and Socioeconomic Trends

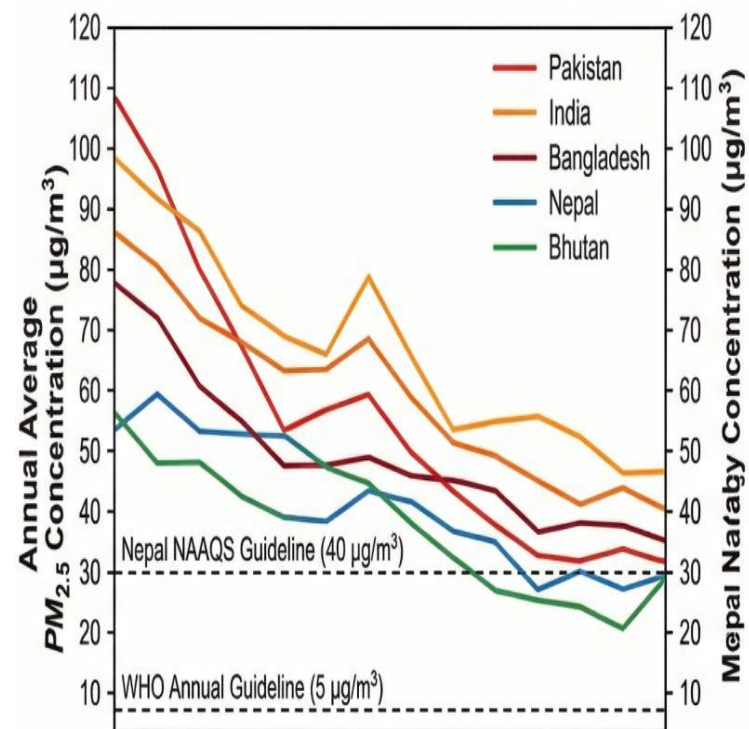
The map (Figure 3a) shows an area of pollution that extends across the Indo-Gangetic Plain (IGP) and covers northern India, Pakistan, and Bangladesh. It also affects the foothills of Nepal. The deep red areas on the map indicate the regions with the worst pollution, with the highest concentrations ($95 \mu\text{g}/\text{m}^3$) (Energy Policy Institute at the University of Chicago [EPIC], 2025a). These areas are typically located around industrial centers and major cities such as New Delhi, Lahore, and Dhaka (EPIC, 2025a). As shown in Figure 3a, the regional haze is driven by primary emission contributors (HEI, 2024).

1. Industrial and Power Plants: There are many of these plants in the IGP and eastern India, contributing significantly to emissions (World Bank, 2023b; HEI, 2024).
2. Vehicular Density: There is a high concentration of vehicles in large urban centers with dense populations (World Bank, 2023b).
3. Biomass Burning: Farmers burn leftover crop residues in fields, releasing pollutants that cross national borders (NASA, 2022c; HEI, 2024).
4. Topography: The terrain and atmospheric circulation patterns transport pollution from the plains toward the Himalayas, where it becomes trapped in valleys such as the Kathmandu Valley (ICIMOD, 2019; World Bank, 2023b).

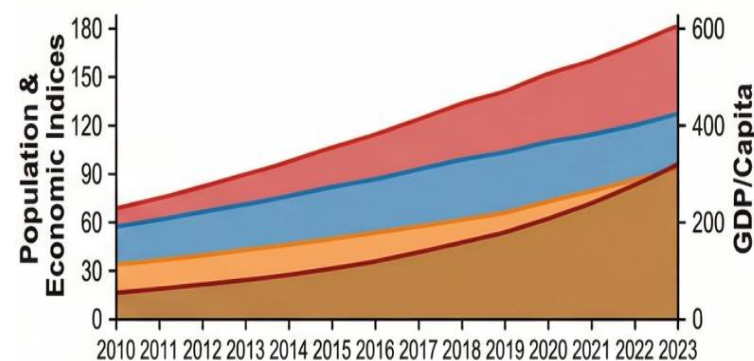
The temporal and socioeconomic trends from 2010 to 2023 show how pollution interacts with development over time (Figure 3b) (World Bank, 2023b; HEI, 2024). Pollution levels have been decreasing in some countries, but they remain far above internationally recommended safe limits (WHO, 2021). For example, Nepal is approaching its national pollution limit of $40 \mu\text{g}/\text{m}^3$, but the World Health Organization guideline of $5 \mu\text{g}/\text{m}^3$ remains far from being achieved across the region (WHO, 2021). Hence, there is a significant gap, in safeguarding public health from air pollution exposure (HEI, 2024). As shown in the area chart (Figure 3c), both population and GDP per capita have been steadily increasing (World Bank, 2023b). The main challenge in the region is balancing economic growth with environmental sustainability. As regional economies expand, total emissions remain high despite improvements in technology and regulatory frameworks (World Bank, 2023b). The pollution problem remains a major issue, and economic growth is closely linked with environmental degradation (World Bank, 2023b; HEI, 2024). Countries in the region need to identify pathways to reduce pollution while continuing economic development. The goal is to align economic growth with environmental protection and public health improvement (WHO, 2021; World Bank, 2023c).



(a)



(b)



(c)

Figure 3: Regional $PM_{2.5}$ pollution in South Asia (a) Regional $PM_{2.5}$ pollution and major emission sources in South Asia (Annual Average, 2023) (b) Temporal trends in regional $PM_{2.5}$ concentrations (c) Key socioeconomic indicators (2010-2023) (Source: World Bank, 2023b & EPIC, 2025b)

4.1.2 Long Term Air Pollution Trend in South Asia

Figure 4 illustrates estimated annual average PM_{2.5} concentrations ($\mu\text{g}/\text{m}^3$) for Bangladesh, India, Pakistan, and Nepal across three major historical eras, contrasted with the WHO annual guideline of $5 \mu\text{g}/\text{m}^3$ (WHO, 2021; HEI, 2025). The data from 1990 to the present are derived from the Global Burden of Disease (GBD) study and *State of Global Air* reports (IHME, 2024a; IHME, 2024b; HEI, 2025). Data before 1990 represent approximated exposure trajectories based on historical anthropogenic emission inventories of PM_{2.5} precursors such as sulfur dioxide and black carbon (Hoesly et al., 2018; IPCC, 2023).

During the period after rapid industrial growth from 1950 to 1990, PM_{2.5} concentrations increased significantly, largely due to biomass burning and the expansion of fossil fuel use in industry and transport (IPCC, 2023; WHO, 2021). As industries expanded and coal-based energy, railroads, and factories increased, air quality deteriorated further (Hoesly et al., 2018). In the 1950s, ambient air quality in the region was already poor due to widespread use of solid fuels in households and informal sectors (WHO, 2021). This level was far above the WHO guideline of $5 \mu\text{g}/\text{m}^3$ (WHO, 2021).

During the “Great Acceleration” from 1990 to 2010, air pollution increased rapidly due to economic growth, expansion of diesel vehicle fleets, and large-scale construction activities (IPCC, 2023; HEI, 2025). These combined sources created persistent regional haze over the Indo-Gangetic Plain (ICIMOD, 2019). Although Nepal has limited large-scale industry compared to neighboring countries, its geographic position results in significant transboundary pollution transport from the Indo-Gangetic Basin (ICIMOD, 2019; World Bank, 2023b). This further worsens air quality in the Kathmandu Valley due to local emissions from vehicles and urban activities (World Bank, 2023a).

From 2010 to 2026, PM_{2.5} concentrations show signs of stabilization and slight decline in some regions after peaking between 2010 and 2015 (WHO, 2021; HEI, 2025). The COVID-19 lockdowns in 2020 temporarily improved air quality due to reduced vehicle and industrial activity (WHO, 2021; NASA, 2022b). However, pollution levels rebounded after restrictions were lifted, although not reaching previous peak levels in some locations (HEI, 2025). Air quality remains far above safe limits. Emerging interventions such as electric vehicles and improved brick kiln technologies may be contributing to slowing the rate of deterioration (ICIMOD, 2019; World Bank, 2023d) (Figure 4).

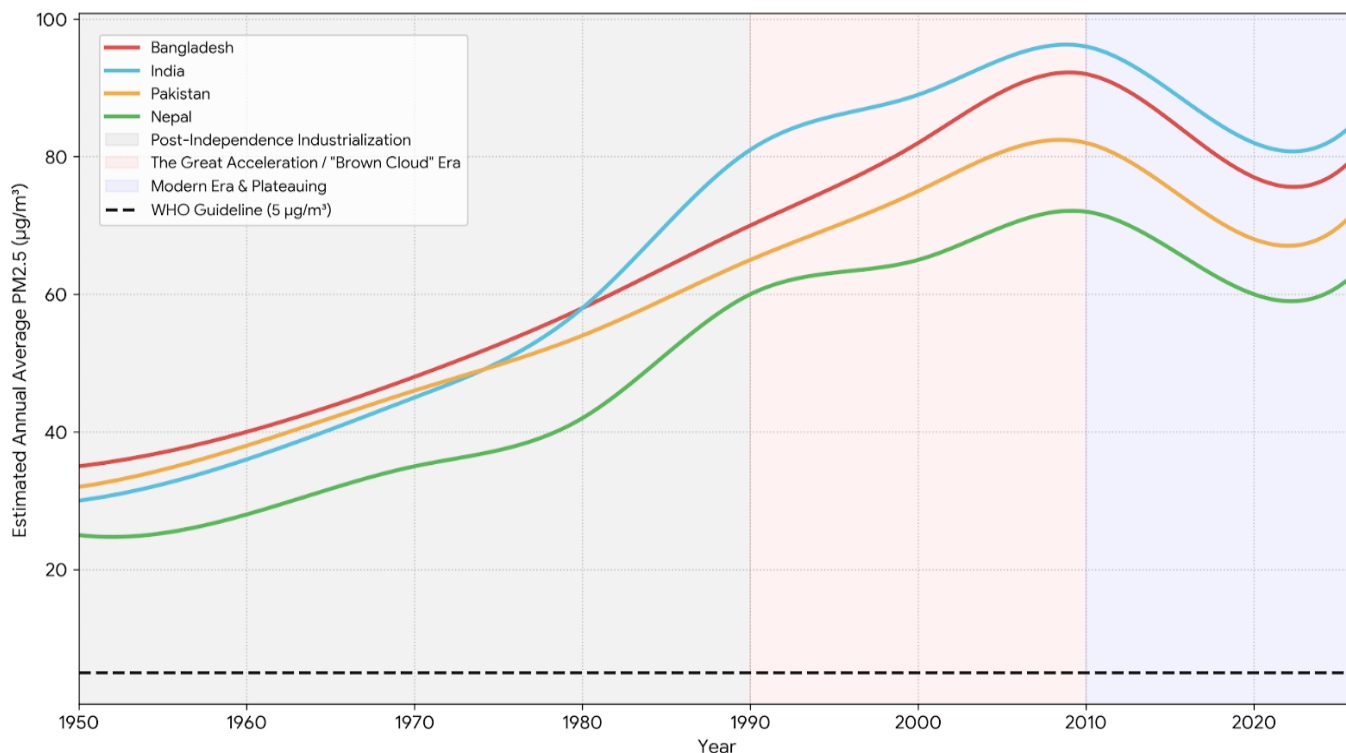


Figure 4: Long-Term Air Pollution Trends in South Asia (1950–2026) (Source: HEI, 2025)

4.1.3 Air Pollution Trends in Major South Asian Countries (2015-2025)

Figure 5 shows the annual concentration of PM_{2.5} in selected countries in South Asia over the last ten years (HEI, 2025; IQAir, 2025). It especially looks at what's happening in Bangladesh, Pakistan, India, and Nepal. The information comes from the 2025 IQAir World Air Quality Report and the HEI's 2025 *State of Global Air* (HEI, 2025; IQAir, 2025). As indicated by the black dashed line at the base of the plot, all four nations consistently exceed the WHO annual guideline of 5 µg/m³ by 8 to 16 times (WHO, 2021; IQAir, 2025) (Figure 5).

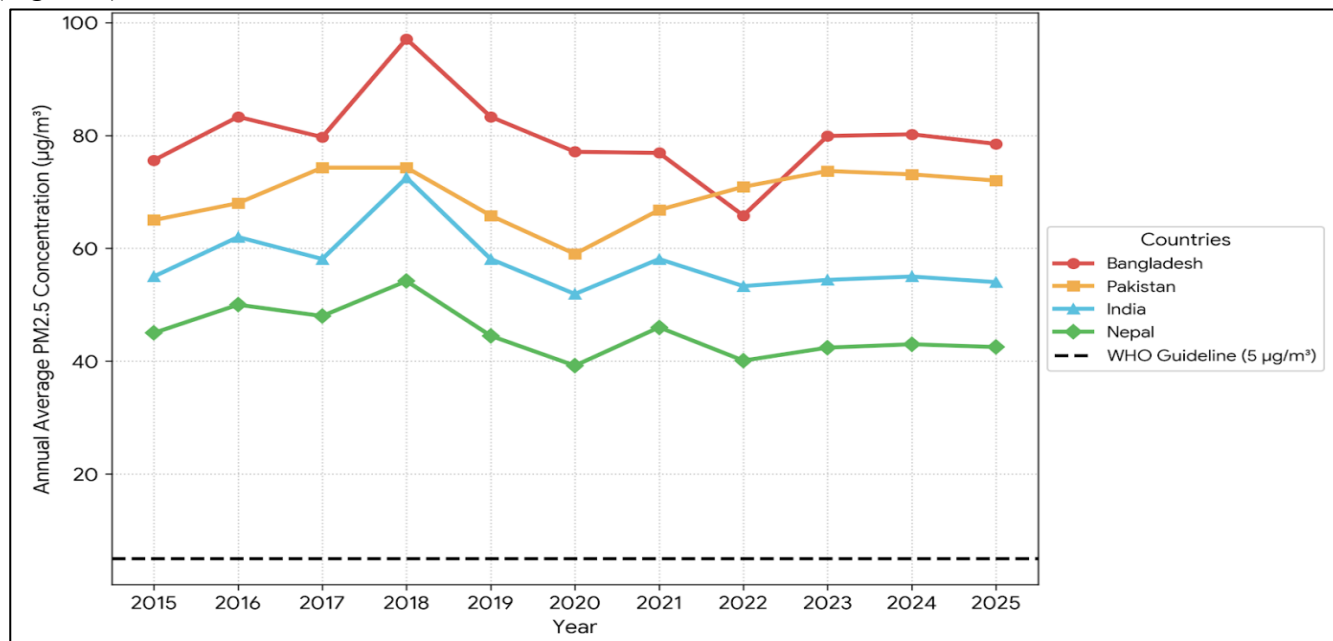


Figure 5: PM_{2.5} Air Pollution Trends in Major South Asian Countries (2015-2025) (Source: HEI, 2025; IQAir, 2025)

Regionally Bangladesh and Pakistan are usually the most polluted countries, often ranking highest in the world with India close behind (HEI, 2025; IQAir, 2025). A notable thing is that pollution concentrations went down around 2020 (WHO, 2021; NASA, 2022b). This happened because of the COVID-19 lockdowns that stopped industrial activity and reduced vehicle emissions (WHO, 2021; NASA, 2022b). However, pollution levels quickly went up in the following years (HEI, 2025; IQAir, 2025). Nepal's national pollution averages are slightly lower, between 40–50 $\mu\text{g}/\text{m}^3$ (World Bank, 2023d; HEI, 2025). Nepal is still heavily affected by pollution from the Indo-Gangetic Plain (ICIMOD, 2019; World Bank, 2023c). Also pollution in the Kathmandu Valley can spike in winter, which is often much higher than national averages shown in this regional overview (Figure 5) (ICIMOD, 2019; HEI, 2025).

4.2 Air Pollution Trend in Nepalese context

4.2.1 Historical trends of air quality (1990–2025)

When looking at air quality of Nepal over time, it is necessary to separate the Kathmandu Valley's air quality from the national overall average (ICIMOD, 2019; World Bank, 2023a). This is because the Terai region's geography and transboundary pollutants from neighboring countries greatly affect the national average (ICIMOD, 2019; World Bank, 2023c). The Department of Environment (DoE) started using Beta Attenuation Monitors (BAM) to track air quality in 2016 (MoFE, 2022). Before that, satellite data based on Aerosol Optical Depth (AOD) was used to estimate pollution levels (Hoesly et al., 2018; NASA, 2022b). Nepal has had an air pollution problem for many years (HEI, 2025). Data from satellite models and the Global Burden of Disease (GBD) study show that pollution in Nepal has been getting worse over the past thirty years (IHME, 2024b; HEI, 2025) (Figure 6).

From 1990 to 2010, the annual average $\text{PM}_{2.5}$ concentration in Nepal remained around 57–58 $\mu\text{g}/\text{m}^3$ (Hoesly et al., 2018; HEI, 2025). In 2011, pollution started to rise sharply, peaking in 2015 at around 75.1 $\mu\text{g}/\text{m}^3$ (HEI, 2025). It then slowly declined to 52.8 $\mu\text{g}/\text{m}^3$ by 2020 (WHO, 2021; HEI, 2025). Despite this recent decline, these values consistently exceed both national and international health standards (WHO, 2021). Figure 8 highlights a significant public health challenge, as concentrations have remained above both the National Ambient Air Quality Standards (NAAQS) and the WHO interim targets throughout the entire 30-year study period (WHO, 2021; MoFE, 2022).

Comparative Analysis (1990–2020)

While analyzing the historical data, over the past 30 years, the annual concentrations of $\text{PM}_{2.5}$ in Nepal have never been within the NAAQS limit of 40 $\mu\text{g}/\text{m}^3$. The closest Nepal came to meeting this standard was in 2010, when the average $\text{PM}_{2.5}$ concentration was 48.4 $\mu\text{g}/\text{m}^3$ (Figure 6) (World Bank, 2022b; GoN, 2026). As of 2020, the $\text{PM}_{2.5}$ concentration in Nepal was 52.8 $\mu\text{g}/\text{m}^3$, which is 32 % higher than the NAAQS of 40 $\mu\text{g}/\text{m}^3$ (Figure 6) (World Bank, 2022b; GoN, 2026). The 2020 $\text{PM}_{2.5}$ concentration in Nepal was more than 10 times higher than the WHO Global Air Quality Guideline of 5 $\mu\text{g}/\text{m}^3$ (Figure 6) (WHO, 2021; World Bank, 2022b). In 2015, the $\text{PM}_{2.5}$ concentration in Nepal reached 75.1 $\mu\text{g}/\text{m}^3$, which was nearly double the national limit and approximately 15 times higher than the WHO Global Air Quality Guideline value (Figure 6) (WHO, 2021; World Bank, 2022b; GoN, 2026). Although $\text{PM}_{2.5}$ concentrations have shown a declining trend in recent years, Nepal has not met the WHO annual guideline value of 5 $\mu\text{g}/\text{m}^3$ at any point during the last 30 years. This shows the huge compliance gap (Figure 6) (WHO, 2021; World Bank, 2022b).

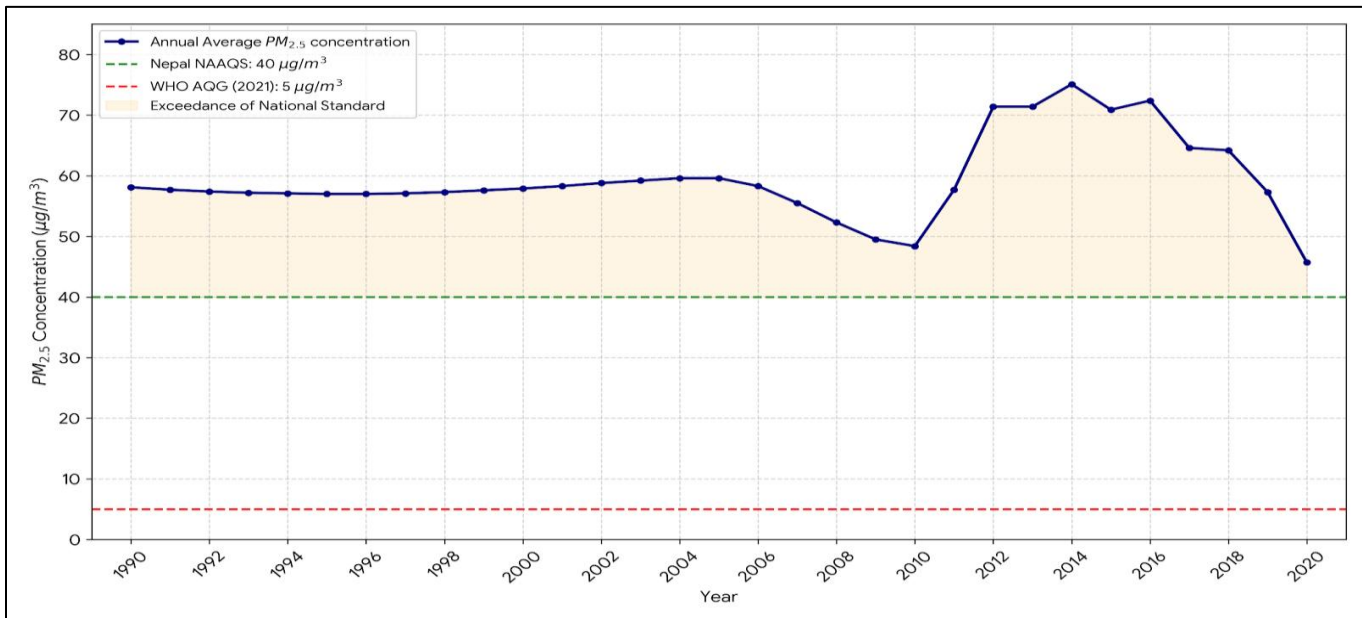


Figure 6: Long- term trend of annual PM_{2.5} in Nepal (1990-2020) with National and WHO standards (Source: World Bank (2022b))

4.2.2 Kathmandu Valley Trend Insights

The historical trend shown in Figure 7 indicates that the Kathmandu Valley experienced very high particulate pollution during the 2000s. Annual mean PM_{2.5} concentrations were approximately 80–100 µg/m³, substantially higher than both the national average and health-based guideline values (World Bank, 2022b). From 2017 to 2020, the Valley witnessed a notable improvement, with annual mean PM_{2.5} concentrations declining to levels below the national average. This trend may be attributed to the increasing influence of transboundary air pollution, regional haze, and widespread forest fires affecting other parts of Nepal, particularly the Terai region, thereby elevating the national average concentrations (Shrestha et al., 2021; ICIMOD, 2024). However, resurgence in pollution was observed in 2021, when extensive forest fires across Nepal contributed to elevated PM_{2.5} levels, reaching an annual concentration of 56.5 µg/m³ (Shrestha, 2021).

The Kathmandu Valley exhibits a unique air pollution profile due to its bowl-shaped topography, which restricts atmospheric dispersion and traps pollutants, particularly during winter temperature inversion events (Panday & Prinn, 2009; Mahapatra et al., 2019). During the 2000s, annual PM_{2.5} concentrations in the Valley frequently exceeded 90 µg/m³ (World Bank, 2022b). More recently, from 2022 to 2024, PM_{2.5} concentrations have shown a declining trend, ranging from approximately 31 to 38 µg/m³. For the first time, these concentrations fell below Nepal's NAAQS annual limit (GoN, 2026). Nevertheless, when compared with the WHO's Global Air Quality Guideline of 5 µg/m³, PM_{2.5} concentrations in the Kathmandu Valley remain approximately six to seven times higher than the level considered safe for human health (WHO, 2021) (Figure 7).

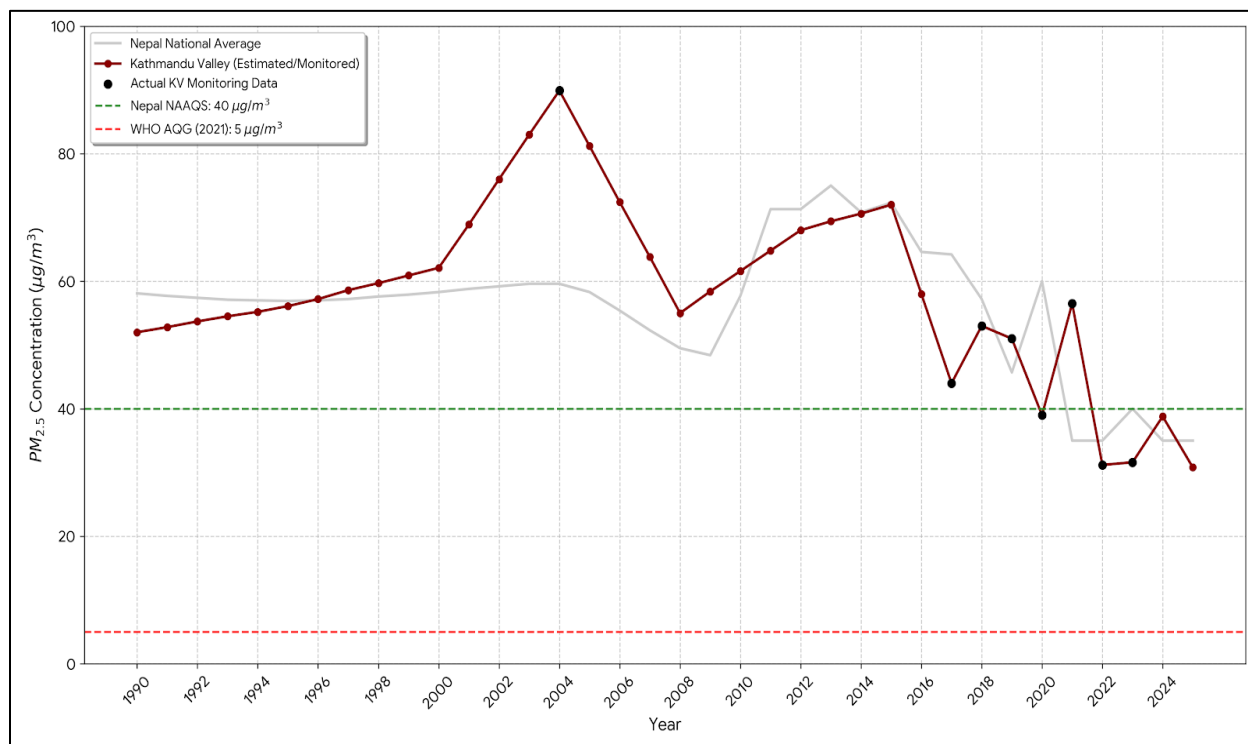


Figure 7: Long- term trend of annual PM_{2.5} concentrations in Kathmandu Valley (1990-2025) (Source: HEI, 2025)

Based on data from the DoE, Government of Nepal, the long-term trend in air pollution (2017–2025) shows a persistent and worsening challenge, primarily driven by rapid urbanization and seasonal factors. PM remains the primary pollutant of concern in Nepal (DoE, 2024). Furthermore, both Satellite derived data and ground stations monitoring data show an increasing trend in AOD, over the past two decades, suggesting an overall deterioration in atmospheric conditions and increasing particulate burden across the region (Kharol et al., 2011; Mahapatra et al., 2019) (Figure 8).

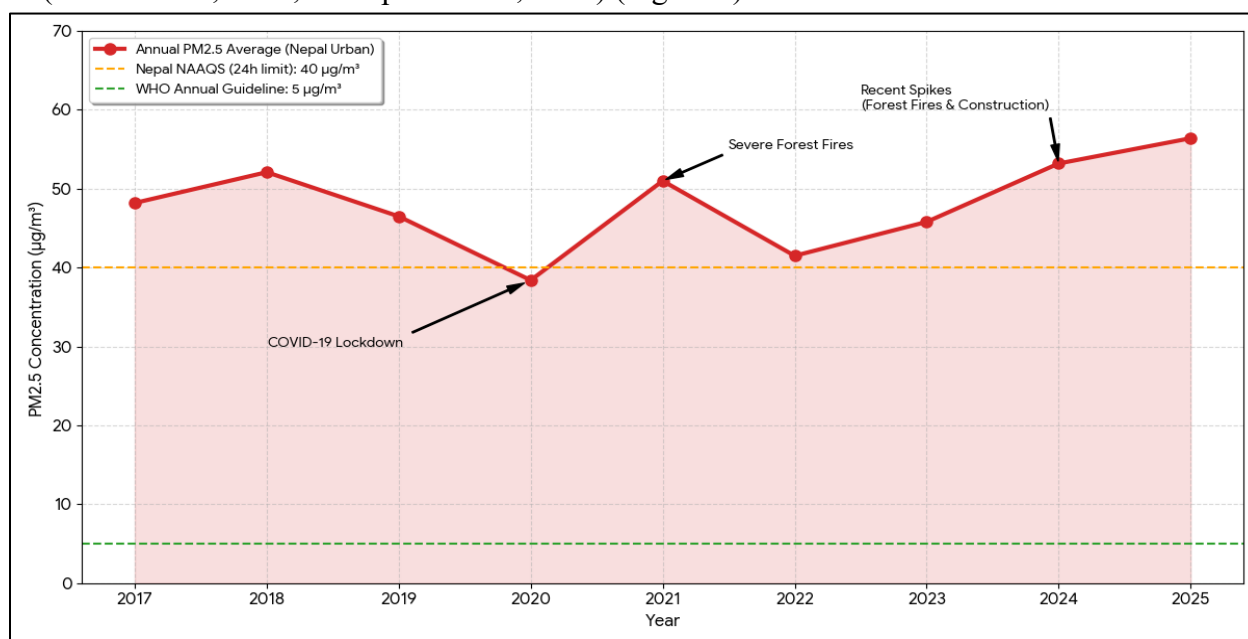


Figure 8: Long-term (2017- 2025) air pollution trend (PM_{2.5}) in Nepal (Source: DoE, 2025/ AQLI and Research Reports, 2025, Analysis based on DoE air quality monitoring data and satellite-derived AOD datasets)

Figure 8 shows that ambient particulate pollution concentrations declined markedly in 2020, primarily due to the nationwide restrictions imposed during the COVID-19 pandemic, which reduced emissions from transportation, industrial activities, and other anthropogenic sources (Shrestha et al., 2021). However, pollution levels subsequently rebounded and frequently exceeded both the WHO guideline and NAAQS. The annual mean PM_{2.5} concentration often remained above Nepal's annual standard of 40 µg/m³, posing a significant long-term public health concern (DoE, 2024; GoN, 2026).

The highest pollution levels were observed in 2021 and 2025, coinciding with severe pre-monsoon forest fire events across Nepal. These biomass burning episodes substantially contributed to elevated particulate concentrations and exacerbated the overall air pollution trend (DoE, 2024; ICIMOD, 2024). In 2020, the annual mean PM_{2.5} concentration decreased to 38.4 µg/m³, which was much lower than usual but still 8 times higher than WHO guidelines. This shows the continued influence of emissions from vehicles, industries, and other anthropogenic activities on ambient air quality in Nepal (WHO, 2021) (Figure 8; Table 6).

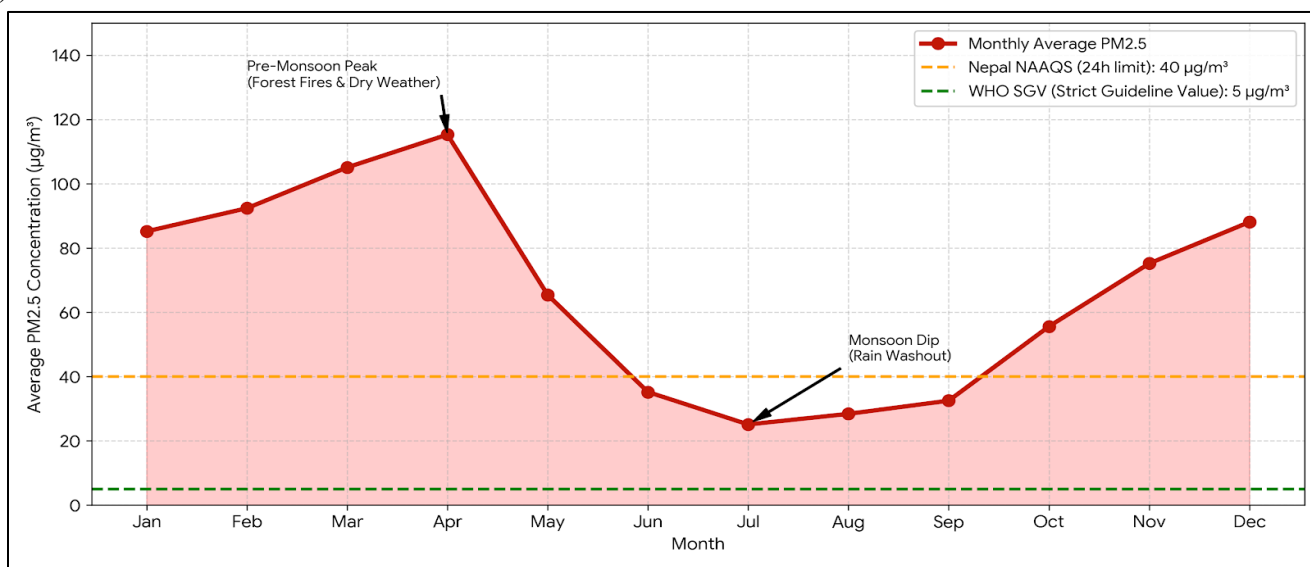


Figure 9: Seasonal Variation of PM_{2.5} in Kathmandu Valley highlighting extreme spikes Vs. SGV (Source: DoE, 2025/ AQLI and Research Reports, 2025, Analysis based on Kathmandu Valley air quality monitoring data)

Figure 9 shows the seasonal variation in PM_{2.5} concentrations in the Kathmandu Valley, compared with NAAQS and WHO Global Air Quality Guideline (5 µg/m³). While annual averages show long-term trends, the monthly breakdown reveals the true public health crisis in the valley. The concentration became alarming during January to April, i.e during winter and before the monsoon season. In March and April forest fires, burning crops and dry weather make PM_{2.5} concentrations go over 115 µg/m³ on average limit (Figure 9). People breathe air that is more than 23 times the SGV (WHO, 2021). From June to September, concentrations decrease approximately to 25 µg/m³. This decline is driven by a reduction in primary emission sources, specifically the seasonal closure of brick kilns, negligible forest fire activity, and decreased space heating combined with the washout effect of monsoon precipitation. Even during these cleaner months Kathmandu's air is still 5 times worse than the suggested guideline (WHO, 2021) (Figure 9). In November and December cold weather causes a phenomenon called "temperature inversion" events that restrict atmospheric dispersion and trap locally emitted pollutants within the Valley (Panday & Prinn, 2009). This traps pollution from vehicles, in the Kathmandu Valley making air pollution bad again by the end of the year (Figure 9).

Table 6: Temporal variation of PM_{2.5} comparing the concentration with WHO and NAAQS

Year	PM _{2.5} Annual Average (Est.)	Status vs. WHO Standard	Status vs. Nepal (24h)
2017	45.9	~9.2x Over	Exceeded
2019	48.0	~9.6x Over	Exceeded
2020	38.4	~7.7x Over	Slightly Below
2021	50.1	~10.0x Over	Exceeded
2023	45.0	~9.0x Over	Exceeded
2025	58.0	~11.6x Over	Heavily Exceeded

Based on representative recent annual averages from the DoE national network, almost every major city and monitoring hub surpassed both the WHO guidelines and the National Standard Guideline. The average concentrations of PM_{2.5} in urban areas like Ratnapark and Pulchowk regularly exceed the WHO annual guideline (5 $\mu\text{g}/\text{m}^3$) by 35% to 60% increase 8 to 10 times (DoE, 2024). While pollution is most severe in Kathmandu, the Terai region (e.g., Lumbini, Biratnagar) often records higher pollution concentrations than the capital during the winter due to transboundary movement and local industrial activities (ICIMOD, 2024). As of early 2026, the trend shows a slight improvement in awareness and monitoring but not yet in ambient air quality (Figure 10).

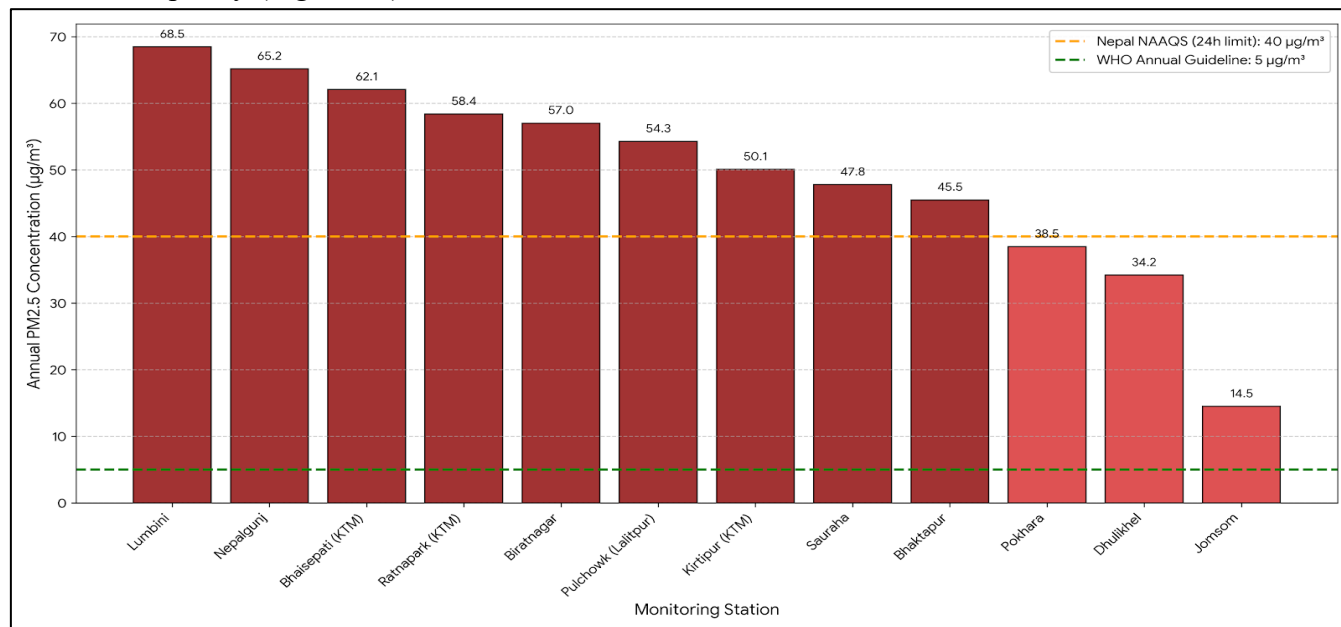


Figure 10: Annual Average PM_{2.5} Concentration across major stations in Nepal compared with National and WHO standards (Source: DoE, 2025/ AQLI and Research Reports, 2025)

The Most Polluted Hubs in the Terai Region like Lumbini and Nepalgunj always have the high pollution concentrations in the country. This is because they are close to the border, which means they get pollution from across the border and they also have local brick kilns and industrial areas (ICIMOD, 2024). The pollution concentrations in Lumbini and Nepalgunj are 13 to 14 times higher than WHO safe limit (WHO, 2021) (Figure 10).

The Kathmandu Valley is also much polluted. Places like Bhaisepati, Ratnapark, Pulchowk and Kirtipur usually have pollution concentrations between 50 $\mu\text{g}/\text{m}^3$ and 65 $\mu\text{g}/\text{m}^3$. This is a little better than the Terai

Region. The Kathmandu Valley traps vehicular emissions and winter dust, keeping concentrations deeply unhealthy year-round (Panday & Prinn, 2009; Mahapatra et al., 2019) (Figure 10).

The Mid-Hills and Tourist Hubs, like Pokhara and Dhulikhel have pollution concentrations relatively lower than Kathmandu but they still exceed the WHO 5 $\mu\text{g}/\text{m}^3$ threshold and often drift around the annual National Standard line of 40 $\mu\text{g}/\text{m}^3$ (WHO, 2021; GoN, 2026) (Figure 10).

The high-altitude area of Jomsom presents a contrasting air quality profile. Due to its sparse population, limited anthropogenic activities, and remote location, Jomsom generally experiences much cleaner air, with an average $\text{PM}_{2.5}$ concentration of 14.5 $\mu\text{g}/\text{m}^3$. However, despite its relatively good air quality, $\text{PM}_{2.5}$ levels in Jomsom still exceed the annual guideline recommended by the WHO (WHO, 2021). This is primarily because the area is occasionally affected by windblown dust transported from surrounding valleys and arid landscapes, which contributes to elevated PM concentrations (Mahapatra et al., 2019) (Figure 10).

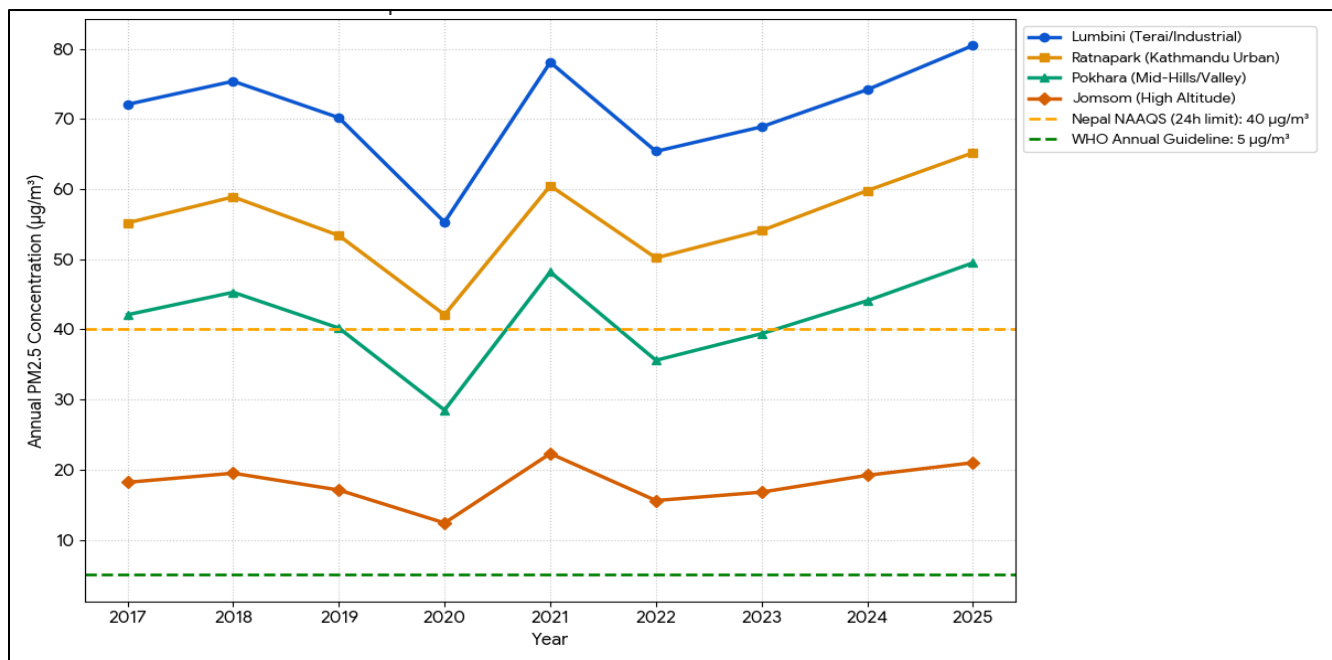


Figure 11: Long term $\text{PM}_{2.5}$ Concentration variation across key stations in Nepal, compared with National and WHO standards (Source: DoE, 2025/ AQLI and Research Reports, 2025)

Figure 11 shows how $\text{PM}_{2.5}$ changes in four areas of the country (Lumbini, Ratnapark, Pokhara and Jomsom) and compares it to the Nepal NAAQS and the WHO annual Guideline. Lumbini is in the Terai has the highest air pollution concentration in the country because of air coming from India (transboundary air flows) and local factories (ICIMOD, 2024). The $\text{PM}_{2.5}$ pollution level showed a notable peak in 2021, which was exceeded most recently in 2025. Ratnapark in the Kathmandu Valley represents the urban center with high vehicular traffic. Trapped by the valley's bowl shape, vehicular emissions and dust keep this station constantly above the national standard limits (Panday & Prinn, 2009; Mahapatra et al., 2019). Pokhara is in the Mid-Hills area. It used to be cleaner than Kathmandu, now it is getting more polluted

because of rapid urbanization and forest fires (ICIMOD, 2024). Jomsom is in a high-altitude area. Even though it is away from cities the air quality is still not good enough to meet the WHO guideline (WHO, 2021). However, the air in Jomsom is still cleaner than, in other parts of the country (Figure 11).

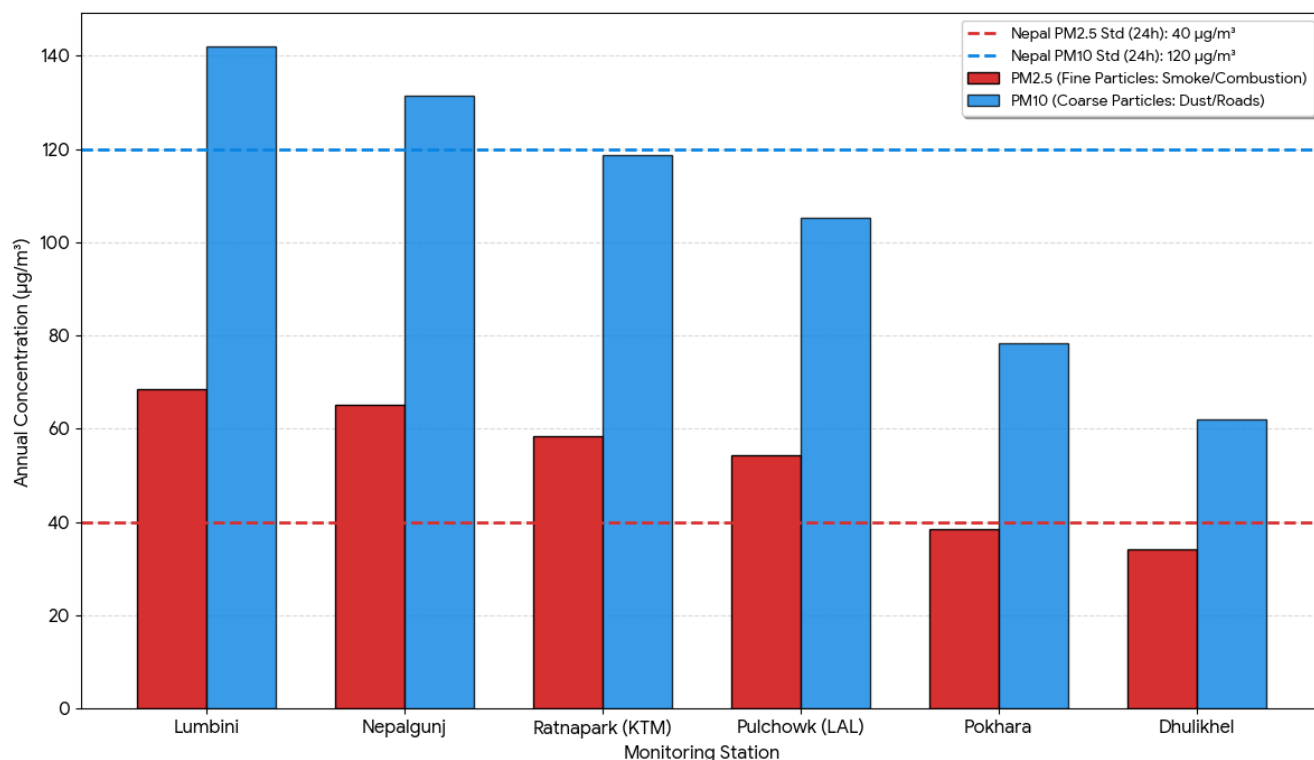


Figure 12: Comparison of PM_{2.5} (Fine) Vs. PM₁₀ (Coarse) across major stations of Nepal (Source: DoE, 2025)

Figure 12 compares two major components of routinely monitored particulate air pollutants. PM_{2.5} is primarily emitted from combustion sources like vehicular exhaust, industrial smoke, and forest fires (Mahapatra et al., 2019). PM₁₀ include larger particles like road dust, construction debris, and crustal materials (WHO, 2021). Stations in the Terai region (Lumbini and Nepalgunj) show extreme concentrations of both. PM₁₀ concentrations in Lumbini ($142.1 \mu\text{g}/\text{m}^3$) are nearly 30 times the WHO annual guideline (which is $15 \mu\text{g}/\text{m}^3$ for PM₁₀) and even exceed the national daily standard (WHO, 2021; GoN, 2026). In Ratnapark and Pulchowk, the PM₁₀ concentrations are significantly higher than PM_{2.5} concentrations, illustrating the massive impact of road dust and infrastructure projects on the city's air (Mahapatra et al., 2019). Even in cleaner areas like Dhulikhel, PM₁₀ concentrations are nearly double the PM_{2.5} concentrations, though both remain lower than the national standards (GoN, 2026).

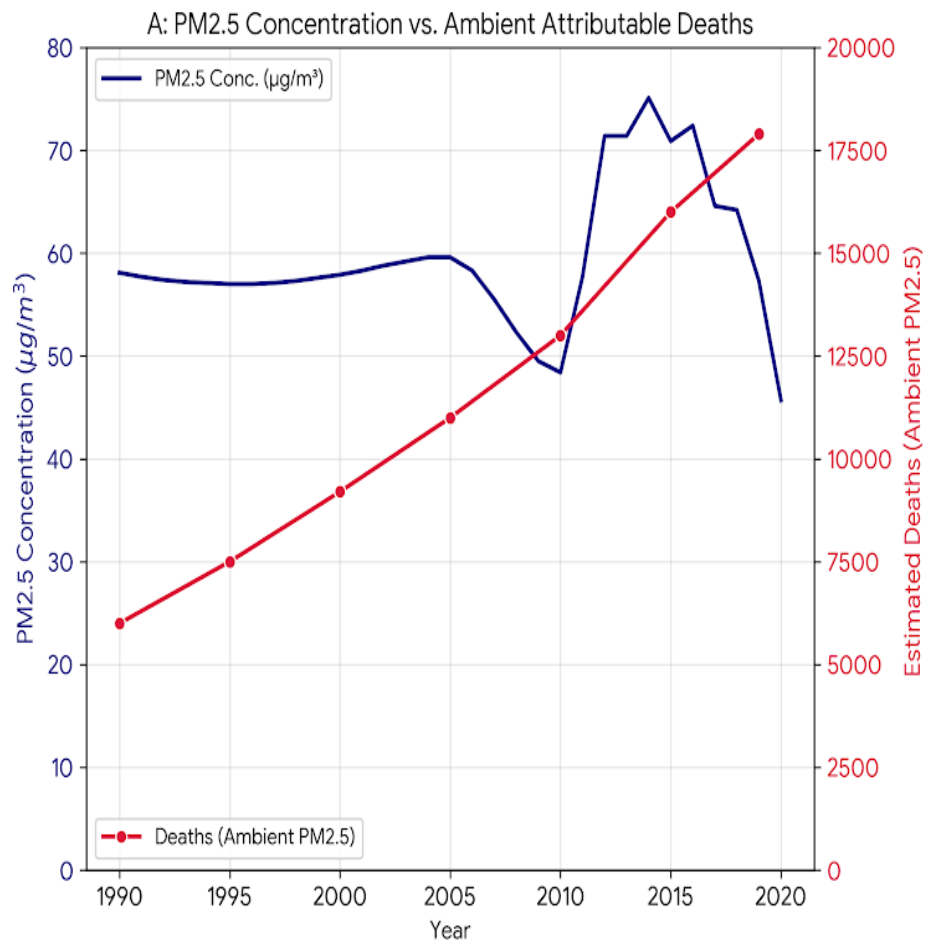
4.3 Health Implications and Disease Burden

The biological cost of sustained pollutant exposure in Nepal is severely reflected in the nation's high rates of respiratory and cardiovascular morbidity. This crisis has evolved into a systemic physiological threat that impacts nearly every organ system. Historical data since 1990 identifies air pollution as the leading risk

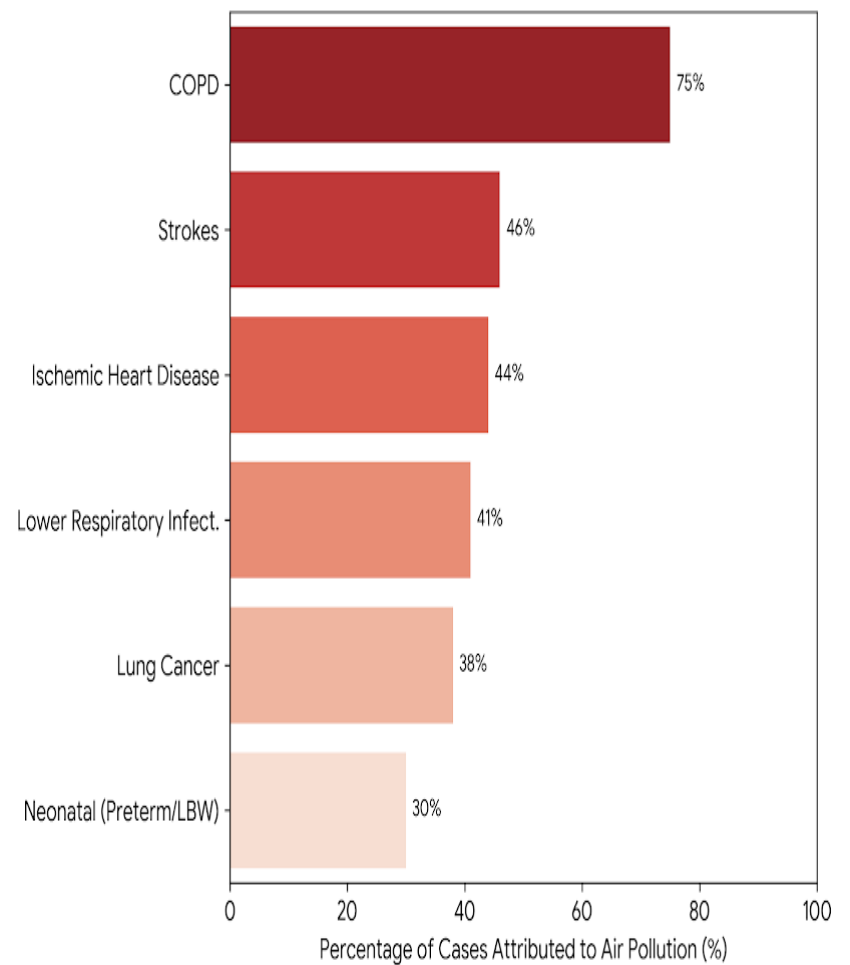
factor for premature death and disability in Nepal, causing between 26,000 and 41,300 deaths annually nearly 23 % of the nation's total mortality (IHME, 2024a; HEI, 2024). Ambient PM_{2.5} is now responsible for approximately 18,000 annual deaths from outdoor exposure alone nearly threefold increase compared to 1990 levels (HEI, 2024).

Air pollution is the primary driver of COPD in Nepal, with 75 % of all cases directly attributable to exposure (IHME, 2024a). Beyond the lungs, pollution contributes to 46 % of strokes, 44 % of ischemic heart disease cases, 41 % of lower respiratory infections, and 38 % of lung cancer cases (GBD 2021 Risk Factors Collaborators, 2024). Approximately 30 % of neonatal deaths and low birth weights are linked to air pollution exposure (UNICEF, 2023; HEI, 2024). Deaths from Household Air Pollution (HAP) have decreased by 42 % due to cleaner fuels, indoor smoke remains a significant threat alongside the rapidly escalating burden of ambient pollution (WHO, 2023c; HEI, 2024).

These findings are further detailed in Figure 13 (a), which compares PM_{2.5} concentrations with the rise in ambient pollution related deaths, and Figure 13 (b), which illustrates the percentage contribution of air pollution to major diseases in Nepal.



(a)



(b)

Figure 13: Ambient Pollution concentration attributable to death (a) PM_{2.5} concentration Vs. ambient attributable deaths (b) Health burden breakdown to disease attribution
(Source: HEI, 2024; World Bank, 2025)

4.3.1 Regional Pollution and Life Expectancy

On average people in Nepal lose 4.1 years of their life because of polluted air, which is even worse than communicable diseases (EPIC, 2024). Current pollution levels reduce the average life expectancy of a Nepalese citizen by 3.3 to 4.6 years. This impact is even more severe in the heavily polluted Terai regions, where the loss can exceed 7.5 years (EPIC, 2024). A composite plot visualizes the impact of PM_{2.5} on life expectancy across four representative geographical regions in Nepal. The data highlights a direct correlation between regional pollution levels and the reduction of life potential (EPIC, 2024). The extreme impact has been seen in the Terai region with the highest pollution concentration i.e. 68.5 $\mu\text{g}/\text{m}^3$, which is recorded as highest throughout nation. Consequently, citizens in this area are losing approximately 6.8 years of their life potential (EPIC, 2024). Likewise, resident of Kathmandu valley faces an average loss of 5.8 years of life with average concentrations of 58.4 $\mu\text{g}/\text{m}^3$ (EPIC, 2024). Similarly, in the Hill and Mountain Regions, even with less polluted areas, the health burden remains significant. Pokhara, located in the hill region (38.5 $\mu\text{g}/\text{m}^3$), observes a loss of 3.8 life years, while Jomsom (14.5 $\mu\text{g}/\text{m}^3$) shows a loss of approximately 1.4 years (EPIC, 2024). This loss occurs because even these relatively cleaner areas do not yet meet the WHO strict guideline value (SGV) (WHO, 2021) (Figure 14). The red error bars included in the visualization (Figure 14) provide a precision of the *average* reflecting the inherent variability and standard errors in these statistical estimations.

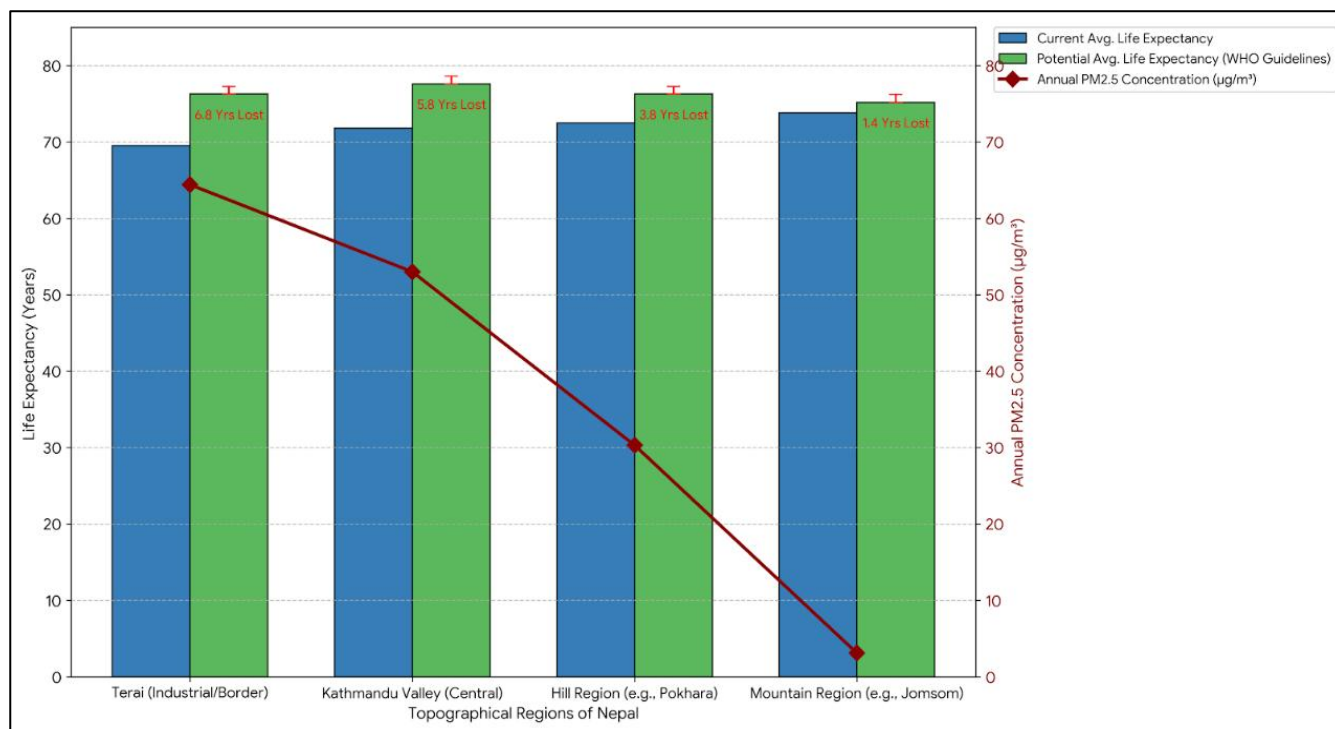


Figure 14: Relationship between PM_{2.5} concentrations and estimated loss of life expectancy across representative regions of Nepal comparing with WHO guideline. Author's analysis based on DoE monitoring data and the EPIC Air Quality Life Index methodology (EPIC, 2024)

4.4 Economic and Demographic Consequences

The public health crisis translates directly into a socio-economic burden that hinders national development. In terms of economic productivity, the World Bank (2016) estimated that an air pollution cost of Nepal is

6 % of its total economy (World Bank, 2016). This happens because people cannot work when they are sick and we have to spend money on healthcare as shown in Table 7 (World Bank, 2016).

Table 7: Key Health, Economic, and Global Burden Indicators Attributed to Ambient Air Pollution in Nepal (Source: World Bank, 2016)

Indicator	Value / Impact	Trend
Total Annual Deaths	26k - 42k	Ambient-related increasing rapidly
Life Years Lost	3.4 - 4.6 Years	Primary external health threat
Economic Cost	6 % of GDP	Major drag on national productivity
Global Rank	#1 (for COPD)	Highest age-standardized death rate for chronic lung disease

These estimates describe the burden of disease attributed to ambient air pollution, including mortality and DALYs, and detail how these burdens are calculated (IHME, 2024b). The high burden of chronic lung disease (e.g., COPD) reinforces that air pollution is a major driver of respiratory health impacts in Nepal (IHME, 2024a). WHO data underpins the global methodology used to estimate air pollution related mortality and DALYs (WHO, 2021).

4.5 Overview of Nepal’s Air Quality Index Status

In recent years, Nepal has consistently ranked among the most polluted countries globally. In April 2025, Kathmandu was ranked as the world's most polluted city, with AQI levels surging to a hazardous 352.

4.5.1 AQI Classification

The AQI is a standardized "yardstick" used globally and in Nepal to communicate daily air pollution levels and their associated health risks. It typically runs on a scale from 0 to 500, where higher values indicate more hazardous conditions as illustrated in Table 8.

Table 8: AQI Classification Framework and Public Health Advisory Protocols for Acute Exposure Mitigation (Source: (EPA, 2024))

AQI Range	Category	Health Implications & Actions
0 – 50	Good	Minimal impact; air quality is considered satisfactory.
51 – 100	Moderate	Acceptable; however, some pollutants may be a concern for a very small number of people.
101 – 150	Unhealthy (Sensitive Groups)	Children, the elderly, and those with respiratory issues should limit outdoor exertion.
151 – 200	Unhealthy	General public may begin to experience health effects; sensitive groups experience more serious effects.
201 – 300	Very Unhealthy	Health alert: everyone may experience more serious health effects.
301+	Hazardous	Public Health Emergency: Entire population is likely to be affected; avoid all outdoor physical activities.

The most significant technical shift of revised PM_{2.5} breakpoints is the lowering of the "Good" (Green) ceiling from 12 µg/m³ to 9 µg/m³ to align with the strengthened primary annual NAAQS. This update reflects the latest epidemiological evidence that significant health impacts occur at lower concentrations than previously regulated. The legally clean air in Nepal (40 µg/m³) is now falls into the "Unhealthy for Sensitive Groups" (Orange) category according to the 2024 EPA breakpoints (35.5 µg/m³) (EPA, 2024). EPA updated breakpoints for 24- hour reporting to accommodate the new annual health standard of PM_{2.5} i.e. 9.0 µg/m³ (EPA, 2024).

If Nepal were to align its air quality with WHO standards, the average life expectancy of its citizens could increase by 3.3 to 3.4 years (EPIC, 2024). The economic burden of health costs and lost productivity makes air quality management not just an environmental goal, but a vital economic necessity. The annual average PM_{2.5} concentrations, sourced from satellite-derived estimates (HEI, 2020) and continuous ground monitoring (DoE, 2023a; DoE, 2023b; IQAir, 2024), were converted into historical AQI categories (Table 9) using standard EPA breakpoint methodology (US EPA, 2018).

Table 9: Historical trends of particulate matter pollution and AQI in both Nepal and the Kathmandu Valley

Year	Nepal PM _{2.5} (µg/m ³)	Nepal AQI	Kathmandu PM _{2.5} (µg/m ³)	Kathmandu AQI
1990	58.1	152	52	142
1991	57.7	152	52.8	144
1992	57.4	152	53.7	146
1993	57.1	152	54.5	148
1994	57	152	55.2	150
1995	56.9	152	56.1	151
1996	57	152	57.2	152
1997	57.2	152	58.6	153
1998	57.6	152	59.7	153
1999	57.9	152	60.9	154
2000	58.3	152	62.1	154
2001	58.8	153	68.9	158
2002	59.2	153	76	162
2003	59.6	153	83	165
2004	59.6	153	89.9	169
2005	58.3	152	81.2	164
2006	55.4	150	72.4	160
2007	52.3	142	63.8	155
2008	49.5	135	55	149
2009	48.4	133	58.4	152
2010	57.7	152	61.6	154
2011	71.3	159	64.8	156
2012	71.3	159	68	157
2013	75	161	69.4	158
2014	70.8	159	70.6	159
2015	72.3	160	72	160
2016	64.6	156	58	152
2017	64.2	155	44	122
2018	57.2	152	53	144
2019	45.7	126	51	139
2020	60	153	39	110
2021	35	99	56.5	152
2022	35	99	31.2	91
2023	40	112	31.6	92
2024	35	99	38.8	109
2025	35	99	30.8	90

National Average (Nepal): Biomass and Regional Transport

The national AQI pattern is influenced not only by urban traffic congestion but also by the combined effects of geographic conditions, agricultural practices, seasonal meteorology, and transboundary air pollution, particularly across the southern Terai belt.

Between 1990 and 2010, national air quality conditions were generally categorized as Moderate to Unhealthy for Sensitive Groups, with the national average AQI typically ranging from approximately 50 to 120. During this period, the mountain regions largely maintained relatively clean air due to their lower population density and limited anthropogenic emissions. In contrast, the Terai plains experienced elevated particulate pollution resulting from the widespread use of biomass fuels, such as firewood and dung, for household energy needs, as well as the open burning of agricultural residues (HEI, 2020; GoN, 2022).

Since 2010, the national AQI has shown a deteriorating trend, with wintertime air quality frequently reaching the Unhealthy category (AQI 151–200). This seasonal decline is strongly associated with meteorological conditions, including temperature inversions, shallow boundary layers, and reduced atmospheric dispersion, which facilitate the accumulation of pollutants near the surface (DoE, 2023b; World Bank, 2023a). In addition to domestic emission sources, Nepal's air quality is substantially affected by transboundary air pollution. During the dry winter months, emissions originating from agricultural residue burning, industrial activities and other combustion sources in the Indo-Gangetic Plain are transported into Nepal through prevailing regional air circulation patterns. Consequently, the national AQI in Nepal is heavily influenced by both local emissions and cross-border pollutant transport (UNEP, 2019; World Bank, 2023c).

Kathmandu Valley: Urbanization and Inversion Dynamics

The air quality history of the Kathmandu Valley is defined by its unique bowl-shaped topography, which facilitates severe winter temperature inversions that physically trap pollutants near the ground (DoE, 2023b; World Bank, 2023a). In the 1990s the air quality in the Kathmandu Valley was not good for people with health problems. The AQI in the Kathmandu Valley was often between 100 and 150 during this time which is unhealthy for sensitive groups. The main reason for this air was old diesel engines and two-stroke three-wheelers like the Bikram Tempos. People were getting sick from breathing this air so GoN finally banned these vehicles in 1999 (Shrestha et al., 2013; MoPE, 2017b).

From 2000 to 2015 the air in the Kathmandu Valley was in unhealthy range. The city was growing fast and this made the air quality even worse during the dry season. The AQI in the Kathmandu Valley would often be between 150 and 200. There was a lot of construction going on and many new roads were being built. Also many traditional brick kilns were releasing a lot of things into the air like dust and black carbon (HEI, 2020; DoE, 2023b; World Bank, 2023d).

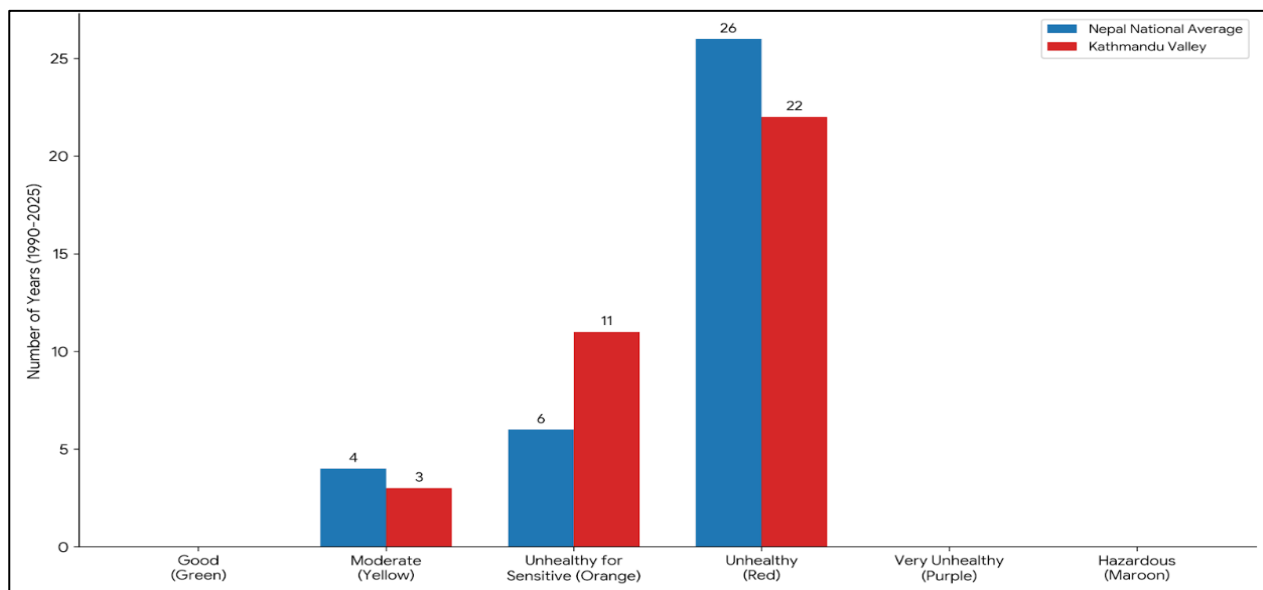


Figure 15: Historical (1990- 2025) frequency distribution of AQI categories of Nepal and Kathmandu Valley

From 2016 to now the air in the Kathmandu Valley has been in really hazardous range. While monsoon rains temporarily improve the AQI to "Good" (0–50), the winter and pre-monsoon (spring) seasons frequently push levels into "Very Unhealthy" (200–300) and "Hazardous" (300+) territory (DoE, 2023b; World Bank, 2023a; IQAir, 2024). For instance, during the massive regional forest fires in April 2021, Kathmandu's AQI exceeded 400, briefly making it the most polluted city globally (IQAir, 2021; UNOCHA, 2021).

Kathmandu Valley has almost double the number of years in the Orange (Unhealthy for Sensitive Groups) category compared to the national average. Nepal's national average peaks slightly higher in the Red (Unhealthy) category (26 years) compared to Kathmandu (22 years).

Figure 15 showing the Annual Distribution of AQI Categories for the Kathmandu Valley. This visualization provides a critical look at how often citizens are exposed to different levels of pollution throughout a typical year.

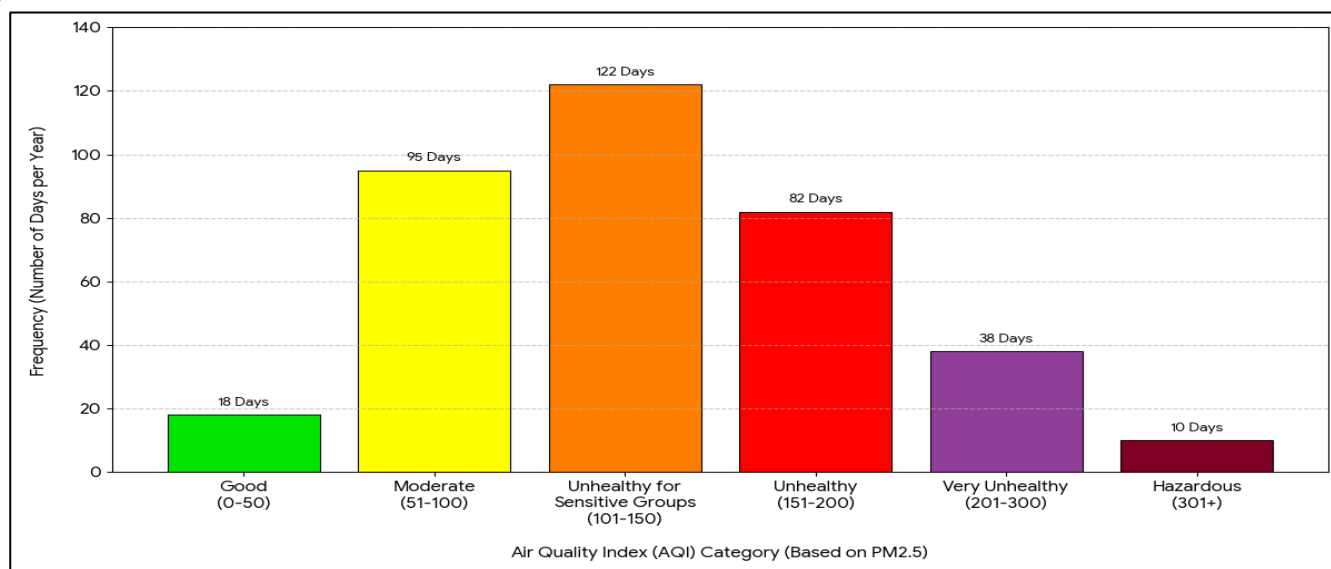


Figure 16: Annual AQI category distribution of Kathmandu based on US EPA/Nepal DoE scale (Source: Derived from DoE 2024–2025 station data for the Kathmandu Valley)

Out of 365 days, Kathmandu typically experiences only about 18 days (less than 5 %) categorized as "Good" (AQI 0-50). These rare days occur exclusively during the peak monsoon season. For more than 250 days a year, the air is either "Moderate," "Unhealthy for Sensitive Groups," or worse. This chronic exposure is why Nepal faces such high rates of respiratory diseases (HEI, 2020; WHO, 2021). For approximately 130 days (over 4 months), the air is classified as "Unhealthy," "Very Unhealthy," or "Hazardous." During these periods, even healthy individuals are advised to limit outdoor activity, and the PM_{2.5} levels are dozens of times higher than the WHO's SGV (EPA, 2018; WHO, 2021). The ~10 "Hazardous" days typically coincide with the worst of the pre-monsoon forest fires (March/April), where the AQI often breaches 300+, turning the valley into a thick blanket of smoke (IQAir, 2021; UNOCHA, 2021). This frequency chart illustrates that pollution is not just a "seasonal spike" but a persistent, year round environmental health threat for the residents of Nepal's urban centers (Figure16).

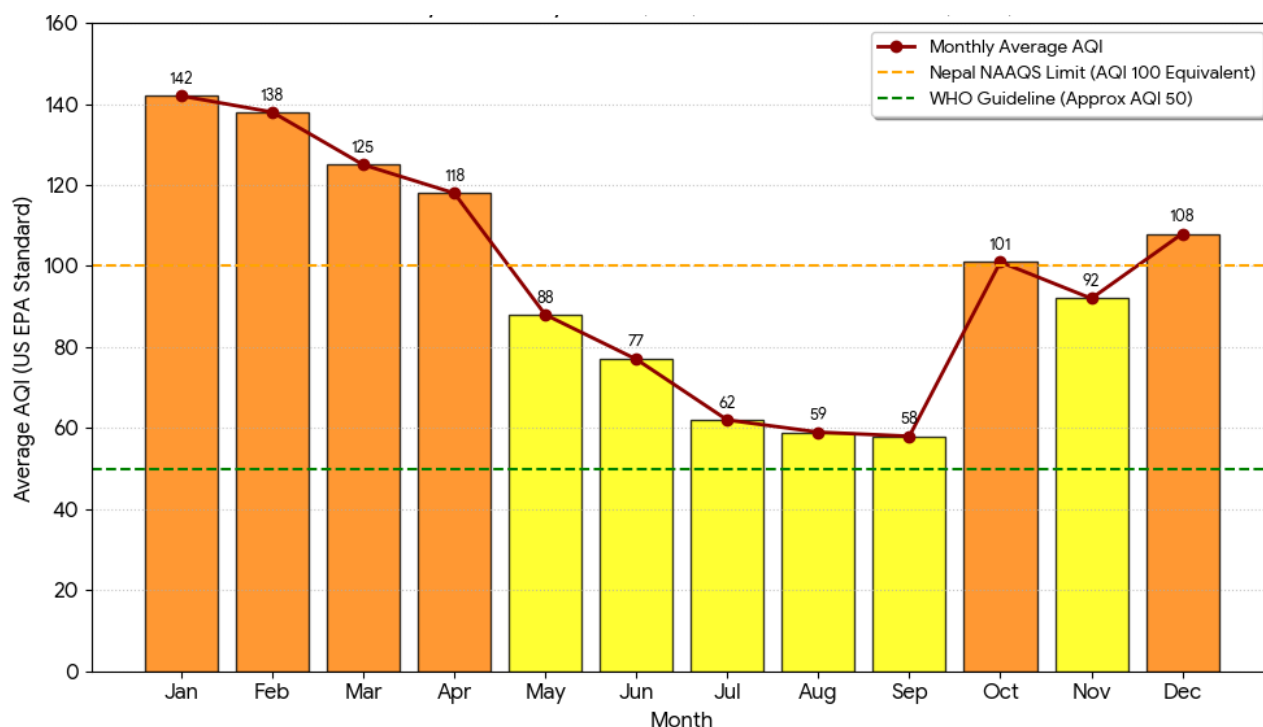


Figure 17: Monthly average AQI trend in Kathmandu (2025) comparing with National and WHO AQI (source: Compiled from DoE real-time data archives and supplementary monitoring from the Ratnapark Central Reference Station)

It seems within the legal standard (AQI <100) during May to September and in November i.e. only for 5 months. The trend breached the national health threshold in rest of the months. WHO AQI standard 50 complies for the month of July, August and September, which is due to monsoon and the October spike (AQI 101) marks the end of the rainy season (Figure 17).

5. Air Quality Monitoring in Nepal

The atmospheric monitoring infrastructure in Nepal has transitioned from a sparse collection of sites to a sophisticated, multi sectoral network integrating federal, diplomatic, and grassroots initiatives. This decentralized data ecosystem is fundamental to guiding regulatory frameworks and public health

interventions, especially within the Kathmandu Valley, where persistent particulate matter levels necessitate robust, evidence-based mitigation strategies (DoE, 2023b; World Bank, 2023d). As of March 2026, air quality monitoring in Nepal has evolved from a few scattered sensors into a more structured, multi-tiered network. While the DoEnv remains the central authority, the landscape now includes significant contributions from municipal governments and international researchers (DoE, 2023; ICIMOD, 2025a; U.S. Department of State, 2026).

5.1 The National Monitoring Network

Nepal Air Quality Monitoring Network is an official monitoring network established and operated by the Ministry of Forests and Environment (MoFE) /DoE. Based on 2026 data of DoE, there are 31 reference grade monitoring stations across the country as shown in Figure 18, province wise (DoE, 2026). Each station monitors PM_{2.5}, PM₁₀. Some advanced sites also measure NO₂, O₃, SO₂ and Carbon Monoxide (DoE 2026).

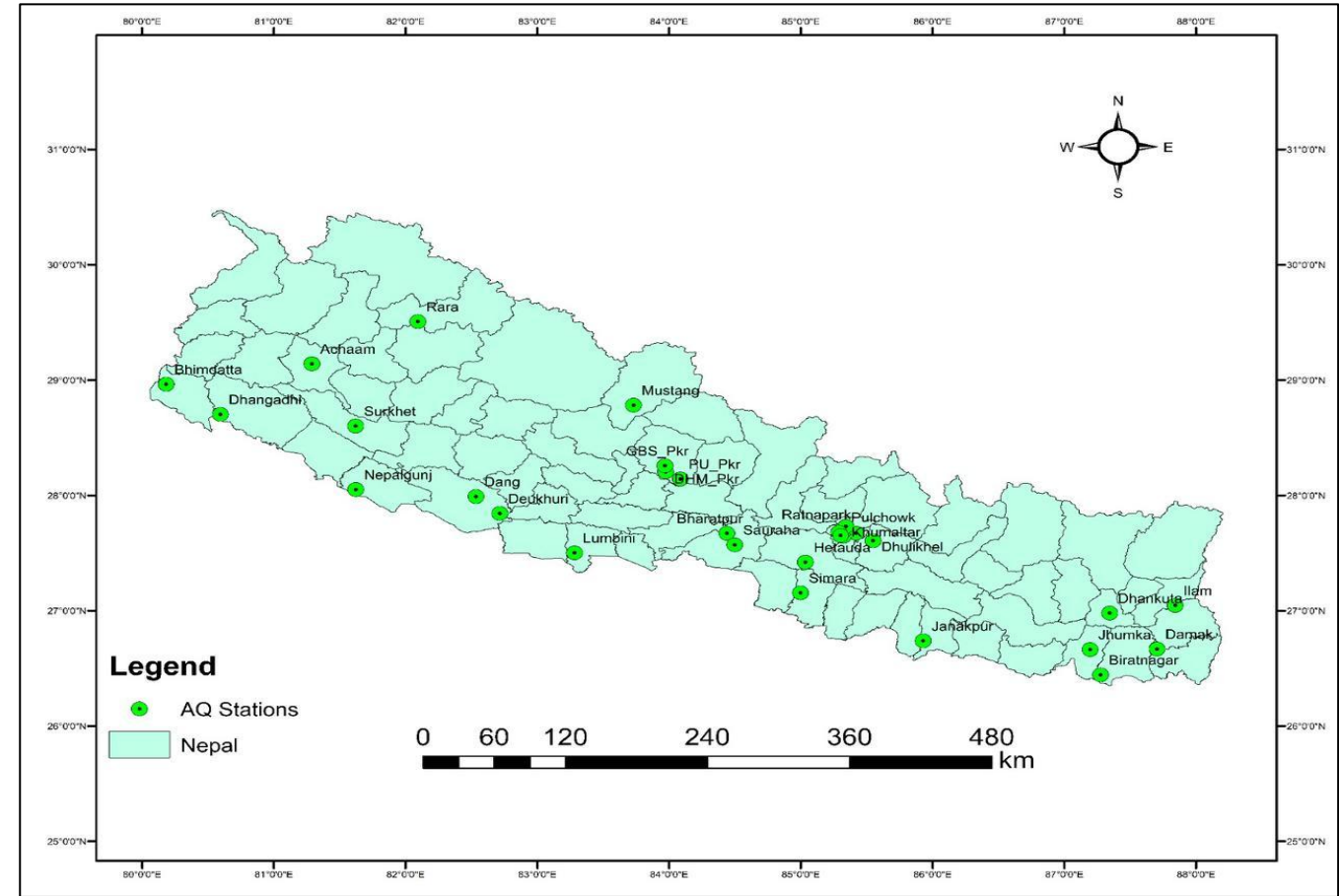


Figure 18: AQ monitoring stations throughout country

Table 10: Province wise distributions of Nepal air quality monitoring network (2026)

Province	Station Name / Location	Station Type & Environment	No. of stations
Koshi Province	Biratnagar	Urban/Industrial (Terai)	5
	Damak	Urban (Terai)	
	Dhankuta	Baseline (Hills)	
	Ilam (Deumai-01)	Baseline (Hills)	
	Jhumka (Sunsari)	Regional/Traffic (Terai)	
Madhesh Province	Janakpur	Urban (Terai)	4
	Birgunj	Heavy Industrial/Transboundary (Terai)	

Province	Station Name / Location	Station Type & Environment	No. of stations
Bagmati Province	Simara	Industrial (Terai)	11
	Gaur	Border/Transboundary (Terai)	
	Ratnapark (KMC)	Urban/Traffic (Valley Core)	
	Pulchowk (LMC)	Urban/Residential (Valley Core)	
	TU Kirtipur	Suburban/Institutional (Valley)	
	Bhaisipati	Residential (Valley)	
	Bhaktapur (Birendra School)	Urban/Residential (Valley)	
	Shankhapark	Urban/Park (Valley)	
	Khumaltar	Suburban/Agricultural (Valley)	
	Dhulikhel (Kavre)	Background/Educational (Hills)	
	Sauraha (Chitwan)	Tourism/Natural (Terai)	
Gandaki Province	Hetauda	Industrial/Regional (Hills)	3
	Bharatpur	Urban (Terai)	
	Pokhara (DHM Station)	Urban/Tourism (Hills)	
Lumbini Province	Mustang (Jomsom)	Pristine/High-Altitude (Mountain)	4
	Pokhara (University)	Institutional (Hills)	
	Lumbini	Cultural/Transboundary (Terai)	
	Nepalgunj	Urban/Transboundary (Terai)	
Karnali Province	Dang (Deukhuri/Lalmatiya)	Industrial/Regional (Inner Terai)	2
	Butwal	Urban/Traffic (Terai)	
	Surkhet	Regional/Urban (Hills)	
Sudurpashchim	Rara (Mugu)	Pristine/Remote (Mountain)	2
	Dhangadhi	Urban/Transboundary (Terai)	
	Achham (Mangalsen-08)	Remote/Hills (Hills)	
Total			31

Bagmati Province has over 35 % of the total network (11 stations), primarily concentrated in the Kathmandu Valley (Table 10). This is due to the valley's unique bowl-shaped topography and the high population density (World Bank, 2023a; DoE, 2026). Stations like Birgunj, Nepalgunj, Dhangadhi, and Janakpur form a critical "Sentinel Belt" along the southern border. These are the primary data points for auditing trans-boundary inflow from the IGP (UNEP, 2019; World Bank, 2023b). Additionally, monitoring networks follow the vertical Transect, monitors the vertical profile of Nepal from Birgunj (90 m) to Jomsom (2,700 m) and Rara (2,990 m). This allows researchers to track how black carbon travels from industrial zones to the Himalayan glaciers (Rupakheti et al., 2017; ICIMOD, 2025b). The real-time data are accessible via the government's official portal at pollution.gov.np (DoE, 2026).

5.2 Embassy and Diplomatic Stations

In Kathmandu, several foreign embassies maintain an official AQ monitoring system to generate long term and high quality data. US Embassy in Kathmandu monitor PM_{2.5} continuously and published data publicly till March, 2025 that can be used for the wide range of analysis (U.S. Department of State, 2026). Similarly, Australian Embassy in Nepal, Kathmandu has also monitor PM_{2.5} with open online data (Australian Department of Foreign Affairs and Trade [ADFAT], 2026). These data sources often serve as benchmarks for independent analysis and comparison (World Bank, 2023a; IQAir, 2024).

5.3 Citizen Science and Low-Cost Sensor Networks

In the past decade, Nepal has experienced rapid growth of community driven, low cost AQ monitoring. These typically use low-cost sensors from manufacturers such as PurpleAir, Nova SDS, AQMesh, or SC-series units (Snyder et al., 2013; WHO, 2021). Citizen science stations are located in Golfutar (Kathmandu), Ramkot (Kathmandu), Kupondole (Kathmandu), Shantichowk (Kathmandu), Pratik Galli (Kathmandu), Gaur (Rautahat, Terai) (ICIMOD, 2025b; OpenAQ, 2026). The real time data from these stations shared via online platform which are useful for local pollution mapping and trend analysis. Such kinds of analysis help identify the pollution hotspots and promote community awareness and engagement to reduce the pollution levels (Conrad & Hilchey, 2011; World Bank, 2023d).

5.4 Emerging City Networks

In recent years, local governments, research institutions, and civil society organizations in Nepal have increasingly adopting low-cost sensor technologies and community based initiatives to better understand the air people breathe every day. These efforts are making air quality monitoring more accessible by generating real time, neighborhood level data, expanding monitoring coverage, raising public awareness, and encouraging active citizen participation. Such collaborations provide valuable evidence for informed decision making and more effective clean air management across the country. By strengthening these partnerships, Nepal can accelerate clean air actions, uphold the constitutional right to a clean and healthy environment, and move toward healthier and more sustainable cities. A notable development during 2025–2026 has been the emergence of hyper-local air quality monitoring, with several initiatives leading this transition, as outlined below:

- Kathmandu Metropolitan City (KMC): KMC has deployed its own network of 18 "Node-S" sensors across various wards (e.g., Kalanki, Teku, Thapathali) to provide neighborhood-level data (Clarity Movement Co., 2025; Kathmandu Metropolitan City, 2025).
- School-Based Monitoring: Organizations like Green Decision Labs have installed sensors in over 40 schools in the valley to correlate air quality with student health, turning data collection into an educational tool (Green Decision Labs, 2026).
- Low-Cost Sensor Expansion: Organizations like Clean Energy Nepal (CEN) have expanded real-time monitoring to 10 new cities outside the valley to address the data gap in the Terai and Hills (CEN, 2025).

5.5 Integrated Technological Advances

Nepal's approach to air quality management is evolving rapidly through the use of emerging technologies and improved access to data. Satellite observations, artificial intelligence, and machine learning are enhancing air quality forecasting, while open-data platforms are making information more transparent and accessible to researchers and the public alike. At the same time, initiatives such as the Nepal Clean Air Program (CAP) Project are strengthening national monitoring systems and regulatory efforts. Together, these advances reflect Nepal's growing commitment to more proactive and evidence-based clean air management. Some of the key initiatives undertaken in Nepal are outlined below:

- Satellite & AI Integration: Agencies like ICIMOD are increasingly using satellite-based "AOD" (Aerosol Optical Depth) data combined with ground-based observations and machine learning to provide 3-day air quality forecasts (Rupakheti et al., 2017; ICIMOD, 2025a).
- Open Data Movement: Most non-government sensors now upload data to global platforms like OpenAQ and IQAir, allowing for international research and greater transparency (IQAir, 2024; OpenAQ, 2026).

- **Nepal CAP Project (2026):** Supported by a 52 million World Bank credit, this new initiative is currently upgrading national monitoring systems and strengthening enforcement of emission standards for the industrial sector (World Bank, 2026). The project aims to reduce PM_{2.5} emissions from industrial and commercial boilers and furnaces while strengthening national air quality management systems in Nepal.

6. Conclusion and Way Forward

6.1 Conclusion

Air pollution in Nepal has become an environmental and public health challenge. Yearly, the air pollution loss 6 % of national economy. This is because people get sick and loss their economic days as they are not able to work. The air quality in the Kathmandu Valley and the Terai region remains highly polluted on most days throughout the year. This is because old factories, vehicular fleet and transboundary "hotspot" emissions. We need to do something to fix the problem. The joint action need to be taken to make the air clean and healthier.

The recent launch of the Nepal CAP Project (2026) is an important milestone in improving air quality and safeguarding public health. The project has received USD 52 million in funding to support these efforts. However, technical solutions such as electric boilers and improved monitoring must be complemented by strong political commitment and regional diplomacy to address the shared air shed of the Indo-Gangetic Plain. Ultimately, clean air should be recognized not as a luxury of development, but as a fundamental requirement for Nepal's public health and economic resilience.

6.2 Way Forward

For Policymakers: Integrated Governance

- **Industrial De-carbonization:** Incentivize small and medium enterprises (SMEs) from coal and biomass to electric or modern biomass boilers, particularly in the food, textile, and pharmaceutical sectors.
- **Strict Emission Enforcement:** Move beyond "fixed limit values" to a system of Continuous Emission Monitoring (CEMS) in high-impact industries like cement and brick kilns to ensure year-round compliance.
- **Cross-Border Diplomacy:** Strengthen regional partnerships under the IGP-Himalayan Foothills framework to manage trans-boundary pollution.

For the Health Sector: Clinical Vigilance

- **Vulnerability Mapping:** Develop localized health advisories specifically for high-risk groups (pediatric, geriatric, and pregnant populations) during the peak dry season (November–May).
- **Medical Training:** Integrate "Environmental Medicine" into the national health curriculum to help clinicians identify and manage the systemic non-communicable diseases (CVD, Type 2 Diabetes) increasingly linked to chronic pollution.

For Urban Planning: Green Infrastructure

- **Zero-Emission Transport:** Accelerate the replacement of fossil-fuel vehicles with EVs by expanding the charging grid and offering tiered tax incentives for electric public transport.
- **Waste Management:** Enforce strict bans on open municipal waste burning by establishing centralized Material Recovery Facilities (MRFs) in all municipalities.

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Glossary

Ambient Air Quality Standard: A legally defined threshold set by regulators (e.g., Nepal's National Ambient Air Quality Standards) specifying the maximum permissible concentration of a given pollutant in outdoor air, used as the benchmark against which monitored pollution levels are judged.

Brick Kiln Emissions: Air pollutants released from traditional brick-firing operations, a major and recurring source of particulate and black carbon emissions discussed as a key contributor to Nepal's seasonal air pollution.

Disability-Adjusted Life Year (DALY): A standard public-health metric combining years of life lost to premature death and years lived with disability due to a given cause, used in the chapter to quantify the overall health burden of air pollution.

Emission Inventory: A structured accounting of the type, quantity, and source of pollutants released into the air over a given area and time period, used as a foundational tool for tracking pollution sources and designing control measures.

Exposure Pathway: The route by which a pollutant travels from its source to reach and affect a person (e.g., inhalation of outdoor air, indoor smoke from cooking), used to explain why certain populations face higher health risks than others.

Low-Cost Sensor Network: A distributed set of relatively inexpensive, often community-deployed air quality monitors that supplement official reference-grade stations, expanding real-time monitoring coverage, particularly relevant to the chapter's discussion of Nepal's expanding monitoring infrastructure.

Monitoring Network: The overall system of fixed and mobile stations (government, satellite-based, and low-cost sensors combined) used to continuously measure air pollutant concentrations across a country or region.

Reference-Grade Monitor: A government- or research-grade air quality measurement instrument that meets strict accuracy and calibration standards, used as the authoritative benchmark against which lower-cost sensors are validated.

Vulnerable Population: Groups such as children, pregnant women, the elderly, and those with pre-existing respiratory or cardiovascular conditions who face disproportionately higher health risks from a given level of air pollution exposure.

CHAPTER: III

Water Resources of Nepal: Status and Issues

Kumar Khatri¹, Chhatra Mani Sharma¹

¹Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal

Email: cmsharma@cdes.edu.np, Khatri.Kumar@cdes.tu.edu.np

Summary

Nepal is widely recognized for its abundant renewable freshwater resources, yet this apparent water wealth contrasts with persistent challenges in water availability, quality, infrastructure, and governance. The country has approximately 6,000 rivers, 3,252 glaciers covering about 5,323 km², and an estimated mean annual river runoff of 225 billion m³. Despite relatively high per-capita water availability, substantial spatial and seasonal disparities contribute to recurrent water shortages, particularly during the dry season. More than 80% of annual precipitation occurs during the monsoon, increasing flood risk during wet months while leaving many regions vulnerable to water scarcity during the dry season. Climate change is further intensifying these pressures through glacier retreat, changing precipitation patterns, and increasing risks of glacial lake outburst floods. Water quality presents an equally important challenge, with widespread faecal contamination of drinking water sources, arsenic contamination of groundwater in the Terai, and increasing pollution from municipal wastewater, industrial effluents, agricultural runoff, and poorly managed solid waste. The degradation of the Bagmati River illustrates the cumulative impacts of rapid urbanization and inadequate wastewater management. These challenges are compounded by fragmented water governance and overlapping responsibilities among federal, provincial, and local governments following Nepal's transition to federalism. Addressing Nepal's water security challenges therefore requires an integrated approach that combines improved water and sanitation infrastructure, evidence-based water quality management, groundwater conservation, climate adaptation, catchment-scale protection, and institutional strengthening. Such an approach is essential to translate Nepal's considerable water resource potential into equitable, resilient, and sustainable water security.

Keywords: Arsenic contamination; Microbial contamination; Himalayan hydrology; Water resources; Water quality

1. Background

Nepal occupies a geographically important position in the Hindu Kush Himalayan (HKH) region and is one of Asia's main sources of freshwater. The country's water system is shaped by three distinct physiographic zones the High Himalayas, the Mid Hills (Middle Mountains), and the Terai lowlands each with its own hydrological character, all feeding into a river network of roughly 6,000 rivers stretching about 45,000 km in total length (WECS, 2011; FAO, 2021). Four large trans boundary river systems the Koshi, Gandaki, Karnali, and Mahakali flow down from the Tibetan Plateau and together produce some of the highest sustained river discharges anywhere in South Asia (Immerzeel et al., 2010).

Nepal received an average annual rainfall of approximately 1,336 mm during 1981–2010, but these national average masks substantial spatial variation, with annual rainfall ranging from less than 500 mm in parts of the High Himalaya to more than 4,000 mm around Pokhara (GoN, MoEWRI, & DHM, 2024). Along the southern slopes of the Annapurna range, annual rainfall can exceed 6,000 mm, whereas the trans Himalayan rain shadow region receives less than 250 mm. Most of the annual precipitation (75–85%) occurs during

the June to September monsoon period (Figure 1) (Sigdel & Ikeda, 2010; DHM, 2020). Nepal’s cryospheric water resources include approximately 3,252 glaciers covering 5,323 km² (Bajracharya et al., 2015; ICIMOD, 2023); plays a vital role in keeping rivers flowing through the dry season across Nepal, India, and Bangladesh.

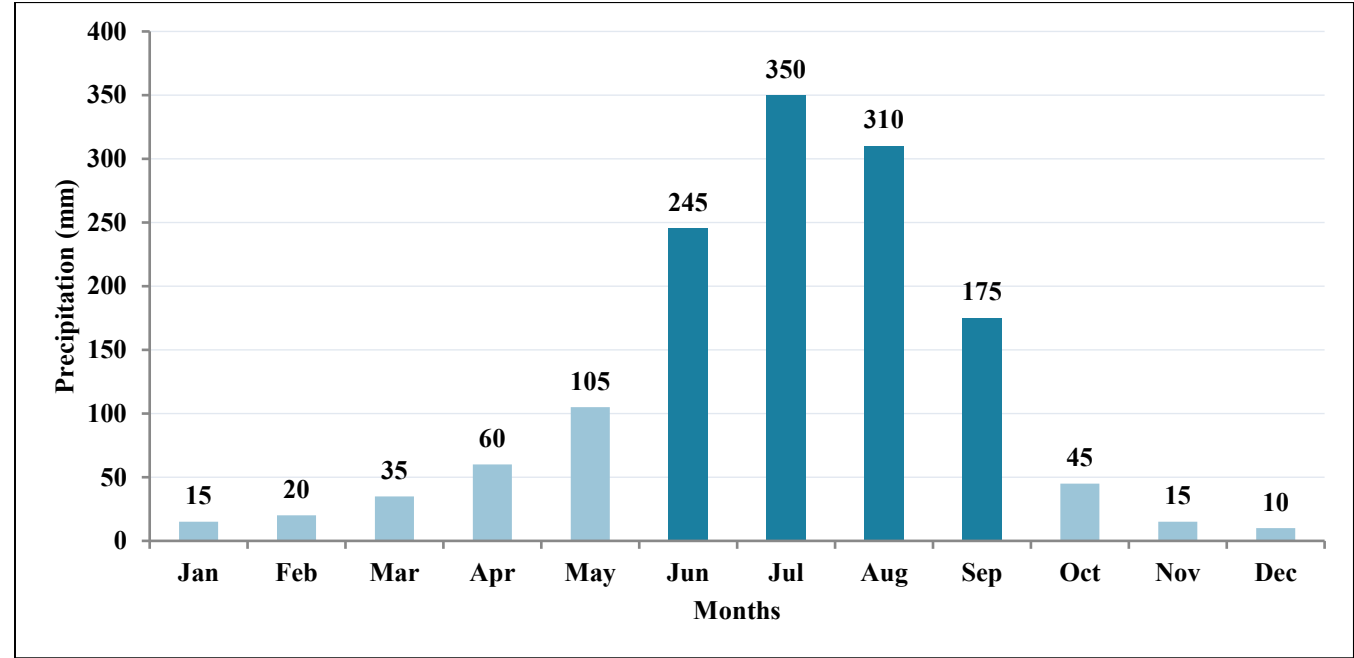


Figure 1: Mean monthly precipitation distribution across DHM stations (1991–2020) (DHM, 2020)

Despite this substantial water endowment, only approximately 15 BCM, equivalent to about 6–7% of the estimated 225 BCM of annual water resources, is currently utilized for socio-economic purposes (Smakhtin et al., 2004; Joseph & Shrestha, 2022). This figure is now outdated, as the ongoing expansion of hydropower, irrigation, and municipal water supply has increased water utilization to approximately 9% of the flow from Nepal’s ten major river basins, while the government’s river basin master plan projects that utilization could reach 25% by 2050 (WECS, 2023). The main barriers include rugged and geographically isolated terrain, high infrastructure costs, limited institutional capacity, recurring political instability, and a fundamental seasonal mismatch: water availability is highest during the monsoon, whereas irrigation demand peaks during the dry season (World Bank, 2019; Joseph & Shrestha, 2022).

A growing body of research indicates that climate change is fundamentally altering Nepal's water resources (DHM, 2021; IPCC, 2021). Under the DHM’s most recent downscaled projections, based on the CMIP6 Shared Socioeconomic Pathways SSP2-4.5 (moderate emissions) and SSP5-8.5 (high emissions), Nepal is projected to continue warming throughout the twenty-first century, with the greatest temperature increases expected in the high-mountain regions (DHM, 2021).

The HKH region has been warming at 0.04 to 0.06°C per year, roughly double the global average (Krishnan et al., 2019). In the short term, accelerated glacier melting may increase river flows; however, this trend is expected to reverse in the longer term as continued glacier retreat reduces ice reserves and contributes to declining water availability beyond the “peak water” threshold (Radić & Hock, 2014; Immerzeel et al., 2020). . Glacial lake outburst flood (GLOF) risks are also increasing. Nepal has recorded approximately 26 GLOF events since 1977, including the August 2024 outburst at Thame (Thyanbo) in the Everest region, which caused extensive damage to Thame village (Veh et al., 2019; ICIMOD, 2024). In future, under a

high-emissions scenario, HKH glaciers could lose up to 75% of their volume by 2100, while ice loss during the 2010s was already approximately 65% higher than during the preceding decade (Figure 2) (ICIMOD, 2023).

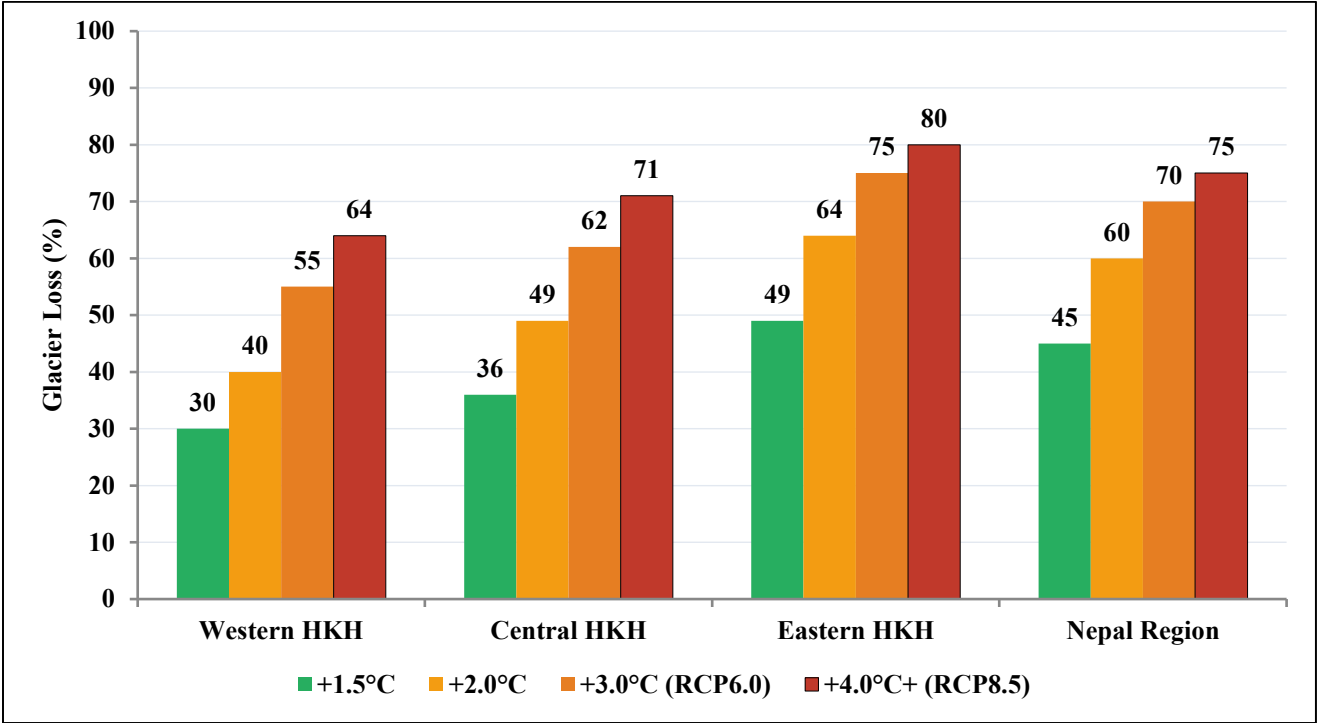


Figure 2: Projected HKH glacier volume loss by 2100 under SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios (DHM, 2021; ICIMOD, 2023)

Water quality degradation has increased alongside rapid urbanization and expanding human activities. The Bagmati River and its major tributaries, including the Bishnumati and Manohara, have experienced substantial deterioration in water quality, associated with unmanaged urbanization, solid-waste disposal, and the discharge of untreated domestic and industrial wastewater (Ghimire et al., 2022). In the Roshi River, agricultural runoff and sediment inputs associated with human activities have also contributed to water-quality degradation (Karki et al., 2023). In the Terai, widespread arsenic contamination of shallow tubewells constitutes a chronic public health emergency (NASC, 2020; Aryal, 2025).

Nepal’s laws and policies demonstrate a strong commitment to water and sanitation. Article 35 of the 2015 Constitution recognizes access to clean drinking water and sanitation as a fundamental right, a commitment reinforced by the Water Supply and Sanitation Act (2022). In practice, however, the division of authority across the three tiers of government has created coordination challenges, making it difficult to translate policy commitments into tangible improvements in water services (GoN, 2021).

2. Water Resources Status of Nepal

2.1 Surface Water Resources

2.1.1 River Systems

Nepal has approximately 6,000 rivers and streams, draining a combined area of approximately 76% with a total channel length of roughly 45,000 km (WECS, 2011; FAO, 2021). These rivers and streams are generally classified into three broad categories based on their sources and hydrological characteristics

Category 1: Snow and Glacier fed Himalayan Rivers

These are fed by high altitude glaciers and snowfields, flow all year round without drying up (Figure 3). The four main river systems Koshi, Gandaki (Narayani), Karnali, and Mahakali together produce over 224 BCM of mean annual runoff (WECS, 2011). Because their flows are influenced by snowmelt, glacier melt, and monsoon rainfall, these rivers are particularly vulnerable to changes in temperature and precipitation patterns. They also form the backbone of irrigation and hydropower systems across Nepal, India, and Bangladesh (Lutz et al., 2014; Immerzeel et al., 2020).

The Koshi River Basin (Sapta Koshi) exemplifies this category, with glacierized headwaters in the Everest Kanchenjunga region feeding a catchment of 27,863 km² within Nepal (Table 1). The basin sustains a mean discharge of approximately 1,409 m³/s, including substantial flows during the dry season. The Gandaki (Narayani) Basin exhibits a comparable snow and glacier buffered hydrological pattern.



Figure 3: A stretch of the Mahakali River in the lowland area

Category 2: Mid-Hill (Mahabharat) Rivers

Rivers such as the Babai, West Rapti, Bagmati, Kamala, Kankai, and Mechi originate in the Mahabharat Range and receive water from a combination of direct rainfall and groundwater springs (Andermann et al., 2012). They generally flow year-round, although their discharge varies seasonally. Increasingly, these rivers are showing signs of declining spring discharge, associated with changes in rainfall patterns and land use dynamics, resulting in reduced dry season flows (ICIMOD, 2023).



Figure 4: A stretch of the Babai River in the Mulghat area

Category 3: Siwalik (Chure) Rivers

The Tinau, Banganga, Sirsia, and Sunsari rivers, among others, originate in the Siwalik Hills and fall into this category. They are short, steep, and highly responsive to rainfall. These rivers carry heavy sediment loads during the monsoon but have very low flows during much of the rest of the year, which substantially limits their potential for irrigation unless adequate storage facilities are developed.



Figure 5: A stretch of Goche River in Mehelkuna, Surkhet

Collectively, Nepal's major river basins contribute an estimated 224 to 225 BCM of mean annual runoff (WECS, 2011), sustaining approximately 70% of the Ganga system's dry season flow and roughly 40% of its annual discharge that underscore Nepal's critical regional hydrological significance (Smakhtin et al., 2004). The key hydrological parameters for each basin are summarized in Table 1.

Table 1: Drainage Areas of Major and Smaller Basin Catchments in Nepal

River Basin	Catchment in Nepal (km²)	Mean Discharge (m³/s)	Annual Runoff (BCM/yr)	Primary Source
Koshi	27,863	1,409	44.4	Glacier + Rain
Gandaki/Narayani	31,464	1,600	50.4	Glacier + Rain
Karnali	41,058	1,397	44.1	Glacier + Rain
Mahakali	5,188	573	18.1	Glacier + Rain
Mid-hill Rivers	~17,000	461	14.5	Rain + Spring
Siwalik Zone Rivers	~23,150	1,682	53.0	Rain
Total	~145,723	7,122	224.5	

Source: (WECS, 2011)

The annual means presented in Table 1 conceal a pronounced wet dry seasonal asymmetry. In snow and glacier fed basins (Koshi, Gandaki, Karnali, and Mahakali), monsoon discharge is typically three to five times higher than dry flow, with snowmelt and glacier melt helping to sustain dry season flows. In contrast, the Mid-Hill and Siwalik basins, which depend more heavily on direct rainfall, exhibit substantially higher wet to dry flow ratios, with dry season discharge declining to a small fraction of monsoon peaks (Sigdel & Ikeda, 2010; Sharma et al., 2021). This seasonal variation, rather than annual water availability alone, is a major driver of Nepal's chronic dry season water stress and underlies the timing mismatch discussed above.

2.1.2 Lakes and Wetlands

Nepal contains an estimated 5,358 wetlands encompassing glacial lakes, oxbow lakes, ponds, and reservoirs that collectively provide ecosystem services including water storage, groundwater recharge, flood attenuation, biodiversity support, and rural livelihood sustenance (MoFE, 2018; ICIMOD, 2023). Some 2,323 glacial lakes covering approximately 75.7 km² in the high Himalayas have expanded measurably under sustained warming (Bajracharya et al., 2015; Veh et al., 2019), and the risk of GLOFs from moraine- and ice dammed lakes constitutes a serious and growing hazard to downstream communities (Rounce et al., 2017; UNDP, 2021), as 26 GLOFs were already recorded since 1977 (Figure 6).

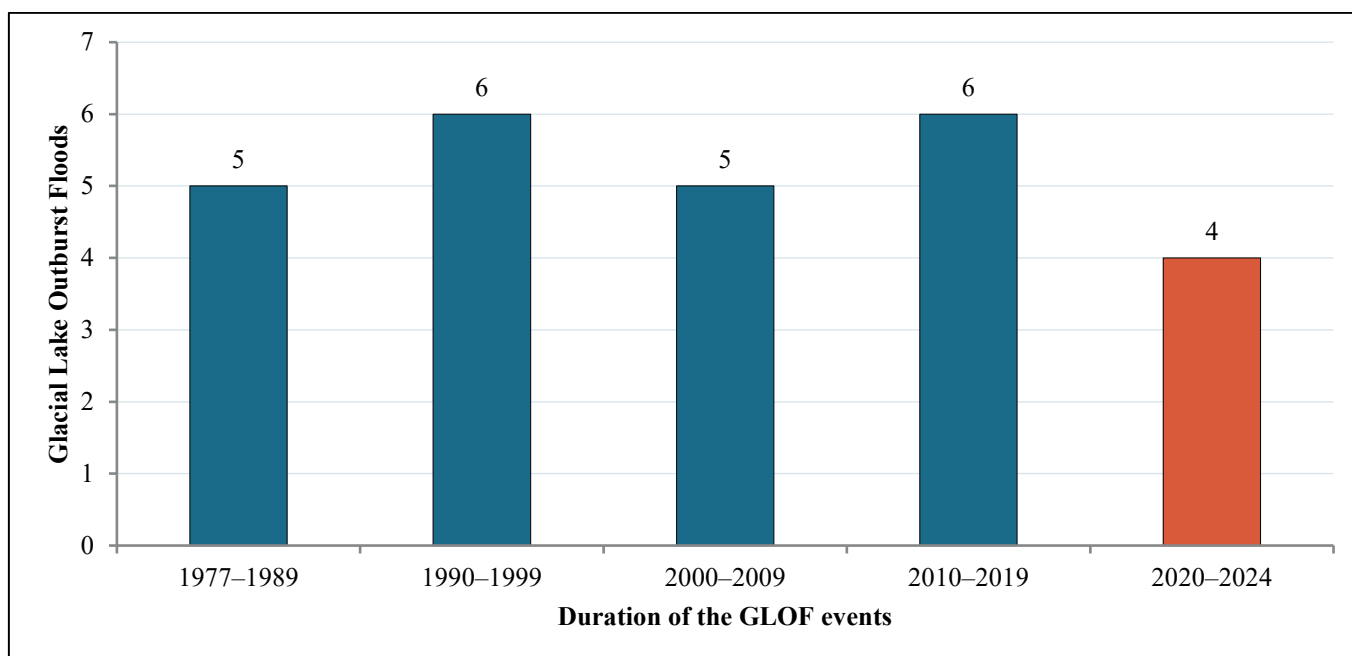


Figure 6: Number of recorded glacial lake outburst flood (GLOF) events in Nepal by period (≈26 events since 1977), including the 2024 Thame GLOF (ICIMOD, 2024)

Nepal has designated ten Ramsar wetlands of international importance spanning ecological zones from the Terai lowlands to high-altitude Himalayan basins (Ramsar Convention Secretariat, 2022). These wetland ecosystems support high levels of biodiversity and provide important ecosystem services, including carbon sequestration, irrigation, fisheries, tourism, and habitat for diverse aquatic and terrestrial species, including fish and waterbirds. These services contribute to the livelihoods and well-being of communities living in and around wetland areas (Baral et al., 2016). Site characteristics of these Ramsar wetlands are detailed in Table 2.

Table 2: Ramsar Wetland Sites of Nepal

Ramsar Site	Area (ha)	Altitude (masl)	Ecological Zone	Location	Designated
Koshi Tappu	17,500	90	Terai	Eastern Nepal	1987
Jagadishpur Reservoir	225	195	Terai	Western Nepal	2003
Ghodaghodi Lake	2,563	205	Terai	Far-Western Nepal	2003
Beeshazari & Assoc. Lakes	3,200	285	Terai	Central Nepal	2003
Mai Pokhari	90	2,100	Middle Mountain	Eastern Nepal	2006
Rara Lake	1,583	2,990	High Mountain	Mid-Western Nepal	2007
Phoksundo Lake	494	3,610	High Mountain	Mid-Western Nepal	2007
Gosaikunda & Assoc. Lakes	1,030	4,700	High Mountain	Central Nepal	2007
Gokyo & Assoc. Lakes	7,770	5,000	High Mountain	Eastern Nepal	2007
Lake Cluster of Pokhara Valley	26,106	742–800	Middle Mountain	Western Nepal	2016

Source: Ramsar Convention Secretariat (2022); MoFE (2018)

2.2 Groundwater and Springs

Groundwater is a critical component of Nepal's water supply, particularly in the Terai lowlands, where it is an important source for irrigation and urban water systems. In the Terai, shallow alluvial aquifers support intensive irrigated agriculture and urban water supply through extensive networks of shallow and deep tubewells (ICIMOD, 2023). In the hills and mountains, groundwater commonly emerges as springs, which serve as important sources of drinking water and support domestic and agricultural needs in many rural communities (Andermann et al., 2012; Khadka & Pathak, 2021). In our country, groundwater accounts for approximately 12% of total irrigation water use (FAO, 2020); however, at the farm level, its contribution may reach 50% during the dry season, highlighting groundwater's critical buffering role in sustaining irrigation during periods of limited surface water availability (IWMI, 2023). In the Terai specifically, groundwater contributes approximately 26% of irrigation water use, with substantial potential for further expansion where aquifer conditions are favorable (World Bank, 2019).

Groundwater pressure is serious and increasing in several parts of the country, although the mechanisms differ markedly between the deep aquifer systems of valleys and the Terai and the shallow spring systems of the hills. In the Kathmandu Valley, prolonged and intensive groundwater extraction has contributed to declining groundwater levels and increasing pressure on groundwater resources. Groundwater depletion and reduced recharge associated with rapid urbanization have also contributed to the decline and drying of traditional stone spouts, locally known as "*Dhunge dharas*" (Prajapati et al., 2021; Pokhrel et al., 2022).

Spring depletion in the mid hills is a distinct but equally serious problem, driven less by groundwater pumping than by reduced recharge from land-use change and rainfall variability. A systematic survey of spring sheds water sources in Kavrepalanchok district documented 5,689 water sources, of which approximately 27% had already dried up while 58% of the remaining active springs were experiencing declining flows (ICIMOD, 2023). These findings provide important empirical evidence of widespread spring decline in the mid hills of Nepal. More broadly, an Asian Development Bank Assessment, 2025 reported that springs and shallow groundwater resources are declining across large parts of Nepal.

The drivers of groundwater depletion are multifactorial, encompassing over extraction, reduced recharge from declining precipitation and vegetation cover, land-use change, climate variability, and inadequate regulatory oversight. Effective groundwater remediation requires integrated management strategies that combine spring shed rehabilitation, controlled groundwater abstraction, managed aquifer recharge (MAR), and community-based monitoring (ICIMOD, 2023; Pant et al., 2024).

2.3 Water Utilization Patterns

Despite Nepal's abundant water resources, access to safe and reliable drinking water remains highly uneven due to inadequate infrastructure, water quality challenges, and institutional limitations. As of 2024, only approximately 16% of the population had access to safely managed drinking water services under SDG indicator 6.1.1 (UN-Water, 2023; JMP, 2025), compared with approximately 19% reported in earlier assessments. This difference may reflect updated survey methodologies as well as the stringent criteria for "safely managed" drinking water services, which require that an improved water source be accessible on premises, available when needed, and free from contamination. There has been real progress in rural areas: household water security, measured on IWMI's composite household water insecurity index (scored 0-15, with higher values indicating greater security), improved from a mean of 4.8 in 2013 to 10.3 in 2025, and more than 91% of rural households now use piped or protected water sources (IWMI, 2023). Nevertheless, nearly half of these sources remain at risk of microbial or chemical contamination (UNICEF, 2022).

Urban water supply in the Kathmandu Valley is under severe pressure from rapid demographic growth, with the population expanding at approximately 4.5% annually, compounded by ageing and inadequate water supply infrastructure (World Bank, 2019). The Kathmandu Upatyaka Khanepani Limited (KUKL), the utility responsible for water supply in the Kathmandu Valley, has historically been unable to meet the Valley's rapidly increasing water demand. The resulting supply deficit has encouraged widespread reliance on alternative sources, including private groundwater extraction, water tankers and other vendors, wells, and bottled water, increasing pressure on groundwater resources and household water-security costs (Udumale et al., 2016; Prajapati et al., 2021).

These urban pressures should not eclipse the sharper disparities between provinces. Access to basic and safely managed drinking water is highest in Bagmati and Gandaki Provinces, where urban piped networks are more developed, and lowest in Karnali and Sudurpaschim Provinces, where rugged terrain, dispersed settlements, and limited infrastructure investment leave a substantially larger share of households reliant on unimproved or seasonal sources (CBS, 2023; JMP, 2025). Framing water access as a Kathmandu Valley problem alone risks obscuring these province-level disparities, which are important for determining how federal and provincial investments in water infrastructure should be prioritized.

The Melamchi Water Supply Project, which diverts water from the Melamchi River in Sindhupalchok district, has helped alleviate water shortages in Kathmandu Valley since its operation began. However, the system remains vulnerable to climate-related hazards and social disruptions. The devastating 2021 monsoon floods severely damaged the project's headworks, while subsequent monsoon-related disruptions have repeatedly interrupted water supply. Supply resumed in October 2024, with the project typically capable of delivering around 170 million litres per day (MLD) to the Valley. However, in November 2025, local residents again halted water diversion for 11 days amid unresolved demands related to compensation, infrastructure, and development commitments. (Kathmandu Post, 2025). These recurring disruptions underscore the need to diversify the Valley's water sources and develop infrastructure that is more resilient to climate-related hazards, social disruptions, and other operational risks.

Nepal's per capita water use across domestic, industrial, and agricultural purposes remains relatively low compared with other South Asian countries, a paradox that starkly illustrates the gap between the country's water resource endowment and reliable access to water in practice (Smakhtin et al., 2004; FAO, 2021).

Sanitation coverage has expanded rapidly but treatment and safe management have lagged considerably. Nepal achieved Open Defecation Free status in 2019, and by 2024 an estimated 53% of the population used a safely managed sanitation service under SDG indicator 6.2.1a (UN-Water, 2023). However, most sanitation systems remain onsite: approximately 89% of households rely on onsite systems such as septic tanks and pit latrines, while only around 11% are connected to a sewer network (CBS, 2021). Moreover, only a small proportion of collected wastewater undergoes treatment at functioning wastewater treatment plants before discharge. (DWSSM, 2023; Karki et al., 2024a). In the Kathmandu Valley, despite approximately 70% notional sewerage coverage, the Guheshwori Wastewater Treatment Plant has a treatment capacity equivalent to a fraction of valley's total wastewater generation (Karki et al., 2024a). SDG indicator 6.3.1 estimates that around 30% of domestic wastewater is safely treated when appropriate onsite treatment and safe faecal-sludge management are included (UN-Water, 2023). The substantial difference between this figure and treatment plant-based estimates highlights the important role of onsite sanitation in Nepal's overall safely managed sanitation coverage, while also pointing to persistent gaps in wastewater collection, treatment, and monitoring. These gaps between sanitation access and effective

wastewater management contribute significantly to water quality degradation and pollution (DWSSM, 2023).

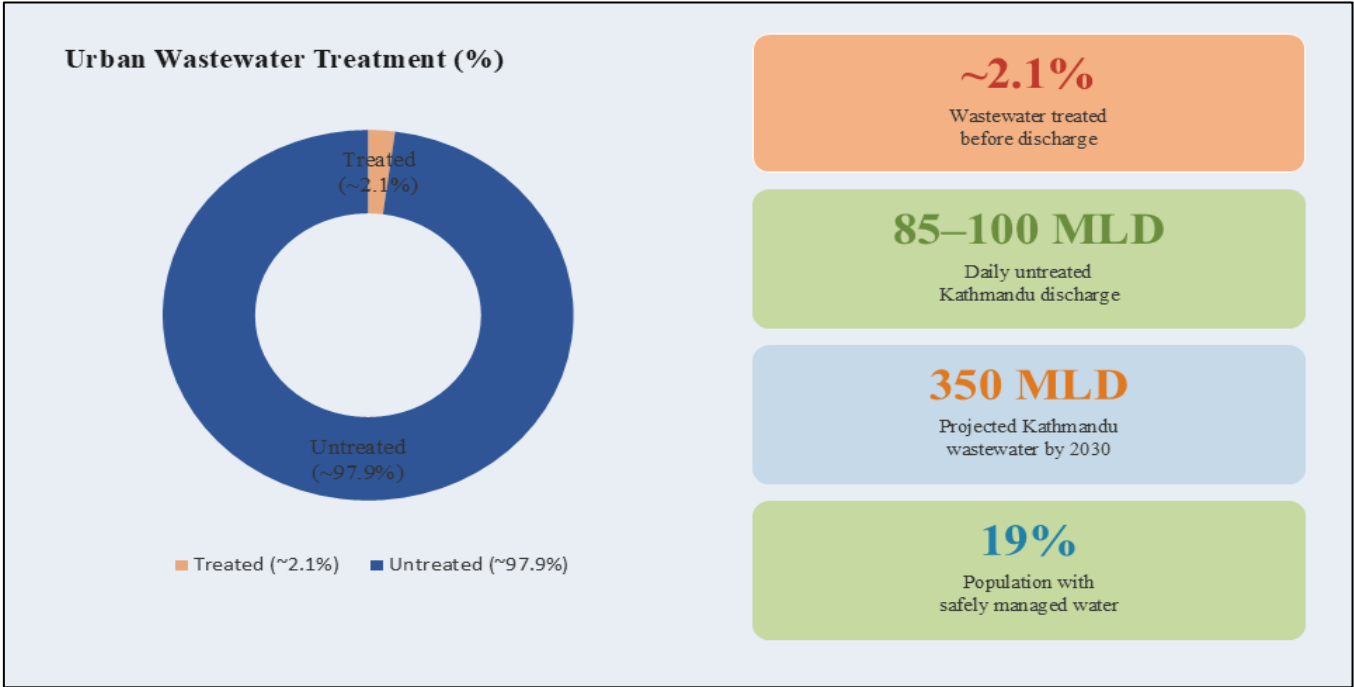


Figure 7: Wastewater treatment gap in Nepal (UN-Water, 2023; Karki et al., 2024a; JMP, 2025)

3. Water Pollution Drivers in Nepal

Before examining specific contaminants, it is useful to distinguish the water quality standards that different uses demand and to separate the drivers of pollution from its observable consequences. Nepal applies distinct regulatory thresholds for drinking water (WHO, 2022 guideline values and the Nepal Drinking Water Quality Standard; GoN, 2006), irrigation water, and treated effluent discharge (the Domestic Wastewater Effluent Standards; MoWS, 2023, which set limits such as pH 6.0-9.0, total suspended solids of 60 mg/L, and biochemical oxygen demand of 50 mg/L for treated discharge). These use specific standards, together with the trace-element benchmarks (Table 3) provide the reference points against which the contamination levels discussed below are assessed.

DHM's own nationwide water quality assessment of Nepal's major rivers offers a complementary river by river baseline against which these pressures can be tracked over time (DHM, 2022). It is also worth being precise about causality: microbial and arsenic contamination are states or impacts rather than drivers in themselves. The underlying drivers are a mix of natural geogenic factors and anthropogenic pressures inadequate sanitation infrastructure, agricultural runoff, industrial and municipal discharge, urban growth, and weak governance and enforcement that jointly produce the contamination patterns observed in the field.

3.1 Microbial Contamination

Microbial contamination, particularly by total and fecal coliforms, including *Escherichia coli*, is a widespread water quality concern in Nepal. Studies have documented bacterial contamination in drinking-water sources across the country's mountain, hill, and Terai regions, with evidence across diverse geographic areas and water-source types. A large-scale assessment of 506 drinking-water samples collected across Nepal found that 88.5% were positive for total coliforms and 56.5% for fecal coliforms, demonstrating the widespread nature of microbial contamination and its potential public health implications

(Rai et al., 2012). A systematic review of 140 peer-reviewed studies identified fecal coliform contamination as the predominant water safety concern, with coliform levels exceeding WHO's guideline of 0 CFU/100 mL in 50 to 90% of samples across most water source types examined (Chattopadhyay et al., 2025; WHO, 2022).

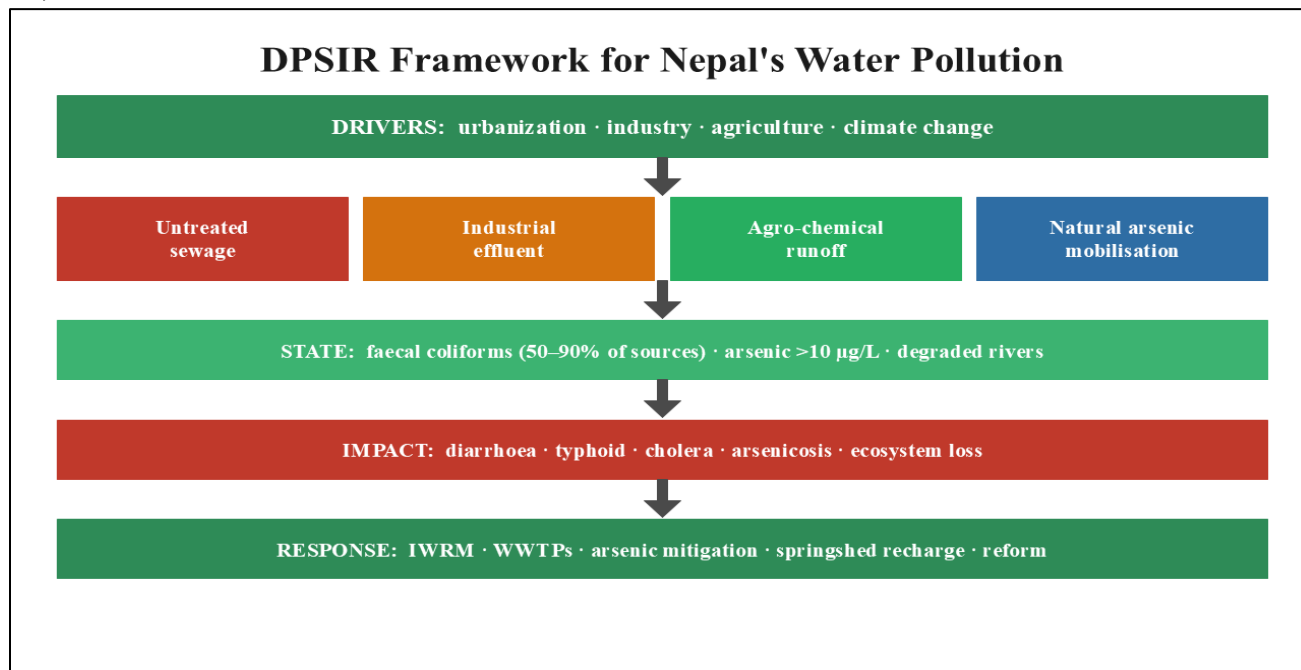


Figure 8: Drivers Pressures State Impact Response (DPSIR) framework linking pollution drivers to health and ecological impacts, and management responses (adapted from Kristensen, 2004)

The primary contamination pathways include inadequate or absent sanitation infrastructure directly a consequence of low sewerage network coverage (11%) and near absent wastewater treatment (<2%), alongside agricultural runoff, uncontrolled discharge of untreated municipal wastewater, cross-contamination between water supply and sewer systems, and untreated manufacturing effluent. Input output modelling identifies the latter as a significant and still growing contributor in industrial corridors (Figure 8) (Chapagain et al., 2020; WHO/UNICEF, 2022). As of 2022, approximately 2.1% of urban wastewater and less than 1% of the total faecal sludge generated in Nepal received treatment before discharge into the environment (World Bank, 2022). Monsoon rainfall can further increase microbial contamination of water sources by enhancing the transport of fecal material and other contaminants into surface water and groundwater systems. Seasonal increases in microbial contamination have been reported in Nepal, with monsoon conditions contributing to greater contamination of drinking-water sources (Bänziger et al., 2022). Point-of-use contamination introduced during collection, transport, and storage of drinking water constitutes an additional pathway, particularly in rural settings where access to safe storage vessels and hygienic practices may be limited (UNICEF, 2022; Aryal, 2025). Collectively, these findings support the adoption of a Water Safety Plan (WSP) approach that addresses risks across the entire drinking water supply chain rather than focusing narrowly on source water quality.

3.2 Arsenic Contamination

Arsenic occurs naturally in Terai groundwaters particularly in shallow tubewells, although elevated concentrations have also been documented in some intermediate depth wells. Thus, well depth alone should

not be considered as a reliable indicator of arsenic safety. Arsenic contamination poses a serious public health concern in Nepal, particularly in the Terai region, where groundwater from shallow and medium-depth tube wells is widely used for drinking and domestic purposes. Arsenic occurs naturally in the alluvial sediments of the Terai and can be mobilized into groundwater under reducing geochemical conditions (Thakur et al., 2011; Diwakar et al., 2015; NASC, 2020). Estimates compiled by the National Arsenic Steering Committee (NASC) from nationwide blanket testing indicate that approximately 2.5 million people in the Terai may have been exposed to drinking water containing arsenic concentrations above the WHO guideline value of 10 µg/L. Of these, approximately 0.5 million may have been exposed to concentrations exceeding Nepal's national limit of 50 µg/L.

More recent monitoring by the Department of Water Supply and Sewerage Management (DWSSM), 2023 found that more than half of the tubewells tested had arsenic concentrations at or above the WHO guideline value (Figure 9; NASC, 2020; DWSSM, 2023). In some of the worst affected districts including Nawalparasi and Rupandehi, arsenic concentrations levels reported between 50 and 100 µg/L (Aryal, 2025). It is worth noting that many Terai households have shifted towards municipal piped water supply over the past decade, and shallow tubewells are now used more for irrigation and livestock than for drinking in some areas. Nevertheless, tubewells remain an important source of drinking water for a substantial rural population. Therefore, an updated, geographically disaggregated exposure data are needed to assess how these changing water use patterns are influencing actual population level health risk.

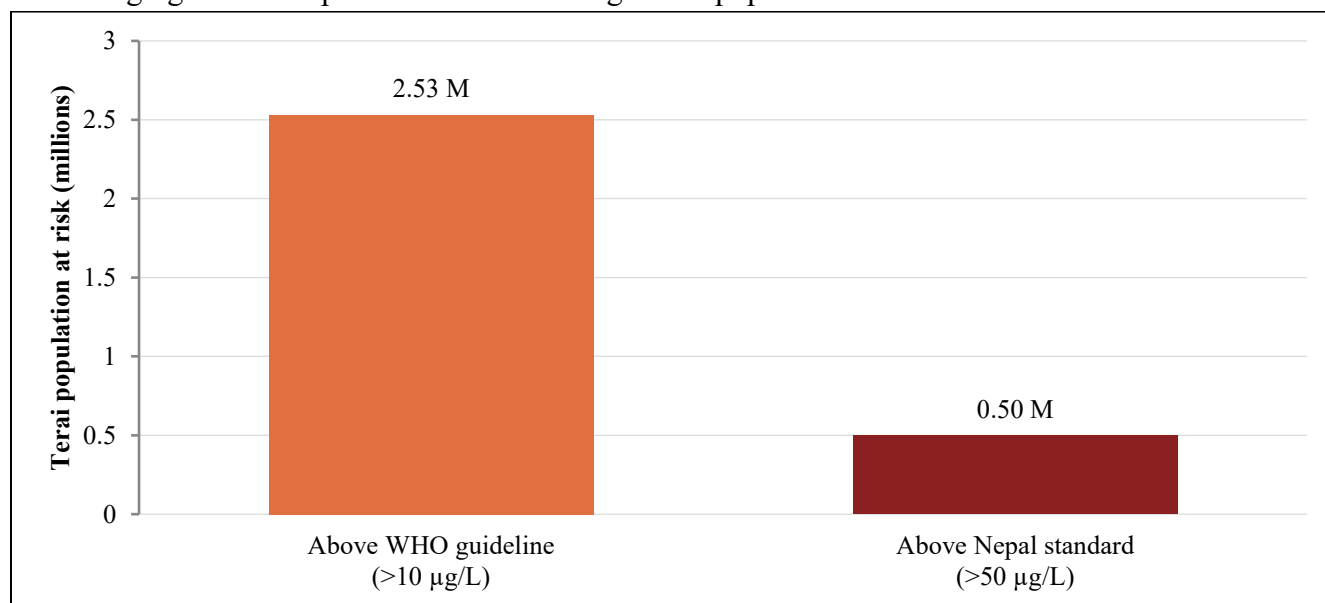


Figure 9: Arsenic exposure in Terai groundwater by concentration threshold (NASC, 2020; DWSSM, 2023)

The geochemical mechanism involves the reductive dissolution of iron oxyhydroxide minerals in anaerobic floodplain sediments, releasing adsorbed arsenic into groundwater, a process facilitated by high organic carbon content characteristic of Holocene alluvial deposits (Nickson et al., 2005; Bhattacharya et al., 2006). In intensively cultivated areas, agricultural activities may further influence arsenic dynamics in groundwater, although geogenic processes remain the principal source of arsenic contamination documented in the Terai aquifers (Thakur et al., 2011; Diwakar et al., 2015).

Beyond arsenic, broader groundwater quality assessments using composite water quality indices in the Kathmandu Valley and Lalitpur have reported elevated concentrations of iron, manganese, as well as microbial contamination alongside localized arsenic exceedances. These findings underscore that arsenic is

one of several groundwater contaminants requiring integrated monitoring rather than isolated attention (Ghimire et al., 2023; Shrestha et al., 2023).

Chronic ingestion of arsenic can cause arsenicosis characterized by cutaneous manifestations (keratosis, melanosis) and substantially elevates risks of cancers of the skin, lung, and bladder, as well as cardiovascular disease, diabetes, and adverse reproductive outcomes (Podgorski & Berg, 2020; WHO, 2022). However, the full burden of arsenicosis related morbidity in Nepal's Terai remains incompletely characterized because of limited health surveillance and diagnostic infrastructure.

3.3 Trace elements and Major Ions

Many water bodies in Nepal have been reported to contain micropollutant elements such as arsenic, cadmium, cobalt, chromium, copper, manganese, lead, and zinc (Table 3), which pose human health hazards above certain concentration thresholds (Paudyal et al., 2016a, 2016b; Tripathee et al., 2016; Pant et al., 2020; Sharma et al., 2021; Kandel et al., 2024). Rivers near urban areas show higher concentrations of these trace elements (e.g., the Bagmati River), reflecting anthropogenic pressures such as urbanization, road development, and agricultural practices linked to rapid population growth (Kandel et al., 2024). Even so, water bodies far from direct human activity also show elevated concentrations of these micropollutants, likely due to long-range transport mechanisms (Tripathee et al., 2016; Sharma et al., 2021; Bhatta et al., 2026), indicating that this pollution cannot be controlled through local management alone and requires transboundary approaches.

Most water bodies nonetheless remain within safe limits, with the notable exception of those near densely populated areas such as the Bagmati River (Kandel et al., 2024). The study of major ions in Nepal's water bodies began in the early twenty-first century (Sah et al., 2000), gaining momentum in recent years with a growing body of publications assessing irrigation water quality in major rivers and lakes (Sharma et al., 2021; Kandel et al., 2024). The main sources of these major ions in Nepalese water bodies are rock weathering processes (Kandel et al., 2024). Continued regulation is necessary to maintain water quality; a recent review of heavy metals and major ions by Kandel et al. (2024) suggests developing a comparable Himalayan Water Quality Index for the region.

Table 3: The average concentrations of TEs ($\mu\text{g L}^{-1}$) of the Himalayan rivers with some national and international standards reported from the references (Kandel et al., 2024)

Name of Rivers	Trace Elements								References
	As	Cd	Co	Cr	Cu	Mn	Pb	Zn	
Gandaki River*	2.02	0.02	0.55	3.02	1.89	6.33	0.61	127.7	(Pant et al., 2020)
Gandaki River ^a	-	0.01	0.15	4.98	1.06	3.77	0.11	4.47	(Tripathee et al., 2016)
Bagmati River ^b	-	0.38	0.58	17.27	11.29	158.71	-	37.05	(Paudyal et al., 2016b)
Indrawati River	-	0.02	0.50	1.34	3.53	14.26	0.69	7.12	(Paudyal et al., 2016a)
Dudhkoshi River	3.68	0.009	0.80	3.10	1.78	28.24	1.82	16.74	(Paudyal et al., 2016a)
Seti (Grand mean)	1.21	0.02	0.38	1.65	1.96	2.56	0.61	38.55	(Pant et al., 2021)
Badigad River (Grand Mean)	0.99	0.00	0.67	2.65	1.97	2.08	0.16	3.05	(Pant et al., 2023)
Global Mean	0.62	0.08	0.14	0.70	1.48	34.00	0.08	0.60	(Gaillardet et al., 2003)
Nepalese Standard ^c	50.00	3.00	-	50.00	1000.00	200.00	10.00	3000.00	(GoN, 2006)
Indian Standard ^d	10.00	3.00	-	50.00	-	100.00	10.00	5000.00	(BIS, 2012)
Chinese Standard ^e	10.00	5.00	-	50.00	1000.00	300.00	10.00	1000.00	(Ministry of Health of China, 2006)

Name of Rivers	Trace Elements								References
	As	Cd	Co	Cr	Cu	Mn	Pb	Zn	
WHO Limit	10.00	3.00	-	50.00	2000.00	400.00	10.00	3000.00	(WHO, 2004)
US EPA ^f	10.00	5.00	-	100.00	1300.00	-	15.00	5000.00	(US EPA, 2012)

* Average concentration from upstream and downstream of Karnali River Basin, Nepal

^a Average concentration in mid-segment of Karnali River Basin, Nepal

^b Urban-river segment of Bagmati River Basin, Nepal

^c Drinking water guideline values of Nepal

^d Drinking water guideline values of India

^e Drinking water guideline values of China

^f US EPA drinking standards of maximum contamination level

3.4 Governance and Institutional Drivers

Nepal's water quantity and water quality management involves an overlapping set of institutions. At the federal level, the Ministry of Water Supply (MoWS) and its Department of Water Supply and Sewerage Management (DWSSM) oversee drinking water and sanitation; the Ministry of Energy, Water Resources and Irrigation (MoEWRI) and its Water and Energy Commission Secretariat (WECS) are responsible for irrigation, hydropower, and basin level planning; and the Ministry of Forests and Environment (MoFE), through the Department of Environment, is oversees pollution control and industrial discharge compliance (GoN, 2021; Karki et al., 2024a). Following the 2015 Constitution, these federal bodies share water-related responsibilities with seven provincial governments and 753 local governments, while utilities such as Kathmandu Upatyaka Khanepani Limited (KUKL) manage service delivery at the local level. It is against this institutional backdrop that the governance shortcomings discussed below should be understood.

A substantial share of Nepal's water pollution challenges can be attributed to weaknesses in governance. Despite relatively progressive legislation including the Environment Protection Act (2019) and the Water Supply and Sanitation Act (2022), enforcement and implementation remain limited in practice (GoN, 2021). Nepal's score of 37 out of 100 on SDG indicator 6.5.1, which measures the degree of implementation of integrated water resources management (IWRM) remains below regional and global averages indicating IWRM principles have yet to be fully translate into effective practice (Figure 10; UN-Water, 2023).

Nepal's federal transition following the 2015 constitution has created layered coordination challenges by distributing water resource management responsibilities across the federal government, seven provincial governments, and 753 local governments. In practice, ambiguities in institutional mandates, overlapping jurisdictions, and limited intergovernmental coordination mechanisms can constrain effective water resource governance (GoN, 2021). Environmental compliance monitoring of r industrial discharges also remains constrained by limited institutional capacity within the Department of Environment and other relevant agencies. Enforcement of penalties for non-compliance remains inconsistent, further weakening the effectiveness of environmental regulations (UNEP, 2022).

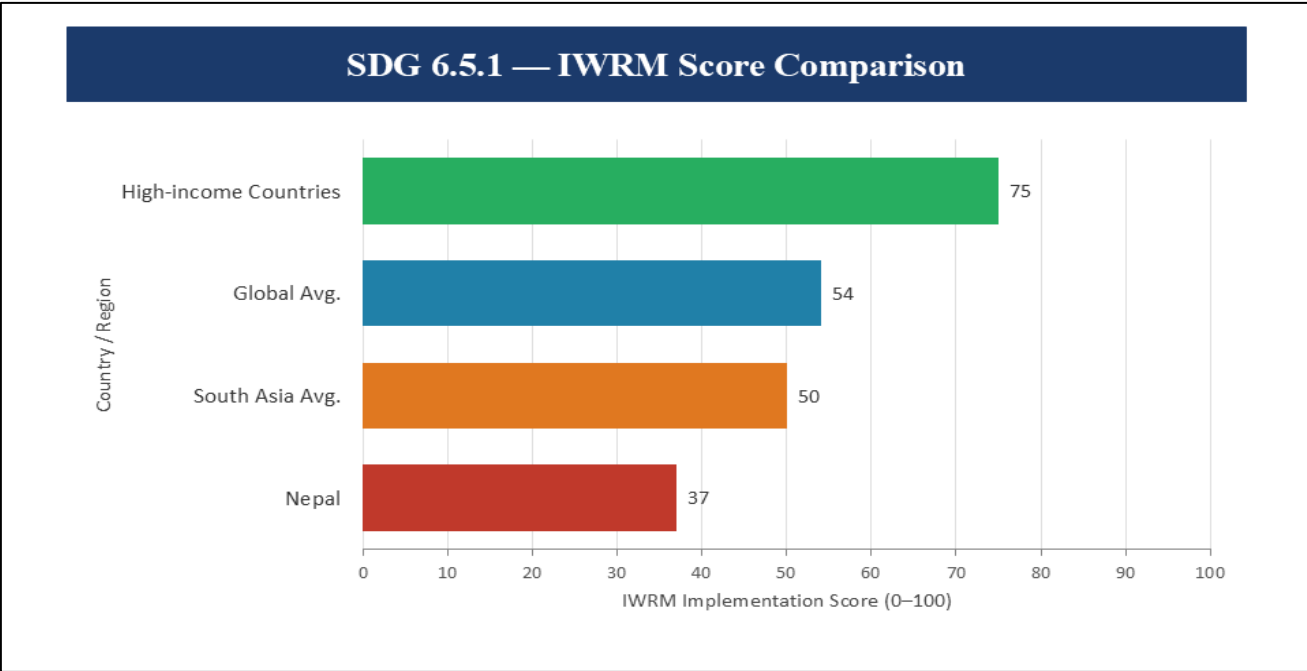


Figure 10: Low SDG 6.5.1 IWRM score of 37/100 (UN-Water, 2023)

Wastewater treatment infrastructure remains severely underdeveloped in Nepal. Of the 18 wastewater treatment plants reportedly constructed in the Kathmandu Valley by 2022, only a limited number were operating continuously at their design capacity owing to challenges including power interruptions, inadequate maintenance, and poor sludge management (World Bank, 2022). The Kathmandu Valley alone discharges an estimated 85 - 100 million liters per day (MLD) of untreated or inadequately treated wastewater into rivers. By 2030, wastewater generation in the valley is projected to reach approximately 350 MLD, while available treatment capacity is expected to remain below half of the projected watershed volume (World Bank, 2022).

3.5 Urbanization and Industrialization

Nepal is urbanizing rapidly with the 2021 census reporting about 66% of the country's 29.2 million people lived in urban areas, following a major reclassification of municipal boundaries (CBS, 2023; World Bank, 2022). In the Kathmandu Valley, rapid urbanization has expanded settlements and infrastructure into river corridors and flood-prone areas, including informal settlements along riverbanks. At the same time, the conversion of natural and agricultural land into roads, buildings, and other impervious surfaces has reduced infiltration and increased surface runoff, placing additional pressure on urban drainage systems and rivers (Dangol & Carrasco, 2019; Bhattarai & Adhikari, 2022). These pressures are reflected in measurable ecological decline: ecological risk assessments of the Bagmati River within Kathmandu have reported consistently elevated risk quotients for heavy metals and nutrients in the densely urbanized areas, with comparatively lower risks in less developed peri urban areas which directly linking to urbanization intensity and river ecosystem extending beyond water quality deterioration alone (Karki et al., 2024b).

Industrial water pollution is concentrated along major industrial corridors around Biratnagar, Birgunj, Hetauda, and Butwal. The key polluting sectors include textiles and dyeing (heavy metals, persistent organic pollutants), tanneries (chromium, sulphides), pharmaceuticals (active pharmaceutical ingredients, endocrine disruptors), food processing (high BOD effluents), and brick kilns (ash and suspended solids)

(UNEP, 2022). An input output analysis of Nepal's manufacturing sector indicates that industrial effluents are an important contributor to river pollution alongside domestic waste water, and suggests that stronger discharge standard enforcement and economic incentives based on the polluter pays principle could improve pollution prevention behaviour among manufacturers (Chapagain et al., 2020). Many small and medium-sized enterprises lack treated effluents into drains and nearby watercourses. The Roshi River, downstream of Hetauda's industrial area, has been identified as experiencing industrial and urban pollution pressure (Karki et al., 2023).

Unregulated riverbed extraction of construction aggregates further alters s channel morphology, increases turbidity, and can exacerbate downstream sedimentation and water quality degradation. Compliance and operational performance among existing wastewater treatment facilities also remain inconsistent. In the Kathmandu Valley, the Guheshwori Wastewater Treatment Plant treats only a fraction of the wastewater generated within its service area, while independent faecal sludge treatment facilities (FSTFs) remain limited despite widespread reliance on onsite sanitation systems. With approximately 89% of urban households depending on onsite sanitation and the resulting septage requiring periodic emptying, transport, and safe treatment, inadequate FSTF capacity leaves a substantial portion of the urban sanitation chain insufficiently managed at the treatment stage (Karki et al., 2024a).

3.6 Climate Change Impacts on Water Quality

Climate change influences water pollution dynamics through multiple mechanisms. Intensifying extreme rainfall events can mobilize surface applied pollutants including faecal matter, agrochemicals, and industrial contamination into water bodies, generating episodic contamination pulses that can overwhelm treatment systems and compromise drinking water safety (Lutz et al., 2016). Conversely, prolonged dry-period low-flow conditions can concentrate pollutants in river by reducing dilution capacity, thereby amplifying the ecological and human health impacts of chronic pollutant discharges (Karki et al., 2023).

Nepal's lakes and reservoirs are also affected by changes in water quality and watershed conditions. Lake Rara, for example, has been characterized as an oligotrophic high-mountain lake with relatively high dissolved oxygen concentrations, although its hydrochemical characteristics reflect the influence of surrounding environmental conditions (Gurung et al., 2018). In lower-elevation lakes such as Phewa, seasonal changes in thermal structure and water chemistry can influence dissolved oxygen availability and aquatic ecosystem functioning. Glacial lake outburst flood (GLOF) events, beyond their direct flood hazard, transport substantial loads of sediments, heavy metals, and organic matter into downstream rivers and reservoirs, with water quality impacts that persist beyond the immediate flood event (Rounce et al., 2017; ICIMOD, 2023). The interaction between climate change and preexisting pollution pressures can produce complex and non-linear water quality responses that challenge conventional management frameworks.

4. Water Pollution and Human Health

The consequences of water-quality and watershed degradation extend beyond domestic water use. Sediment accumulation and watershed degradation can reduce the storage capacity and functional value of lakes, with implications for agricultural irrigation, fisheries, recreation, and hydropower. In Phewa Lake, watershed degradation and increased sediment influx have contributed to substantial lake shrinkage and declining storage capacity, potentially affecting the multiple ecosystem services provided by the lake (Watson et al., 2019).

4.1 Waterborne Disease Burden

Unsafe drinking water is one of the important risk factors for illness and mortality in Nepal. Waterborne diseases, including acute diarrhoea, typhoid, cholera, hepatitis A, and intestinal parasitic infections, affect children under five who are vulnerable to the health impacts of inadequate water, sanitation and hygiene condition (UNICEF, 2022; WHO, 2022). Diarrhoeal diseases remain an important cause of morbidity and mortality among children in Nepal and are closely associated with inadequate WASH services (MoHP, 2021; WHO, 2022).

Enteric fever is highly endemic in the Kathmandu Valley, where contaminated water and inadequate sanitation contribute to transmission of *Salmonella* Typhi and *Salmonella* Paratyphi A (Karkey et al., 2008). Intermittent water supply and deteriorating distribution infrastructure can further increase the risk of faecal contamination, as low pressure in drinking water pipelines and their proximity to sewage networks may facilitate sewage ingress into the water supply. Environmental studies have detected *S. Typhi* and *S. Paratyphi A* in Kathmandu drinking water sources, highlighting the potential role of contaminated water in enteric-fever transmission, which has also been consistently documented among febrile patients in Kathmandu (Karkey et al., 2008; Karkey et al., 2016).

Monsoon flooding can amplify the risk of waterborne diseases by contaminating drinking water sources, damaging sanitation infrastructure, and increasing human exposure to faecally contaminated floodwater. These disruptions can increase the risk of diarrhoeal and other water-related disease outbreaks, particularly among populations with limited access to safe water and sanitation (WHO, 2021; UNICEF, 2022). Cholera, caused by *Vibrio cholerae*, remains endemic in Nepal, with periodic outbreaks associated with inadequate access to safe drinking water and sanitation. For example, a cholera outbreak in Kapilvastu in 2021 resulted in more than 1,300 acute diarrhoeal cases and six deaths, while a cholera outbreak was also reported in Kathmandu Valley in 2022 (WHO, 2021; EDCD, 2022).

4.2 Vulnerability and Social Determinants

The health burden of water pollution is unevenly distributed across Nepal, with low-income, marginalized, and geographically isolated communities often experiencing greater exposure and fewer resources to manage water-related health risks. Dalits, Janajati, and women may face disproportionate vulnerabilities because of socioeconomic constraints, limited access to safe water and sanitation, and the substantial responsibility women often bear for collecting and managing household water. These inequalities can increase reliance on unsafe water sources and create additional barriers to accessing healthcare when water-related illnesses occur (UNICEF, 2022). In the Terai, communities dependent on shallow tubewells are particularly vulnerable to multiple water quality hazards, including arsenic, fluoride, and microbiological contamination, highlighting the cumulative nature of water related health risks in areas where access to safe alternative water sources is limited (NASC, 2020). Children are particularly vulnerable to the health consequences of unsafe water and inadequate sanitation. Recurrent diarrhoeal illness during early childhood can contribute to malnutrition, impaired growth, and adverse developmental outcomes, potentially affecting children's physical and cognitive potential over the longer term (WHO, 2022). These effects can reinforce existing socioeconomic disadvantages and contribute to the intergenerational dimensions of poverty.

Women and girls also experience disproportionate burdens associated with water insecurity. In households where water is not available on the premises, women and girls are frequently responsible for water collection, which can impose substantial time and labour demands and reduce opportunities for education, employment, and other activities. Limited access to adequate water, sanitation, and hygiene facilities can

also constrain menstrual health and hygiene management and increase exposure to health and safety risks (UNICEF, 2022). These gendered burdens extend beyond conventional measures of disease morbidity and mortality and should therefore be considered when assessing the broader health and socioeconomic consequences of water insecurity.

4.3 Arsenicosis and Chronic Health Effects

Chronic ingestion of arsenic contaminated water is a major exposure route for inorganic arsenic (classified carcinogenic by International Agency for Research on Cancer) and can cause arsenicosis, a chronic systemic condition characterized by skin pigmentation changes (melanosis), hyperkeratosis, and other systemic effects, including peripheral neuropathy and increased risks of skin, bladder, and lung cancers (IARC, 2004; Podgorski & Berg, 2020; WHO, 2022). In Nepal's Terai, widespread arsenic contamination of groundwater and documented cases of arsenicosis highlight the continuing public-health significance of chronic arsenic exposure (Aryal, 2025).

Beyond carcinogenicity, chronic arsenic exposure is associated with cardiovascular disease, type 2 diabetes, adverse pregnancy outcomes, and impaired child neurodevelopment (Podgorski & Berg, 2020; WHO, 2022). In Nepal's Terai, arsenicosis disproportionately affects rural communities, where chronic illness and visible skin manifestations can impose additional socioeconomic and psychosocial burdens on affected households.

5. Water Resources Conservation and Management

Sustainable water resources conservation in Nepal requires a multidimensional approach integrating hydrological restoration, water-quality management, institutional strengthening, and climate adaptation. Responsibility for water governance is distributed across Nepal's federal structure; therefore, conservation strategies must work within and strengthen this institutional architecture. Among the priority actions, institutional reform and improved wastewater and faecal-sludge management are foundational because they support the effectiveness of more targeted interventions, including spring shed rehabilitation and arsenic mitigation.

Springshed management and groundwater recharge are critical priorities in Nepal's hill and mountain landscapes. Community-based spring shed rehabilitation, including protection of recharge areas, restoration of traditional water sources, vegetation management, and other nature-based measures, can help restore spring systems and strengthen local water security (ICIMOD, 2023). Recent work in Kavrepalanchok demonstrates the scale of the challenge: mapping across seven municipalities identified 5,689 water sources, with 27% already dry and 58% of active springs showing declining flows (ICIMOD, 2025). Such evidence highlights the need to integrate spring shed management into local development plans, budgets, and climate-adaptation strategies.

Integrated catchment management linking upstream land use, sediment control, riparian restoration, and downstream water quality management is essential for reducing diffuse pollution from agricultural and urban areas (FAO, 2021).

Payment for ecosystem services and other upstream–downstream financing mechanisms may provide additional incentives for watershed conservation where appropriate, as demonstrated by community-based PES initiatives in the Koshi Hills of Nepal (Bhatta et al., 2018). Wastewater treatment and faecal sludge management should likewise be treated as urgent infrastructure priorities, particularly in rapidly urbanizing areas where conventional sewerage systems are costly or difficult to extend (World Bank, 2022).

Arsenic mitigation in the Terai requires sustained investment in safe alternative water supplies, household water-treatment options where appropriate, and systematic community-based testing and spatial mapping (NASC, 2020). National arsenic surveillance should integrate hydrogeological information, water quality monitoring, and health data to enable spatially targeted interventions. Institutional strengthening is equally important, including clearer intergovernmental responsibilities, improved provincial and local capacity for water quality monitoring, stronger implementation of integrated water resources management, and effective enforcement of environmental standards (GoN, 2021).

Future water security in Nepal will be shaped by three interacting pressures. First, water demand is expected to increase across hydropower, irrigation, and municipal sectors. WECS projections indicate that water use across ten major river basins could increase from approximately 9% of annual flow to 25% by 2050 (WECS, 2023). Second, climate change and continuing glacier and snow-cover changes will alter the timing and magnitude of water availability, potentially increasing seasonal water stress in several Himalayan basins (Radić & Hock, 2014; Immerzeel et al., 2020). Third, continued urbanization and population growth will concentrate both water demand and pollution load in major urban corridors. Together, these pressures suggest that existing supply demand and wastewater treatment gaps could widen under a business-as-usual trajectory. Strengthening institutions, protecting water sources, expanding wastewater and faecal sludge management, and investing in climate resilient water infrastructure should therefore be treated as urgent priorities rather than longer term aspirations.

6. Conclusion

Nepal faces a striking water security paradox: despite being relatively rich in water resources, the country continues to experience seasonal shortages, unreliable water supplies, widespread water quality problems, and declining groundwater resources. The underlying challenge is therefore not simply water availability, but the combined effects of inadequate infrastructure, fragmented institutions, governance weaknesses, climate change, and rapid urbanization.

Water quality has emerged as a major public health and environmental concern. Microbial contamination contributes to waterborne diseases, arsenic contamination of groundwater poses a persistent health risk in the Terai, and elevated concentrations of trace elements and major ions can affect human health and water suitability for irrigation. The limited coverage and poor functioning of wastewater-treatment systems further intensify these challenges, creating risks for both public health and aquatic ecosystems.

Climate change interacts with existing water related pressures, often intensifying their impacts on water availability, quality, and security. Increasing risks from glacial lake outburst floods, declining springs, changing flood and drought patterns, and shifts in hydrological regimes are likely to place additional pressure on Nepal's water resources and water quality. Without scientifically grounded and locally appropriate adaptation strategies, these interacting pressures could further undermine national and local water security.

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Glossary

Arsenicosis: A chronic health condition resulting from long-term exposure to arsenic, particularly through the consumption of arsenic-contaminated drinking water. It may cause characteristic skin lesions, including melanosis and hyperkeratosis, and is associated with an increased long-term risk of cancers and other adverse health effects.

Catchment (river basin): The area of land from which precipitation and surface runoff drain into a particular river, lake, wetland, or other water body.

Cryosphere: The frozen components of the Earth's water system, including glaciers, snow, ice, and permafrost, which play an important role in storing and releasing freshwater and regulating river flows.

DPSIR Framework (Drivers–Pressures–State–Impact–Response): An analytical framework used to examine relationships between underlying societal or environmental drivers, the pressures they create, resulting changes in environmental conditions, associated impacts, and policy or management responses.

Faecal coliform: A group of bacteria used as an indicator of faecal contamination in water. Their presence may indicate potential contamination by disease-causing microorganisms; *Escherichia coli* is one of the most widely used specific indicators of faecal pollution.

Glacial Lake Outburst Flood (GLOF): A sudden and potentially catastrophic release of water from a glacial lake, often caused by the failure or breach of a moraine or ice dam, posing significant flood risks to downstream communities and infrastructure.

Integrated Water Resources Management (IWRM): A coordinated approach to managing water, land, and related resources that seeks to maximize social and economic benefits equitably while maintaining the sustainability of vital ecosystems.

Major ions: The principal dissolved inorganic constituents of natural water, such as calcium, magnesium, sodium, potassium, bicarbonate, sulphate, and chloride, commonly used to assess water chemistry and suitability for different uses.

Transboundary river: A river or river basin that crosses or forms part of an international boundary and therefore requires cooperation and coordinated management among the countries sharing its water resources.

CHAPTER: IV

Land-Cover Transition Directions and Topographic Influence in Nepal, 2001-2022: A National Analysis Using NLCMS Data

Motilal Ghimire

Central Department of Geography, Tribhuvan University, Kirtipur, Nepal

Summary

Nepal has experienced rapid urban growth, changes in agriculture, forest regeneration, and significant variations in terrain, leading to complex shifts in land cover that affect food security, ecosystem management, and spatial planning. This study measures national land-cover changes from 2001 to 2022, identifies the main trends in land-cover transitions, and analyzes how these changes differ by elevation and slope using 30-meter resolution data from the National Land Cover Monitoring System (NLCMS). Land-cover changes were examined using a national cross-tabulation matrix, while analyses stratified by elevation and slope assessed where major gains and losses were concentrated topographically. The forested area grew from 59,224.5 to 63,993.4 square kilometers, an increase of 8.1%, while cropland decreased from 38,973.0 to 33,325.7 square kilometers, a decline of 14.5%. Built-up areas expanded dramatically from 260.2 to 4,758.8 square kilometers, marking the largest proportional growth. Overall, 108,188.1 square kilometers (73.3%) remained unchanged in land cover, whereas 39,327.9 square kilometers (26.7%) changed. The most significant transition was from cropland to forest, covering 5,891.8 square kilometers, compared to 1,626.3 square kilometers shifting from forest to cropland. Cropland accounted for 79.0% of the new built-up land. Urban growth was heavily concentrated in accessible areas, with 84.3% of built-up land located below 2,000 m elevation and 74.3% on slopes of 10 degrees or less. These findings demonstrate a linked pattern of shrinking cropland, expanding forests, and rapid urban development in low-relief areas. The study underscores the importance of better protecting productive farmland, promoting more compact urban growth, implementing forest management tailored to local conditions, and planning land use with consideration of topography in Nepal.

Keywords: Elevation; Land-cover change; slope; topographic influence; urban expansion

1. Introduction

Land use and land cover changes affect ecosystem services, carbon storage, biodiversity, water cycles, agricultural production, and vulnerability to natural disasters. In mountainous countries, these changes vary greatly depending on factors like elevation, slope, accessibility, and climate. Nepal presents a particularly complex case because its short north-south span includes the Terai plains, mid-hills, high mountain valleys, and the Himalayan cryosphere. Nepal has also experienced rapid social and economic shifts. Factors such as rural migration, declining farm labor, road development, urbanization, livelihood diversification, and community-based forest management have transformed land use for agriculture and forestry. Past research has highlighted farmland underuse and abandonment in the hills, forest regrowth in community-managed areas, and urban expansion along transportation routes and in flatter regions (Ojha et al., 2017; Bhawana & Race, 2019; Tripathi et al., 2020; Bhattarai et al., 2023).

A broader review shows that land-cover change patterns and extents vary widely across Nepal's ecological and socioeconomic contexts (Rai et al., 2023). The National Land Cover Monitoring System provides a

consistent yearly record based on Landsat data for nationwide analysis (Aryal, 2022; FRTC, 2022, 2024). However, focusing only on overall net changes does not reveal detailed land-cover exchanges or where these changes happen on the terrain. A transition matrix helps identify areas of persistence, gross gains, and gross losses, while analyzing changes by elevation and slope shows if they are mainly in accessible lowlands, cultivated hill slopes, or high-altitude regions. Using these approaches together is essential because low-relief areas simultaneously support settlements, transportation, productive farmland, and remaining natural ecosystems.

This study aims to: (1) measure nationwide land-cover changes from 2001 to 2022; (2) identify the main directions of gross land-cover transitions; (3) describe how land-cover classes are spread and have changed across various elevation and slope categories; and (4) assess the environmental and policy impacts of declining agricultural land, forest dynamics, urban expansion, changes along river corridors, and land-cover trends in high mountain regions.

2. Materials and Methods

2.1 Study area

Nepal extends from the low-elevation Terai to peaks exceeding 8,000 m and contains strong gradients in temperature, precipitation, vegetation, settlement density, and land-use suitability. The mapped national area used in this analysis is 147,516.0 km².

2.2 NLCMS land-cover data

Annual land-cover maps from 2001 to 2022 were obtained from Nepal's National Land Cover Monitoring System (NLCMS), developed by the Forest Research and Training Centre. This dataset includes yearly data from 2000 to 2019, released in 2022, along with updates for 2020 to 2022, published in 2024. The raster data were downloaded in May 2026 from the ICIMOD Regional Database System.

NLCMS uses 30-meter resolution Landsat images and cloud-based processing via Google Earth Engine (Uddin et al., 2015). Its approach combines training and reference data, applies Random Forest classification to initial layers, performs temporal consistency checks, and uses decision rules to produce the final land-cover categories. The national summaries identify ten classes: waterbody, glacier, snow, forest, riverbed, built-up area, cropland, bare rock or soil, grassland, and other wooded land. For terrain and transition analyses, we consolidated these into nine land-cover types by merging snow and glacier into one class, while keeping grassland and other wooded land separate. Bare soil and bare rock were combined into a single class.

Validation was conducted for selected endpoint years rather than annually. The overall accuracy was 84.80% for 2019 (kappa coefficient 0.73) and 84.97% for 2022 (kappa 0.76), based on more than 4,000 reference points. Class-level uncertainty was higher for less common and more heterogeneous classes such as grassland, other wooded land, bare surfaces, riverbed, and snow (FRTC, 2022, 2024).

2.3 Terrain data and stratification

Elevation and slope were derived from the 30-meter ALOS digital elevation model. The DEM was projected to WGS 84/UTM Zone 44N and overlaid with the 2001 and 2022 land-cover rasters at 30-m resolution. Elevation was classified into six bands: <1,000 m, 1,000-2,000 m, 2,000-3,000 m, 3,000-4,000 m, 4,000-5,000 m, and >5,000 m above sea level. Slope was divided into nine classes: $\leq 5^\circ$, 5.0-10.0°, 10.1-15°, 15.1-20°, 20.1-25°, 25.1-30°, 30.1-35°, 35.1-40°, and $\geq 40^\circ$.

2.4 Normalization, mixed-pixel correction and percentage presentation

The 30-meter overlay was adjusted to match the published NLCMS national land-cover totals for the years 2001 and 2022. For quality control specific to terrain, built-up areas located above 4,000 meters elevation and on slopes of 40 degrees or steeper were classified as mixed or misclassified pixels. Any apparent net increase in cropland on slopes steeper than 35 degrees was also considered a mixed-pixel issue on steep slopes: existing cropland was preserved, but the net increase was redistributed among grassland, other wooded land, and bare rock or soil, while maintaining the national class totals and slope-class areas. Land-cover composition within each elevation and slope category is presented as a row percentage, and changes are shown as the difference in percentage points between 2022 and 2001. The final column shows the total area of each terrain class in square kilometers. Further details on the reconciliation and mixed-pixel redistribution methods can be found in Section 4.5. The results of this analysis should be viewed as indicative rather than exact values.

2.5 Construction and interpretation of the transition matrix

The 2001-2022 transition matrix was created by summing the normalized four-dimensional table over elevation and slope. The rows correspond to the 2001 source classes, while the columns correspond to the 2022 destination classes; cells along the diagonal represent persistence, and off-diagonal cells show the estimated transition directions. The correction for built-up areas at high elevations is maintained in both the transition and elevation analyses. Additional corrections for built-up areas on slopes of 40° or more and for mixed cropland pixels on slopes greater than 35° are applied only to the slope-specific summaries found in Tables 5 and 6; the overall national class totals remain unchanged, so the national transition matrix stays the same. Snow and glacier areas, as well as bare soil and rock areas, are each combined into single categories. Grassland and other wooded land are kept as separate classes.

3. Results

3.1 National land-cover trends

According to Table 1, the forested area increased by 4,768.9 km², growing from 59,224.5 km² in 2001 to 63,993.4 km² in 2022, which represents an 8.1% rise. Cropland decreased by 5,647.3 km², dropping from 38,973.0 to 33,325.7 km², a 14.5% reduction. The built-up area saw the largest relative growth, expanding from 260.2 to 4,758.8 km², which is an increase of 4,498.6 km² or 1,728.9%, making it 18.3 times larger than in 2001.

Snow-covered regions grew by 2,098.5 km², a 57.1% increase, while glacier areas remained almost unchanged, with a slight rise of 13.2 km² (0.3%). Water bodies shrank by 58.4 km² (8.8%), riverbeds by 585.9 km² (33.9%), bare rock or soil by 3,615.0 km² (31.8%), grassland by 186.2 km² (0.9%), and other wooded land by 1,286.5 km² (24.4%). It is important to interpret changes in cryospheric and bare-surface areas cautiously, as factors such as seasonally and annually varying snow cover, shadows from clouds and terrain, mixed pixels, and classification errors may affect the accuracy of these measurements.

Table 2: Published national land-cover area and change, 2001-2022

Land-cover category	2001 (km ²)	2022 (km ²)	Net change (km ²)	Relative change (%)	2022/2001 ratio
Waterbody	660.7	602.4	-58.4	-8.8	0.91
Glacier	4,494.0	4,507.2	+13.2	+0.3	1.00
Snow	3,673.6	5,772.1	+2,098.5	+57.1	1.57
Forest	59,224.5	63,993.4	+4,768.9	+8.1	1.08

Land-cover category	2001 (km ²)	2022 (km ²)	Net change (km ²)	Relative change (%)	2022/2001 ratio
Riverbed	1,726.1	1,140.2	-585.9	-33.9	0.66
Built-up area	260.2	4,758.8	+4,498.6	+1,728.9	18.29
Cropland	38,973.0	33,325.7	-5,647.3	-14.5	0.86
Bare rock or soil	11,357.4	7,742.5	-3,615.0	-31.8	0.68
Grassland	21,880.8	21,694.6	-186.2	-0.9	0.99
Other wooded land	5,265.6	3,979.2	-1,286.5	-24.4	0.76
Total	147,516.0	147,516.0	-0.0	0.0	1.00

Note: Values are the published national endpoint totals used as controls for normalization. Bare rock and bare soil are combined. Snow and glacier remain separate in this national summary but are combined in Tables 2-6 because they share one ID in the overlay spreadsheet. Percentages are calculated relative to the 2001 area; positive signs indicate gains and negative signs indicate losses.

3.2 Gross land-cover transition directions, 2001-2022

The transition matrix shows that 108,188.1 km², or 73.3% of Nepal's normalized mapped area, stayed within the same land-cover category between 2001 and 2022, while 39,327.9 km² (26.7%) experienced a change in class (Table 2 and Figures 1, 2, and 3). Forest areas gained approximately 9,707.7 km² from other land-cover types and lost 4,938.9 km², leading to a gross turnover of 14,646.6 km² and a net gain of 4,768.9 km² as reported. Cropland gained 4,713.5 km² but lost 10,360.8 km², resulting in a gross turnover of 15,074.3 km² and a net loss of 5,647.3 km². The most significant directional change was from cropland to forest, with 5,891.8 km² converted, compared to 1,626.3 km² shifting from forest to cropland, yielding a net exchange of 4,265.5 km² favoring forest expansion. Expansion of built-up areas was primarily due to conversion from cropland. Of the 4,503.6 km² newly classified as built-up, 3,559.3 km² (79.0%) originated from cropland, 621.6 km² (13.8%) from grassland, 164.4 km² (3.7%) from riverbeds, and 113.3 km² (2.5%) from forest, with minor contributions from other classes. Additionally, the matrix estimates that 3,026.4 km² of bare rock or soil transitioned to snow or glacier, while 585.5 km² changed in the opposite direction. This high-elevation contrast remains sensitive to seasonal variations and spectral classification effects.

Table 3: Land-cover transition matrix, 2001-2022 (km²)

2001 / 2022	Water	Snow/ glacier	Forest	Riverbed	Built-up	Cropland	Bare rock/ soil	Grassland	Other wooded land	2001 total
Water body	428.2	1.9	7.9	38.4	17.6	45.8	3.8	115.6	1.5	660.7
Snow or glacier	24.0	6,226.3	12.7	0.1	0.1	0.7	585.5	1,312.8	5.5	8,167.6
Forest	5.2	0.4	54,285.7	5.8	113.3	1,626.3	11.6	1,955.8	1,220.5	59,224.5
Riverbed	59.0	0.2	33.7	496.4	164.4	566.5	1.1	399.1	5.8	1,726.1
Built-up area	0.2	0.0	0.0	1.2	255.2	2.6	0.0	0.9	0.0	260.2
Cropland	19.8	0.0	5,891.8	66.9	3,559.3	28,612.2	0.3	495.3	327.3	38,973.0
Bare soil or rock	33.9	3,026.4	56.8	79.0	14.8	3.4	3,993.3	4,127.5	22.3	11,357.4
Grassland	30.6	1,022.8	1,747.5	452.0	621.6	2,113.5	3,120.4	12,133.5	638.8	21,880.8
Other wooded land	1.5	1.3	1,957.3	0.3	12.4	354.8	26.5	1,154.1	1,757.4	5,265.6
2022 total	602.4	10,279.3	63,993.4	1,140.2	4,758.8	33,325.7	7,742.5	21,694.6	3,979.2	147,516.0

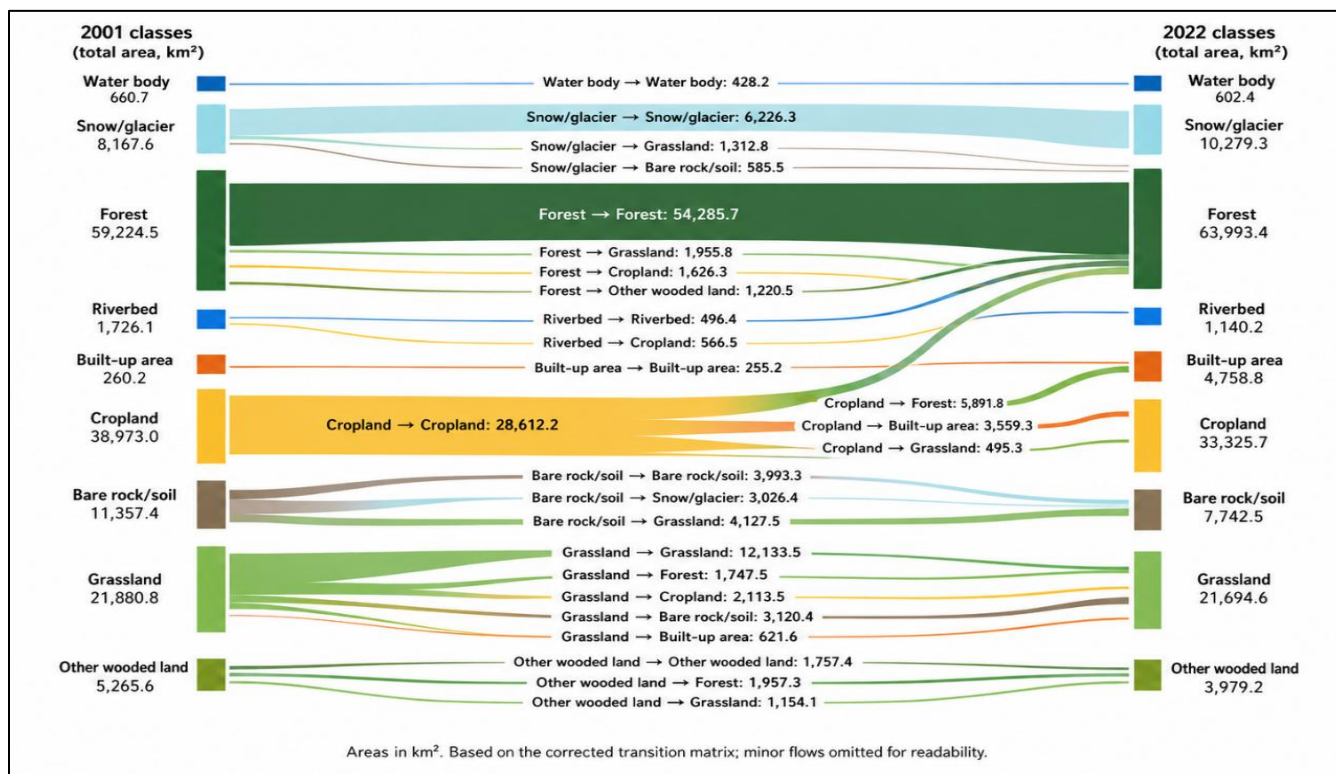


Figure 5: Dominant land cover transitions directions, Nepal (2001-2022). Flow thickness is proportional to transition area (km²). Major transitions only

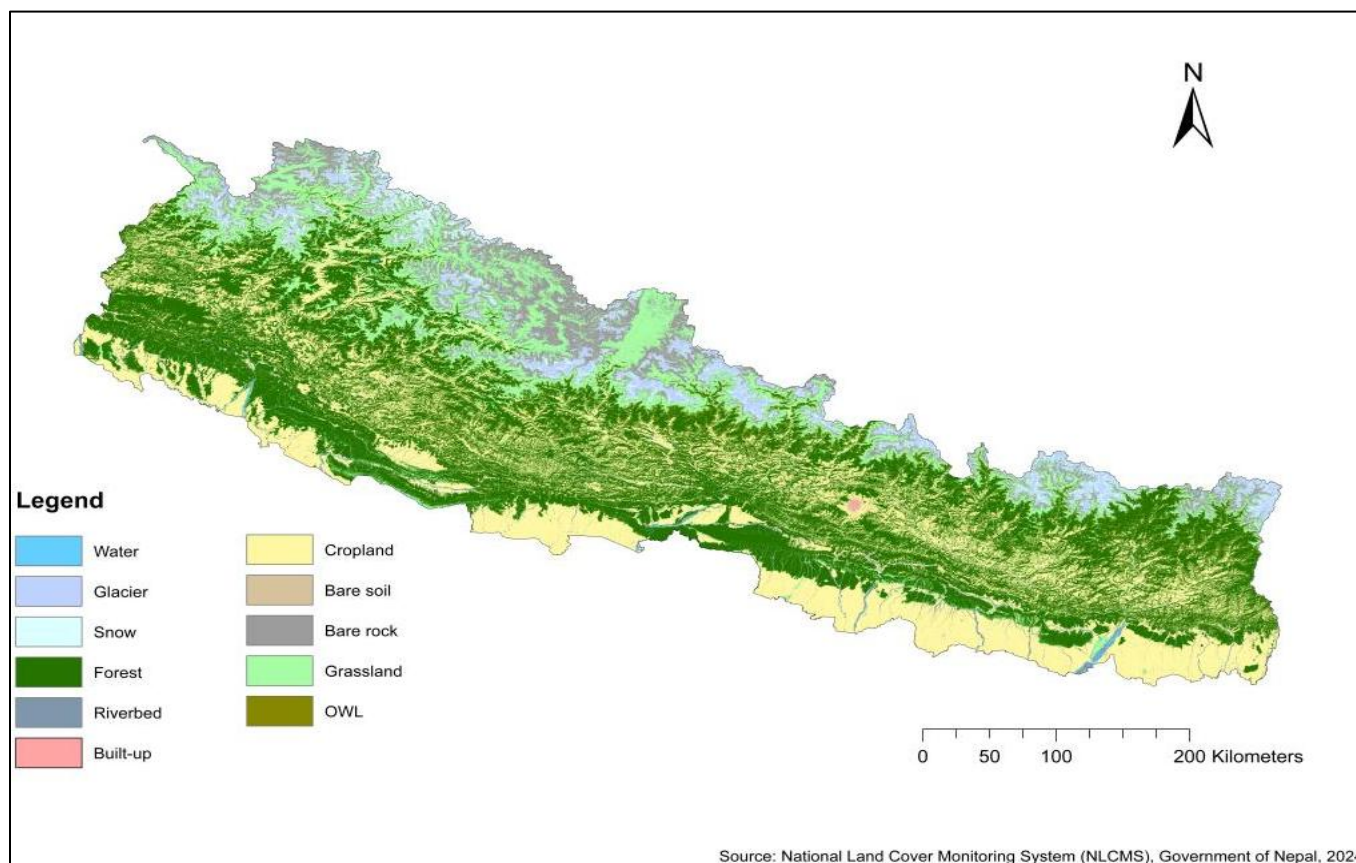


Figure 6: Land-cover map of Nepal for 2001

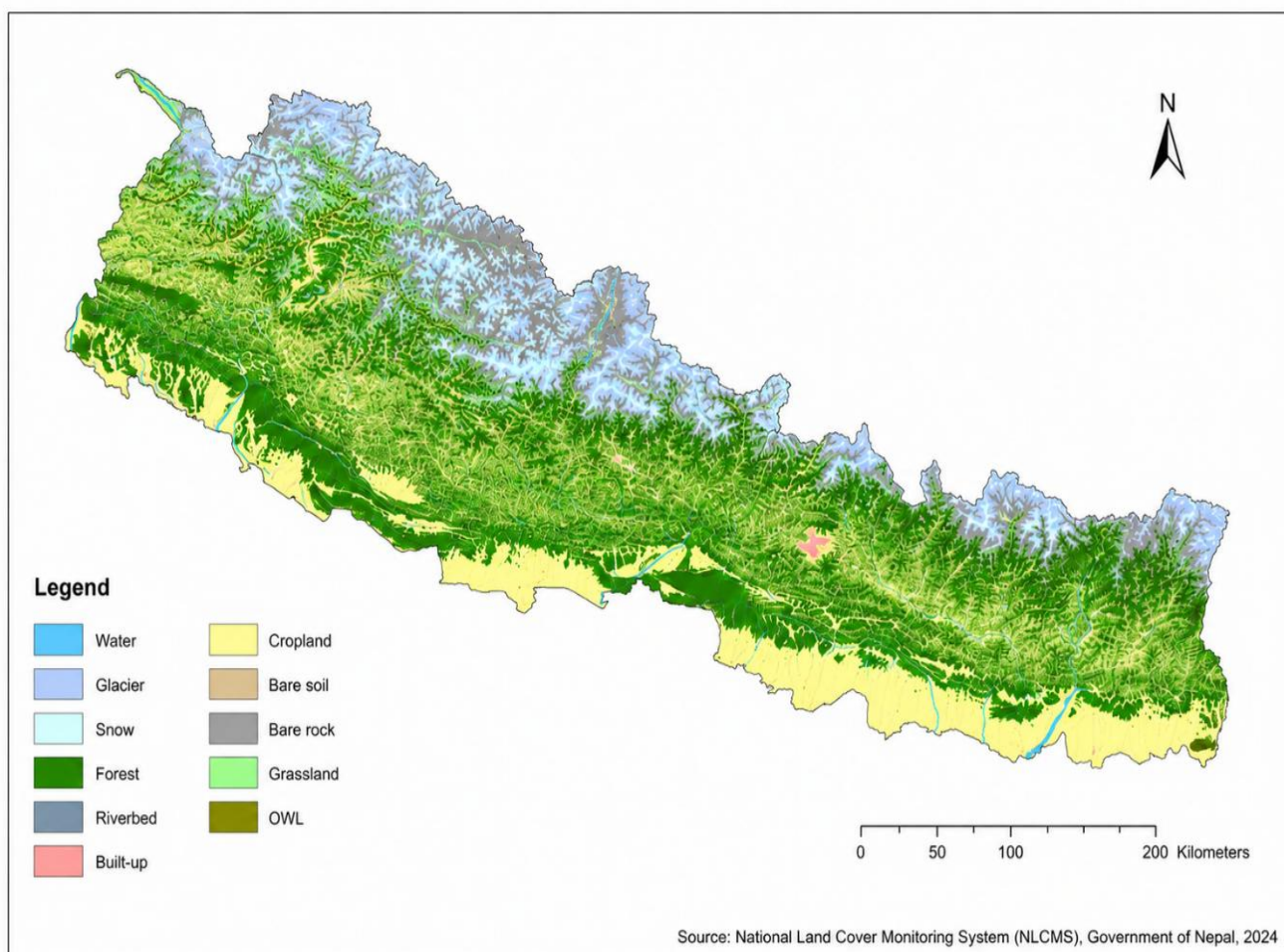


Figure 7: Land-cover map of Nepal for 2022

3.3 Topographic distribution of land cover in 2022

The 2022 elevation profile reveals a distinct transition from cropland-forest environments at lower elevations to grasslands, bare ground, and snow or glaciers at higher altitudes (see Table 3). Below 1,000 meters, forests covered 49.8% of the area, cropland made up 38.1%, and built-up areas accounted for 5.4%. Between 1,000 and 2,000 meters, forest coverage rose to 61.0%, cropland decreased to 28.5%, and built-up land represented 3.4%. The highest forest proportion was found between 2,000 and 3,000 meters, where it comprised 67.1%, cropland was 15.2%, and grassland 9.8%.

Above 3,000 meters, the landscape composition shifted significantly. From 3,000 to 4,000 meters, grassland dominated with 46.1%, followed by forest at 35.8%, other wooded land at 7.5%, cropland at 5.8%, and built-up land at 3.0%. Between 4,000 and 5,000 meters, grassland (41.3%), bare rock or soil (33.0%), and snow or glacier (18.3%) were the main land types. Above 5,000 meters, snow and glacier covered 56.2%, grassland 25.6%, and bare rock or soil 16.8%. Built-up areas were absent above 4,000 meters after applying the mixed-pixel correction.

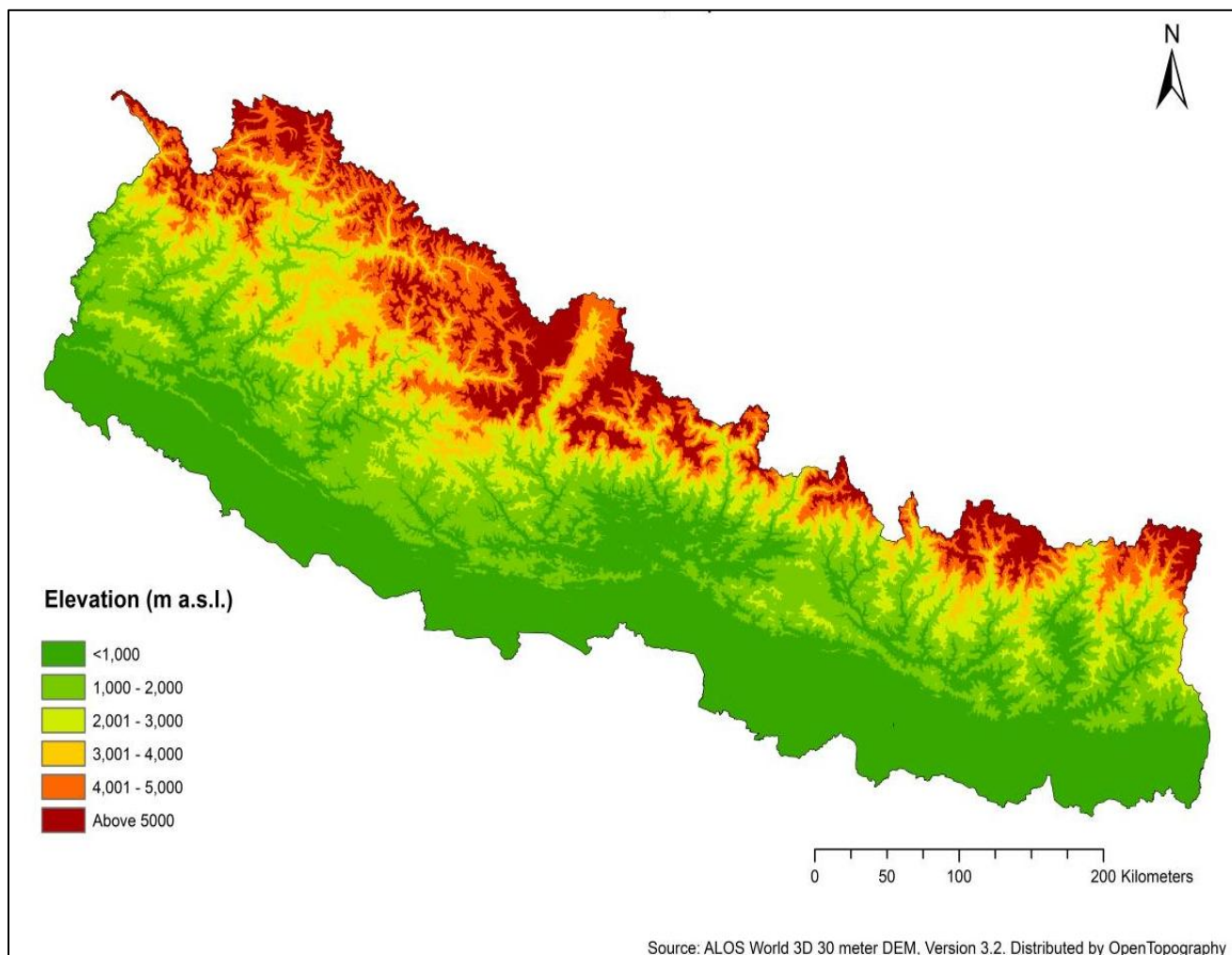


Figure 8: Elevation zones of Nepal

Table 4: Normalized land-cover composition by elevation band in 2022 (% of band area; total area retained in km²)

Elevation zone	Water	Snow/glacier	Forest	Riverbed	Built-up	Cropland	Bare rock/soil	Grassland	Other wooded	Total area (km ²)
<1000	0.4	0.0	49.8	1.0	5.4	38.1	0.0	4.3	1.0	54,189.0
1000-2000	0.0	0.0	61.0	0.0	3.4	28.5	0.0	3.3	3.8	32,083.5
2000-3000	0.0	0.0	67.1	0.0	1.8	15.2	0.0	9.8	6.1	17,832.6
3000-4000	0.0	0.0	35.8	0.9	3.0	5.8	0.9	46.1	7.5	14,018.4
4000-5000	1.6	18.3	2.6	2.6	0.0	0.2	33.0	41.3	0.4	16,489.6
>5000	1.0	56.2	0.2	0.1	0.0	0.0	16.8	25.6	0.1	12,902.9

Note: Percentages are normalized within each elevation band and sum to 100.0% by row.

Elevation significantly influenced both the direction and extent of changes in land composition (Figure 9). Below 1,000 meters, cropland decreased by 7.1 percentage points (pp), while built-up areas grew by 5.2 pp and forested areas by 4.8 pp; riverbeds declined by 2.1 pp. Between 1,000 and 2,000 meters, the most notable change was a reduction in cropland (-8.8 pp) accompanied by increases in forest (+8.2 pp) and built-up land (+3.2 pp), along with smaller decreases in grassland (-1.7 pp) and other wooded land (-0.9 pp). From 2,000 to 3,000 meters, changes were less pronounced: built-up land rose by 1.7 pp and cropland by 1.6 pp, whereas other wooded land and grassland fell by 2.1 and 1.4 pp, respectively. The 3,000 to 4,000 meters range exhibited a different trend, with cropland (+5.4 pp) and built-up land (+2.7 pp) increasing, while forest (-4.9 pp) and other wooded land (-3.6 pp) decreased. At elevations between 4,000 and 5,000 meters, snow and glacier coverage expanded by 6.1 pp, whereas grassland and bare rock/soil declined by 5.8 and 3.6 pp, respectively. Above 5,000 meters, the most significant changes included a 23.8-pp reduction in bare rock/soil, balanced by increases in grassland (+14.8 pp) and snow/glacier (+8.5 pp). It is important to interpret these high-altitude changes cautiously due to seasonal variations and sensitivity in spectral classification.

Elevation band (m)	Water	Snow/ glacier	Forest	Riverbed	Built-up	Cropland	Bare rock/soil	Grassland	Other wooded	Total area (km ²)	Change (percentage points)
<1000 m	-0.1	0.0	4.8	-2.1	5.2	-7.1	0.0	-0.5	-0.2	54,189.0	
1000–2000 m	0.0	0.0	8.2	0.0	3.2	-8.8	0.0	-1.7	-0.9	32,083.5	
2000–3000 m	-0.1	0.0	0.3	0.0	1.7	1.6	0.0	-1.4	-2.1	17,832.6	
3000–4000 m	-0.1	-0.1	-4.9	0.8	2.7	5.4	0.3	-0.5	-3.6	14,018.4	
4000–5000 m	0.2	6.1	0.8	2.3	0.0	0.2	-3.6	-5.8	-0.2	16,489.6	
>5000 m	0.2	8.5	0.2	0.1	0.0	0.0	-23.8	14.8	0.0	12,902.9	

Figure 9: Land-cover change by elevation band in Nepal, 2001–2022. Values represent the percentage-point change in the share of each land-cover class within individual elevation bands. Positive values indicate an increased share, whereas negative values

Slope significantly influenced the composition of land cover (see Table 5). On gentle slopes of 5 degrees or less, cropland was the predominant land use in 2022, covering 61.2% of the area, followed by forest at 16.9% and built-up areas at 11.6%. For slopes between 5 and 10 degrees, forest became the dominant land cover at 47.2%, with cropland making up 19.4%, snow and glaciers 10.7%, grassland 9.2%, and built-up land 7.0%. On slopes ranging from 10.1 to 35 degrees, forests generally occupied about half or more of the area (48.0% to 55.5%), while cropland decreased from 20.7% to 13.5%, and built-up areas dropped from 3.9% to 0.6%. After adjusting for cropland on steep slopes, cropland accounted for 10.0% on slopes of 35.1 to 40 degrees and 6.2% on slopes of 40 degrees or more. In the steepest category ($\geq 40^\circ$), forest (36.4%) and grassland (30.8%) were the main land covers, followed by bare rock and soil (10.5%), snow and glaciers (10.2%), cropland (6.2%), and other wooded land (5.6%), with no built-up areas present. The changes in percentage points further highlight these trends across slope gradients (Figure 11).

On slopes of 5 degrees or less, built-up land increased by 11.0 percentage points, while cropland decreased by 9.1 points and riverbeds by 3.6 points. Between 5 and 10 degrees, built-up areas grew by 6.5 points and

forest cover by 4.1 points, whereas cropland and bare rock/soil declined by 6.9 and 4.1 points, respectively. From 10.1 to 30 degrees, forest gains remained strong, increasing by 5.2 to 7.3 points, while cropland losses were significant, decreasing by 2.9 to 6.6 points. Cropland remained relatively stable between 30.1 and 35 degrees and, due to the correction applied for steep slopes, showed no net change at slopes of 35.1 to 40 degrees and those above 40 degrees. In the steepest slope category ($\geq 40^\circ$), grassland increased by 3.2 points, while other wooded land (-1.9 points), forest (-1.1 points), and bare rock/soil (-1.0 points) all declined; built-up areas showed no change due to the specific slope correction applied.

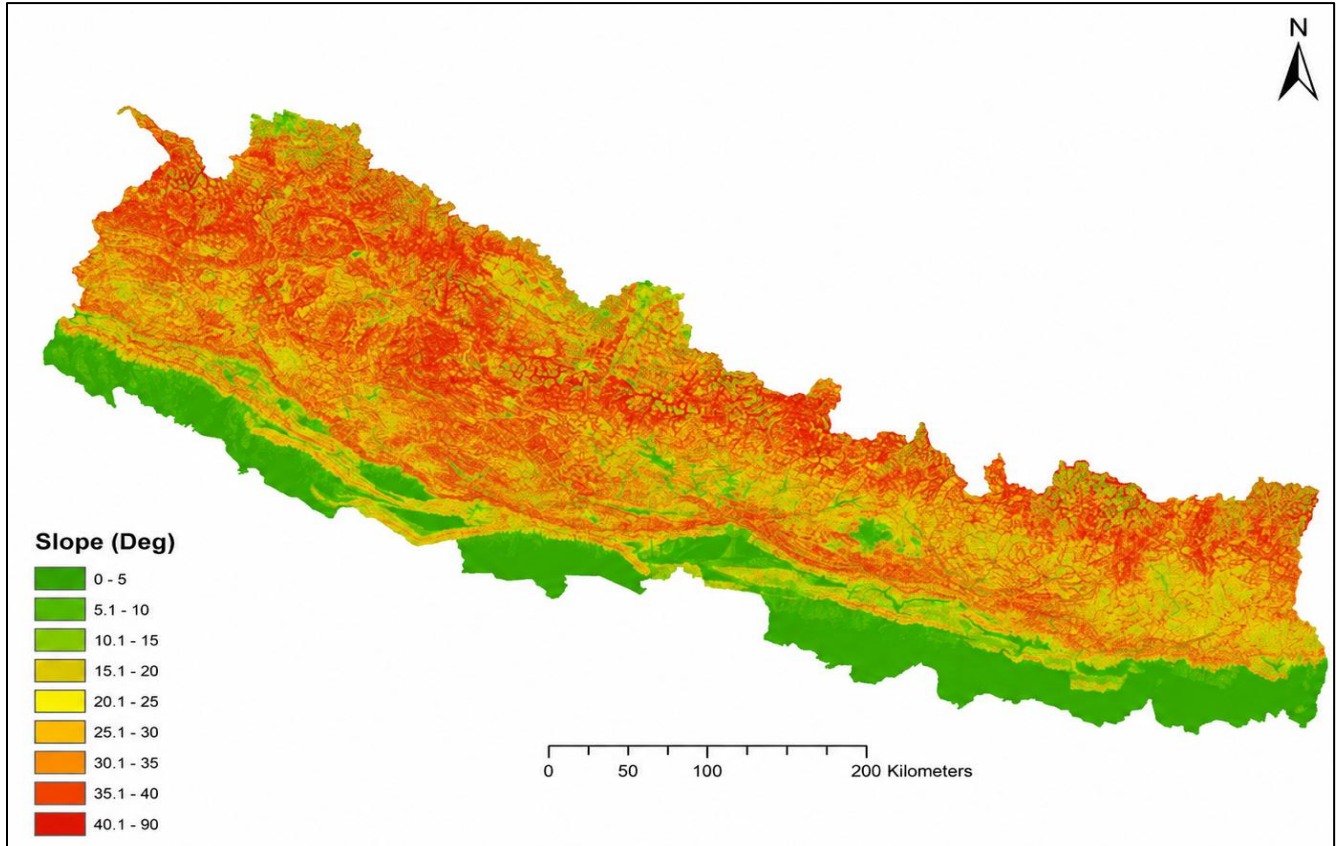


Figure 10: Slope classes

Table 5: Corrected normalized land-cover composition by slope class in 2022 (% of class area; total area retained in km²)

Slope class	Water	Snow/glacier	Forest	Riverbed	Built-up	Cropland	Bare rock/soil	Grassland	Other wooded	Total area (km ²)
≤ 5	1.3	1.2	16.9	2.2	11.6	61.2	0.4	4.8	0.4	25,788.7
5.0-10.0	1.4	10.7	47.2	1.3	7.0	19.4	3.3	9.2	0.5	7,731.3
10.1-15	0.6	10.9	48.0	1.0	3.9	20.7	4.1	10.0	0.8	9,130.4
15.1-20	0.3	8.5	52.1	0.7	2.4	21.3	4.0	9.5	1.2	12,400.4
20.1-25	0.1	7.3	55.0	0.5	1.5	19.4	4.3	10.1	1.8	15,577.6
25.1-30	0.1	6.9	55.5	0.4	0.9	16.2	5.1	12.3	2.6	17,608.4
30.1-35	0.1	6.5	53.1	0.3	0.6	13.5	6.3	15.9	3.7	18,427.5
35.1-40	0.0	6.4	49.5	0.3	0.4	10.0	7.5	20.9	5.0	16,531.8
≥ 40	0.0	10.2	36.4	0.3	0.0	6.2	10.5	30.8	5.6	24,319.8

Note: Percentages are normalized within each slope class and sum to 100.0% by row.



Figure 11: Land-cover change by slope class in Nepal, 2001–2022. Values represent the percentage-point change in the share of each land-cover class within individual slope classes. Positive values indicate an increased share, whereas negative values indicate a decreased share between 2001 and 2022

Note: Built-up pixels on slopes $\geq 40^\circ$ are treated as mixed/misclassified and constrained to 0.0%. Apparent net cropland expansion on slopes $> 35^\circ$ is also treated as mixed-pixel uncertainty: persistent cropland is retained, but the apparent expansion is redistributed to grassland, other wooded land, and bare rock/soil. The final column retains the total area of each slope class in km².

4. Discussion

4.1 Gross turnover behind net forest gain and cropland decline

The transition matrix confirms that the national increase in forest area and decrease in cropland are part of broader two-way land changes. Forest gross turnover amounts to 14,646.6 km² (comprising 9,707.7 km² gained and 4,938.9 km² lost), while cropland gross turnover totals 15,074.3 km² (with 4,713.5 km² gained and 10,360.8 km² lost). Nationwide, 73.3% of land remained in the same category, whereas 26.7% shifted to a different class. Thus, looking only at net area changes conceals significant spatially offsetting processes such as clearing, regrowth, abandonment, recultivation, and other land system transitions.

The most significant directional exchange continues to be the reciprocal conversion between cropland and forest: 5,891.8 km² changed from cropland to forest, and 1,626.3 km² from forest to cropland. The net exchange of 4,265.5 km² favoring forest closely matches the national net forest increase. This trend aligns with studies indicating that agricultural underuse in Nepal's hills results from interacting factors like labor availability, migration, economic conditions, and environmental pressures, with abandonment often followed by forest regeneration under both private and community management (Jaquet et al., 2015; Ojha et al., 2017, 2022; Bhawana & Race, 2019; Maharjan et al., 2020; Tripathi et al., 2020; Smith et al., 2024). Earlier GIS analyses from the Middle Hills also demonstrated that community forestry institutions can influence forest cover trends (Gautam et al., 2002), while the reverse conversion points to localized agricultural expansion or reactivation.

The ecological importance of forest gain depends on forest quality. The NLCMS forest category may include secondary regrowth and areas exceeding a canopy cover threshold but does not directly evaluate species composition, stand age, connectivity, biomass, or biodiversity. Recent mixed-method research in Nepal reveals that forest expansion on former farmland can involve both actively managed private forests and natural regeneration, highlighting the need to differentiate forest extent from ecological condition (Smith et al., 2024). Although agricultural decline can reduce pressure on marginal slopes and encourage vegetation recovery, it may also decrease local food production, alter cultural landscapes, cause fuel accumulation, and increase wildlife-related risk for remaining farms (Ojha et al., 2022). Therefore, forest gain and cropland decline should be understood as interconnected land system changes rather than simply positive or negative outcomes.

4.2 Urban expansion and competition for low-relief land

The most significant proportional national change was the growth of built-up areas, mainly occurring in low-lying and gently sloping regions that also support much of Nepal's farmland. The adjusted transition matrix estimates that 4,503.6 km² of new built-up land appeared between 2001 and 2022. The largest contributor to this increase was cropland, accounting for 3,559.3 km² (79.0%), followed by grassland with 621.6 km² (13.8%), riverbeds with 164.4 km² (3.7%), and forests with 113.3 km² (2.5%). This pattern, dominated by cropland conversion, aligns with remote sensing data from Nepal's Tarai region, where urban growth has predominantly replaced agricultural land (Rimal et al., 2020), as well as with broader findings of rapid urbanization and peri-urban changes in Nepal (Bhattarai et al., 2023).

The correction for mixed pixels significantly reduces false indications of built-up areas at higher elevations. By 2022, 74.3% of built-up land was located on slopes of 10 degrees or less, and 84.3% was situated below 2,000 meters in elevation; no built-up areas were found above 4,000 meters or on slopes of 40 degrees or more, according to terrain-specific corrected data. This pattern reflects the preference for flatter, more accessible land for construction, transportation, services, and markets, while also highlighting direct competition with productive agricultural land in the Terai, valley floors, and peri-urban areas. Similar studies in the Tarai have identified scattered urban expansion over farmland as a significant challenge for land-use planning and food security (Rimal et al., 2020).

4.3 Topographic differentiation of land-cover change

The terrain analysis based on percentages reveals changes in the makeup of specific elevation and slope categories, rather than just showing differences in their physical size. In the two lowest elevation ranges, the proportion of cropland dropped significantly (-7.1 and -8.8 percentage points), while forest areas grew by 4.8 and 8.2 percentage points, and built-up land increased by 5.2 and 3.2 percentage points. A similar trend is seen on gentle slopes: for slopes of 5 degrees or less, built-up areas rose by 11.0 percentage points as cropland decreased by 9.1 percentage points; on slopes between 5 and 10 degrees, built-up and forest areas increased by 6.5 and 4.1 percentage points respectively, while cropland fell by 6.9 percentage points. These shifts align with factors such as agricultural viability, accessibility, road development, settlement pressures, land markets, community forestry, and natural vegetation growth. Research throughout Nepal also highlights strong connections between migration, labor availability, terrain, and land management (Jaquet et al., 2015; Maharjan et al., 2020).

The initial slope classification suggested an apparent increase in cropland of about 121.6 km² on slopes of 35.1-40 degrees and 819.3 km² on slopes of 40 degrees or more, despite a significant decline in cultivated

land on gentler, more accessible slopes. Since widespread new farming on such steep slopes is physically and agronomically unlikely at a 30-meter resolution, this apparent 940.9 km² expansion was considered to be due to mixed-pixel confusion involving grass-like vegetation, other woody plants, and exposed soil or rock, rather than actual cropland growth. After adjusting for this, cropland shows no net increase above 35 degrees, although existing cropland remains. This approach aligns with broader evidence that terrain limitations, combined with labor, profitability, and accessibility factors, influence hill agriculture in Nepal, rather than encouraging large-scale farming expansion on the steepest slopes (Jaquet et al., 2015; Ojha et al., 2017; Maharjan et al., 2020).

4.4 High-elevation transitions and classification sensitivity

High-elevation compositional changes were dominated by snow/glacier, bare rock or soil, and grassland. At 4,000-5,000 m, snow/glacier increased by 6.1 pp while grassland and bare rock/soil declined by 5.8 and 3.6 pp. Above 5,000 m, bare rock/soil declined by 23.8 pp, while grassland and snow/glacier increased by 14.8 and 8.5 pp, respectively. These percentage-point shifts are consistent with the large reciprocal transitions between bare rock/soil and snow/glacier in the national transition matrix, but they should not be interpreted directly as glacier advance or persistent snow gain. Built-up remains 0.0% above 4,000 m under the mixed-pixel correction.

Spectral similarity among seasonal snow, glacier ice, exposed substrate, sparse alpine vegetation, cloud, and terrain shadow increases uncertainty in high-mountain mapping. Landsat-based work in Nepal's Langtang Valley has shown that cloud, deep shadow, aspect, and seasonal timing can bias snow-cover observations (Girona-Mata et al., 2019), while glacier-mapping research in the Manaslu region demonstrates that debris-covered ice can be spectrally similar to surrounding rock and moraine and may require topographic or SAR information for reliable separation (Robson et al., 2015). Because snow and glacier are combined in the overlay ID, process-specific interpretation is especially limited. The high-elevation percentage shifts should therefore be treated as changes in mapped surface composition between the two endpoints, not as direct measures of glacier mass balance, snow persistence, or vegetation response.

4.5 Methodological limitations

The terrain and transition tables are based on a 30-meter pixel overlay covering 148,279.4 km², which is 763.4 km² (0.52%) larger than the officially published national control area of 147,516.0 km². Additionally, the raw class totals differ from the published NLCMS endpoint totals. To reconcile this, constrained iterative proportional fitting (IPF) was applied to align the published 2001 and 2022 class totals while preserving the observed terrain-area structure.

Since the published class areas are rounded to one decimal place, minor adjustments below the rounding threshold were made solely to ensure that the endpoint targets summed to the same national area. This adjustment alters the statistical distribution of area but does not represent independent validation at the pixel level. To prevent apparent inconsistencies caused by combining row-normalized percentages with national column totals, the elevation and slope tables are shown only as within-row percentages, with the terrain-class area included in the final column; changes are expressed as percentage-point differences between the two endpoint shares.

Two structural-zero rules were applied for built-up land in the terrain summaries. First, the raw overlay showed 35.2 km² of built-up land above 4,000 meters in 2001 and 66.2 km² in 2022; these areas were considered mixed or misclassified, so built-up land was set to zero above 4,000 meters. Second, the raw

overlay contained only 2.8 km² of built-up land on slopes of 40 degrees or steeper in 2001 and 7.2 km² in 2022. Although these amounts were small in the raw data, the 2022 steep-slope value was amplified during normalization.

Therefore, built-up land was also set to zero in the $\geq 40^\circ$ slope category for the slope-specific tables, and the slope-by-class distribution was rebalanced while maintaining national class totals and slope-class area totals. These rules do not imply that isolated buildings or infrastructure cannot exist above 4,000 meters or on slopes of 40 degrees or more. A separate correction addressed apparent cropland expansion on slopes steeper than 35 degrees. Initially, the corrected slope allocation suggested increases of 121.6 km² at 35.1–40° and 819.3 km² at $\geq 40^\circ$, totaling 940.9 km². Because this pattern contrasted with significant cropland declines on gentler slopes and was susceptible to 30-meter spectral mixing among cultivated vegetation, grassland, sparse woody cover, and exposed soil or rock, only the net expansion was treated as mixed-pixel uncertainty; the existing cropland area was preserved.

Within the two steep-slope classes, the removed cropland area was redistributed proportionally among grassland, other wooded land, and bare rock/soil based on their local 2022 areas. Equivalent class-area adjustments were made across slopes $\leq 35^\circ$ to keep published national class totals and slope-class area totals unchanged. This approach is a conservative analytical constraint and does not constitute independent ground validation. Additionally, the overlay combines snow with glacier, and results may be influenced by classification errors, DEM-land-cover alignment issues, resampling, boundary discrepancies, image acquisition timing, seasonal snow, terrain shadows, and spectral mixing.

4.6 Policy implications

Protecting farmland is a key issue in planning. Cropland accounted for the largest share of newly developed land (79.0%), with new construction mainly occurring on flat, low-lying areas after adjusting for mixed pixels. These results support strategies for compact urban growth, safeguarding prime farmland, controlling linear development along highways, and explicitly considering agricultural land loss in municipal and provincial land-use plans. Similar concerns about urban expansion onto farmland have been noted in the Tarai region (Rimal et al., 2020). In hilly areas, however, policies should differentiate between cropland at risk of urban conversion and land that is no longer farmed due to labor shortages, low profitability, or poor accessibility. Research based on fieldwork suggests that effectively reusing abandoned farmland may require labor-saving, market-driven approaches rather than simply encouraging recultivation (Subedi et al., 2022).

Forest policies need to address both the area covered and the condition of forests. Although the national forest area has increased, corrected data still show a gross loss of 4,938.9 km² alongside a gross gain of 9,707.7 km². Policy evaluations should distinguish between mature forests, secondary growth, plantations, shrub-to-forest densification, and fragmented forests. They should also link community forestry, restoration efforts, fire management, invasive species control, and livelihood planning to local factors driving agricultural abandonment and forest turnover. Studies from Nepal indicate that community forestry, private

tree planting, and agricultural abandonment can together contribute to forest cover gains, but the resulting landscapes require ongoing management (Gautam et al., 2002; Tripathi et al., 2020; Smith et al., 2024). Planning that takes hazards into account is also crucial. Expansion of built-up areas is focused on low-relief land and includes some development on riverbeds and forested areas. Building near active river channels, drainage routes, and unstable slopes can increase risks of flooding, erosion, and drainage issues. In high mountain regions, significant changes among snow/glacier, bare ground, and grassland should be interpreted carefully, considering classification uncertainties and supported by consistent yearly monitoring.

5. Conclusions

The NLCMS data reveal significant changes in land cover across Nepal from 2001 to 2022. During this period, forest areas grew by 4,768.9 km², cropland decreased by 5,647.3 km², and built-up areas expanded by 4,498.6 km². Overall, 73.3% of the country's land remained in the same category, while 26.7% experienced changes. The most prominent shift was from cropland to forest, covering 5,891.8 km², compared to 1,626.3 km² changing from forest back to cropland. Additionally, cropland accounted for 79.0% of the newly developed built-up land. These trends suggest that the reduction of cropland, growth of forests, and rapid urbanization are closely linked aspects of Nepal's recent land-use changes.

Topography played a major role in shaping where these changes occurred. In 2022, 84.3% of built-up land was located below 2,000 meters in elevation, and 74.3% was on slopes of 10 degrees or less, highlighting the concentration of urban growth in easily accessible, flat areas. Within specific terrain categories, the most notable lowland changes included a 7.1 percentage point drop in cropland below 1,000 meters and an 8.8 percentage point decrease between 1,000 and 2,000 meters, both accompanied by increases in forest and built-up land. On slopes of 5 degrees or less, built-up areas grew by 11.0 percentage points while cropland shrank by 9.1 percentage points. In contrast, higher and steeper regions showed more varied changes involving snow and glaciers, bare land, grasslands, forests, and other wooded areas; however, these results should be interpreted with caution due to greater classification uncertainties in such terrains.

The main implications for land management include ongoing losses of productive farmland, rapid urban expansion in accessible low-relief areas, and uncertainty about the ecological quality and connectivity of the newly gained forest areas. These findings highlight the need for stronger protection of prime agricultural land, more compact and strategically planned urban development, locally tailored forest and restoration management, and greater consideration of elevation and slope in land-use planning. Therefore, national-level monitoring should be supplemented with local validation and more detailed assessments to better balance urban growth, food security, ecosystem conservation, and hazard-aware planning in Nepal.

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Glossary

Digital Elevation Model (DEM): A raster dataset representing the elevation of the Earth's surface, used here to derive elevation bands and slope classes.

Kappa coefficient: A statistical measure of classification accuracy that accounts for the agreement expected to occur by chance.

Land-cover class: A discrete category, such as forest, cropland, or built-up area, used to classify the type of surface cover in a given location.

Mixed pixel: A pixel that contains more than one land-cover type, often leading to classification error in areas of complex terrain or fine-scale land-use patterns.

National Land Cover Monitoring System (NLCMS): Nepal's official annual land-cover mapping system, developed by the Forest Research and Training Centre using Landsat satellite imagery.

Random Forest classification: A machine-learning method that combines many decision trees to classify satellite imagery into land-cover categories.

Stratification: Dividing a study area into sub-groups, such as elevation or slope bands, so that patterns can be analyzed separately within each group.

Transition matrix: A table showing the area or percentage of land that changed from one land-cover class to another between two time points, with unchanged land shown along the diagonal.

CHAPTER: V

Forest and Biodiversity

Ramesh Prasad Sapkota¹, Udhab Raj Khadka¹

¹Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal

Email: rsapkota@cdes.edu.np, ukhadka@cdes.edu.np

Summary

Nepal is rich in floral and faunal diversity, with a high level of endemism. The forests in Nepal range from tropical lowland to alpine woodlands and scrub in the Himalayas. These forests play a crucial role in maintaining biodiversity, supporting ecosystems and species, and contributing significantly to local livelihoods by providing fuelwood, fodder, timber, and non-timber forest products (NTFPs). The abundance and distribution of faunal diversity are across the tropical and sub-tropical forests to the sub-alpine and alpine pastures, and snow-covered peaks of the Himalaya. These areas harbor numerous endangered species, and contribute significantly to ecological stability and ecosystem services. Although the country has diversity in floral and faunal assemblages with substantial ecological and economic significances, they are threatened by multitude of disturbances such as over exploitation, increased anthropogenic pressure and habitat destruction, including the novel disturbances such as climate change. Despite such challenges, Government of Nepal is committed in conserving the natural biological integrity, via. policy and legal frameworks and have practiced both in-situ and ex-situ approaches. In this chapter, efforts have been made on updating the current status of forest and biodiversity in Nepal, the threats associated with them, and conservation practices and major achievements made to date. For this purpose, information and data related to the thematic area from published documents by research scholars and concerned organizations have been reviewed. The information of this book chapter may be useful for researchers, planners and policy makers working in the forest and biodiversity conservation sector.

Keywords: Biodiversity; Captive Breeding; Forests; Protected Areas; Wildlife

1. Introduction

Nepal has an area of 147,516 km² and spans the length of about 800 km with an average north-south width of about 200 km, lying between latitudes 26°22' and 30°27' N, and longitudes 80°04' and 88°12' E (FRTC, 2024; MoFE, 2025). Within this short spatial range, elevation varies from about 60 m in the eastern Terai to 8848.86 m at Mount Everest (<https://dmgnepal.gov.np>; FRTC, 2022). The country encompasses major physiographic zones, viz Terai, Siwaliks, Mid-hills, Mountains, and High Himalayas (LRMP, 1986; Table 1). The Terai consists of fertile lands and dense forests; the hill region consists of uplands, valleys, rivers, lakes, waterfalls, streams, springs, and snow-capped mountains. The average annual precipitation of the country is about 1500 mm, with a mean annual minimum and maximum precipitation of about 250 mm in the rain-shadow areas located at north of the Himalaya near the Tibetan plateau and more than 2700 mm along the southern slopes of the Annapurna Himalaya range, respectively (DHM, 2017). The temperature fluctuates with topographic and orographic variation showing a distinct variation of average annual minimum temperature across the north-south gradient. The southern lowland regions record minimum temperature of about 18°C, while the northern high-altitude areas experiencing freezing temperature (DHM, 2017). About 80% of precipitation occurs between June and September. The country has Koshi, Gandaki, Karnali and Mahakali as four major Himalayan River systems. In addition, medium-sized perennial rivers

arise from the High Mountain, and a number of seasonal streams originate from the Siwalik Hills (MoFSC, 2014a). With its unique topographic characteristics, the country also shows variation in climate conditions. The climate ranges from tropical humid Terai to alpine cold semi-desert condition in the trans-Himalayan region.

Local communities, especially in the rural areas, depend on natural resources for their livelihood (Khadka, 2016). Plants are used as food, fuelwood, medicine and non-timber forest products. In the meantime, the anthropogenic disturbances are causing degradation of natural ecosystems. This review discusses the existing status of forest and biodiversity, and existing practices in Nepal for their conservation.

Table 1: Physiographic and bio-climatic zones of Nepal

Physiographic zone	Surface area (%)	Elevation (m)	Bioclimatic zones
Terai & Siwalik	29	Below 500	Hot monsoon and tropical
		500-1000	Hot monsoon and sub-tropical
Mid-hills	29	1000-2000	Warm temperate monsoon
		2000-3000	Cold temperate monsoon
Mountains	19	3000-4000	Sub-alpine
		4000-5000	Alpine
High Himalayas	23	Above 5000	Tundra-type and Nival

Source: LRMP (1986)

2. Forests

Out of the total area of Nepal, forest area covers 43.38% (6,399,341 ha) in 2022, against, 41.71% (6,152,806 ha) in 2019 (FRTC, 2024). Cropland and grassland cover about 22.6% and 14.7% of the total land area, respectively. Likewise, Bare rock, snow, built up areas, glaciers, OWL, riverbeds, water bodies, and bare soil cover approximately 19% of the land cover (Figure 1). Forests and OWL together account for 46.08% of the total land area of Nepal. This is an increase of 0.75% of forests and OWL from 2019.

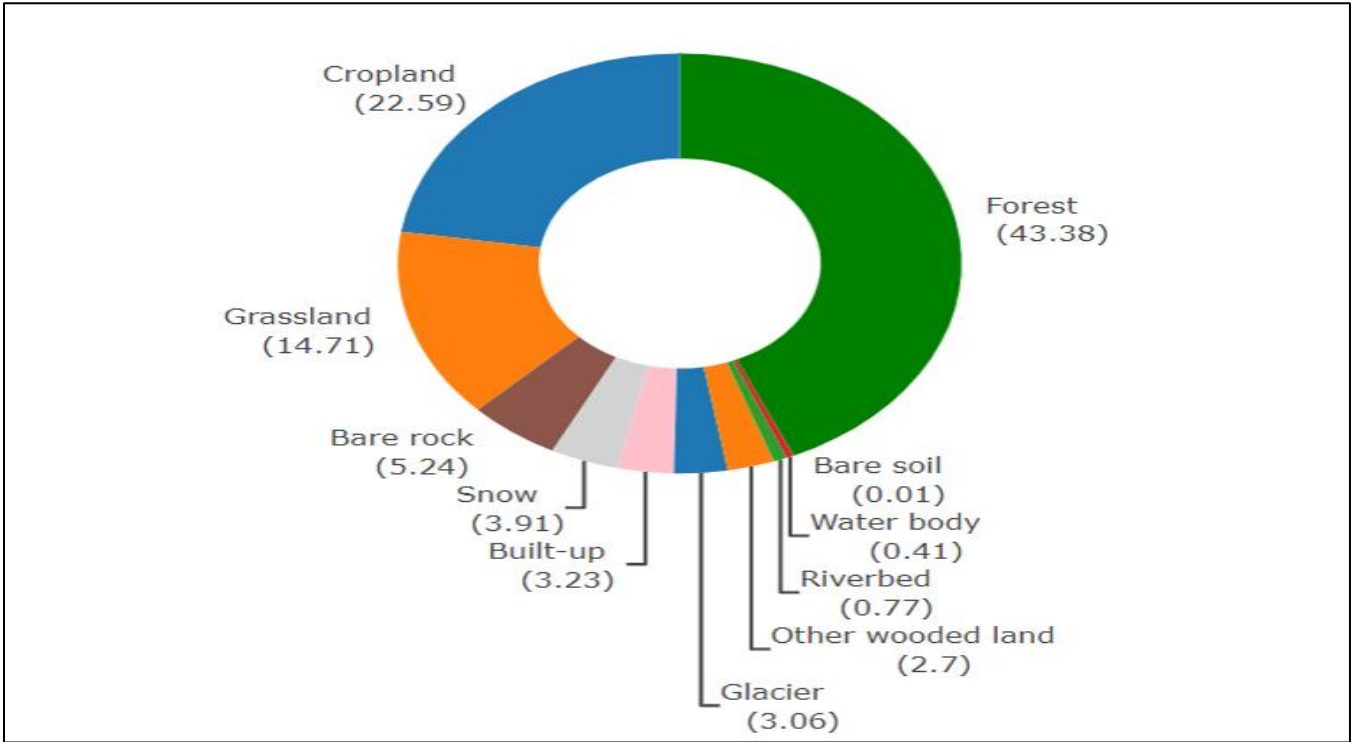


Figure 1: Land cover area of Nepal in 2022 AD (Data Source: FRTC, 2024)

2.1 Forest types

Nepal has 35 forest types (Stainton, 1972). These forests are categorized into 10 major groups. These groups include tropical, subtropical broad-leaved, subtropical conifer, lower temperate broad-leaved, lower temperate mixed broad-leaved, upper temperate broad-leaved, upper temperate mixed broad-leaved, temperate coniferous, sub-alpine and alpine scrub forests (Table 2).

Table 2: Major forest types, their elevation ranges and description (MoFSC, 2002)

SN	Forest type	Elevation (m)	Description
1.	Tropical forest	below 1,000	Southern part: Dominance of <i>Shorea robusta</i> forests. Forests along streams and rivers: Abundance of <i>Senegalia catechu</i> , <i>Dalbergia sissoo</i> , <i>Michelia champaca</i> , <i>Bombax ceiba</i> . Western Foothills: <i>Terminalia/Anogeissus</i> forests.
2.	Subtropical broad-leaved forest	1,000-2,000	Central and eastern Nepal: <i>Schima wallichii/Castanopsis indica</i> forests. Periphery of Arun River on subtropical foothills: <i>Cedrela/Albizia</i> forests. Moist places: <i>Alnus nepalensis</i> forests.
3.	Subtropical pine forest	1,000-2,200	South-facing slopes of the Mid-hills and Siwalik Hills in western and central Nepal: <i>Pinus roxburghii</i> forests.
4.	Lower temperate broad-leaved forest	2,000-2,700 (western part) and 1,700-2,400 (eastern part)	Mid-hills: <i>Alnus nitida</i> , <i>Castanopsis tribuloides/C. hystrix</i> , <i>Lithocarpus pachyphylla</i> , and <i>Quercus</i> forests. Riverbanks of Mugu Karnali, at 2,130-2,440 m: <i>Alnus nitida</i> forests. Western Nepal: <i>Quercus leucotrichophora/Q. lanuginosa</i> forests and <i>Q. floribunda</i> . Central and eastern Nepal: <i>Q. lamellosa</i> forests. Eastern Nepal: Dominance of <i>Lithocarpus pachyphylla</i> .
5.	Lower temperate mixed broad-leaved forest	1,700-2,200	Confined to north and west-facing slopes: Tree species of Lauraceae family.
6.	Upper temperate broad-leaved forest	2,200-3,000	Central and eastern Nepal (south facing slopes): <i>Quercus semecarpifolia</i> forests (but absent in heavy rainfall areas such as the upper Arun and Tamor valleys and the hills lying north of Pokhara).
7.	Upper temperate mixed broad-leaved forest	2,500-3,500	Central and eastern Nepal (mainly on north and west-facing slopes): <i>Acer</i> and <i>Rhododendron</i> species are prominent. Western Nepal: <i>Aesculus/Juglans/Acer</i> forests.
8.	Temperate coniferous forest	2,000-3,000	<i>Pinus wallichiana</i> , <i>Cedrus deodara</i> , <i>Cupressus torulosa</i> , <i>Tsuga dumosa</i> and <i>Abies pindrow</i> forests characterize the forest type. <i>Pinus wallichiana</i> , extending to 3,700 m. Western Himalayas: <i>Cedrus deodara</i> , <i>Picea smithiana</i> , <i>Juniperus indica</i> and <i>Abies pindrow</i> forests. Upper Bheri River Valley: <i>Cedrus deodara</i> . Langtang and Budi Gandaki valleys: <i>Larix himalaica</i> forests occur only in the Eastern Himalaya: <i>Larix griffithiana</i> extends to 3,940 m.
9.	Sub-alpine forest	3,000-4,100	<i>Abies spectabilis</i> , <i>Betula utilis</i> , and <i>Rhododendron</i> forests
10.	Alpine scrub	above 4,100	Inner valleys: <i>Juniperus recurva</i> , <i>J. indica</i> , <i>J. communis</i> , <i>Rhododendron anthopogon</i> , and <i>R. lepidotum</i> associated with <i>Ephedra gerardiana</i> , and <i>Hippophae tibetana</i> . North of Dhaulagiri and Annapurna: <i>Caragana versicolor</i> , <i>Lonicera spinosa</i> , <i>Rosa sericea</i> , and <i>Sophora mocroftiana</i> . Alpine meadows; Above 5,200 m: Mosses and lichens (scattered locations).

SN	Forest type	Elevation (m)	Description
			About 6100 m: Species like <i>Stellaria decumbens</i> and <i>Parrya lanuginosa</i> are recorded, but beyond 6,000 m in the Arctic desert/nival zone, even mosses do not survive.

2.2 Forest management categories

In Nepal, forests have been categorized based on the management regime or systems under which forests are managed, protected and utilized. Major categories include national and private forests. Accordingly, the national forests are categorized into government-managed forests, community forests, leasehold forests, religious forests, collaborative forests, and forest conservation areas (Table 3). Community based forest management, especially community forestry program, is one of the most successful and widespread systems, where local forest user groups are given the responsibility to manage and use forest resources as guided by the forest operational plans (Figure 2).

Government-managed forests are under the direct control of the government of Nepal, while leasehold forests are allocated to poor households or groups to improve their livelihoods and restore degraded land. Forest conservation areas are managed to conserve biodiversity, ecological values, and important natural resources, whereas religious forests are entrusted to religious institutions for protection and management. Likewise, collaborative forest management strategy is practiced mainly in the Terai region, where local communities, local governments, and forest authorities jointly manage forest resources and share benefits. Some districts have plantation forests with both native and exotic species. Most commonly planted species in the Terai forests are *Dalbergia sissoo*, *Eucalyptus* spp., and *Tectona grandis*. Likewise, *Pinus roxburghii*, *P. wallichiana*, *P. patula*, and *Alnus nepalensis* are massively planted in the Mid-hills.

Table 3: Forest types based on management regime and their responsible management authority

SN	Management regime	Management authority
A. Government managed forests		
1.	Government-managed Forests	Government (Division Forest Office/Provincial Forest authorities)
B. Community managed forests		
Outside protected areas		
1.	Community Forests	Community Forest User Group (CFUG)
2.	Leasehold Forests	(a) Organizations for specific objectives as specified in the Article 26 of the Forest Act, 2076 (b) Leasehold Forest User Group
3.	Collaborative Forests	Jointly managed by Province and Local Government and local users/community as per Article 23 of Forest Act, 2076
4.	Forest Conservation Areas	Government with special conservation measures
5.	Religious Forests	Religious body, institution, or community entrusted by Government
Inside protected areas (including buffer zone)		
1.	Buffer Zone Community Forests	BZCF User Groups, User Committee of the Buffer Zone
2.	Buffer Zone Leasehold Forests	
3.	Buffer Zone Religious Forests	
4.	Buffer Zone Forests	
C. Private forests		

1. Private Forests	Individual, family, institution, or private organization on private land
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(Source: GoN, 2019; MoFE, 2020)

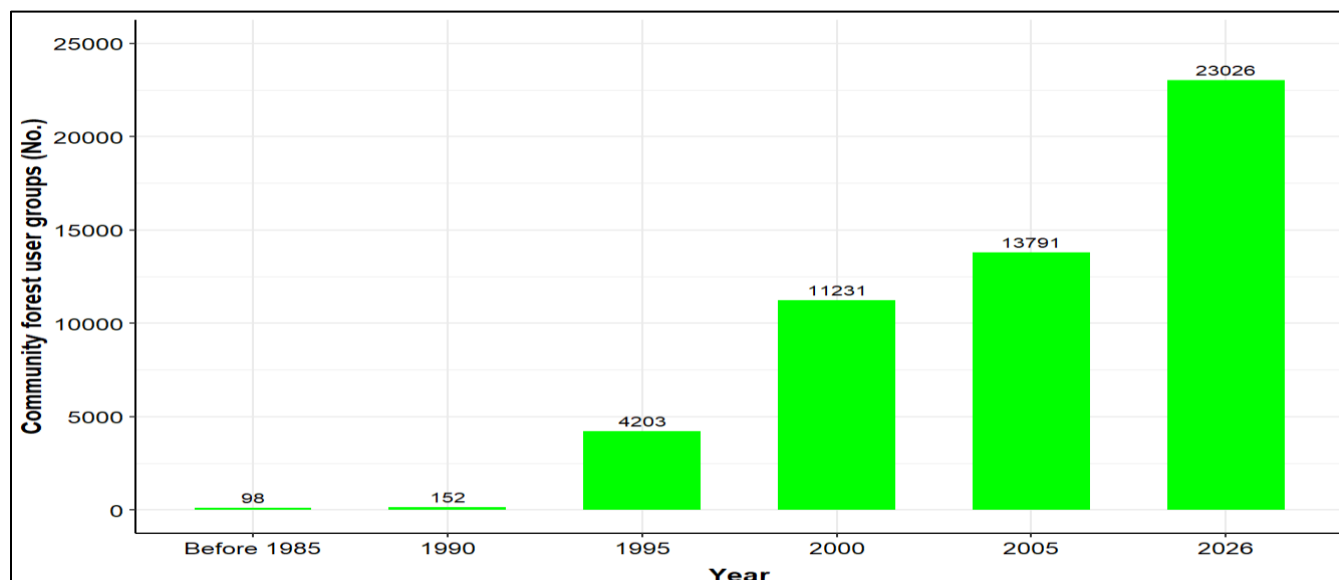


Figure 2: Number of community forest user groups with years in Nepal (Data sources: Magrath et al., 2013; <https://fecofun.org.np>)

3. Biodiversity

Nepal accounts only about 0.1% of the total land area of earth. It, however, harbors 1.9% of the world's known floral and 1.3% of faunal species (MoFSC, 2014b; Table 2; Table 3). The elevation and climatic variations in the country is contributing to high level of ecosystem, genetic and species diversity (MoFE, 2025).

3.1 Ecosystem diversity

Nepal has 118 ecosystems; of which majority (112) are forest ecosystems including shrub-lands, rangelands and alpine meadows areas. Of the remaining, 4 are cultivated ecosystems, 1 is water ecosystem, and 1 is glacier/snow/rock ecosystem (BPP, 1995). The highest number of ecosystems (53) are in the Middle Mountains, followed by the High Himalaya and Mountain together (38), the Terai (14) and Siwalik (12). The remaining one, water ecosystem, occurs in all zones, except the Siwalik (BPP, 1995). The natural lakes in Nepal ranges from tropical lowland of the Gangetic plain to the alpine Higher Himalaya, and are an important area for assessing the influence of altitude and climate on the wetland health and quality (Khadka, 2016). Nepal has more than 6000 rivers and rivulets, and these river systems along with the standing aquatic ecosystems harbor endemic species of plants and animals, including migratory and globally threatened species. These wetlands also have crucial role in conserving floral diversity. 25% of Nepal's vascular plants, including 26 endemic species of the flowering plants are wetland dependent (MoFSC, 2014b).

3.2 Species diversity

3.2.1 Floral and faunal diversity

The species diversity is relatively high in Nepal with over 5600 species of flowering plants (including gymnosperms), and over 6000 species of non-flowering plants (Table 4). The faunal diversity includes 1556

vertebrates and 10341 invertebrates (Table 5). Lichens, bryophytes, pteridophytes and gymnosperms among plants, and proportion of butterflies, birds and mammals among the animals are relatively high in Nepal compared to the global share.

Table 4.: Floral species diversity in Nepal

S.N.	Group	Global species ¹ (No.)	Species in Nepal ² (No.)
1.	Angiosperms	369000	5619
2.	Gymnosperms	1113	26
3.	Pteridophytes	11800	583
4.	Lichens	-	1086
5.	Bryophytes	21925	1217
6.	Fungi*	157648	2470
7.	Algae**	26900	1101
Total		588386	12480

*All species within kingdom Fungi; **Green (Charophyta, Chlorophyta), Red (Rhodophyta) and Brown (Ochrophytina) Algae; ¹IUCN (2025); ²DPR (2025)

Table 5: Faunal species diversity in Nepal

S.N.	Group	Global species* (No.)	Species in Nepal (No.)**	Share of global species in Nepal (%)
1.	Mammals	6774	213	3.14
2.	Birds	11195	902	8.06
3.	Reptiles	12386	151	0.99
4.	Amphibians	9081	60	0.64
5.	Fishes	37109	255	0.69
6.	Mollusks	87626	238	0.27
7.	Moths	NA	3958	NA
8.	Butterflies	NA	664	NA
9.	Arachnids (Spiders)	39490	175	0.44
10.	Rotifer	NA	61	NA
11.	Crustaceans	NA	59	NA
12.	Other insects	NA	10,204	NA
13.	Platyhelminthes	NA	168	NA

*IUCN (2025); **MoFE (2018) (various sources compilation); reference for birds' data: DNPWC and BCN (2025); reference for fish data: Khatri et al. (2020); reptiles data Rai et al. (2022); additional reference for reptile data Gautam et al. (2026); Bhattarai et al. (2025b); Bhattarai et al. (2025c); Praschag et al. (2022); Subba et al. (2025); additional reference for mammal data Subba et al. (2026); additional reference for amphibian data Gautam & Bhattarai (2022); Hofmann et al. (2024); Bhattarai et al. (2025a)

3.2.2 Agro-biodiversity

Nepal is rich in agricultural diversity due to variability in altitudinal range, climate and geographical distribution. This variation allows farmers to cultivate a different variety of crops, including rice, wheat, maize, millet, barley, pulses, fruits, vegetables, tea, coffee, ginger, and cardamom. The fertile Terai region is known for producing major food grains, while the Mid-hills support terrace farming of maize, millet, fruits, and vegetables. In the Himalayas, farmers grow crops such as barley, buckwheat, and potatoes and raise livestock like yaks and sheep. In Nepal, agro-ecosystems cover 22.6% of the total area and supports about 62% of the households. However, the cultivated area has been gradually declining since 2000 (26.4 to

22.6%) (FRTC, 2024). The majority of agricultural land lies in the Terai region (65.4%). Altogether, 634 species belonging to 165 families of wild edible plants are documented in Nepal. Of these, 422 species of angiosperms, one species of gymnosperms, 34 species of ferns, 169 species of mushrooms, and eight species of lichens are reported (Chaudhary et al., 2025). For conservation and utilization of the agro-biodiversity, Nepal Agriculture Genetic Resources Center (National Gene Bank) has been established with its five banks as seed bank, field gene bank, tissue bank, DNA bank, community seed bank and community field bank. Out of about 30,000 estimated accessions, the center has access to 11,389 genetic resource accessions (MoFE, 2018).

3.2.3 Endemic biodiversity

Nepal is home to several endemic plants, animals, and other organisms. The endemic species are important components of Nepal's biodiversity. However, habitat destruction, climate change, and other environmental pressures have threatened their survival. Considering the endemism in different physiographic regions, the High Mountains region has high (63%) endemism of plants compared to Mid-hills (38%) and Terai/Siwaliks region's endemism (6%). Similarly, 160 animal species, including two mammals (*Apodemus gorkha* and *Myotis csorbai*), one bird (*Acanthoptila nipalensis*), 19 species of herpeto-fauna (Rai et al., 2022), and 15 species of fish (Khatrri et al., 2020) are reportedly endemic to Nepal. In addition, there are 22 species of terrestrial gastropods are endemic to the country (Budha et al., 2015). Likewise, the country has 348 endemic flowering plants (DPR, 2025).

3.3 Genetic biodiversity

Nepal is rich in genetic diversity due to a varying range of climates and ecosystems, and spatial extent between the Tibetan Plateau and the Indian Subcontinent ranging from tropical climate in the southern Terai to alpine climate in the Himalayas. Within this span, Nepal supports variety of plant and animal species with considerable genetic variation. This variability help species adapt to environmental changes, resist diseases, and maintain healthy populations. Furthermore, Nepal is also recognized as a center of diversity for several important crops, including rice, millet, barley, and various indigenous fruits and vegetables, many of which are locally adapted varieties (Khadka, 2016). In Nepal, genetic resources like seeds of crops and livestock breeds have high values and play important role in survival of the local communities, however, collection of the plant genetic resources and the protection of native breeds of livestock are with little considerations.

4. Forest Resources and Socio-economy

Nepalese economy is dependent on agriculture land, forests, grasslands, and wetlands. These ecosystems support variety of biological resources which are linked to the livelihoods and well-being of the people (MoFSC, 2014b). Of the total gross domestic product, 24% contribution to it is from agriculture sector (MoF, 2026), and ensures dependency of local community livelihood in these ecosystems. Similarly, non-timber forest products (NTFPs) have important role in providing subsistence support, medicinal values and supporting rural economies (Kadariya et al., 2024). In Nepal, more than 2000 vascular plant species are considered as NTFPs, among which 1624 species are reported to have medicinal values (MoFSC, 2012). On average 13,230 metric tons of medicinal and aromatic plant products worth about USD 39.34 million are exported from Nepal to more than 50 countries (Ghimire et al., 2016). Similarly, tourism is another important source of income and about 60% of the total visitors to Nepal visit the protected areas (DNPWC,

2025; Figure 3). The increase in revenue from the protected areas during the period from fiscal year BS 2069/2070 to 2080/2081 (Figure 4) signifies the substantial increase in number of nature-based tourism (DNPWC, 2024a). Out of the total revenue generated from the protected areas, about 30-50% is required to be shared with buffer zone management and community development committees. In addition to direct economic benefits, the ecosystem services from the protected areas are incredible for supporting the livelihood of thousands of households.

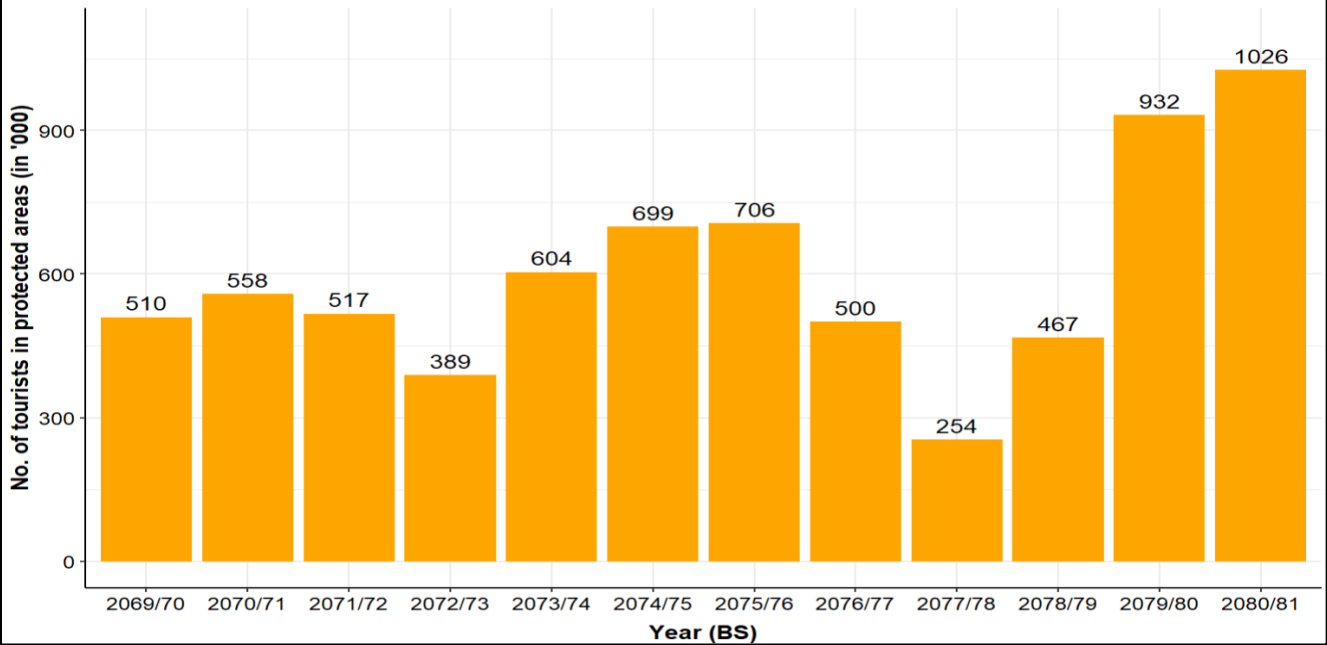


Figure 3: Number of tourists who visited protected areas across different years (Data source: DNPWC, 2024a)

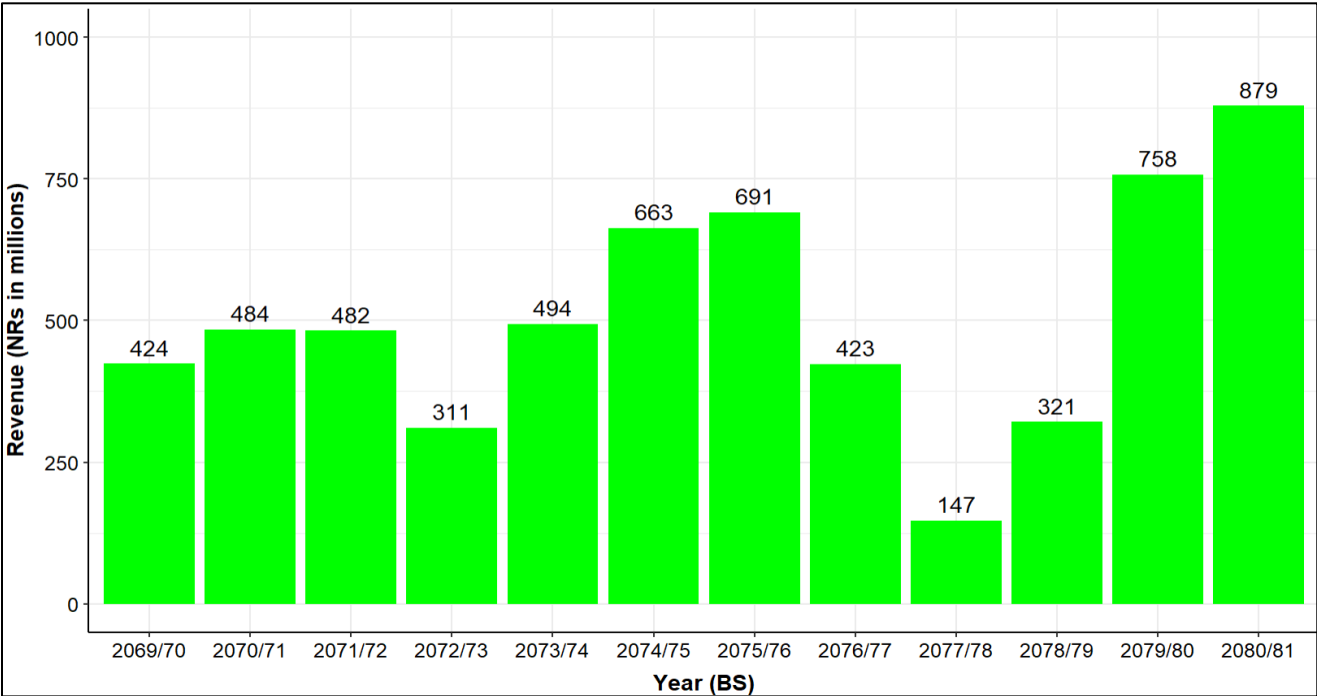


Figure 4: Annual revenue generated from the protected areas (Data source: DNPWC, 2024a)

The biological products derived from the country's rich biodiversity are exported to international markets. The biomaterials include plant parts (roots, tubers, barks, leaves, flowers, fruits and seeds, whole plants, gums and resins, and miscellaneous parts of other plants). For example; Soap nut tree (*Sapindus mukorossi*), Nepal pepper (*Zanthoxylum armatum*), lichens (*Parmelia* sp.), Cotton paper (*Persia bombycina*) and 'Chiraita' (*Swertia chirata*) are the five major species with highest export value (Olsen, 2005). Nepal has additional scope for increasing the economic value of medicinal and aromatic plants. Moreover, there are no significant deposits of fossil fuels, therefore the country relies heavily on biomass energy. For instance, out of 626 PJ energy consumed in a year, 63.87% is derived from the traditional sources, 33.03% from commercial and 3.1% from the renewable energy resources (WECS, 2024). The fuel-wood has remained the main source of energy followed by agricultural residue, animal dung and other biomass such as agro-based waste and forest related industries waste (WECS, 2024).

5. Threat to Biodiversity

Biodiversity in Nepal is threatened by several human-induced and natural causes. The most common threats include habitat loss and fragmentation, urbanization, construction activities, etc. In addition, still there are cases of illegal hunting and wildlife trade affecting flagship species. Similarly, introduction of invasive alien species, overexploitation of forest products and medicinal plants are also causing a serious threat in Nepal. The invasive alien plant species (IAPS) have been reported increasing over the period of time. In 2005, 2016, 2017, 2019 and 2025, the number of IAPS respectively accounts 21, 25, 26, 26 and 29 (FRTC, 2025; Shrestha, 2016; Shrestha et al., 2017; Shrestha et al., 2019; Tiwari et al., 2005). Among the threats, anthropogenic stressors have aggravated global extinction in recent days (IPBES, 2019). Moreover, disturbances such as climate change and environmental pollution (air, water, and soil) adversely affect the ecosystems and native species. Despite the negligible contribution to green-house gas emissions, Nepal is vulnerable to climate change (MoFE, 2025). Rising temperatures, changing rainfall patterns, glacier melting, floods, landslides, droughts, and forest fires are altering habitats adversely impacting many species. These threats have synergistic impacts to forests and biodiversity degradation. Forest and wetland degradation, and increasing human-wildlife conflict further resulting to biodiversity loss. These threats not only endanger biodiversity (Table 6), but also weakens ecosystem services (MA, 2005; MoFSC, 2014b; IPCC, 2023). These impacts further increase vulnerability.

Table 6: Floral and faunal species of Nepal in CITES Appendices

Group	I	I/II	I/II/NC	I/III	II	III	Grand total
Animalia	58	5	1	1	132	42	239
Plantae	2				539	4	545
Grand total	60	5	1	1	671	46	784

Source: <https://checklist.cites.org/>

6. Forests and Biodiversity Conservation

Nepal has practiced both in-situ and ex-situ conservation strategies. Of the two, in-situ conservation, conservation of biodiversity in the natural habitat, is a dominant type. The conservation of biodiversity inside the protected areas in wild is an example of in-situ conservation. The protected area establishment began by enacting the National Parks and Wildlife Conservation Act, 1973. After that, in 1980 the Department of National Parks and Wildlife Conservation (DNPWC) was established for conservation and management of the protected areas and associated biodiversity. The DNPWC is the responsible government

entity for the Ramsar Convention, Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the focal administrative authority for World Heritage Convention (UNESCO), Global Tiger Forum (GTF) and Convention on Biodiversity (CBD).

6.1 In-situ conservation

Conservation of wild species in their natural habitat not only conserve wildlife species, but also the habitats, ecosystems, biodiversity and wilderness. Among the 118 ecosystems types in Nepal, more than two third lie in the protected areas. The protected areas like national parks, wildlife reserve, hunting reserve, conservation areas, and buffer zones are the approaches of forests and biodiversity conservation and management (Table 7). These protected areas cover 23.7% of the total area of Nepal including 498.4 km² area of newly established conservation area, Badimalika-Ramarosan Conservation Area (DNPWC, 2024a; NTNC, 2026). The Chitwan National park, also the World Heritage Site (DoI, 2002) (Table 8) is the first protected area of Nepal. These national parks have crucial roles in conserving flagship species, such as tiger, rhinoceros, Asian elephant, snow leopard and red panda (Table 9). Moreover, these protected areas have also maintained the information centers for providing park related information, which are also used for research and educational purposes. These centers mainly house wildlife parts and also display iconic materials found in and around the area. Such information centers are present in almost all of the protected areas. Furthermore, considering the global significance of wetlands, Nepal has declared 10 Ramsar sites in different ecological belts of the country for the management and conservation of wetlands and associated biodiversity (Table 10). Some of these wetlands have supported livelihoods of thousands of households residing nearby, and some are of cultural and religious significance.

Table 7: List of the protected areas in Nepal

S.N.	Protected area	Declaration year	Area (km ²)	Physiographic zone	Buffer zone area (km ²)
National parks					
1.	Chitwan National Park	1973	952.63	Terai/Siwalik	729.37
2.	Langtang National Park	1976	1710	High Mountain	420
3.	Rara National Park	1976	106	High Mountain	198
4.	Sagarmatha National Park	1976	1148	High Mountain	275
5.	Shey-Phoksundo National Park	1984	2712	High Mountain	1172
6.	Khaptad National Park	1984	225	Middle Mountain	216
7.	Bardia National Park	1976, 1984	968	Terai	507
8.	Makalu Barun National Park	1991	1500	High Mountain	830
9.	Shivapuri Nagarjun National Park	2002	159	Mid-hills	118.61
10.	Banke National Park	2010	550	Terai	343
11.	Shuklaphanta National Park	2017	305	Terai	243.5
12.	Parsa National Park	2017	627.39	Terai/Siwalik	285.3
13.	Chhayanath National Park	2025	843	High Mountain	177
Wildlife reserve					
1.	Koshi Tappu Wildlife Reserve	1976	175	Terai	173
Hunting reserve					
1.	Dhorpatan Hunting Reserve	1987	1325	Middle Mountain	NA
Conservation area					
1.	Annapurna Conservation Area	1992	7629	Middle Mountain	NA
2.	Kanchanjunga Conservation Area	1997	2035	Middle Mountain	NA

S.N.	Protected area	Declaration year	Area (km ²)	Physiographic zone	Buffer zone area (km ²)
3.	Manasalu Conservation Area	1998	1663	High Mountain	NA
4.	Krishnasar Conservation Area	2009	16.95	Terai	NA
5.	Gaurisankar Conservation Area	2010	2179	High Mountain	NA
6.	Api Nampa Conservation Area	2010	1903	High Mountain	NA
7.	Badimalika-Ramarosan Conservation Area	2026	498.4	Middle Mountain	NA

NA = Not applicable

Table 8: List of the world heritage sites in Nepal

S.N.	Site	Place of establishment	Physiographic zone	Existed year (AD)
1.	Haunumandhoka Durbar Square	Kathmandu	Mid-hills	613
2.	Patan Durbar Square	Lalitpur	Mid-hills	1565
3.	Bhaktapur Durbar Square	Bhaktapur	Mid-hills	1427
4.	Pashupatinath Temple	Kathmandu	Mid-hills	5 th Century
5.	Swayambhunath Stupa	Kathmandu	Mid-hills	5 th Century
6.	Bouddhanath Stupa	Kathmandu	Mid-hills	5 th Century
7.	Changunarayan Temple	Bhaktapur	Mid-hills	306
8.	Chitwan National Park	Chitwan	Terai	1984
9.	Sagarmatha National Park	Solukhumbu	High Mountain	1979
10.	Lumbini	Rupandehi	Terai	1997

Table 9: Status of tigers and rhinoceros in Nepal (Source: MoFE, 2018; DNPWC & DFSC, 2022; DNPWC, 2024b; <https://dnpwc.gov.np>)

Year	Tiger population (No.)	Year	Rhinoceros population (No.)
2009	121	2000	612
2013	198	2005	446
2018	235	2008	435
2022	355	2011	534
2026	429	2015	645
		2021	752

Table 10: Distribution of Ramsar sites in Nepal

S.N.	Ramsar Site	Location	Physiographic zone	Inclusion date	Area (ha.)	Elevation (m)
1.	Koshi Tappu	Koshi	Terai	17 December 1987	17500	78
2.	Beeshazari and Associated Lakes	Chitwan	Terai	13 August 2003	3200	286
3.	Ghodaghodi Lake Area	Kailali	Terai	13 August 2003	2563	205
4.	Jagadishpur Reservoir	Kapilvastu	Terai	13 August 2003	225	197
5.	Gokyo and Associated Lakes	Solukhumbu	High Mountain	23 September 2007	7770	4700-5000
6.	Gosaikund and Associated Lakes	Rasuwa	High Mountain	23 September 2007	1030	4000-4700
7.	Phoksundo Lake	Dolpa	High Mountain	23 September 2007	494	3611.5
8.	Rara Lake	Mugu	High Mountain	23 September 2007	1583	2990
9.	Mai Pokhari	Ilam	Mid-hills	28 October 2008	90	2100

S.N	Ramsar Site	Location	Physiographic zone	Inclusion date	Area (ha.)	Elevation (m)
10.	Lake Cluster of Pokhara Valley	Kaski	Mid-hills	2 February 2016	26106	750

Source: Ramsar (2026)

Forest Conservation Area

Forest conservation areas are forest areas that are established to conserve biodiversity, wildlife habitats, watersheds, and natural resources allowing sustainable use by the local communities. Nepal has established 11 forest conservation areas in various ecological regions to conserve valuable ecosystems and endangered species (DoF, 2018) (Table 11). Apart from these 11 forest conservation areas, several other forest areas are under consideration for declaration (MoFE, 2020).

Table 11: Forest conservation areas and their conservation significance

Forest	Year established	Area (ha)	Location (District)	Physiographic zone	Conservation significance
Kankre Bihar	2002	175.5	Surkhet	Siwalik	Historical; archeological and biodiversity
Madhane	2010	13761	Gulmi	Mid-hills	Biodiversity; ecotourism
Barandabhar	2011	10466	Chitwan	Terai	Biological corridor; wetland; habitat for several endangered species
Panchase	2011	5775.7	Kaski, Parbat, Syanja	Mid-hills	Biodiversity; eco-tourism; religious
Laljhadi-Mohana	2011	29641.7	Kailali, Kanchanpur	Terai	Biological corridor; wetland
Basanta	2011	69001.2	Kailali	Terai	Wildlife habitat and corridor
Khata	2012	4503.7	Bardia	Terai	Wildlife habitat and corridor
Dhanushadham	2012	430	Dhanusha	Terai	Historical; religious; biodiversity
Resunga	2018	19282	Gulmi	Mid-hills	Religious, watershed; biodiversity
Thaple-Satyabati-Salimedaha	2018	37843	Gulmi	Mid-hills	Watershed; biodiversity
Godawari-Phulchowki	2022	2128.88	Lalitpur and Kavreplanchowk	Mid-hills	Biodiversity, Natural beauty, geological and geographic status, ecosystem and threatened animals/plants, and historical religious and cultural heritage

(Source: DoF, 2018 & MoFE, 2020; <https://dofsc.gov.np>)

6.2 Ex-situ conservation

Nepal has also made efforts for *ex-situ* conservation (protecting species outside their natural habitats) of biodiversity with the establishment of botanical gardens, conservation centers zoo, and breeding centers for

preserving genetic resources. This strategy provides additional protection and backup when populations are severely threatened.

Botanical gardens and herbarium

Government of Nepal has established 12 botanical gardens (Table 12). Department of Plant Resources (DPR) under Ministry of Agriculture, Forests and Environment manages these gardens. These gardens serve as both ex-situ and in-situ conservation centers, as well as place for educational activities. The National Botanical Garden, Lalitpur, manages diverse plant species of medicinal and social importance (DPR, 2025). Moreover, for keeping records of plant specimens, the National Herbarium (KATH) established in 1960 under the Department of Plant Resources, is consistently collecting and preserving plant specimens, identifying and classifying plants, maintaining a reference collection, supporting botanical research and providing specimens for research and educational purposes. The Herbarium houses over 165,000 specimens of plants (<http://plantdatabase.kath.gov.np/>). In addition to KATH, Herbarium of Central Department of Botany, Tribhuvan University, TUCH, established in 1965, houses over 22,000 plant specimens (<https://www.cdbtu.edu.np/pages/12/herbarium>).

Table 12: Distribution of botanical gardens in Nepal

S.N.	Name	Location (District)	Physiographic zone	Altitude (m)	Established year
1.	National Botanical Garden	Godavari, Lalitpur	Mid-hills	1515	1962
2.	Brindaban Botanical Garden	Hetauda, Makawanpur	Siwalik	500	1962
3.	Mountain Botanical Garden	Daman, Makawanpur	Mid-hills	2320	1962
4.	Tistung Botanical Garden	Tistung, Makawanpur	Mid-hills	1900	1962
5.	Dhakeri Botanical Garden	Dhakeri, Banke	Terai	130	1962
6.	Mulpani Botanical Garden	Kapurkot, Salyan	Mid-hills	2000	1990
7.	Dhitachor Botanical Garden	Dhitachaur, Jumla	Mid-hills	2500	1990
8.	Maipokhari Botanical Garden	Maipokhari, Ilam	Mid-hills	2200	1992
9.	Dhanushadham Botanical Garden	Dhanushadham, Dhanusha	Terai	100	1998
10.	Godavari Botanical Garden	Godavari, Kailali	Terai	130	1998
11.	Dewahariya Botanical Garden	Dhangadhi, Kailali	Terai	100	1998
12.	World Peace Biodiversity Botanical Garden	Pokhara, Kaski	Mid-hills	1500	2013

Source: DPR (2025)

Captive breeding

Breeding and raising wild animals in controlled environments such as zoos, wildlife reserves or breeding centers is also an important example of ex-situ conservation in Nepal. For example, the Gharial Breeding Centre at Kasara, Chitwan, established in 1978, is successful in breeding crocodiles.

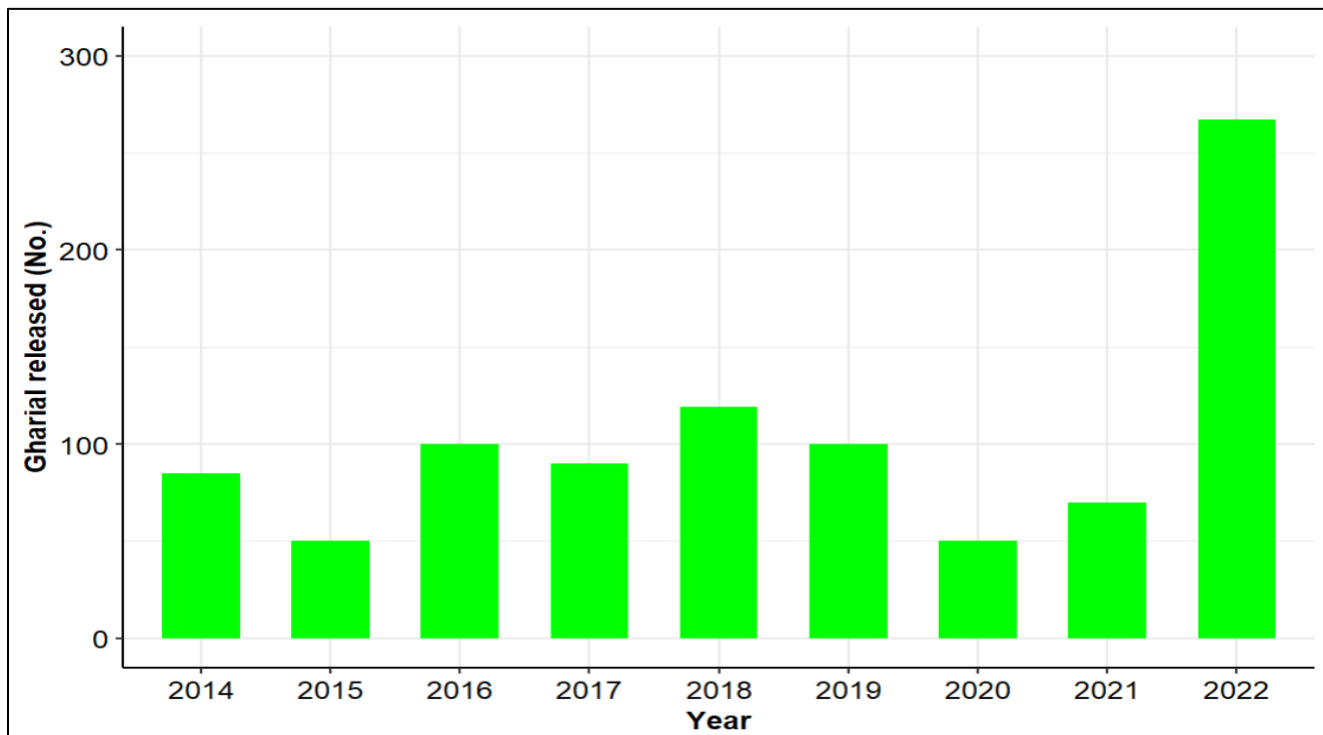


Figure 5: Gharials released from Gharial Breeding Center, Chitwan National Park to nearby rivers from 2014 to 2022 (Data source: DNPWC, 2024a)

When the population of gharials was near to extinction, the breeding efforts at the center revived the population of the species. Each year, significant number of individuals of gharial crocodiles are released in rivers from Gharial Breeding Center of Chitwan National Park (Figure 5). Gharial breeding has also been initiated in Bardia National Park. During the period from 1981 to 2024, the Gharial Breeding Centers released 1910 gharials bred into different rivers of Nepal (DNPWC, 2024a). Similarly, the Elephant Breeding Centre, established in 1989, at Khorsor, Chitwan has played vital role in elephant conservation. The elephant stables in Shuklaphanta, Bardia, Banke, Chitwan, Parsa, and Koshi Tappu are notably contributing for elephant breeding. In addition, the Government of Nepal has set standards for commercial wildlife rearing, breeding and utilization (MoFE, 2023). Under this provision, the species such gharial crocodile (*Gavialis gangeticus*), black buck (*Antelope cervicapra*), impeyan pheasant (*Lophophorus impejanus*), crimson-horned pheasant (*Tragopan satyra*) and cheer pheasant (*Catreus walllichii*); and other wild species such as barking deer (*Muntiacus vaginalis*), spotted deer (*Axis axis*), sambar deer (*Rusa unicolor*), monkey (*Macaca mulata*), hog deer (*Axis porcinus*), wild boar (*Sus scrofa*), snakes and 10 species of birds are permitted for commercial farming. The individuals and institutions involved in farming, export and import of wildlife should be abided by the CITES, and other related international laws.

Central zoo

The Central Zoo, established in 1932 AD, is located at Jawalakhel, Lalitpur. Initially, the zoo was established as private zoo by Juddha Shamsheer Jung Bahadur Rana, the then Prime Minister. The ownership was transferred to Government of Nepal in 1951. Its management has been handed over to the National Trust for Nature Conservation (NTNC) for 60 years starting from 1995. The zoo has vital role in conservation education and is also involved in research activities, and capacity building programs. Records

of 2025 shows that it has collection of 1400 animal species belonging to 120 species, including 40 species of mammals, 58 species of birds, 11 species of reptiles and eight species of fishes (NTNC, 2025).

Conservation centers

In order to conserve the genetic resources and biodiversity, Department of Forests and Soil Conservation has established seed stand for tree species which are economically important in various eco-regions. Similarly, the department has established breeding seed orchards and specialized plantations. The purpose of these orchards and plantations are to produce genetically improved seeds through controlled breeding of the selected parent trees and focus has been given in conserving of the species such as *Pterocarpus marsupium*, *Senegalia catechu*, *Butea monosperma*, *Choerospondias axillaris*, *Elaeocarpus sphaericus*, *Michelia champaca*, and *Neolamaeckia cadamba*. Currently, Forest Seed Laboratory and Storage Center, Banke has four breeding seed orchards, eight seed production areas and six species conservation plots, and one provincial fruit garden (FSLSC, 2024). In 2008, the DNPWC established a Vulture Conservation and Breeding Center at Kasara inside the Chitwan National Park. The breeding center was established with the aim of ensuring long term survival of two vulture species viz. *Gyps tenuirostris* (slender billed vulture) and *Gyps bengalensis* (oriental white-rumped vulture) (MoFSC, 2014a). However, with its limited success, it was noticed that protecting and supporting vultures in wild is more effective to recover the population, the center is closed. Moreover, there are community-managed 'vulture restaurants' in Nawalparasi, Rupandehi, Dang, Kailali, and Kaski districts, established by the Bird Conservation Nepal (BCN) and Himalayan Nature at different locations, where vultures are provided with safe and diclofenac-free carrion (MoFSC, 2014a). In addition, Nepal has also zoological gardens. Some examples of zoological gardens include National Zoological Garden (established in 2015 with an area of 2.45 km²) at Bhaktapur, Bhanubhakta Zoological Garden (established in 2017 with an area of 4.25 km²) at Tanahun, and Pachbhaiya Zoological Udyan Center at Lekhnath, Pokhara.

Natural history museum

The Natural History Museum (NHM) was established in 1975 under Tribhuvan University, Institute of Science and Technology. The museum is on a hillock of the world heritage site of ancient Swoyambhunath Stupa, Kathmandu. The museum has the reflection of Nepal's natural history. It also serves as a platform for research and education. The NHM functions as a scientific entity for CITES implementation of faunal species in Nepal. The museum houses about 35,332 specimens of Nepalese flora and fauna, and manages exhibition to public. The museum also manages the Swoyambhu Environment Garden. The garden harbors medicinal plants, including a public park, an experimental park, and a nursery. The foci of the NHM are tracing, collecting and preserving the holistic natural artifacts on Geology, Earth history and evolution, Anthropology, Botany, Geography, environmental issues, and biodiversity. In addition, the Central Department of Zoology, Tribhuvan University manages Central Department Zoology Museum of Tribhuvan University (CDZMTU), particularly for 4100 animal specimens (<https://www.cdztu.edu.np/museum-collection/>).

6.3 Active and passive restoration interventions

Nepal is adopting different approaches of restoration interventions for conservation of forests and biodiversity. The active restoration strategies involve direct involvement of people in the degraded ecosystems, for example enrichment planting, removal of invasive species, direct control of fire, soil and

watershed conservation etc. Such activities, for example, are being a part of community forest programs. Active restoration strategies are particularly crucial for severely degraded forests and in the sites where natural regeneration are not sufficient. Passive restoration interventions, however, are the practices which aim the ecosystems to recover naturally after the disturbing factors are ceased. Existing practices of exclusion of forest areas from uncontrolled grazing, forest fires, illegal logging and excessive harvests are some examples of passive interventions in Nepal.

7. Protected species

The Government of Nepal has listed 39 animal species in the protected category under the National Parks and Wildlife Conservation Act, 1973 (with amendments) (GoN, 1973) (Table 13). Similarly, under the Forest Act 2019, the Government of Nepal has banned the collection, use, sale, distribution, transportation, and export of three plant species: *Dactylorhiza hatagirea* (Panch Aunle in Nepali), *Juglans regia* (Okhar) bark, and *Neopicrorhiza scrophulariiflora* (Kutki) (GoN, 2019). The government has also banned the export of rock exudes (Shilajit) except for their processed products, and upon the permission of the Department of Forests, transportation, export, and felling of seven tree species can be made for commercial purposes (Table 14).

Table 13: Distribution of the protected faunal species in Nepal

SN	Scientific name	English name	Local name
Mammals			
1.	<i>Macaca assamensis</i>	Assam Macaque	Asami Rato Bandar
2.	<i>Manis pentadactyla</i>	Chinese Pangolin	Kalo Salak
3.	<i>Manis crassicaudata</i>	Indian Pangolin	Tame Salak
4.	<i>Caprolagus hispidus</i>	Hispid Hare	Laghukarna Kharayo
5.	<i>Canis lupus</i>	Grey Wolf	Bwanso
6.	<i>Ursus arctos</i>	Brown Bear	Himali Rato Bhalu
7.	<i>Ailurus fulgens</i>	Red Panda	Habre
8.	<i>Prionodon pardicolor</i>	Spotted Linsang	Silu Biralo
9.	<i>Prionailurus bengalensis</i>	Leopard Cat	Chari Bagh
10.	<i>Felis lynx</i>	Lynx	Pahan Biralo
11.	<i>Neofelis nebulosa</i>	Clouded Leopard	Dhwanse Chituwa
12.	<i>Panthera tigris</i>	Royal Bengal Tiger	Pate Bagh
13.	<i>Panthera uncia</i>	Snow Leopard	Hiun Chituwa
14.	<i>Elephas maximus</i>	Asian Elephant	Hatti
15.	<i>Rhinoceros unicornis</i>	Greater One-horned Rhino	Gainda
16.	<i>Sus salvanius</i>	Pygmy Hog	Pudke Bandel
17.	<i>Moschus chrysogaster</i>	Alpine Musk Deer	Kasturi Mriga
18.	<i>Cervus duvauceli</i>	Swamp Deer	Bahrasingha
19.	<i>Bos gaurus</i>	Gaur	Gauri Gai
20.	<i>Bos grunniens</i>	Wild Yak	Chauri Gai
21.	<i>Bubalus arnee</i>	Wild Water Buffalo	Arna
22.	<i>Ovis ammon</i>	Great Tibetan Sheep	Nayan
23.	<i>Pantholops hodgsoni</i>	Tibetan Antelope	Chiru
24.	<i>Antelope cervicapra</i>	Blackbuck	Krishnasar
25.	<i>Tetracerus quadricornis</i>	Four-horned antelope	Chauka
26.	<i>Hyaena hyaena</i>	Stripped Hyaena	Hundar
27.	<i>Platanista gangetica</i>	River Dolphin	Shons
Birds			

SN	Scientific name	English name	Local name
1.	<i>Buceros bicornis</i>	Giant Hornbill	Gaj Dhanesh
2.	<i>Catreus wallichii</i>	Cheer Pheasant	Cheer
3.	<i>Houbaropsis bengalensis</i>	Bengal Florican	Khar Mayur
4.	<i>Lophophorus impejanus</i>	Impeyon Pheasan	Danphe
5.	<i>Ciconia nigra</i>	Black Stork	Kalo Bhundiphor
6.	<i>Ciconia ciconia</i>	White Stork	Seto Bhundiphor
7.	<i>Tropan satyra</i>	Crimpson-horned Pheasant	Munal
8.	<i>Sypheotides indicus</i>	Lesser Florican	Sano Khar Mayur
9.	<i>Grus antigona</i>	Saras Crane	Saras
Reptiles			
1.	<i>Gavialis gangeticus</i>	Gharial Crocodile	Gharial Gohi
2.	<i>Python molurus</i>	Asiatic Rock Python	Ajingar
3.	<i>Varanus flavescens</i>	Golden Monitor Lizard	Sun Gohoro

Source: GoN (1973)

Table 14: Distribution of protected floral species in Nepal

SN	Scientific name	English name	Local name	Potential use
I. Banned for collection, use, sale, distribution, transportation and export				
Angiosperms				
1.	<i>Dactylorhiza hatagirea</i>	Orchid	Panchaunle	Tonic
2.	Bark of <i>Juglans regia</i> (National forest only)	Walnut Bark*	Okharko Bokra	Medicine
I (a). Banned for export without identification and certification by Department of Plant Resources and Permission by Department of Forests and Soil Conservation				
1.	<i>Neopicrorhiza scrophulariiflora</i>	-	Kutki	Medicine
II. Banned for export outside the country without processing (Not applicable for cultivated products)				
Angiosperms				
1.	<i>Cinnamomum glaucescens</i>	-	Sugandakokila	Medicine
2.	<i>Rauvolfia serpentina</i>	Serpentine	Sarpagandha	Medicine
3.	<i>Nardostachys jatamansi</i>	Spike nard	Jatamansi	Medicine
4.	<i>Valeriana jatamansi</i>	Vallerian	Sugandhwal	Medicine
Gymnosperms				
5.	<i>Abies spectabilis</i>	Himalayan fir	Talispatra	Medicine
6.	<i>Taxus</i> spp.	Himalayan yew	Lauth Salla	Medicine
7.	<i>Rock exudate</i>		Silajit	
III. Banned for harvest, transportation and export for commercial purpose				
Angiosperms				
1.	<i>Dalbergia latifolia</i>	Rose Wood	Satisaal	Timber
2.	<i>Juglans regia</i>	Walnut	Okhar	Medicine, timber
3.	<i>Pterocarpus marsupium</i>	Indian Kino tree	Bijayasal	Timber
4.	<i>Shorea robusta</i>	Common Sal	Sal	Timber

Source: DPR (2025)

*Protection of Walnut is from National Forest only.

8. International Commitments and Agreements

Nepal is committed in managing biodiversity following the national requirements and multilateral environmental agreements (MEAs) to which it is a party (Table 15). The MEAs provide opportunities and keep the country in obligation for conservation of wild floral and faunal species. These agreements and conventions help improve and harmonize conservation related legislations and governance within and

among countries to follow standards, and binding legal measures and strengthened conservation efforts to enhance national capacity for setting conservation agenda. For example, Nepal has made success in the implementation of different international commitments, such as CBD (1992), CITES (1973), Ramsar (1971) and World Heritage Convention (1972).

In addition, Nepal is committed to global affiliations pertinent to biodiversity conservation, including the World Trade Organization (WTO), the World Conservation Union (IUCN), the Global Tiger Forum, the World Conservation Strategy, World Charter for Nature and Nagoya Protocol. Therefore, there is need of implementing these international agreements.

Table 15: Major conventions and agreements related to forest and biodiversity signed and implemented by the Government of Nepal

Convention	Enforcement Year
World Heritage Convention, 1972	1978
United Nations Framework Convention on Climate Change, 1992	1994
Convention on Biological Diversity, 1992	1994
Cartagena Protocol on Bio-safety to the CBD, 2001	In the process of ratification
Nagoya Protocol, 2018	2018
Kyoto Protocol, 1997	2005
Paris Agreement, 2016	2016
United Nations Convention to Combat Desertification, 1995	1996
United National Convention on the Law of the Sea, 1982	1998
Convention on Wetland of International Importance Especially as Waterfowl Habitat, 1971	1971
Convention on International Trade in Endangered Species of Wild Fauna and Flora, 1973	1975
International Treaty on Plant Genetic Resources for Food and Agriculture, 2001	2004
International Big Cat Alliance	2025
Global Tiger Forum	2002
South Asia Wildlife Enforcement Network	2011

9. Policies, Strategies and Regulatory Framework

In Nepal, biodiversity conservation is supported by a combination of policies, strategies, and legal frameworks that aim to protect ecosystems together with promoting sustainable use and community participation. Over recent years, there is considerable change and transformation of biodiversity sector policies. The concept of conservation and eco-friendly economic growth is visualized since the 9th Five Year Plan (1997-2002) that was further refined and internalized in the following 10th Five Year Plan (2002-2007). The present 16th Five Year Plan (2024-2028) has placed the forest and biodiversity conservation within the broader agenda through combination of sustainable forest management, biodiversity conservation, climate resilience and community participation.

Government of Nepal has formulated and implemented various legislative frameworks to facilitate sustainable economic growth. These provisions also aim to enhance local participation in biodiversity conservation and natural resources management (Table 16). Similarly, policies pertaining to the community-based forest management and protected area management are being effectively implemented.

However, there are also some policy gaps, particularly relating to sustainable utilization and sharing of biological resource use. Likewise, there seems lack of strategy to activate and capacitate local governments for biodiversity management (MoFSC, 2014a). The effective implementation of multilateral environmental agreements is also a gap in biodiversity conservation in Nepal.

Table 16: Major national policies and legal frameworks related to forest and biodiversity in Nepal

Constitution of Nepal, 2015 Plans/Policies/Strategies Sixteenth Five-Year Plan, 2024-2028 Agrobiodiversity Policy, 2014 Herbs and Non-Timber Forest Products Development Policy, 2004 Industrial Policy, 2011 Land Use Policy, 2015 National Animal Breeding Policy, 2021 National Climate Change Policy, 2019 Rural Energy Policy, 2006 National Forest Policy, 2019 National Environment Policy, 2019 National Irrigation Policy, 2024 Environment Protection Rules, 2020 National Wetland Policy, 2012 National Water Resource Policy, 2020 Protected Areas Management Strategy, 2022 - 2030 Rangeland Policy, 2012 Tourism Policy, 2025 Integrated Strategic Plan of National Forest 2025-2043 National Comprehensive Watershed Management Strategy, 2023 Acts Aquatic Animal Protection Act, 1960 Environment Protection Act, 2019 Forest Act, 2019 Local Government Operation Act, 2017 National Parks and Wildlife Conservation Act, 1973 National Trust for Nature Conservation Act, 1982 Pasture Land Nationalization Act, 1974 Plant Protection Act, 2007 Private Forest Nationalization Act, 1957 Seed Act, 1988 Soil and Watershed Conservation Act, 1982 Tourism Act, 1978 Water Resource Act, 1992 CITES Act, 2017	Rules/Regulations Bardia National Park Regulation, 1997 Buffer Zone Management Regulation, 1996 Carbon Trade Regulation, 2025 Chitwan National Park Rules, 1974 CITES Regulation, 2019 Convention of International Trade in Endangered Wildlife and Plant Regulation, 2020 Conservation Area Management Rules, 1997 Environment Protection Regulation, 2020 Forest Regulation, 2022 Kanchanjunga Conservation Area Management Regulation, 2007 Khaptad National Park Regulation, 1988 Mountain National Parks Regulation, 1980 Mountaineering Expedition Regulations, 2002 National Parks and Wildlife Conservation Regulation, 1974 Plant Protection Rules, 2010 Plant Quarantine and Protection Rules, 2010 Seed Regulation, 2024 Shivapuri Nagarjun National Park Regulation, 2019 Water Resource Rules, 1993 Wildlife Reserve Regulation, 1978 Guidelines/Directives Buffer Zone Management Guideline, 1999 Wildlife Damage Relief Guideline, 2023 Commercial Farming, Reproduction and Utilization Standards of Wild Animals, 2023
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10. Conclusion

Nepal is home to diverse floral and faunal species with significant share to global biodiversity. Nepalese economy and livelihoods are dependent on the forests and biodiversity. The local communities use

substantial quantity of wild plants as their food crops, NTFPS and other livelihood options. In addition, fuelwood obtained from the forest is still a primary source of energy for rural households. Despite, these resources are under threat due to over exploitation from anthropogenic activities. Several floral and faunal species have been listed under threatened category. In addition, the pressures are exacerbated by climate anomalies. Considering the multiple pressures leading to environmental impairment and habitat degradation, Government of Nepal has executed both in-situ and ex-situ conservation strategies. Among the conservation approaches, community forestry program and protected areas are the successful examples for managing forest and biodiversity in recent decades. In addition, Nepal is also committed to the several conventions and agreements, and has simultaneously formulated policies, laws and rules to monitor the achievements made so far. Yet, there seems gaps in their implementation. Thus, regular monitoring the status of biodiversity, and prevailing threats under changing socio-economic dimensions help strengthen conservation programs.

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Glossary

Agro-biodiversity: The variety and variability of crops, livestock, and other cultivated organisms maintained within agricultural systems.

Buffer Zone: The area surrounding a national park or protected area that is managed with local community participation to reduce pressure on protected resources, minimize human–wildlife conflict, and share conservation benefits.

Captive Breeding: The breeding and raising of wild animals under controlled conditions, such as in zoos, wildlife reserves, or dedicated breeding centres, as a form of ex-situ conservation.

Endemism: The occurrence of a species exclusively within a particular geographic region and nowhere else in the world.

Ex-situ Conservation: The conservation of species outside their natural habitats, such as in zoos, botanical gardens, seed banks, or breeding centres.

Flagship Species: A species selected to represent a conservation cause because it can attract public attention, awareness, and support for biodiversity conservation.

In-situ Conservation: The conservation of species and ecosystems within their natural habitats, including through protected areas and other forms of habitat-based conservation.

Invasive Alien Plant Species (IAPS): Non-native plant species that become established and spread rapidly in an ecosystem, potentially threatening native species, ecosystems, and biodiversity.

Non-Timber Forest Products (NTFPs): Forest-derived products other than timber, including medicinal plants, fodder, fuelwood, fruits, fibres, and other materials that contribute to local livelihoods and rural economies.

Passive Restoration: A restoration approach in which degraded ecosystems are allowed to recover naturally after the removal or reduction of major disturbances such as grazing, logging, or fire.

CHAPTER: VI

Solid waste Management

Kishor Kumar Maharjan¹; Binod Baniya²

¹Department of Environmental Science, Tri-Chandra Multiple Campus, Tribhuvan University

²Department of Environmental Science, Patan Multiple Campus, Tribhuvan University

Email: kishor.maharjan@trc.tu.edu.np; bbaniya@cdes.edu.np

Summary

Solid waste management has become a growing environmental and public health concern in Nepal due to rapid urbanization, changing lifestyles, tourism and increasing consumption of packaged products. The composition of waste has gradually changed from largely organic materials toward a more mixed waste stream. Although organic waste remains a major component, its potential for composting and resource recovery is not fully utilized. Waste management practices vary across Nepal. In many municipalities, waste is still collected and transported to dumping or landfill sites with limited segregation and treatment. Open dumping along riverbanks, roadsides and open spaces remains common in some areas. Open burning of waste is also practiced, particularly where transportation and disposal facilities are limited. Rural municipalities face additional difficulties because of poor road access, high transportation costs, limited recycling facilities and low public awareness. Household composting and vermicomposting are practiced in many urban and rural communities. Kitchen and food waste are commonly converted into compost and used in home gardens, flowerpots and rooftop farming. However, problems such as odor, leachate, insects, rodents, limited space and lack of technical knowledge discourage some households from continuing the practice. Proper training on carbon and nitrogen balance, moisture, aeration and composting methods can improve household level composting. Several municipalities demonstrate promising practices. Waling promotes source segregation, recycling and vermicomposting. Dhankuta has developed a community-based system combining segregation, composting and recycling. Dhangadhi operates a material recovery facility and processes organic waste into compost and biogas. Bhaktapur promotes composting through subsidized compost bins and integrated waste fees. Madhyabindu has established an organic fertilizer production center. Despite these examples, Nepal still needs greater investment in sanitary and secure landfills, composting plants, material recovery facilities and recycling systems. Strict source segregation, public participation, private sector partnerships, awareness, monitoring and enforcement are essential for moving Nepal from a disposal-based system toward sustainable resource recovery and a circular economy.

Keywords: Composting; e-waste; source segregation; vermicomposting; waste composition

1. Background

Solid waste is the undesirable or discarded materials produced by human activities in residential, commercial, institutional, industrial, and agricultural sectors. It includes a wide range of materials such as biodegradable wastes including food and garden wastes, and non-biodegradable waste such as plastics, metals, paper, glass and electronic waste. The rate of urbanization, population, and shifting consumption patterns have amplified the amount and complexity of solid waste generated. Consequently, the effective management of solid waste has become a major environmental and public health concern.

The generation of solid wastes in Nepal has been growing at an alarming rate over the past years especially in the urban areas. The findings showed that the waste produced by the country is about a million metric tons per year. Among various sources, households make largest contribution of approximately 386,690 mt (metric tons) per year and the next important contributor is the business establishments with 245,884 mt per year. In educational institutions, the annual output amounts to about 103,244 mt, whereas as industries amount to 94,392 mt. The annual generation from health institutions is approximately 101,507 mt and other sectors produce approximately 66,220 mt (CBS, 2022). Organic waste is the largest part of the solid waste composition, then plastics, paper and paper products, glass, and metals (ADB, 2013; SWMTSC, 2017; CBS, 2020).

Regarding the disposal processes, the major disposal method is landfilling /dumping which is the place where approximately 389,983 mt of waste is dumped annually. The second biggest part which is about 315,069 mt per annum is disposed into the environment. The burning is equal to approximately 22,075 mt per year. Recycling uses up the least amount of waste where only approximately 8,690 mt per year. The recycled materials are normally plastics, paper and paper products and metals (CBS, 2022).

Management of waste in Nepal is still in its developing stages and it remains mostly focused in collection and disposal. Many municipalities do not segregate waste at the source typically. The waste collected is taken to landfills and dumping sites. The informal sector is the main recycling sector since waste pickers and scrap dealers collect useful materials such as plastics, paper and metals. There are composting programs in a few cities and centers, but they are still small in size. Poor infrastructure, insufficient separation practices, community awareness, legal enforcement and financial constraints remain a problem in the implementation of effective waste management.

The Solid Waste Management Act in Nepal is important in the local governments in solid waste management. Their duties are the collection of waste, transportation of waste, waste treatment, and ultimate disposal. The municipalities also have the role of promoting waste segregation at the source, conducting of awareness campaigns among the people, and also encouraging them to participate in recycling and composting their waste. Also, local bodies involve the private sectors and community-based organizations in order to enhance service delivery. Nevertheless, the lack of technical capacity, shortage of budget, and absence of long-term planning are the issues that challenge many municipalities and influence the efficient waste management.

The mismanaged solid waste may have severe effects on the environment and health. The causes of soil and ground water contamination are due to the formation of leachates during open dumping and the uncontrolled landfilling. Organic waste decomposes into methane, which is an effective greenhouse gas. Waste combustion also emits harmful pollutants such as dioxins and particulate matter that effect on the quality of

air and human health. Plastic debris causes obstruction of the drainage systems and enhances the chances of urban flooding. Also, the uncontrolled waste creates habitats to the disease vectors such as flies, mosquitoes, and rodents, which contributes to high risk of infectious diseases. These effects demand the necessity of sustainable waste management approaches such as waste minimization, segregation, recycling and environmentally friendly disposal.

2. Hazardous solid waste in Nepal

The Basel Convention classified hazardous waste into a number of categories depending on their origin and their chemical properties. These are waste in the categories of medical and clinical and pharmaceutical waste, biocidal waste, waste containing wood preservatives, waste containing organic solvents and wastes contaminated with heavy metals like lead, mercury, and cadmium. Wastes that are characterized by hazardous properties (toxicity, corrosivity, flammability, and infectiousness) are also taken into consideration by the Convention.

Among them, healthcare waste and electronic waste are identified as one of the largest sources of hazardous waste streams. The medical waste, especially infectious waste produced in hospitals, laboratories, and clinics, are very harmful to human beings. Besides health care waste, e-waste consists harmful materials such as heavy metals, flame retardants and other toxic elements and when such wastes are not disposed of, they affect soil, water and the air. Thus, healthcare waste, as well as e-waste, is one of the significant hazardous waste streams that should be handled carefully, treated, and disposed of in an environmentally friendly manner to reduce the risk to human health and the environment.

2.1 Healthcare waste in Nepal

Healthcare wastes is a very important public health and environmental issue. Under the Solid Waste Management Act, 2011, the term healthcare waste is used to refer to harmful waste produced by hospitals, clinics, pharmacies, blood banks, pathological labs, animal health institutions and health research establishments. Such definition shows that healthcare waste is produced by a large number of institutions and that it is difficult to manage this waste safely. To be more specific, the (MoHP, 2020) introduce a more extensive list of sources such as primary health care centers, health posts, Expanded Programme on Immunization (EPI) clinics, outpatient clinics, dental and maternity centers, dialysis units, pharmacies, veterinary hospitals, ambulance services and even home-based care.

The amount of healthcare waste produced per bed per day in Nepal is about 1 to 1.7 kg of healthcare waste in hospitals and healthcare facilities (MoHP, 2020). Even though approximately 55-75 percent of this waste can be compared to the household waste, the rest of it is toxic and can be extremely dangerous to health. Nevertheless, in the absence (not sufficiently applied) of correct segregation of wastes at the point of

generation, the total volume should be handled as hazardous wastes which greatly increases the cost of management and the risks.

Although the country has national guideline and standard operating procedures, few healthcare facilities have clearly defined waste management systems. Hazardous waste in most instances is combined with general waste and discarded at the landfills/dumping sites or simply burnt at the hospital premises. Moreover, majority of hospitals are not willing to treat/manage infectious liquids waste and radioactive waste. The liquid waste is directly discharged into public sewer. These practices can contribute to environmental pollution, elevate occupational health hazards, and spread infectious diseases.

These gaps are further depicted by the recent findings of inspections. A survey carried out by the Environment Department of Kathmandu Metropolitan City found out that some of the private hospitals in Kathmandu Valley were disposing hazardous medical waste, such as used syringes, without any remedies such as autoclaving. This is not a safe practice that poses a high risk of the transmission of the infection and also indicates the poor implementation of the regulations of handling the healthcare waste (Nepal Health News, 2025).

The situation has been attempted to be improved as a result of institutional and international collaboration. Health care foundation Nepal (HECAF) has been at the forefront in the introduction of the right and sustainable health care waste management technologies. The idea of Clean, Green, Healthy Hospitals has also been introduced into Nepal with the aid of Health care without harm and World Health Organization South-East Asia regional office and its first implementation carried out in the National kidney center in 1999. These efforts have helped to create awareness, institutional capacity and set exemplary models of safe waste management, although it has been difficult to have a uniform implementation throughout the country.

Bharatpur Hospital, Chitwan is a good example of a practice where the healthcare waste management is exceptionally effective. Being one of the seven federal government hospitals chosen to reflect the healthcare system of Nepal, Bharatpur Hospital showed the best organized and effective waste management practices among the other institutions under study (Adhikari et al., 2025).

All the wards in the hospital have color-coded dustbins that help the hospital to segregate the wastes at the source. Informative and clear posters are located in the ward entrances and other visible places explaining the correct practice of segregating waste to the healthcare worker, patients, and other visitors (Photo 1 & 2). In line with the national standards, waste is classified as general and hazardous.

In order to minimize the chances of cross-contamination, general and hazardous waste are transported by different trolleys, and each set of waste have its designated route (Photo 3) and separate treatment area (Photo 4). There are two large autoclave machines used to treat infectious waste with the support of a well-built validation system to achieve proper sterilization (Photo 5). Waste is again sorted after treatment to recover recyclable material, and thus, the final amount of waste that needs disposal is decreased.



Photo 1 & 2: Waste segregation at ward entrance and ward side at Bharatpur Hospital



Photo 3 Waste transportation lift for infectious waste **Photo 4** Treatment and storage area at Bharatpur Hospital



Photo 5: Autoclave



Photo 6: Storage box for recyclable waste at Bharatpur Hospital

The primary strength of the system of Bharatpur Hospital is that it incorporates both the environmental and economic advantages. Through adequate segregation, recycling, and sale of reusable materials, the hospital makes about NPR 2 million per annum due to waste. Recyclable waste has safe storage facilities that are well maintained hence hygienic handling. The better waste management actions have led to clean hospital surroundings and less chance of infection. Also, the generated revenue helps in enhancing the services to the patients and ensuring that there is a better healthcare environment.

Moreover, environmentally friendly practices that are being practiced by the hospital include using organic waste to produce biogas which helps the institution recover energy in addition to decreasing the total amount of waste. Formal reporting system, regular audits, using checklists are the institutional mechanisms that allow gaps to be identified and guarantee continuous improvement. Segregation, transportation and autoclaving are among all the major activities that are carried out according to the national standard operating procedures.

Similar practice of waste management can be seen in Khwopa Hospital, Bhaktapur and Norvic International Hospital, Alka Hospital, People's dental Hospital etc. Such hospitals have tried to dispose of their wastes in a more systematic and environmentally friendly. They focus on segregation of waste at its origin, effective management of organic waste and hazardous healthcare waste as part of their day-to-day activities. These kinds of initiatives allow to minimize environmental risks, increase the hygiene level in the hospital premises and show how the healthcare institutions can contribute to the effective and sustainable waste management.

Even though healthcare waste management in Nepal is associated with many problems, the case of Bharatpur Hospital proves that it is possible to find effective and sustainable solutions. Healthcare facilities will be able to turn waste management into a system that safeguards the health of the population, promotes environmental sustainability, and creates economic value with proper infrastructure, awareness, unwavering following guidelines and constant monitoring.

2.2 E-waste in Nepal

2.2.1 E-waste

Electronic waste or more often referred to as e-waste is all electrical and electronic equipment (EEE) and its components that have been discarded by the owner as waste with no intentions of reuse. It operates a large number of end-of-life products such as household products, information and communication technology. e-waste is also known as Waste Electrical and Electronic Equipment (WEEE), electronic waste or e-scrap.

e-waste incorporates a large range of items that are used in homes, institutions, and companies. These include large electrical products like refrigerators, stoves, washing machines, and hair dryers and smaller electronic products like mobile phones, wireless headphones, and tablets. As the world is becoming more electrified and digital, the electronics and digital technologies are influencing the way in which the people live, work, learn, communicate, and do business. Their usage and replacement are also increasing, as more people have access to such devices (Baldé et al., 2024).

Consequently, global e-waste has evolved to be one of the fastest-growing solid waste streams. In 2022 alone, the world produced some 62 million tons of e-waste but only some 22.3% was properly collected and recycled. Millions of electrical and electronic equipment are disposed of each year as they become obsolete, damaged or as a result of newer technologies becoming available. These e-wastes are very harmful to human health and environment unless well handled (WHO, 2024). A significant part of this waste is

processed by the means of informal and unsustainable recycling, and a significant amount of waste is kept at home and in warehouses, deposited in the open space, or illegally exported. These types of improper recycling may also cause up to 1,000 chemical substances to enter the environment including dangerous neurotoxins like lead, which increase environmental pollution and human health risks (WHO, 2024).

2.2.2 Global and regional e-waste generation

The production of e-waste around the world will continue to rise steadily between 2014 and 2030 in both terms of total production and per capita production (Figure 1). The amount of e-waste produced around the world is 44.4 million tons (Mt) in 2014 or 6.4 kg/capita. In 2023, e-waste is increased to 61.3 Mt worldwide and 8 kg/capita, which shows that the issue has been growing steadily. It is expected to keep growing to 67.2 Mt in 2026 and 71.1 Mt in 2028. It is projected that in 2030, the world will produce 74.7 Mt of e-waste, which is equal to 9 kg per capita. The data show that the amount of e-waste generated all over the globe has steadily increased during the 17-year time span. The total e-waste is estimated to grow to 30.3 Mt between the year 2014 and 2030 with corresponding per capita generation rising to 9 kg to 6.4 kg. This tendency states that there are growing demands in consumption of electrical and electronic devices, decreasing durability of the products and this becomes more difficult to manage as an e-pollution globally (Forti et al., 2020).

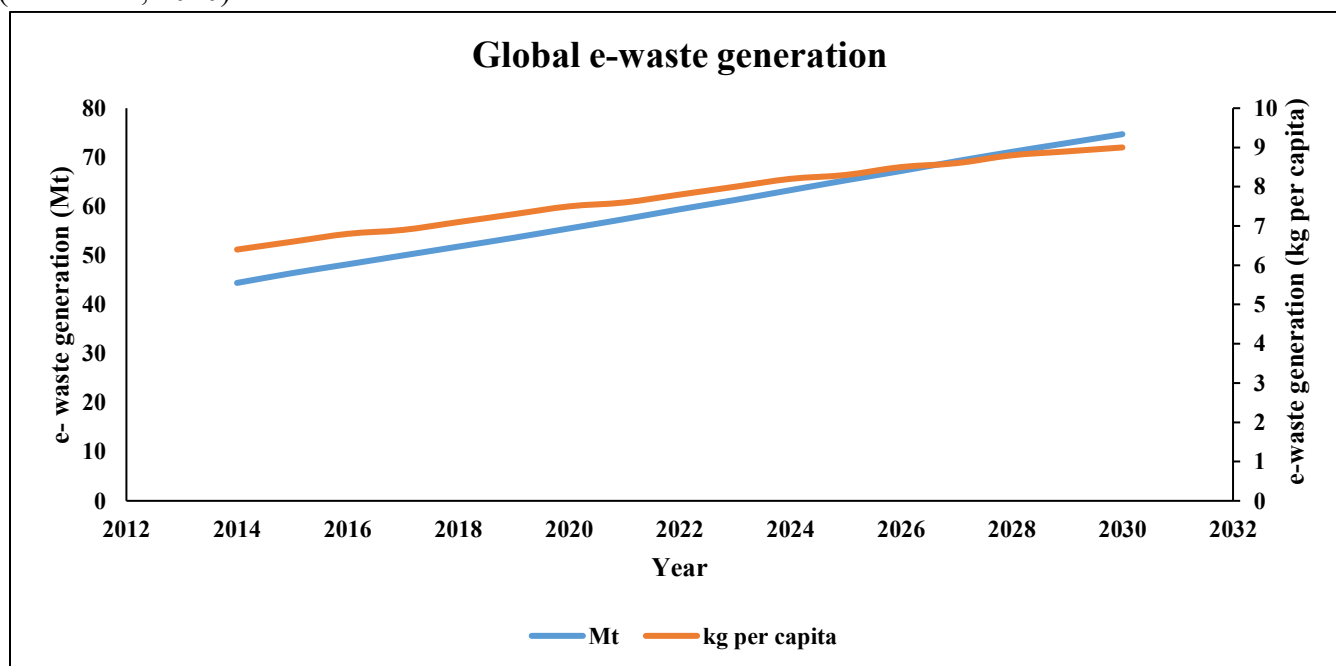


Figure 1: Global e-waste generation

The e-waste generation across the continents in 2019 indicates significant changes in the total amount and per capita amount. The overall amount of e-waste generated in the five continents is 53.6 Mt. Asia contributes the highest amount of 24.9 Mt at 47% of the total amount but the amount per person is 5.6 kg. The Americas produce 13.1 Mt and this is 25% with a comparatively high per capita of 13.3 kg. Europe generates 12 Mt, which is constituting 22 percent of the world e-waste quantity, but has one of the highest rates of per capita generation at 16.1 kg. Africa plays the smallest contribution of only 2.9 Mt which is equal to 5 percent and has the lowest per capita generation of 2.5 kg. The total amount of 0.7 Mt (1%), which is produced in Oceania, is the lowest, but the per capita value is the highest, 16.2 kg (Table 1 & Figure 2). In

general, the result show that the total e-waste generation is mostly in Asia, but Europe and Oceania have the highest per capita production, which is indicative of a higher level of consumptive production of electronic equipment.

Table 6: Regional e-waste generation (Source: Forti et al., 2020)

Continents	Total e-waste generation (Mt)	Kg per capita
Americas	13.1	13.3
Africa	2.9	2.5
Asia	24.9	5.6
Europe	12	16.1
Oceania	0.7	16.2

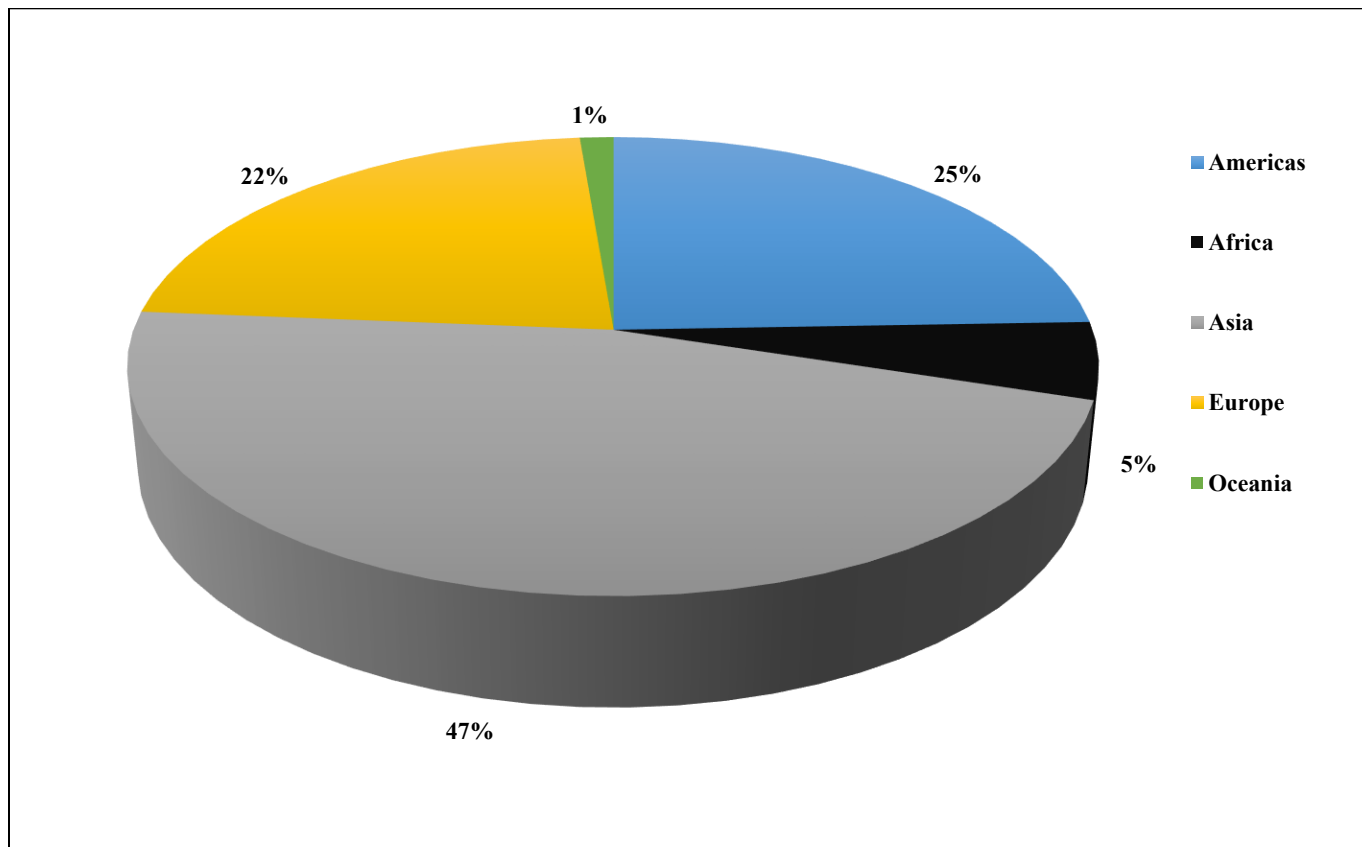


Figure 2: Regional distribution of e-waste generation (%)

2.2.3 E-waste generation in Nepal

The amount of e-waste generated in Nepal is growing rapidly over the years. The total amount of e-waste in 2013 was 13,000 tons. This figure rose to 18,000 tons in 2017, with slow growth. There was a more pronounced increase in the years 2019 where the production of e-waste was 28,000 tons. The trend has been growing in 2023, where the total e-waste reached approximately 42,000 tons, which indicate the increased usage of electronic gadgets and the decrease of the duration of a product life. The projection shows that the figure will increase greatly to 69,000 tons in 2026 (NepaliTimes, 2025), meaning that the rate of the growth of e-waste will increase markedly. In general, the data indicate that the amount of e-waste produced in Nepal grew over five times between 2013 and the estimated one of 2026 (Figure 3). This endlessly

increasing trend demonstrates the necessity of appropriate collection systems, recycling facilities, and efficient policy actions to control the e-waste in the country in a sustainable manner.

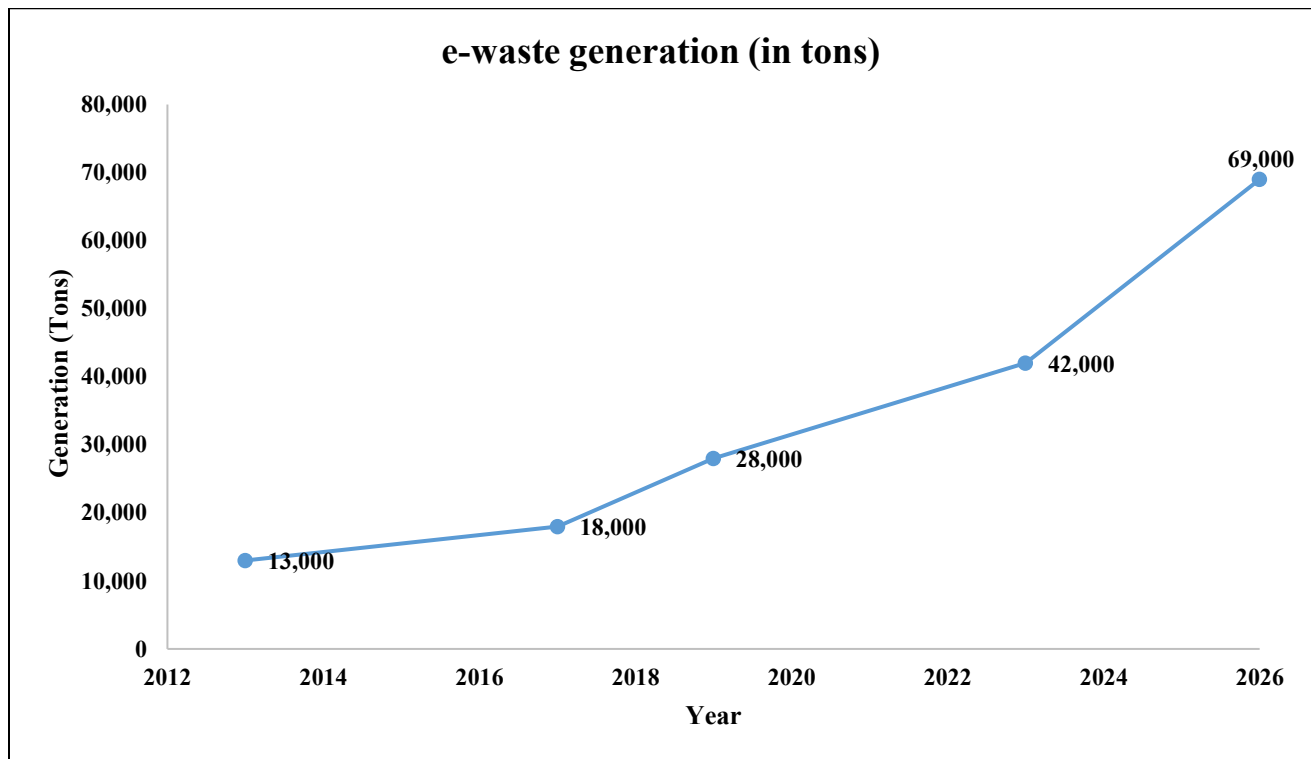


Figure 3: E-waste generation (tons) in Nepal

3. Solid waste management in Nepal

Solid waste has become one of the most burning environmental problems in Nepal especially in the urban areas. The growth in population, urbanization, changing lifestyles, and consumption have greatly contributed to the production of municipal solid waste. The primary role of waste management is carried out by the municipalities, where the collection, transportation, treatment and disposal of waste are performed but the lack of infrastructure, financial limitations and the poor institutional capacity still pose a challenge to effective waste management practices.

Organic materials including food waste, vegetable residues, and agricultural byproducts constitute the largest portion of municipal solid waste in Nepal. Many studies revealed that organic waste makes up over 50 percent of all waste produced in most municipalities (ADB, 2013; SWMTSC, 2017; Lohani et al., 2025). Others are plastics, paper, glass, metals, and textiles. The large percentage of biodegradable waste is a significant resource to recover via composting and vermicomposting. When organic waste is properly managed, it could help decrease the amount of waste produced and transported to landfill and generate useful organic fertilizer that can be used in agriculture.

Waste management practices in most municipalities continue to be based on simple collection and disposal despite such opportunities. Waste is usually transported to a landfill facility or temporary dumping site without being properly treated or segregated. Poor source segregation is one of the greatest issues with the waste management system. The mixing of various waste together complicates the recycling and recovery of resources and aggravates the environmental effects of waste disposal.



Photo 7 Disposal site at Bharatpur Metropolitan City)



Photo 8 Segregated recyclable waste for sale (Bharatpur Metropolitan City)

Pokhara Metropolitan City, Kaski

In Pokhara Metropolitan city, the old sanitary landfill site at Bachhebudha was closed because it was only 2 km from Pokhara International Airport, posing a risk due to its proximity. Currently, waste is being dumped at the Lameahal landfill site as shown in photos, which is about 13 km from the airport. However, Lameahal is not a sanitary landfill site; the waste is covered with earth daily to prevent bad odors. The metropolitan city has fully handed over waste collection to private companies. Currently, six private waste collection companies operate in Pokhara. The estimated waste generation in the metropolitan area is 180-200 tonnes per day (TPD). In other way, households generate an estimated total of 134 TPD. Of this, 82 TPD (61%) is organic wet waste and 52 TPD (39%) is inorganic waste (PPPC, Gandaki & CDES, TU, 2024).



Photo 9: Waste sampling for segregation at Lameahal sanitary Landfill site of Pokahara Metropolitan City



Photo 10: Kitchen waste sampling at household level for Calorific Measurement at Pokahara Metropolitan City

Kushma Municipality, Parbat

The Kusma Municipality has taken approx. 5 Ropani land in rent for 10 years in Alaichibari which is located at ward no 4 of Kusma Municipality to manage the solid waste. The municipality has collected 2-ton organic waste and 1.5-ton of inorganic waste daily from household and dumped in the dumping sites i.e., at Alaichibari landfill site on the way to Beni/Baglung. Total daily waste generation at Kusma Municipality is 6.75 TPD in which 1 TPD is collected in daily basis (PPPC, Gandaki & CDES, TU, 2024).



Photo 11: Waste at Alaichibari Dumping site, Kusma Municipality



Photo 12: Haphazard dumping of glass waste at Alaichibari Dumping site, Kusma Municipality

Gaidakot Municipality, Nawalpur

Currently, waste is being dumped at the bank of Narayani River. The total Municipal waste generation is 16.14 ton/day in which average per capita MSW (g/capita/day) is 199.91. In Gaidakot Municipality, the area covers 159.93 km² with a total population of 80,737, resulting in a population density of 505 persons per km². There are 17,151 households across 18 wards, with an average household size of 4 members. Each household generates about 0.72 kg of waste per day, equivalent to 152.69 grams per capita daily. Altogether, household waste amounts to 12.33 tons per day, while institutional and commercial sources contribute 0.32

tons and 3.49 tons per day, respectively. In total, municipal solid waste generation reaches 16.14 tons per day, with an average per capita generation of 199.91 grams per day (PPPC, Gandaki & CDES, TU, 2024).



Photo 13: Proposed Landfill site at Debachuli Gaidakot Municipality, Kawasoti



Photo 14: Current dumping at the bank of Narayani River in Gaidakot

Chame Rural Municipality, Manang

Chame Rural Municipality has several expectations from the federal and provincial governments, including recommendations for treatment and dumping in cold climates, improved transportation management for segregated recyclable waste, and technical knowledge for managing and operating a sanitary landfill site and other waste management technologies. Municipal solid waste is collected every morning. The rural municipality has managed to segregate cartons, glass bottles, and other recyclables, except plastics at the dumping site. The total waste generation at Chame rural municipality was 0.18 TPD in which 0.14 TPD waste were collected in daily basis. The average residential waste generation (g/day/person) is 146 (PPPC, Gandaki & CDES, TU, 2024).



Photo 15: Stack of glass bottles segregated at Chame dumping site



Photo 16: Dumping site at Chame Rural Municipality



Photo 17: Segregated plastic bottles at Chame dumping site

Beside landfilling, biogas plant (waste to energy), incinerator and mini waste plastic pyrolysis plant are surrogate the waste management practices. Installation of waste to energy plant is a win-win endeavor. It generates energy making us less dependent on imported fuel, produces organic fertilizer, creates job opportunity which uplifts the local people's economic standard and aids in climate change mitigation and the sustainable management of municipal solid waste. In Kathmandu valley, sanitary landfilling technique were applied in the Bancharedada, Nuwakot (JICA, 2024). In Dhangadi, biogas plant for organic waste has been installed and produces 50 LPG cylinder in a day which consume 30 TPD waste per day. Simultaneously, compost and liquid fertilizer are produced in Dhangadi (MoUD, 2025). The hospital waste is also managed by sanitizing and autoclaving before discharging into the community. Kitchen waste in all the municipalities has the highest energy content, averaging 2710 cal/g calorific values in the Chame, which are 3168 cal/g in Pokhara, 3077 cal/g in Kusma and 2363 cal/g in Gaidakot municipality. (PPPC, Gandaki & CDES, TU, 2024) The higher calorific values of kitchen waste recommend energy generation potential in that area. Kitchen waste is also having a big problem. Every year, 1.3 billion tonnes of food is wasted globally, when it rots in fields or landfills, this waste equates to 18 million tonnes of CO₂ emissions (WEF, 2024). Waste glass is a type of construction and demolition waste, which carries significant environmental burdens and can be recycled. The glasses are also used as alkali activated binder production (Ruan et al., 2020). Some glasses are also produced from river-born silicate minerals; therefore, some glasses can be crushed, cleaned, and remelted as a secondary raw material to produce new glass and other products (Rajib et al., 2022).

3.1 Best practices of Solid waste management in Nepal

Dhangadi Sub Metropolitan city

Dhangadi produces around 56 metric tons of waste per day and has opted to use a model of waste management that is based on a public and a private partnership. Waste is carried to a material recovery facility (MRF) that is set in the fiscal year 2080/2081. Micro segregation of organic and inorganic waste is done at this facility. The organic waste goes through the processing stage to compost and biogas, and those

that can be recycled like plastics and metals are sold to dealers. The municipality applies source segregation by imposing fines and by promoting awareness initiatives conducted by social mobilizers. These have enhanced service provision and waste recovery. However, there are still problems with the expansion of services to the rural wards and the incorporation of informal waste workers, as well as the enhanced marketing of biogas (MoUD, 2025).

Bhimeshwor Municipality, Dolakha

The daily waste quantity that Bhimeshwor Municipality produces is approximately 4 metric tons and most of it is organic. The municipality has also developed a material recovery and composting plant and presented a simple segregation system based on the stickers. Bio-degradable waste is placed in green stickers bucket system whereas the non-biodegradable waste is placed on red stickers. A conveyor belt is used to sort waste, plastics are recycled and organic waste is composted. The system has also enhanced the practice of segregation but the amount of revenue received through the collection fees cannot meet the cost of operation. At present, the municipality relies on open dumping which is temporary, but a sanitary landfill is planned. The primary challenges are financial sustainability, inconsistent behavior of segregation, and infrastructure (MoUD, 2025).

Dhankuta Municipality

Dhankuta Municipality produces approximately 6 metric ton of waste materials per day and has adopted an effective strategy of the public-private partnership. Households separate the waste at the source, make use of the organic waste by composting it on their home or feeding their animals. Non-biodegradable waste is collected for recycling. Because of proper segregation, biodegradable waste ends in the landfill in only some 10 percent. There are leachate management and composting plants on the site (MoUD, 2025).

Madhyapur Thimi Municipality

The municipality of Madhyapur Thimi followed a new method of composting based on Japanese CNBM. The project aims at making odorless compost in scientific and environmentally friendly ways. The project shows the possibility of adapting technology to the local waste streams especially organic waste which constitute a significant part of municipal waste in Nepal. The resulting compost can be used in the agricultural sector and encourages the reuse of resources (Moktan & Chandra, 2023).

Bhaktapur Municipality

Bhaktapur Municipality has about 28 tons of garbage which is handled in a dedicated sanitation department. The waste management charges are part of the municipal tax system which makes compliance high. In order to encourage segregation, the municipality offers compost bins at subsidized prices and also sells compost at affordable prices. This has enhanced financial stability with this integrated billing system. Nonetheless, Bhaktapur does not have a material recovery facility, and the space and growing tourist related waste are still putting a pressure on the system (MoUD, 2025).

The Bhaktapur Municipality has been engaged in composting to handle the household, restaurant, school and hospital canteen organic waste. The municipality uses the Tokazai technique, which is a simple and practical composting technique that assists in producing the compost (Photo 18). This practice that has been adapted locally helps decrease the amount of waste and encourages urban farming and gardening. Simultaneously, inorganic waste is dealt with the partnership with Doko Recyclers. Recyclable plastics, paper, metals among others are collected and recycled. This scheme demonstrates how municipal efforts

and collaboration with the private business world can contribute in enhancing waste separation and resource recovery.



Photo 18: Urban composting in Bhaktapur Municipality

Waling Municipality

The success of strict segregation and community involvement can be proved in Waling Municipality. The separation of waste is mandatory to the households and failure to comply results fines or non-collection of waste. The segregated waste is kept apart by municipal workers when collecting it. Non-biodegradable waste materials are sold to recycling firms and this results in the municipal revenue. The vermicompost is made by using biodegradable waste which is operated by a cooperative. Other households also prepare vermicompost themselves, which makes the production of waste in small amount (Annapurna Express, 2023).

Tilottama Municipality, Rupandehi

Tilottama Municipality has implemented source segregation on the household level with separate collection schedules. There are two trucks to be used every twice a week, one to carry biodegradable wastes and the other non-biodegradable wastes. This basic working strategy promotes segregation and enhances efficiency of handling of wastes (Annapurna Express, 2023).

Madhyabindu Municipality

Madhyabindu municipality has begun the process of making compost through windrow composting process from municipal waste. Organic waste is mixed with leaves and cow dung. The mixture is then made windrow and decomposed so as to form compost (Photo 19). The project is being carried out with the cooperation of Gandaki State Government as part of the New Development Program of the Chief Minister.



Photo 19: Windrow composting in Madhyabindu Municipality

3.2 Waste management in Rural municipality

Managing household waste in Nepal in many rural municipalities is still being conducted in the traditional way. Organic waste such as kitchen scraps and crop residues is usually mixed with cow dung in pits and left to break down on natural condition. This resulting compost is normally used in agricultural fields. This is however not a uniform practice in all the rural areas. In some places, organic wastes are mixed with non-biodegradable materials and disposed in open spaces, rivers and streams, and other water bodies. Moreover, both organic and inorganic waste are also normally open-burned.

The fact that transporting waste is expensive and that the roads are inaccessible also worsens waste management in remote settlements. Since recyclable products are not easily transported to the markets, plastics, glass bottles, and other waste products that can be reuse and recycled are often disposed into rivers and streams. Plastic waste is normally burnt and those that are partially burnt or discarded are left in agricultural land (Photo 20 & 21). The rural residents are not well aware of health and environmental hazards of improper disposal of waste, such as water pollution, soil pollution and respiratory complications due to open burning.



Photo 20 & 21: Waste burning in Bogtan Phudsil Rural Municipality, Doti

3.3 Waste management in household level

Management of organic waste is common at the household level. Bin composting and vermicomposting is done in many households in Kathmandu Valley and other areas in Nepal. Though exact data on such practitioners are not available, such small-scale efforts are becoming more evident in urban and peri urban regions. Kitchen and food waste by most households are used to generate compost which is used in flowerpots, kitchen gardens and rooftop farming. This can be used to control a part of the organic waste in the source and the level of waste delivered to the municipal collection systems.



Photo 22: Vermicomposting practice in household level at Kalimati, Kathmandu

Nevertheless, the household composting is constrained by a number of challenges that restrict its continuity. Some of the problems encountered by the users include the formation of leachates, foul smell, and the presence of rodents and insects. To a great extent, these technical issues are associated with the lack of training and the knowledge about the process of composting. They usually lack knowledge of the right proportion of carbon rich and nitrogen rich materials. Because the household waste is primarily made of the nitrogen rich kitchen waste, there are limited sources of carbon, thus poor compost quality, smelling and moisture issues. Consequently, other households abandon composting after the first experiences. Urban homes also have also limited space which is another significant limitation. Moreover, several residents of rented homes in Kathmandu valley do not prefer using composting as they do not have a permanent location or the consent of the houseowner.



Photo 23: Household compost bin



Photo 24: Compost making worms (*Eisenia fetida*)

3.4 Challenges in solid waste management in Nepal

Solid wastes management in Nepal is under a constantly growing pressure due to the economic activities that generates high volumes of solid wastes including the hazardous e-waste, batteries, and medical waste. Poorly resource systems, and changing lifestyles result in the proliferation of plastics and disposables and a decline in traditional organic waste. Rapid urbanization, lack of coordination at all governmental levels and deep-rooted misconceptions that consider waste as the responsibility of the municipalities rather than collective responsibility make the current practices of open dumping, riverside disposal and open burning ineffective and unsustainable. Municipalities allocate 70-80 percent of their budgets on basic collection, and there remains little to spend on treatment/recycling or sanitary landfills.

Over the last three decades, urban centers in Nepal have witness changing perceptions on sanitation and waste, with increasing awareness of solid waste issues and possibilities such as recycling; however, individuals do not take action and adhere to traditions such as not in my backyard, while there is limited consideration by the federal government and municipalities in sustainable solid waste management as focus remains on other urban utilities and infrastructures. Although the Solid Waste Management Act 2011 required source segregation, there remains poor enforcement, with home owners neglecting sorting, no controls and monitoring, and continued illegal dumping and open burning. Municipalities also face poor infrastructure, lacking sufficient waste trucks, population-sized bins, proper transfer stations, and facing access issues due to narrow roads and bad hillside conditions, resulting in long trips to dumps. In addition, poor technical knowledge limits skills in compost, biogas, and large-scale recycling, creating a gap where waste is not converted into fertilizer or energy. Furthermore, inadequacy of human and financial resources, including lack of qualified personnel and insufficient funding, leads to inadequate waste collection vehicles, irregular collection processes, open dumping, burning, and inadequate landfill location.

3.4.1 Challenges of waste management in mountain region

Nepal is a globally recognized destination for mountaineering and trekking. However, the increasing number of trekkers and climbers has resulted in substantial quantities of solid waste, including plastics, food packaging, glass bottles, metal cans, oxygen cylinders, batteries, tents and human waste, posing a significant threat to the fragile mountain environment. Evidence from Ghandruk, a major tourist destination in the Annapurna region, indicates that organic waste constitutes approximately 60% of the total waste stream, while recyclable materials such as plastics and glass are becoming increasingly prevalent. The average waste generation rate was reported to be 261.3 g per capita per day (Adhikari et al., 2024). These findings demonstrate that traditional waste management practices, which primarily focus on organic waste management, are no longer sufficient for rural tourist destinations.

Open burning of non-recyclable waste remains a major concern in many tourist areas. Organizations such as the Annapurna Conservation Area Project (ACAP) continue to collaborate with local communities to improve awareness on impact of improper waste management (Adhikari et al., 2024). Nevertheless, increasing tourist arrivals continue to place considerable pressure on Nepal's fragile mountain ecosystems. A big concern has been increased about the garbage on Mount Everest such as increasing amounts of abandoned oxygen cylinders, tents, food packaging, and climbing gear at high camps which is difficult and hard to remove. It has estimated that 40–50 tonnes of waste remain on Everest, much of it frozen into glaciers. This littered with frozen garbage, and cleanup is likely to take years (Gurubacharya, 2024).



Photo 25: Dirty Everest and messing of trash, South China Morning Post, Photo Source: Bhandari, 2024



Photo 26: Faecal matter and garbage cleared off of Mount Everest, published by Condé Nast Traveller India; Photo source: Sherpa, 2010

To address these concerns, Nepal has introduced several regulatory mechanisms. The Mountain Expedition Rules (2002) require climbers to bring back all non-biodegradable waste, including plastics, metals, and oxygen cylinders. The rules also mandate the use of portable toilets and proper management of human waste, bring back human waste. In addition, the Environment Protection Act (2019) and Solid Waste Management Act (2011) provide legal support for managing waste generated during mountain expeditions (Biswakarma et al., 2023).

The Sagarmatha Pollution Control Committee (SPCC) has been established to manage waste within the Sagarmatha National Park, including Mount Everest and its surrounding areas. The SPCC has implemented designated waste collection and disposal systems at different elevations, with regular transportation of waste to lower elevations for proper treatment and disposal. Despite these initiatives, reports continue to highlight inadequate waste management practices and significant environmental pollution in mountain regions

(Biswakarma et al., 2023). Solid waste management remains one of the most pressing issues in the Mt. Everest region and has been exacerbated by the rapid growth of tourism. Open and unsightly landfill sites located near villages along major trekking routes are creating serious environmental and public health concerns due to the routine burning of waste, release of toxic chemicals and contamination of groundwater resources (Byers et al., 2020).

3.4.2 Challenges of construction and demolition waste management

Construction and demolition (C&D) waste, commonly referred to as debris, has emerged as a significant environmental challenge in Nepal due to rapid urbanization, infrastructure development and the increasing frequency of natural disasters. Debris is generated during the construction, renovation, maintenance, demolition and excavation of buildings and infrastructure, often in substantial quantities (Obradović & Šperac, 2022). In Nepal, the issue became particularly evident following the 2015 Gorkha Earthquake, which generated an estimated 3.23 million tons of debris within the core areas of Kathmandu Valley. However, only 1.07 million tons were managed within two years, while a considerable portion (0.63 million tons) was openly dumped along riverbanks, roadsides, and vacant spaces (Poudel et al., 2019). Improper disposal of debris not only degrades landscapes and obstructs drainage systems but also contributes to river pollution and increases the risk of flooding and soil instability. Furthermore, debris generated from disaster affected areas occupies extensive land areas and requires significant financial resources, technical expertise, and long periods for collection and treatment.

3.4.3 Challenges in Urban Composting in Nepal

Urban areas have major challenges in utilizing composting as an effective waste management intervention, even though organic waste makes up a significant percentage of the municipal solid waste. The local authorities prioritize the use of landfilling and dumping because of the lack of resources and thus they do not invest in the composting infrastructure. These problems hinder the sustainable waste management.



Photo 27 & 28: Urban composting conducted by NEPCEMAC at Chalnakhel, Kathmandu

Most budgets distributed by municipalities are used in the collection and transportation of waste, leaving small portions to composting and safe disposal, where landfilling and open dumping is the most common and there are very few cities using sanitary landfills, with low interest on composting despite successful

small-scale community composting experiments in Nepal. Poor interest in composting is also seen in households due to lack of awareness, cultural shifts towards disposable plastics, and decreasing willingness to segregate wastes, while attitudes to compost, earthworms and general management are negative without education, requiring specific programs for behavior change. Source segregation is not very successful in cities such as Kathmandu, where mixed waste is received at transfer stations and mixed with recyclable non-biodegradable materials, making composting difficult, while insufficient space in rental housing discourages composting practices and leads to disposal of organic wastes in landfill site. Composting is further limited by shortages of carbon-rich waste such as dry leaves and saw dust in urban areas, high equipment costs for composting machines and plants, lack of proper training on composting process, and poor monitoring and practices that result in inconsistent compost with immature compost, pathogens or weeds.

Several new technologies have been emerged and practiced to manage solid waste at global, regional, national scales. In China, one of the large waste generators in the world where the amount of MSW collected has been largely decoupled from economic growth and incineration has become an increasingly widespread treatment method for MSW (Chen et al., 2010). Globally, the amount of collected MSW incinerated with energy recovery has reached approximately 324 million tons per year (Levaggi et al., 2022). In 2016, waste incineration contributed to approximately 1 per cent of global renewable energy generation, corresponding to a global total of 52 TWh of electricity (IRENA, 2018). The Waste to Energy (WTE) incineration plants have become the preferred alternative to landfilling in Europe and the US, and their numbers are also increasing in Asia (Makarichi et al., 2018). The advantages of waste incineration over conventional landfills are that it requires less land resources than landfilling, reduces the volume of waste by up to 90%, and converts solid waste into energy. Furthermore, incineration prevents the release of methane gas and mitigates soil and water contamination. The solid residues from the plant are inert and can be disposed of in a landfill or blended with building construction materials. Thus, landfilling serves as an alternative energy source, thereby playing a vital role in addressing the energy crisis, offsetting fossil fuel consumption, and increasing the renewable energy share while assisting waste management (CBS, 2021). Beside landfilling, biogas plant (waste to energy), incinerator and mini waste plastic pyrolysis plants are surrogate waste management practices. Installation of waste to energy plant is a win-win endeavor. It generates energy making us less dependent on imported fuel, produces organic fertilizer, creates job opportunity which uplifts the local people's economic standard and aids in climate change mitigation and the sustainable management of municipal solid waste. In Kathmandu valley, sanitary landfilling technique were applied in the Bancharedada, Nuwakot. In Dhangadi, biogas plant for organic waste has been installed and produces 50 LPG cylinder in a day which consume 30 TPD waste per day. Simultaneously, compost and liquid fertilizer are produced in Dhangadi. The hospital waste is also managed by sanitizing and autoclaving before discharging into the community (PPPC, Gandaki & CDES, TU, 2024)

Kitchen waste is also having a big problem. Every year, 1.3 billion tonnes of food is wasted globally, when it rots in fields or landfills, this waste equates to 18 million tonnes of CO₂ emissions (WEF, 2024). Waste glasses are the type of construction and demolition waste, which carries significant environmental burdens and can be recycled. The glasses are also used as alkali activated binder production (Ruan et al., 2020). Some glasses are also produced from river-born silicate minerals, Glass is primarily manufactured from silica (SiO₂), which is commonly obtained from quartz-rich river or beach sand. Waste glass can be crushed, cleaned, and remelted as a secondary raw material to produce new glass products, thereby reducing the demand for virgin silica resources (Rajib et al., 2022). This management and recycling of construction and

demolition waste offer environmental benefits and conservation of natural resources. The new magnetic composite materials can be prepared by wet chemical synthesis methods using crushed glasses and iron and steel waste powders as raw materials (Rada et al., 2023).

4. Conclusion and Recommendation

The generation and composition of solid waste in Nepal has gradually shifted over time. Most of the solid waste that was produced in the past was organic in nature and was mostly food waste and biodegradable products. At present, non-biodegradable waste like plastics, packaging materials and other wastes have however, become very high with urbanization and change in consumption pattern. Moreover, there is an expansion of hazardous waste such as electronic waste and it is a major challenge that should be addressed. Large percentage of organic waste that can be composted and reused is not handled well. There are also programs of composting in certain municipalities, but these are not on regular way. As a result, valuable organic resources are being disposed in dumping sites. Moreover, most of the municipalities do not have sanitary landfills, compost plants and resource recovery centers. In the absence of such infrastructures, effective segregation, recycling and treatment of waste cannot be easily achieved. Very few municipalities have shown the comparatively efficient waste management systems, and mostly succeeded in collaboration with the private sector and community involvement.

Sustainable solid waste management in Nepal can be attained through formulation of appropriate strategies and action plans at the municipal level to provide safe and ecofriendly services with the emphasis being on resource recovery rather dumping. Such plans should consider SWM as an urban infrastructure just like roads and water supply and increase technologies such as composting and biogas over time and maintain control as per Solid Waste Management Rules 2013 that provide monitoring of segregation, processing, and disposal. For the effective solid waste management, local bodies must motivate communities, individual companies, women, youth, and NGOs with rewards, service discounts, public recognition, and penalties for violations, while strengthening policies through updating 2011 Act, providing training to municipal staff and communities, and establishing public-private partnerships for funding and operations are necessary. At the same time, site-specific solutions such as household composting, community composting/vermicomposting, and anaerobic digestion should be prioritized, along with regular monitoring through ward committees, audits, and digital reporting apps to track segregation and landfill diversion and scale proven approaches.

Waste management in high altitude regions of Nepal requires innovative and site-specific strategies due to the unique challenges of remoteness, difficult terrain, extreme weather conditions, high transportation costs and increasing waste generation from tourism and mountaineering activities. Effective management can be achieved by strengthening the implementation and monitoring of the Mountain Expedition Rules (2002)

and enforcing penalties for non-compliance. Waste management initiatives should be expanded beyond Everest Base Camp to include higher camps and other major trekking destinations across the Himalayas. Source segregation at trekking lodges, tea houses and campsites along with decentralized waste collection, transfer stations and composting facilities at lower elevations can significantly reduce the volume of waste requiring transportation. The promotion of reusable, lightweight, and biodegradable materials as well as the exploration of innovative transportation options such as drones and cable systems may further improve waste handling in inaccessible areas. In addition, stronger collaboration among local governments, conservation organizations, trekking agencies and local communities is essential with successful models such as ACAP and SPCC serving as examples for replication in other Himalayan regions. Finally, environmental awareness programs and long-term scientific monitoring are necessary to encourage responsible behavior among visitors and stakeholders and to evaluate the effectiveness of waste management interventions over time. Nepal should strengthen policies and guidelines for construction and demolition waste management, establish designated recycling and disposal facilities, promote the reuse of construction materials, and integrate debris management into urban planning and disaster preparedness strategies. Such measures would help reduce environmental impacts and improve the resilience and sustainability of rapidly developing urban areas.

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Glossary

Autoclaving: A treatment method that uses high-pressure steam to sterilize waste.

Bin composting: Method of preparation of compost in bin.

Carbon rich waste: Waste which is rich in carbon such as dry leaves, paper, hay, saw dust etc.

E-waste: Electrical and electronic wastes that have been discarded by the owner.

Hazardous waste: Waste materials that pose potential risks to human health and the environment due to their toxic, corrosive, flammable, reactive, or infectious nature.

Resource recovery: Conversion of waste into useful economical products or useful energy

Source segregation: Separation of waste at the site of generation.

Transfer station: Temporary facility where waste is collected from households and market place and transferred from collection vehicles to larger trucks for transportation to treatment plants or landfill sites.

Vermicomposting: Method of compost preparation with the help of earthworms and microorganisms.

Windrow composting: Large scale composting method in which organic waste mostly agricultural waste is piled into long rows called windrows and regularly turned to supply oxygen.

CHAPTER: VII

Energy and Environment in Nepal

Rashila Deshar¹, Suman Man Shrestha¹

¹Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal

Email: rdeshar@cdes.edu.np, suman.shrestha@cdes.tu.edu.np

Summary

Nepal is experiencing socioeconomic transition, moving from a traditional biomass-based society to a modern electricity-based economy. Historically, the energy sector has shown significant dependency on solid biofuels, which constituted 63.9% of the total energy composition up until 2024. While traditional sources like fuelwood remain dominant in rural areas, the nation has undergone an unprecedented growth of hydroelectric power generation capacity, from being a sufferer of prolonged dreadful load-shedding to becoming a seasonal exporter of clean energy. The energy-emission nexus highlights that the energy sector is Nepal's largest greenhouse gas (GHG) emitter, comprising 50% of total national emissions by 2050 according to estimates. This issue is largely because of reliance on imported petroleum and coal in the transport and industrial sectors. The combustion of low-grade coal in brick kilns and traditional biomass fuel for cooking purposes significantly contributes to black carbon and particulate matter, leading to the melting of Himalayan glaciers. Despite all these perspectives, Nepal has achieved a remarkable 45% reduction in energy intensity per unit of gross domestic product (GDP) since 1990, suggesting that Nepal is successfully managing to decouple its economy from wasteful energy usage. Nepal's sustainability plan can be visualized through the nation's third nationally determined contribution (NDC 3.0). It outlines a challenging goal to reduce net GHG emissions by 26.79% by 2035 compared to business-as-usual (BAU) levels. Policy goals include increasing clean energy capacity to 28,500 MW and achieving 95% sales share of private electric vehicles by 2035. These targets support Sustainable Development Goal (SDG) 7 (affordable and clean energy) and align with the country's goal of achieving net-zero emissions by 2045. However, achieving these targets presents major hurdles, particularly a substantial financing gap and limited technical resources.

Keywords: Energy Efficiency; Fossil Fuel-based Emissions; GDP; NDC; Renewable Energy

1. Background

Energy plays a significant role in human life and is also one of the major inputs for the economic development of a country. The energy sector plays a major role in the economic development of Nepal, promoting industrial productivity and economic stability (Dhungel, 2007; Surendra et al., 2011). Although Nepal was scheduled to graduate from least developed country (LDC) status to a developing country by 2026 (NPC, 2024a), this has now been deferred to 2029 (UN, 2026), indicating how national energy demand has shifted from a basic need to an economic strength. Energy supports economic growth and enables the development of the nation, addressing several societal issues related to the well-being of people (Gippner et al., 2013; Sapkota et al., 2013). Energy has penetrated deep into the economies, facilitating services such as cooking, heating, cooling, lighting, operation of appliances, information and communication technology, and the functioning of machines (Surendra et al., 2011; Kafle et al., 2020). Therefore, energy and its resources are considered important national assets. Additionally, it is important to follow the path of

sustainable energy, which will open avenues for transforming lives and economies and safeguarding the planet (Surendra et al., 2011; Gippner et al., 2013).

For a country like Nepal, with rapidly growing energy demands, a reliable energy sector is most essential. Nepal has no commercially viable major fossil fuel, gas, or coal reserves; as a result, most Nepalese citizens rely on biomass and imported fossil fuels, which directly impact forest health and air quality (Pokharel & Chandrashekar, 1994; Baral et al., 2019). Historically, biomass has been a major contributor to Nepal's energy consumption, contributing up to 68% of the country's entire energy mix as of 2020 (WECS, 2024). In rural mountainous regions, the dependency on fuelwood and agricultural residues has significant effects on the environment, including indoor air pollution and forest destruction (Banerjee et al., 2025; Ghimire & Mishra, 2025). Hydroelectricity has emerged as Nepal's main energy source for both economic growth and environmental sustainability (Adhikari, 2012; Bhatt, 2017). With technological changes, economic growth, demographic changes, and the spread of electricity transmission lines, there has been a change in the energy requirement patterns of Nepalese society. Therefore, Nepal is shifting from a traditional biomass-dependent society to a modern electricity-driven economy (Bhatta & Lohani, 2025; Khadka et al., 2025). Furthermore, Nepal's commitment to utilize its renewable energy within the framework of its NDC 3.0 can be regarded as an important opportunity for its economic and environmental benefits (GoN, 2025). It aims to capitalize on local renewable resources of hydropower and solar energy to ensure energy security and achieve economic growth without depending on traditional biomass and petroleum imports (Khan et al., 2025). In the last decade, Nepal has experienced an unprecedented expansion of its hydroelectric capacity. In addition, Nepal has transitioned from a nation with prolonged dreadful load-shedding to a seasonal exporter of clean energy to the South Asian grid (Gyanwali et al, 2022; Aryal et al., 2024; NEA, 2025). The surplus renewable energy allows Nepal to grow its economy without relying on imported fossil fuels, saving foreign currency and reducing carbon emissions (York & McGee, 2017; Subedi & Dahal, 2025).

In the context of environmental statistics, the energy-emission nexus refers to the direct correlation between fuel combustion and climate change. The Third National Communication (TNC) and the latest Biennial Transparency Report (BTR1) identify the energy sector as the nation's largest emitter, projected to account 50% of total emissions, excluding land use, land-use change, and forestry (LULUCF) by 2050 (MoFE, 2025a). This is primarily due to the dependency of transport and industrial sectors on imported petroleum products and coal. The environmental impact is not limited to CO₂ emissions. The combustion of traditional biomass and low-grade coal in brick kilns contributes significantly to black carbon and particulate matter (PM_{2.5}), inducing the urban heat island effect in urban areas and accelerating glacial melt in the Himalayas (Pandey et al, 2012; Rybarczyk et al., 2025; Wang et al., 2025).

The Government of Nepal has integrated energy and environment into its main development strategy through the 16th National Plan (FY 2024/25–2028/29). The plan prioritizes green economy initiatives, targeting to increase per capita electricity consumption to over 700 kWh by 2029 (NPC, 2024b). Additionally, Nepal's NDC 3.0 under the Paris Agreement, submitted in May 2025, sets an ambitious target to reduce net GHG emissions by 26.79% by 2035 compared to the BAU scenario (GoN, 2025). These initiatives support SDG 7 (affordable and clean energy), SDG 12 (responsible consumption), and SDG 13 (climate action), ensuring energy statistics as a vital tool for pursuing sustainable development progress (South & Alpay, 2025). The 16th Five-Year Plan and the Global 2030 Agenda for Sustainable Development visualize the critical importance of the energy-environment nexus. To address the dynamics, this chapter provides a comprehensive overview of Nepal's sectoral energy consumption, historical energy balances, and expanding renewable energy adoption. It quantifies energy flows across various sources and analyzes

their environmental footprints, particularly fossil fuel dependencies and sub-sectoral GHG emissions. By evaluating territorial, consumption and extraction-based emissions along with BAU and NDC 3.0 policy projections, this chapter also provides the empirical baseline needed to track Nepal’s journey toward its net-zero 2045 commitment, which aligns with global SDGs and safeguards environmental sustainability.

2. Energy scenario and consumption pattern of Nepal

Nepal is currently undergoing a major socioeconomic transformation as it is scheduled to graduate from LDC status (NPC, 2024a). This transition is supported by consistent long-term economic growth, with GDP per capita increasing from USD 204 in 1990/91 (CBS, 1991) to USD 1,496 in 2024/25 (NSO, 2025). Although the country is undergoing rapid urbanization, the demographic distribution remains predominantly rural, with approximately 77.6% of the population residing in rural areas (World Bank, 2024; NSO, 2025), a gradual decline from the 83% recorded in the 2011 census (CBS, 2012). Despite changes in its dynamics, the economy continues to rely heavily on agriculture, accounting for 24.1% of the national GDP (MoF, 2024). Under this developmental framework, Nepal’s energy matrix is classified into three primary streams. The first is traditional energy, which comprises fuelwood, agricultural residues, and animal dung. The second category is commercial energy, which consists of petroleum products, coal, and grid-scale hydropower. The third category is renewable energy that includes solar, wind, biogas, and various small-scale hydro systems (WECS, 2023) (Figure 1). The total percentage of each major energy flow indicates that traditional energy (63.9%) is more dominant than commercial (33%) and renewable (3.1%) energy flows, as illustrated in Figure 2 (WECS, 2024). The lack of financial and technical resources continues to compel the rural population to rely on these inefficient and health-hazardous solid fuels for household use (Bhandari & Stadler, 2011; WECS, 2024).

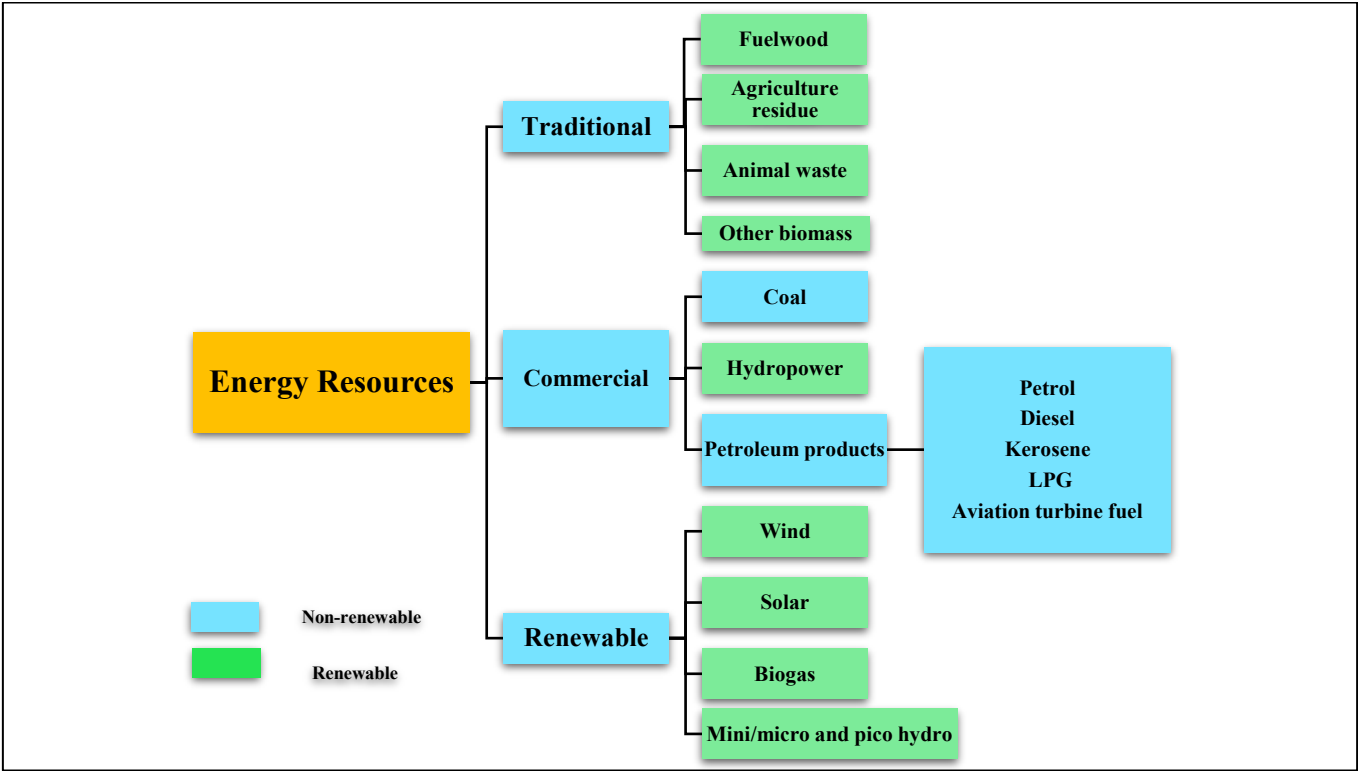


Figure 1: Energy sources of Nepal (Adapted from: WECS, 2023)

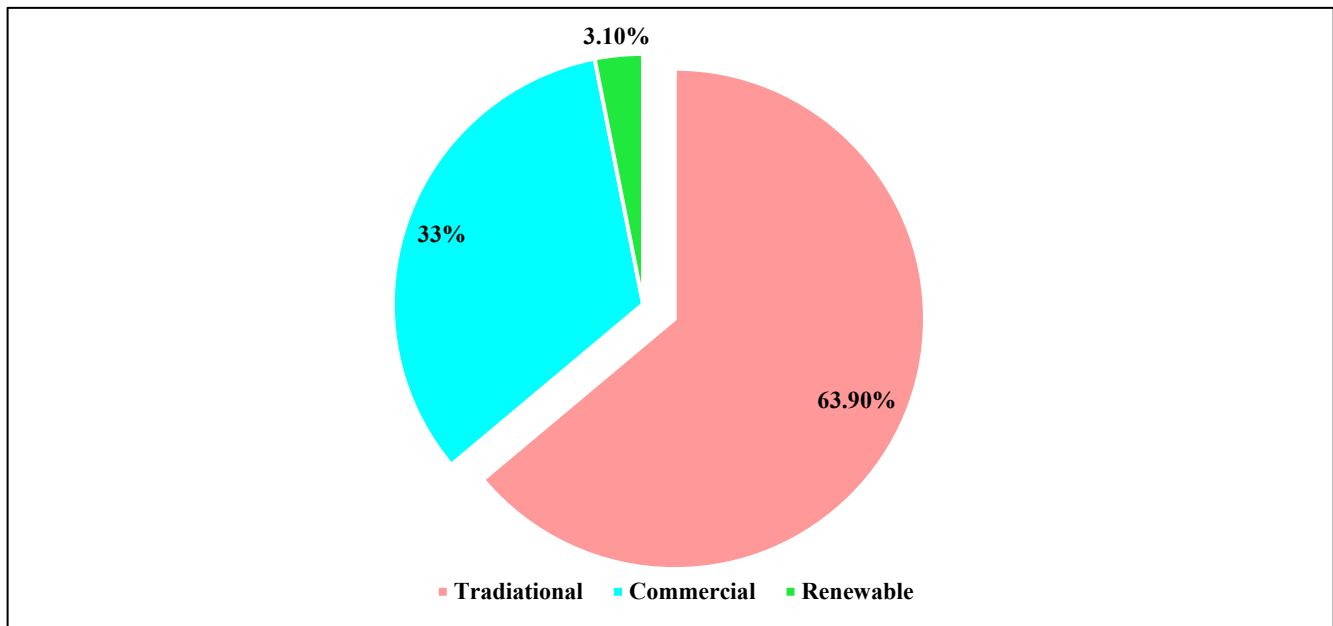


Figure 2: Energy consumption pattern of Nepal in 2024 (Data source: WECS, 2024)

The energy consumption pattern in Nepal suggests a considerable dependence on non-commercial sources of energy and an emerging modern energy infrastructure. The pattern can be divided into traditional energy, commercial fuel (petroleum and coal), commercial grid electricity, and off-grid renewable energy, as illustrated in Figure 3 (WECS, 2024). The most prominent source of energy consumption in Nepal is traditional energy sources, which contribute more than 340 PJ. The energy sources include biomass such as fuelwood, agricultural residues, and animal dung. The consumption of biomass in rural households is dominant due to limited access to modern energy alternatives.

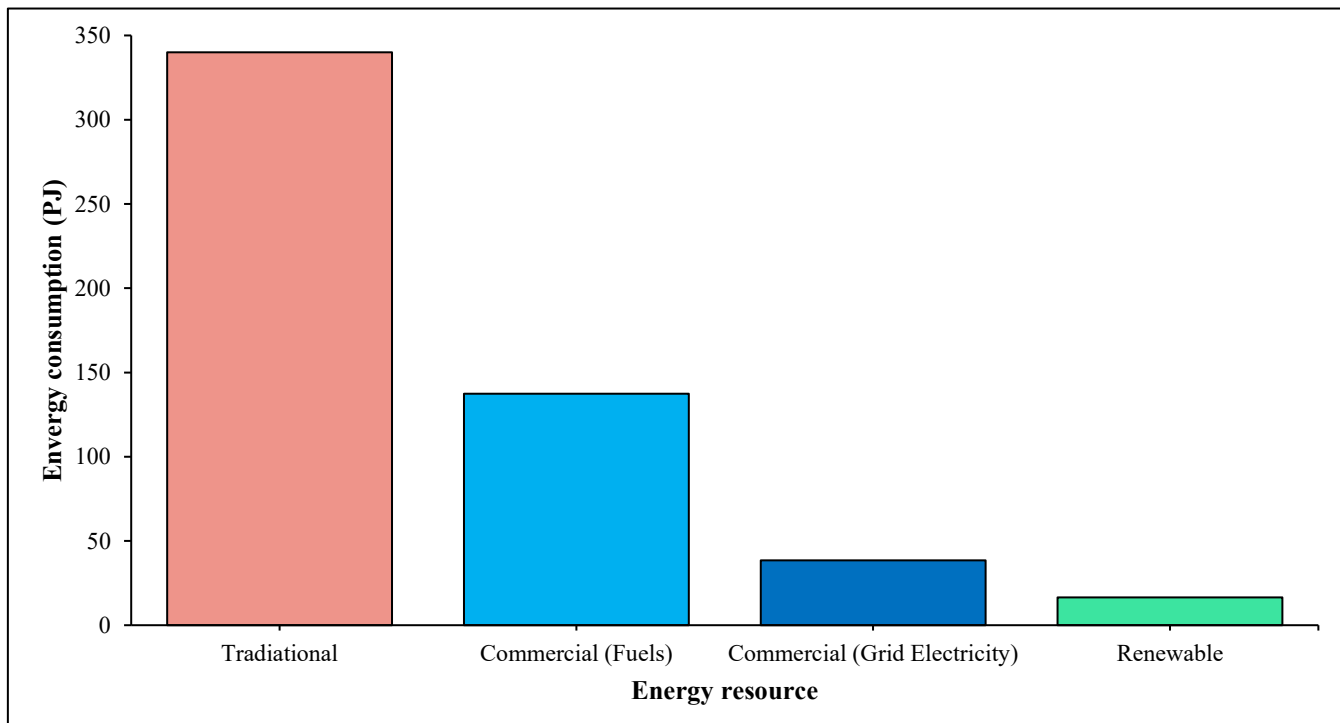


Figure 3: Energy consumption pattern in Nepal (Data source: WECS, 2024)

The traditional source of energy in Nepal is predominantly dependent on fuelwood. According to the National Census 2021, the percentage of households relying on fuelwood as their primary cooking fuel has dropped to 51% from 64% in 2011 (NSO, 2023). Although there is a reduction in the national average trend, the dependency on fuelwood is not geographically uniform. In the mountainous region and hilly region, 96% and 65.5% of the households, respectively, depend on forests for fuelwood. Nepal's forest and other wooded land (OWL) cover 45.31% of the country's total area (FRTC, 2024). The dependency on fuelwood has decreased to approximately 51% nationally, and more than 80% of rural households, particularly in the mountainous and hilly regions, still depend on forests for timber, fuelwood, and fodder for subsistence (NSO, 2023; FRTC, 2024).

Fuelwood, as a traditional source of energy, is derived from forests (43.38%) and OWL (2.70%) in Nepal, accounting 46.08% of Nepal's total land area, which is a slight increase (0.75%) since 2019 to 2022 (NLCMS, 2024). In Nepal, there is uneven distribution of forests and OWL in all the provinces. The largest share of the country's total forest is in Koshi (19.28%), followed by Bagmati (18.12%), Lumbini (16.05%), Sudurpaschim (15.66%), Karnali (13.72%), Gandaki (13.48%) and Madhesh (3.69%) (Figure 4). There is a slight increase in forest cover in Koshi, Madhesh, Lumbini, and Sudurpaschim provinces, while it decreased scantily in Bagmati, Gandaki, and Karnali between 2019 and 2022 (FRTC, 2024).

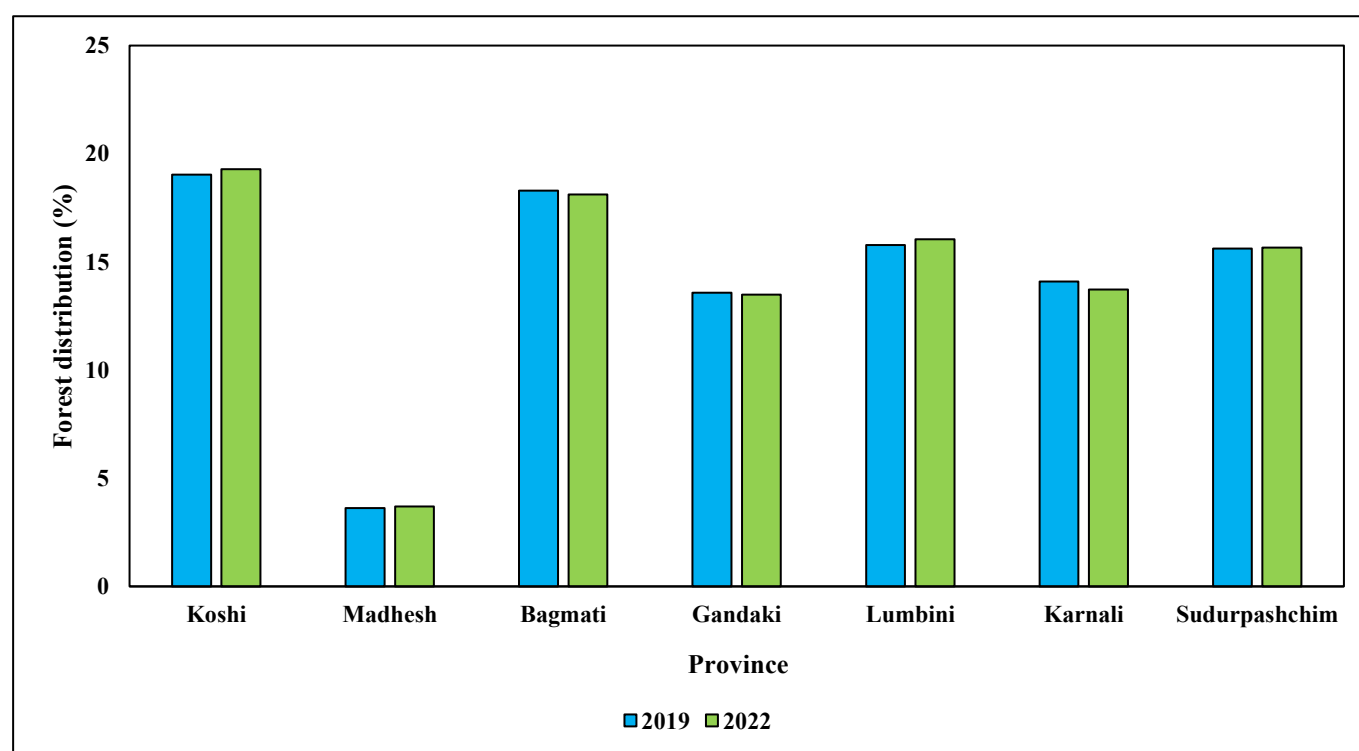


Figure 4: Forest distribution in seven provinces of Nepal between 2019 and 2022 (Data source: FRTC, 2024)

In Nepal, community forests constitute the second-largest management regime after government forests and are managed by local communities for sustainable resource use, supporting conservation and development. The forests are the primary source of fuelwood for the majority of rural households. The total area covered by community forests constitutes 15.67% of the total area of Nepal (Pandey & Shah, 2023). Forest expansion in Nepal has mainly been attributed to community forestry interventions, especially in

mountainous regions (Gautam et al., 2002; Niraula et al., 2013; Poudel et al., 2015). Koshi has the largest community forest coverage among the seven provinces of Nepal, followed by Bagmati, Lumbini, Sudurpashchim, Karnali, Gandaki, and Madhesh (Figure 5). The community forest distribution varied significantly across the provinces (Pandey & Shah, 2023). The variation in the distribution is associated with the contribution of community management in meeting local energy demand. Furthermore, as a signatory of multiple international multilateral environmental agreements, Nepal's community forests remain a matter of concern for both local and international communities (NPC, 2019).

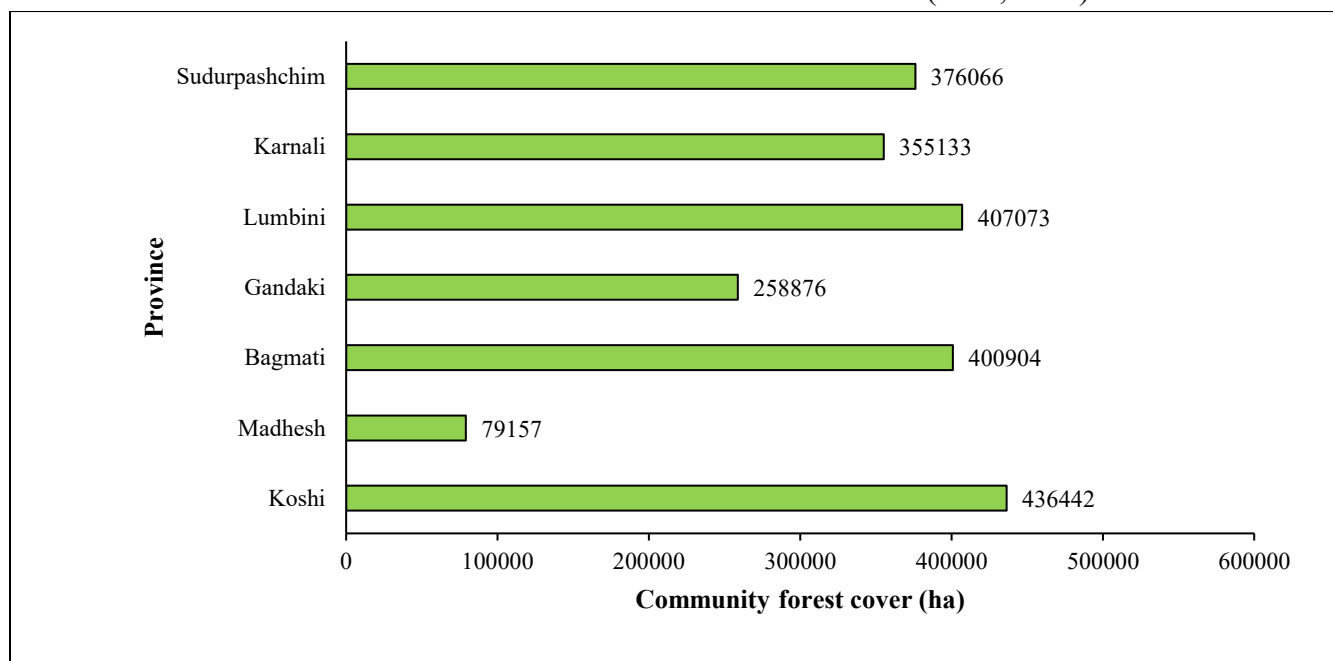


Figure 5: Community forest coverage in different provinces of Nepal (Data source: Pandey & Shah, 2023)

Within the traditional energy consumption pattern in Nepal, agricultural crop residues and animal dung also serve as a source of traditional energy for the majority of rural households (Figure 3). Various agricultural crop residues generated from paddy, wheat, millet, and corn are the major sources. Paddy is the most abundant, accounting for more than half of the total share (Gadal et al., 2019). The open burning of crop residues is practiced in Nepal, resulting in air pollution (Sadavarte et al., 2019).

The commercial fuels are the second-largest source of energy consumption in Nepal, accounting for approximately 137 PJ (Figure 3). This category comprises imported petroleum products (diesel, petrol, and LPG) and coal. These fossil fuels are the primary contributors to CO₂ emissions within the country's energy-emission nexus (Khadka et al., 2015; Raihan & Tuspekova, 2022). With the expansion of transport and industrial sectors, the heavy reliance on commercial fuels poses challenges for Nepal to meet targets under the NDC 3.0 commitments.

The third category is commercial grid electricity consumption, which is approximately 39 PJ (Figure 3). It is a lower percentage of the total volume of energy consumption in comparison to biomass or fossil fuels and is recognized as the most important sector of energy for Nepal's sustainable development. Nepal's grid electricity is generated from large and medium hydropower projects, and other off-grid renewable sources include micro-hydropower, solar, biogas, and hybrid systems (Kafle, 2024; Bhattarai et al., 2026). Therefore, achieving Nepal's net-zero target by 2045 requires increasing use of commercial grid electricity and reducing commercial fuels and traditional energy.

The renewable energy, excluding large-scale hydro projects, accounts for the lowest energy consumption of about 17 PJ (Figure 3). This includes solar, wind, biogas, and micro/pico-hydro power. The use of these energy sources is important for decentralized energy access in remote mountainous regions where grid expansion is geographically and financially challenging (Thapa et al., 2020).

The energy-emission nexus of Nepal is currently imbalanced (Figure 3). The high traditional energy consumption leads to CH₄ and black carbon emissions, while the commercial fuels consumption causes CO₂ emissions. Therefore, grid expansion and electricity supply are necessary to mitigate these environmental impacts. Further, Nepal has committed to achieve net-zero emissions as guided by NDC 3.0 with highly ambitious sector-wide policy intervention measures. These measures target to increase renewable energy to 28,500 MW capacity using hydropower by 2035 and extend aggressive electrification in all end-users without imported fossil fuel (GoN, 2025).

2.1 Historical trend of Nepal's energy sector

The historical trend of traditional energy (biofuel and waste) share in Nepal has reduced from 86.3% in 2000 to 64.6% in 2023 (IEA, 2025a). This is the most significant structural change in traditional energy. Commercial energy shares (coal and coal products, oil and oil products, and hydropower) increased by nearly twofold, rising from 13.7% in 2000 to 34.4% in 2023 (Figure 6). The peak commercial share was reported in 2020 at 31.3%. Modern renewables (solar, wind, and others renewable) have no significant growth rate, with no contribution in 2000 to only 1% in 2023 (IEA, 2025a).

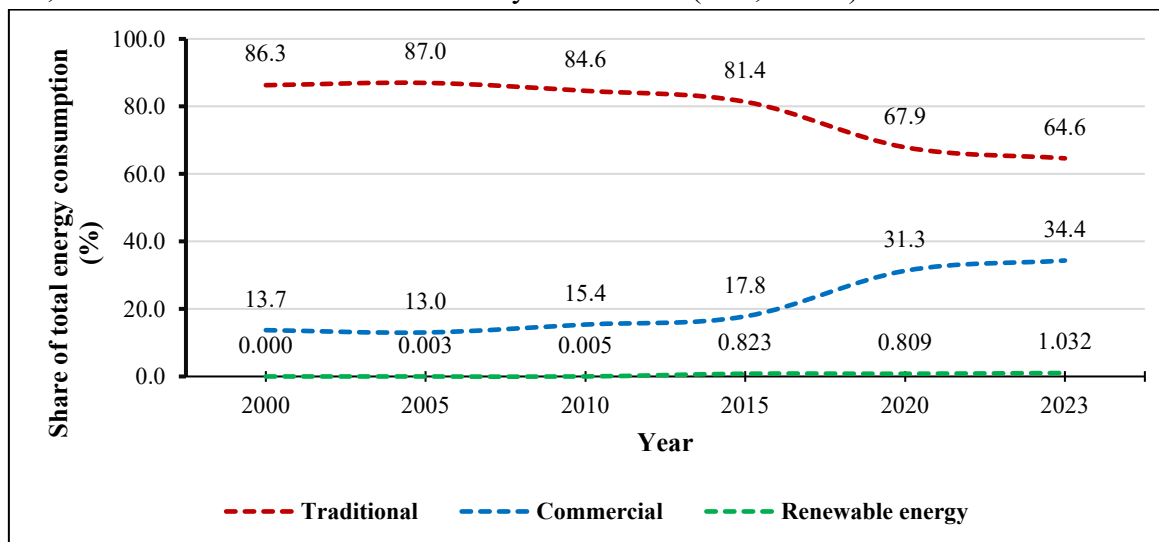


Figure 6: Historical trend of energy share by different sectors. (Data source: IEA, 2025a)

The continuous drop in the percentage of traditional energy share indicates a steady shift toward modern cooking fuels, particularly LPG and electricity. The implication of such a shift can be beneficial for improving indoor air quality and forest conservation. Hydropower, classified as commercial energy, has undergone rapid growth, with an increase of nearly 4.6 times over 23 years from 2000 to 2023 (Figure 6). This might be considered one of the factors contributing to the decline of traditional and fossil fuels. It should be noted that the rapid rise of hydropower energy from 3.51% in 2020 to 7.93% in 2023 is particularly noteworthy (IEA, 2025a). The influence of national policies such as the 16th Five-Year Plan and the Alternative Energy Promotion Centre (AEPCC) initiatives in developing alternative energy sources

other than large hydropower production could be related to the increase in hydropower energy. The trend suggests that Nepal is well positioned to meet its 2029 planning targets for a modern energy mix.

2.2 Renewable energy technologies and environmental significance

The Government of Nepal recognized the valuable role of renewable energy technologies in meeting the energy requirements of rural communities back in the 1980s during the 7th Five-Year Plan (AEPC, 2023). Since then, there has been a growing emphasis on promoting and advancing renewable energy technologies by integrating them into various development plans and programs. Thereafter, Nepal is progressing at a rapid pace in the development of renewable energy technologies. Hydropower continues to be the main renewable energy in generating power, and it ranges from large-scale grid-based hydropower that connects to the national grid to mini, micro, and pico hydropower for remote rural areas (NEA, 2025; WECS, 2024). Among non-grid renewable energy sources, biogas contributes a dominant share, accounting 65.0% of the total energy share, followed by solar energy (31.4%), micro and pico-hydropower (3.5%), and wind energy (0.1%) (WECS, 2024).

With the development of technologies such as biogas plants and improved cookstoves (ICS), the polluting traditional firewood pits are being replaced in rural areas. High-altitude wind energy is becoming a more common power source due to the lack of national grid facilities (AEPC 2023; WECS, 2024). Promotion of renewable energy technologies in Nepal has generated substantial environmental benefits by reducing dependence on traditional biomass and fossil fuels. Technologies such as biogas plants, ICS, electric cookstoves, solar energy systems, and micro-hydropower have contributed to a significant reduction in fuelwood consumption. These technologies have helped in lowering pressure on forest resources and supporting forest conservation efforts (NSO 2023; WECS, 2024). Further, renewable energy-based clean cooking technologies, including biogas, ICS, and electric cookstoves, have improved indoor and outdoor air quality and helped reduce health risks related to household air pollution posed by traditional cooking practices (Singh et al., 2012; WHO, 2021; Bravo et al., 2026).

The use of renewable energy also supports climate change mitigation by replacing carbon-intensive fuels and reducing GHG emissions. The renewable energy technologies installed during FY 2023/24 yielded an estimated annual reduction of approximately 31,259 tCO₂eq (AEPC, 2024). The GHG emission reduction achieved by renewable energy technologies installed during FY 2023/24 is elucidated in Figure 7. The technology-wise emission reduction shows electric cooking stoves achieved the highest overall reduction (9,977 tCO₂eq), closely followed by domestic biogas (9,126 tCO₂eq) and metallic improved cooking stoves (6,942 tCO₂eq). Among electricity-generating systems, micro hydro projects contribute the highest reduction (3,245 tCO₂eq), while solar home systems (831 tCO₂eq), institutional solar photovoltaic systems (769 tCO₂eq), and photovoltaic pumping systems (307 tCO₂eq) contribute moderate reductions (Figure 7). Large biogas plants that include institutional, urban and community biogas plants account for the smallest reduction (61 tCO₂eq) because of a smaller number of operations (369) compared to domestic biogas plants (1,423,242) in FY 2023/24 (AEPC, 2024). An individual large biogas plant actually mitigates significantly more carbon per system than a single domestic unit (Wang et al., 2018). However, large-scale biogas technology in Nepal is relatively new and faces challenges such as technical aspects and high initial capital investment and operational costs (Cheng et al., 2024). These contributions demonstrate the important role of renewable energy technologies in advancing Nepal's environmental sustainability, climate commitments, and low-carbon development pathway.

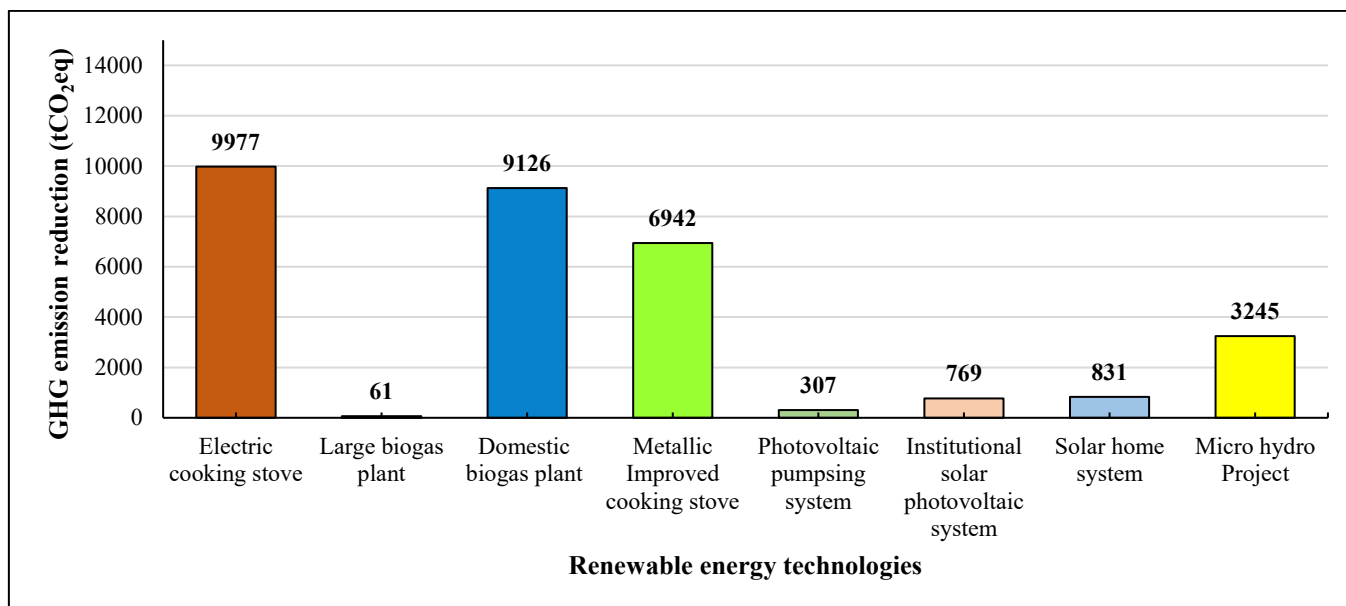


Figure 7: Emission reduction achieved by renewable energy technologies (Data source: AEPC, 2024)

2.3 Total energy supply by sources

The total energy supply (TES) includes all the energy produced in or imported to a country, minus that is exported or stored, representing all the energy required to supply end users in a country (UN, 2018; IEA, 2025b). The balance item of the flows described above and the stock changes represents the amount of energy available in the national territory during the reference period. This aggregate TES is equal to primary energy production plus import of primary and secondary energy minus export of primary and secondary energy minus international (aviation and marine) bunkers minus stock changes (UN, 2018).

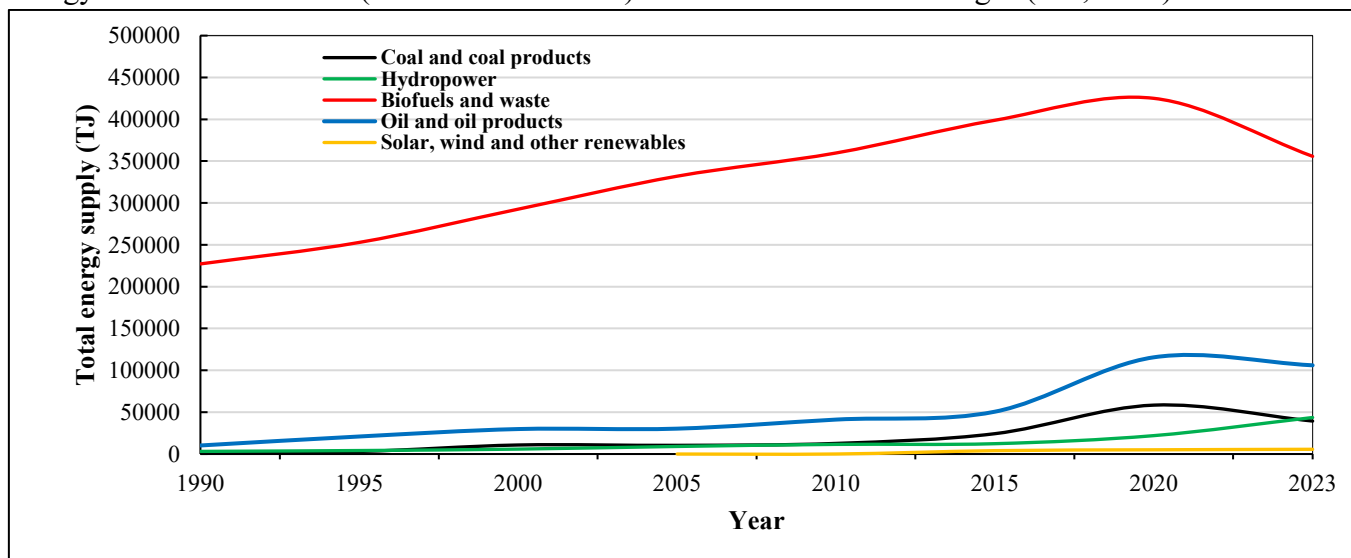


Figure 8: Total energy supply by different sources from 1990 to 2023 in Nepal. (Data source: IEA 2025b)

The energy system in Nepal has traditionally relied on traditional energy sources. However, at present the country is undergoing a transition to commercial energy sources. The TES in Nepal between 1990 and 2023 suggests the transition from traditional biomass to a more diverse energy mix. Although biomass energy use is dominant, the country has experienced significant growth in fossil fuels and hydropower (Figure 8). Biofuels and waste are still the dominant sources, primarily consisting of fuelwood, agricultural residue,

and animal dung used for cooking and heating in rural areas. The consumption trend has increased from 227,193 TJ in 1990 to 355,722 TJ in 2023 (IEA, 2025b). Though its absolute volume is increasing, the percentage share of the total energy mix is gradually declining as other commercial sources grow faster. Despite disruptions caused by the 2020 pandemic, a clear trend toward the consumption of commercial energy persisted, which might be due to modernization and widespread electrification.

The use of fossil fuels such as coal and coal products has grown tremendously, increasing significantly from 2,034 TJ (1990) to 39,427 TJ (2023) (IEA, 2025b). This is largely driven by the industrial sector, particularly cement industries and brick kilns (Parajuli et al., 2014; Shrestha & Malla, 1996). The peak in 2020 for coal (58,445 TJ) reflects high industrial activity before the recent economic shifts. In Nepal, oil and oil products are fully imported and used primarily for transport and heating (Sharma & Shrestha, 2023). The data visualizes a rise from 10,208 TJ in 1990 to approximately 29,843 TJ by 2000, continuing to escalate as urbanization and vehicle ownership increase (Figure 8). The hydropower and renewable energy supply have increased from 3,157 TJ in 1990 to 5,875 TJ in 2000, with significant growth after 2015. The usage of coal and oil rose sharply to meet the needs of a growing economy and increased mobility. By 2023, hydropower was a key driver for reducing fossil fuel dependency in the industrial and residential sectors. Modern renewable energy sources such as solar, wind, and biogas represent the smallest share but have grown over the last decade due to government subsidies for off-grid solutions (Neupane & Parajuli, 2024; Adhikari et al., 2025).

Nepal's increasing reliance on imported coal and oil creates economic vulnerability to global price rises due to the 2026 Iran War (Rashid et al., 2026), making the country energy insecure. Though the trend of biofuels continues to rise, the national energy strategy aims to replace this with hydropower to reduce indoor air pollution and deforestation (Abdaly, 2025; Saini et al., 2026), indicating that Nepal is in a transition phase where the total energy supply is increasing to support a developing economy, and at the same time, the country is struggling to dissociate that growth from fossil fuel imports.

2.4 Energy efficiency

Nepal is still an agrarian country where the share of agriculture accounts for about 24.1% of the national GDP (MoF, 2024). This implies that Nepal's transformation into a developing country can be regarded as an opportunity to shift from traditional biomass to a high-efficiency hydropower-based economy that allows to avoid the high pollution phase experienced by other developed industrial countries. According to the International Energy Agency (IEA), energy intensity, which is a ratio of TES to GDP that measures how much energy a country uses to generate one unit of economic output (IEA, 2025c). The TES is more reliable for understanding Nepal's energy efficiency. The GDP adjusted for purchasing power parity (PPP) is considered the benchmark for the calculation of TES in Nepal. It is widely used to track energy efficiency, economic structure, and progress toward the SDG, specifically SDG Target 7.3 (Abdaly, 2025). The decrease in the energy intensity of Nepal from 7,201 MJ to 3,977 MJ per unit of GDP PPP (1990-2023) can be considered an example of structural modernization. As Nepal transitions from an LDC status, its energy efficiency is not simply an environmental goal but also a fundamental economic strategy for the protection of natural resources, reducing dependence on imported fuel, and keeping economic growth inclusive and

sustainable (Figure 9). Nepal required about 7,201 MJ to produce one unit of GDP PPP in 1990, while in 2023 it required only about 3,977 MJ to produce the same unit of economic value. Since Nepal's GDP has grown significantly since 1990, the MJ/GDP unit has slipped by 45% (World Bank, 2023; IEA, 2025c), depicting that the economy is expanding without requiring a proportional increase in energy waste.

Nepal needs energy efficiency as a key strategy for its sustainable development due to several reasons. Nepal has been dependent on high-priced fossil fuels such as petroleum and coal for its commercial use. Energy saving can be achieved by each unit of energy efficiency, which means switching from a 10% efficient wood stove to 80% efficient induction cooking stove (Malla et al, 2025; Subedi & Dahal, 2025). This will enhance economic resilience and reduce Nepal's import dependency. Nepal still relies heavily on traditional fuel and forest biomass, and the decrease in biomass use to 64.62% in 2023 indicates that switching to modern energy directly reduces pressure on forests. In order to reduce the carbon footprint of Nepal, improved efficiency is required, which means less fuel is burned per unit of economic activity. This supports Nepal's commitments to net-zero emissions (GoN, 2021; Acharya et al, 2025), reciprocating the ambitious target of per capita electricity consumption set by the 15th Five-Year Plan without overloading the nation's infrastructure (Bhattarai et al., 2026).

The TES per unit of GDP (PPP) from 1990 to 2023 exhibits a downward slope, indicating that Nepal's energy efficiency is improving over time (Figure 9), which visualizes a high intensity phase from 1990 to 2010. In the early 1990s, energy intensity was at its peak, exceeding 7,201 MJ per 2015 USD PPP. This intense energy use might be due to the high dependence on traditional biomass, which has low thermal efficiency compared to economic value. The intensity of energy consumption has a fluctuating transition phase between 2010 and 2020 and did not decrease steadily, starting from 5,275 MJ per 2015 USD PPP and finally reducing to 3,977 MJ per 2015 USD PPP by 2020. This corresponds with the rapid growth of hydropower and the shift toward more efficient commercial energy sources, which might be due to the transformation from traditional biomass to commercial (hydropower/grid) as the main driver of the efficiency. Traditional energy has high energy loss during combustion, whereas electricity has a much higher conversion efficiency, leading to a lower MJ requirement per unit of GDP (Khan et al. 2025; Malla et al., 2025).

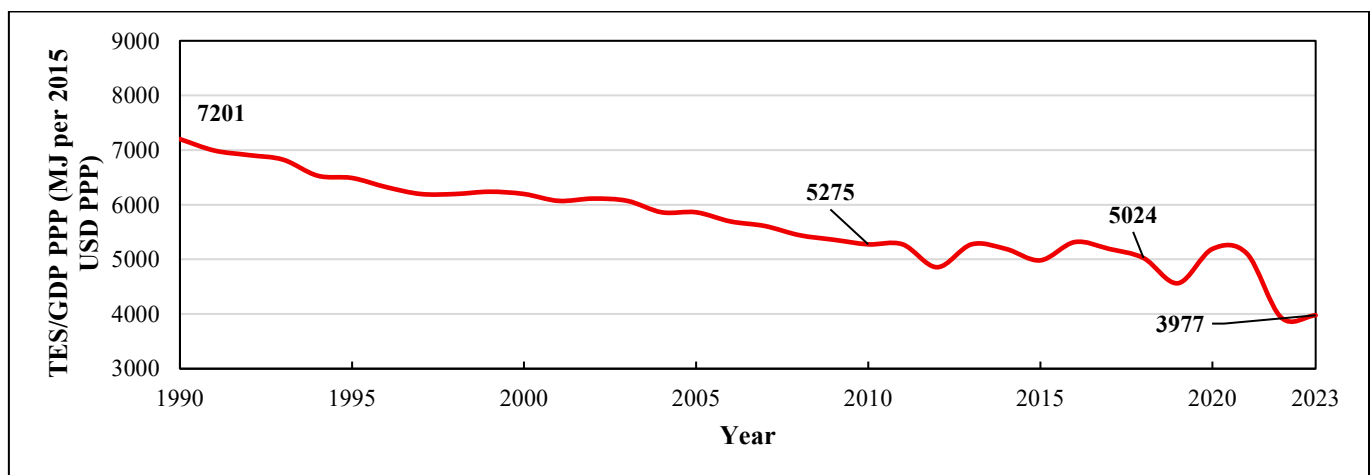


Figure 9: TES per unit of GDP from 1990 to 2023 in Nepal. (Data source: IEA, 2025c)

There is a significant drop after 2021, where intensity has reached its lowest at 3,977 MJ by 2023, indicating a modern development breakthrough (Figure 9). This is related to the massive rise in domestic hydropower production along with the highest renewable energy share of 8.96%. Energy intensity in Nepal during the historical period (1990–2023) depicts a significant gain in economic productivity per unit of energy, demonstrating a reduction from over 7,000 MJ to approximately 4,000 MJ per 2015 USD PPP. This highlights the efficiency gains of transitioning from traditional biomass to a modern hydropower-centric energy contribution. Further, this downward trend demonstrates the successful impact of the 14th and 15th Five-Year Plans of Nepal, which prioritized energy diversification and increased domestic electricity production. The current trend ensures that the goals set under the 15th Five-Year Plan are achieved, considering the projected share of commercial energy at 45% by 2025. Even though the 15th Five-Year Plan's timeframe ended in 2024, its targets served as the benchmark for both the current 16th Five-Year Plan (2024/25–2028/29) and the NDC 3.0 (2025). Achieving these targets is key to meeting the required efficiency rate, which aligns with international climate commitments and UN energy goals.

Nepal's TES per unit of GDP between 1990 and 2023 provides a clear empirical basis for tracking progress toward UN SDG Target 7.3. This target specifically aims to double the global rate of improvement in energy efficiency by 2030. By reducing energy intensity from over 7,000 MJ to approximately 4,000 MJ (1990–2023), Nepal has demonstrated a significant historical commitment to SDG Target 7.3. The UN SDG Target 7.3 explicitly calls for doubling the global rate of improvement in energy efficiency by 2030. Between the two-decade (1990 to 2010) period, Nepal improved its energy efficiency at a modest rate of 1.5% annually. Over the last five years (2018–2023), the rate has increased to 4.5% annually (IEA, 2025c). This data shows that Nepal is currently improving its energy efficiency at nearly three times its historical rate, suggesting the country is not only meeting the SDG target of doubling its rate, but it is significantly exceeding it. The acceleration in energy efficiency is supported by the massive expansion of domestic hydropower facilities. This proves that the transition from traditional biomass (low efficiency) to grid electricity (high efficiency) is the primary cause of Nepal's big achievement. The 4.5% annual improvement is an exceptionally high rate for any developing economy. This confirms that Nepal is successfully decoupling its economic growth from its energy consumption footprint. If Nepal maintains the pace of 4.5% annual improvement in energy intensity up until 2030, the energy intensity can drop well below 3,000 MJ per unit of GDP.

3. Energy-emission nexus

As Nepal prepares to graduate from LDC (NPC, 2024a; UN, 2026), energy serves as the primary driver of this transformation, which simultaneously increases the country's GHG footprint. This energy-emission nexus is clearly reflected in Nepal's transition from a biomass-driven emission to a fossil fuel-driven (Figure 10), showing that GHG emissions have been growing at the rate of 3.18% per annum between 1994 and 2022. The emissions in 1994 show that CH₄ was higher (81%) than CO₂ (14%), and N₂O (5%) of total GHG equivalent emissions. By 2022, the changes to CO₂ (54%), CH₄ (43%), and N₂O (3%) show a change in the mix of emission gases due to changes in fuel types (MoFE, 2025a). The CH₄-dominant emissions in the past were significantly contributed by biomass use, while present fossil fuel use has risen sharply, contributing to higher CO₂ emissions (MoFE, 2025a).

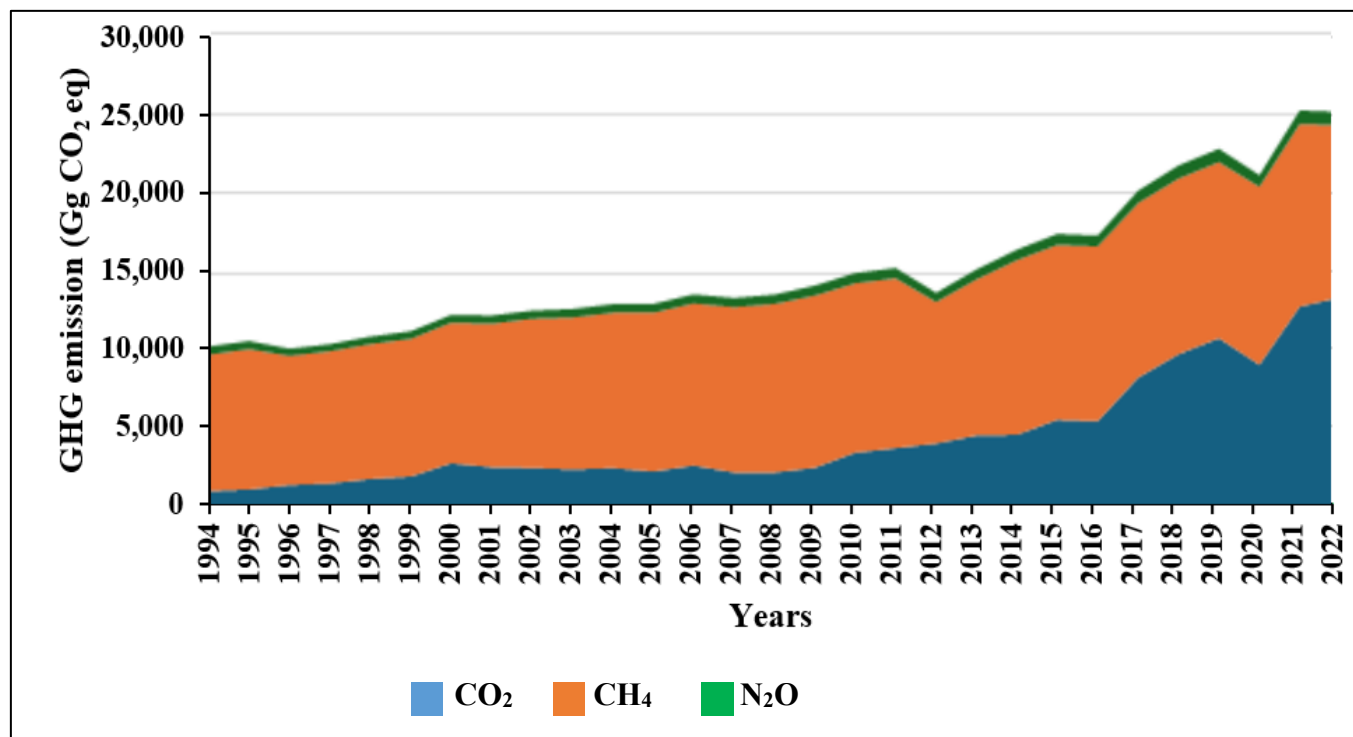


Figure 9: GHG emissions from the energy sector from 1994 to 2022 (Adapted from: MoFE, 2025a)

There is a sharp increase in CO₂ emissions starting in 2016 (Figure 10), which may be due to intensive post-earthquake reconstruction (Acharya et al., 2022), rapid road network expansion, and a massive influx of petroleum-based vehicle imports (WECS, 2022). Similarly, CH₄ emissions were the highest, accounting for 81% and 43% in 1994 and 2022, respectively. The emissions were contributed by traditional biomass (firewood) and agricultural residues used for heating and cooking. The smallest component of N₂O (3%) of the total is primarily emitted from specific industrial processes and high-temperature combustion in the transport sector (MoFE, 2025a).

3.1 Sub-sectoral emission pattern

The energy sector is categorized into six main sub-sectors, which include residential, transport, commercial, electricity generation, agriculture, and manufacturing industries (MoFE, 2025a). The energy sector emissions across various sub-sectors between 1994 and 2022 show an increasing trend in total emissions, with an increase starting sharply around 2015 (Figure 11). The residential sector, which is the most dominant and most energy-consuming sector, contributing a huge share of emissions. This is mainly due to high reliance on traditional biomass such as firewood, agricultural residue, and animal dung. The residential sector emissions are high because of incomplete combustion, leading to the release of CH₄ and N₂O. There is a gradual decrease in the intensity of the sector due to electrification of cooking and use of LPG among urban households (WECS, 2024; MoFE, 2025a).

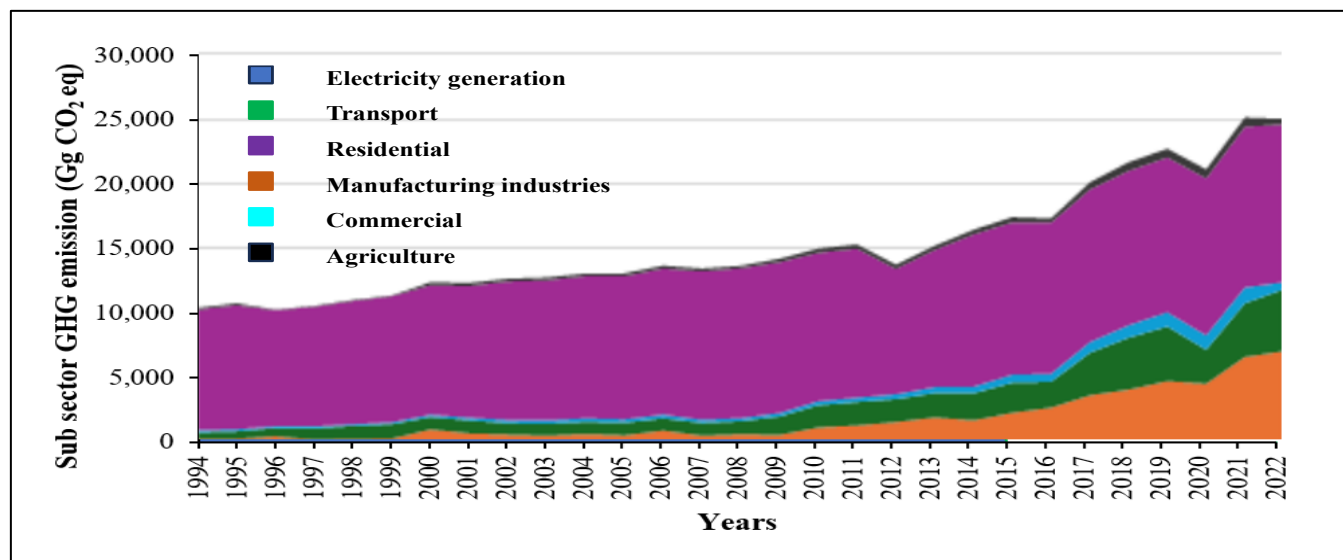


Figure 10: GHG emissions from the energy sub-sector from 1994 to 2022 (Adapted from MoFE, 2025a)

The emission from the transport sector have observed a notable rise since 2015, which is attributed to dependency on imported petroleum products such as diesel and petrol. The high growth rate of this subsector is related to the average annual vehicular growth rate of 14% (CEN, 2019). The primary sources of urban air pollution and CO₂ emissions are from the transport sector. Despite the recent initiative for electric vehicles, the rapid increase in the number of heavy-duty vehicles and motorbikes continues to rise emissions (Bajracharya & Bhattarai, 2016).

The emissions from manufacturing industries have grown steadily. The manufacturing industry sector's energy emissions are contributed mainly by the combustion of coal and biomass in high-heat industries like cement, brick, and steel. The primary fuel source is coal, followed by biomass and diesel. The use of low-grade coal in brick kilns is a main source of both CO₂ and black carbon. This type of emission is difficult to control because coal cannot be completely substituted by electricity in high-thermal industries. Therefore, industrial emissions have peaked after 2015 due to massive reconstruction demands for post-earthquake recovery (Acharya et al., 2022; Parajuli & Adhikari, 2025).

The commercial and agriculture sectors contribute minimally to total emissions. The overall trend reflects increasing energy demands across residential, industrial, and transportation sectors, driven by population growth, urbanization, and industrialization (WECS, 2024; MoFE, 2025a). The energy use in hotels, hospitals, and government offices mainly shares this emission. The main sources of energy in this sector are LPG for cooking and diesel for backup generators (WECS, 2024). This sector consumes less energy relative to other sectors (MoFE, 2025a). The commercial (6.29%) and agricultural (17.67%) sectors have the highest rate of grid-electricity adoption (WECS, 2024). Therefore, this sector has the most promising path toward decoupling as it is rapidly electrifying its heating and cooling systems. Diesel used for irrigation pumps and farm machinery is the main cause of emissions in the agricultural sector. Direct energy use in the agricultural sector is primarily from diesel-powered irrigation pumps, tractors, and tillers (Raihan & Tuspekova, 2022). The agriculture sector as a whole, particularly livestock, is a massive emitter of CH₄ (Thakuri et al., 2020), whereas the energy-specific emissions are relatively low because many activities are still manually operated or are slowly shifting toward electrification.

Electricity generation has a relatively smaller share, and it is in a declining trend after 2015 due to increased availability of clean electricity generation plants. Electricity generation plants have near-zero direct GHG

emissions, which is attributed to the generation of electricity using hydropower plants in Nepal. Therefore, it is classified as a renewable and non-combustion source of energy in national GHG accounting.

3.2 Fossil fuel-based emission contribution

Three distinct phases of CO₂ emissions contributed by fossil fuels in Nepal are illustrated in Figure 12. The sectoral emission trend visualizes slow but steady growth between 1995 and 2010, with total emissions increasing from 1,570 Gg CO₂-eq to 3,870 Gg CO₂-eq. The trend began to rise from 2010 to 2015, reaching 5,922 Gg CO₂-eq (MoFE, 2025a). From 2015 to 2022, there is a sharp vertical rise after 2015. By 2022, emissions reached 13,568 Gg CO₂-eq. This period coincides with increased urbanization and the expansion of the road network after the promulgation of the new constitution in 2015 (Bhattarai et al., 2023). These periods reflect a massive surge in fossil fuel imports, specifically for transportation and the industrial sector (NOC, 2026).

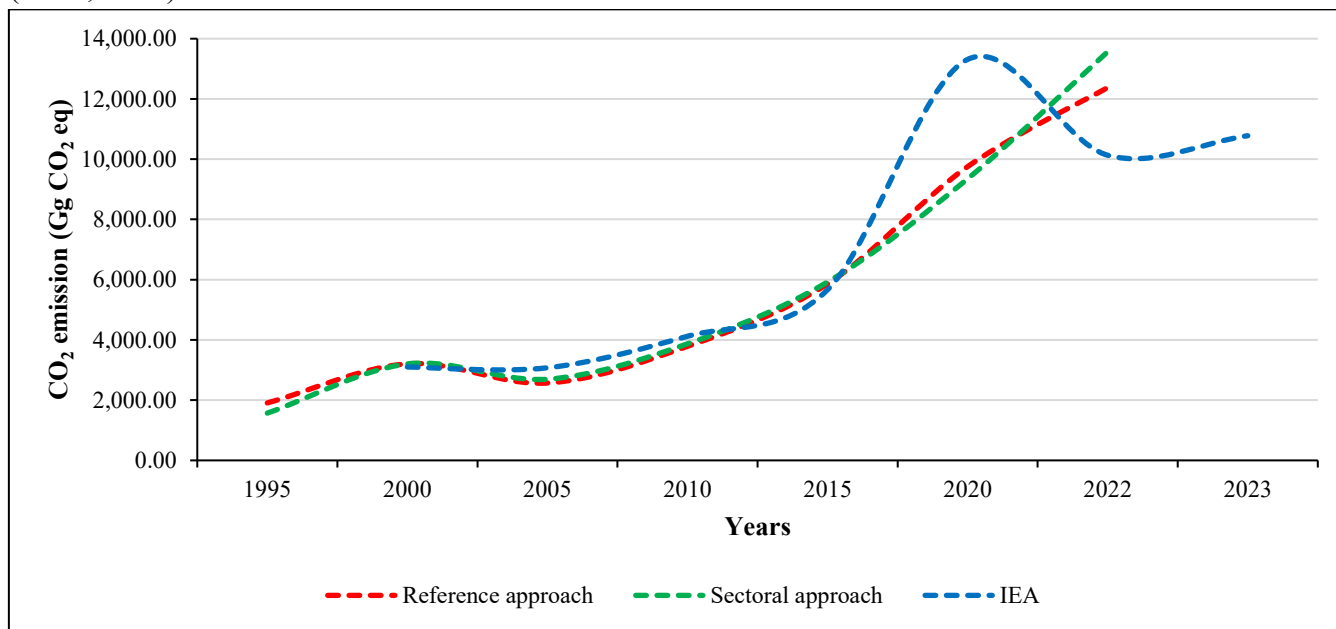


Figure 11: CO₂ emissions from fuel combustion in Nepal (Data source: MoFE, 2025a and IEA, 2025d)

These sectoral, reference, and IEA approaches have their own methodology and reliability and vary from each other. The sectoral approach is a bottom-up approach, where emissions are calculated using the sum of fuel used in the sectors such as transport, industry, and residential (MoFE, 2025a). The reference approach is a top-down approach, where emissions are calculated based on the sum of total energy supply of fuels (production + imports - exports). This approach is generally higher than the real consumption due to possible unreported losses, stock changes, and inaccuracies in accounting for energy trade/fuel movements (MoFE, 2025a). The reference approach acts as a verifier for the sectoral approach. However, the IEA approach is different from the two approaches due to the various emission factors, excluding certain local fuels.

The gap between the sectoral approach (green line) and the reference approach (red line) is currently higher. In GHG inventory standards, a difference of >5% usually indicates the need for a technical review (MoFE, 2025a). The sectoral approach is the official inventory value used for NDC tracking, while the IEA value serves as an international benchmark. The Government of Nepal's First BTR report provides the context for the data. Transport (diesel/petrol) and manufacturing/construction (coal) sectors are the primary drivers of the post-2015 surge (MoFE, 2025a). Despite Nepal's clean electricity (hydropower), TES is still

dominated by fossil fuels for non-electric needs. In addition, a small plateau in the IEA data around 2020-2023 is explained by the slow pace of development due to the COVID-19 pandemic, followed by an active promotion of electric vehicles (EVs) and electric cooking described in the Second NDC (2020).

3.2.1 Fossil fuel-related emissions in Nepal (Base Year 2011)

Nepal's fossil fuel emissions in the National GHG Inventory Framework are reported under the energy sector of the IPCC Guidelines (2006) and include CO₂ emissions from transport fuel combustion (diesel, petrol, and aviation fuel), industrial fossil fuel combustion (coal and furnace oil), and household and commercial combustion (LPG and kerosene) (MoFE, 2021). The fossil fuel emissions profile for Nepal in the base year (2011) highlights the country's specific carbon footprint before the recent acceleration in hydropower and electric vehicle adoption. The total emissions for the energy sector were recorded at 14,703 Gg CO₂-eq in the base year 2011 (GoN, 2020; MoFE, 2021). In GHG accounting, the energy sector specifically refers to emissions resulting from the combustion of fuels for transport, manufacturing, heating, and cooking. This figure represents the combustion-based carbon intensity of the Nepalese economy during that period.

Nepal's GHG emissions from fossil fuels are almost from imported petroleum products, principally used in the transport, industry, and residential cooking and heating sectors. Nepal has no commercial extraction of coal, oil, or natural gas, and therefore, fossil-fuel-based emissions are limited to combustion during domestic use (MoFE, 2021). Under NDC 3.0, fossil fuel emissions are addressed primarily through energy system electrification, fuel substitution, and efficiency improvements, rather than fuel switching within the fossil category (GoN, 2025).

3.2.2 Territorial, consumption, and extraction-based emissions

Territorial-based emissions are the emissions physically released within Nepal's national boundaries. However, this measurement excludes emissions from traded goods, specifically the CO₂ emitted in the production of goods elsewhere that are later imported (OWID, 2025). Therefore, the annual territorial CO₂ emitted by Nepal is the emissions from coal used in the industrial processes such as brick kilns (MoFE, 2021; Thakuri et al., 2024) or small-scale manufacturing, combustion of liquid fuels, primarily used in the transport sector and for backup power generation (Sadavarte et al., 2019; MoFE, 2021; ATO, 2024; Rajbhandari et al., 2024). Nepal's sector-wise territorial-based emissions include the agriculture sector that emits CH₄ from livestock (enteric fermentation) and N₂O from agricultural soils and fertilizer use (Thakuri et al., 2020; MoFE, 2021).

The territorial emissions from the energy sector include fuel combustion for electricity, heating and manufacturing, whereas the transport sector includes domestic aviation and road transport within Nepal (IEA, 2025d). The territorial waste sector contributes to CH₄ emissions from landfills and wastewater treatment (GoN, 2021; MoFE, 2021). The emissions from the land-use change sector are the CO₂ released when land use changes, sometimes grouped under LULUCF. They mostly come from deforestation, forest degradation, turning forests or other ecosystems into cropland or pasture, and draining peatlands (Ritchie & Rosado, 2025). These estimates are uncertain because they depend on limited data and assumptions about

land cover, the amount of carbon stored in ecosystems, and management of land. Therefore, Ritchie and Rosado (2025) provide versions both including and excluding LULUCF. For Nepal, this distinction is critical, as the country's strong history of community forestry means that the land-use sector can fluctuate between a carbon "sink" and "source" relative to its fossil fuel emissions.

Production-based emissions are the emissions generated during domestic production activities such as fuel extraction, refining, and electricity generation from fossil fuels. Since Nepal has no fossil fuel extraction or refining facilities, the electricity generation is predominantly renewable, and the country's production-based emissions in these activities are negligible. However, electricity imported from India during the dry season accounts for an indirect carbon footprint, shifting these emissions from production-based to consumption-based emissions. Production-based fossil fuel emissions are therefore limited to combustion in industries and services, not from fuel production and electricity generation. Extraction-based emissions are those generated during the physical mining of coal or the drilling of oil and natural gas. As Nepal does not possess any commercial fossil fuel extraction or refining industries, its contribution to this specific accounting category remains nearly zero. This distinction explains why Nepal's fossil fuel footprint is highly dependent on import-based consumption, which is small in total magnitude.

Consumption-based emissions include GHG emissions generated from fossil fuels and industries, where land-use change emissions are excluded (Ritchie & Rosado, 2025). These emissions also include emissions that are generated anywhere in the world to produce the goods and services consumed by people in Nepal. Nepal accounts for 0.05% of global emissions (Global Carbon Budget, 2025). Consumption-based emissions are often called the carbon footprint and form a key part of the energy-emission nexus. Understanding this relationship is vital for a country transitioning to graduate from LDC status. Nepal imports almost all of its machinery, electronics, and vehicles from countries like India and China (TrendEconomy, 2024), and the carbon emitted in the countries to manufacture Nepal's imports is added to the country's total (Yamano & Guilhoto, 2020), suggesting that Nepal is a net importer of carbon. Nepal is a very small global emitter under all accounting methods, though its consumption share is slightly higher than its production share. As GDP per capita rises to US\$ 1,496, the consumption-based emissions are expected to grow faster than production-based emissions.

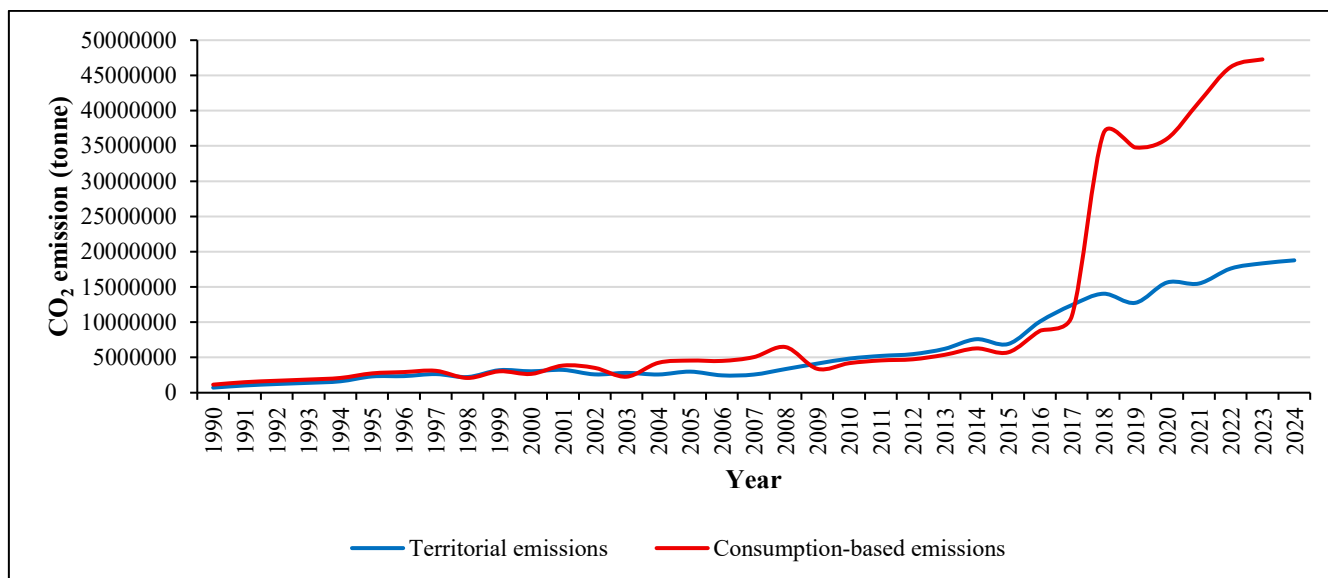


Figure 12: Territorial and consumption-based emissions of Nepal (Data Source: Global Carbon Budget, 2025)

The difference between territorial and consumption-based emissions reveals that Nepal’s global climate footprint is much higher than its domestic reporting suggests. The physically released emissions within national borders have grown gradually to about 18.4 million tonnes by 2024. On the other hand, consumption-based emissions have experienced a dramatic surge, accounting for 47.3 million tonnes (Global Carbon Budget, 2025) (Figure 13). The increase in this carbon gap indicates that Nepal’s GDP per capita rises corresponding to the country’s transition to LDC graduation, and its economic progress is supported by carbon-intensive product imports such as vehicles, machinery, and manufactured goods. Besides, Nepal is a minor producer of direct emissions (0.05%) globally, the country emerged as a major importer of carbon due to the carbon

3.3 Projected fossil fuel emissions under BAU and NDC 3.0

The future emission projections for Nepal’s energy sector present a noticeable gap between unconstrained growth and strategic climate intervention. Figure 14 visualizes Nepal’s projected GHG emissions under BAU and NDC scenarios for 2030 and 2035, along with the absolute emission reductions achieved through mitigation efforts for 2030 and 2035. Under the BAU scenario, emissions are expected to rise from 32,965.9 Gg CO₂-eq in 2030 to 37,908.7 Gg CO₂-eq by 2035, which is linked with high dependence on fossil fuels in terms of economic growth. In contrast, the implementation of NDC 3.0 targets is projected to limit these emissions to 28,251.6 Gg CO₂-eq in 2030 and will be stable at 29,362.3 Gg CO₂-eq by 2035. It suggests that policy-driven action will lead to a more substantial reduction in GHG emissions, targeting an absolute reduction to 4,714.3 Gg CO₂-eq in 2030 and a subsequent decrease to 8,546.4 Gg CO₂-eq by 2035, indicating that aggressive mitigation measures can successfully decouple national development from carbon intensity.

There is a clear contrast between the historical emissions of Nepal and its projected climate trajectories, highlighting the urgent necessity of the NDC 3.0 framework (Figure 15). Starting from a 2011 historical baseline of 28,166.06 Gg CO₂-eq, the BAU scenario predicts a rapid rise of net emissions to 51,780.74 Gg CO₂-eq by 2030 and 62,056.49 Gg CO₂-eq by 2035. This is an almost 120% increase in emissions over 24

years (2011-2035), indicating the carbon cost associated with the development path. However, the NDC targets scenario considerably reduces this increase to 42,914.21 Gg CO₂-eq in 2030 and 45,428.69 Gg CO₂-eq in 2035 (Figure 15). The proposed mitigation targets (II A) would lower net GHG emissions relative to the BAU scenario by 8,866.53 Gg CO₂-eq (17.12%) in 2030 and 16,627.80 Gg CO₂-eq (26.79%) in 2035. This will help to reduce 96% by 2030 and 97% by 2035 of the total targeted emission reduction with the support of international climate finance and support (GoN, 2025). The total emissions reduction from NDC targets, including the mitigation policies and measures outlined in section II, subsection B, is expected to be higher than estimated and is not quantifiable yet (GoN, 2025). Nevertheless, the NDC targets of Nepal will effectively bridge the gap between national economic growth and the long-term goal of environmental sustainability.

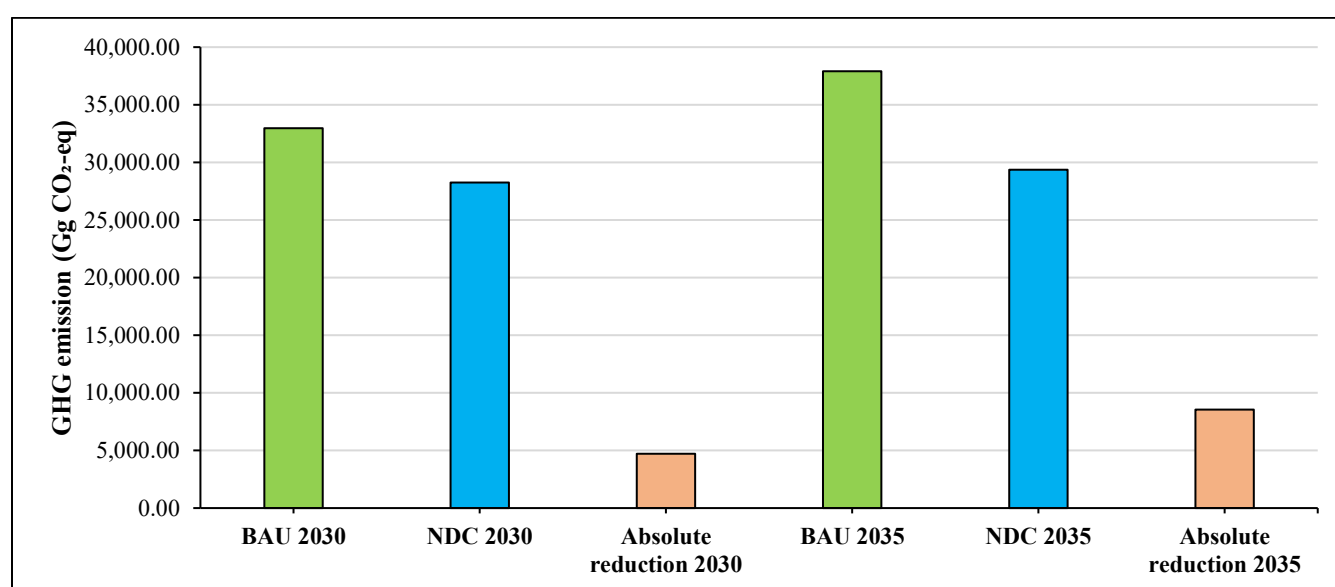


Figure 13: Projected fossil fuel-dominated energy sector GHG emissions under BAU and NDC 3.0 scenarios, 2030 and 2035

The BAU emissions (2030, 2035) and emissions after NDC 3.0 (2030, 2035) show that fossil fuel emissions from Nepal are only from imported fuels, with transport being the biggest consumer of fossil fuel. The NDC 3.0 marks a significant change towards decarbonization and not merely an optimization process, resulting in a reduction of emissions mainly through electrification, although extraction-based emissions are not relevant to Nepal.

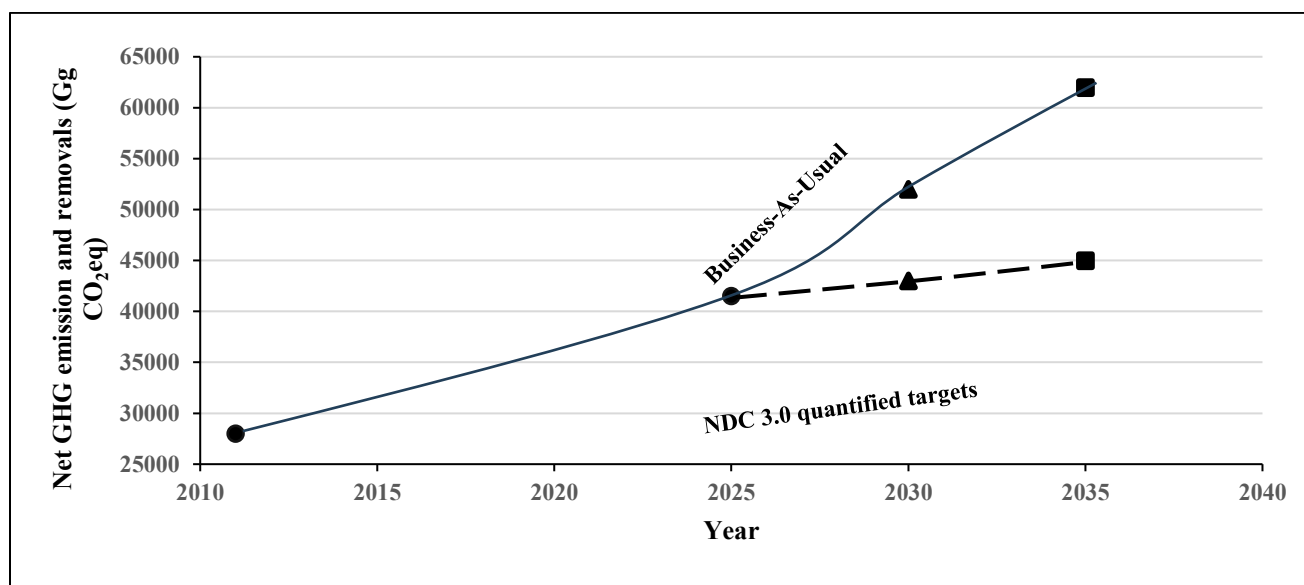


Figure 14: Net GHG emissions and removals in 2011 and projected emissions pathways for 2030 and 2035 (Adapted from: GoN, 2025)

4. Nepal's NDC targets in relation to GHG emissions

Nepal's climate policy from broad activity-based goals has shifted toward a sophisticated, economy-wide mitigation framework, reflecting its commitment to the Paris Agreement despite its contributing only 0.027% of global emissions (MoFE, 2021; MoFE, 2025b). This strategic shift is documented across four key submissions to the United Nations Framework Convention on Climate Change (UNFCCC), namely the Intended Nationally Determined Contribution (INDC- 2016), First NDC (2016), Second NDC (2020), and the highly ambitious NDC 3.0 (2025). The latest framework introduces rigorous and quantified targets, most notably an economy-wide GHG reduction of 26.8% below BAU levels by 2035 and a doubling of renewable energy capacity to 28,500 MW. This progression is a strong commitment to achieving net-zero emissions by 2045 and utilizing the nation's vast hydropower potential as a primary lever for both domestic and regional decarbonization (MoFE, 2020; MoFE, 2025b).

There is an existing disparity between the aforementioned NDCs and increasing levels of historic emissions that almost doubled from 10,500 units recorded in 1994 to 25,000 units in 2022 (WECS, 2024). The growth is associated with modernizing the energy mix, with less traditional biomass usage that has been compensated for by using more petroleum and coal in the industrial and transport sectors. The NDCs offer a way out of this situation through electrification. The gaps between ambitious legislative frameworks and actual sectoral emission trajectories are critical challenges for Nepalese policymakers in the context of 2035 and 2045 milestones.

The biggest challenge for Nepal to meet the commitments is a massive financing gap, with implementation costs estimated at USD 73.7 billion (USD 48.4 billion for mitigation and USD 25.3 billion for adaptation) by 2035 (NPC, 2024b; MoFE, 2025b). There is approximately 85% of the total is conditional on international climate finance, highlighting high dependency on external financial flows and global climate funds. Besides financial constraints, the country needs to increase technical and organizational capacity to effectively carry out large-scale mitigation projects and sustain their operation over the long term. Consequently, Nepal's policy framework has become more precise and data-driven. Arrangements of

sustainable funding and enhancement of domestic institutional capacity are essential to translate these international commitments into measurable environmental results in the near future.

The evolution of Nepal's climate commitments, as presented in Table 1, illustrates a clear transition from aspirational, qualitative goals to a sophisticated, data-driven, and economy-wide mitigation and adaptation framework. The INDC-2016 and First NDC-2016 were largely activity-based and lacked quantified GHG reduction targets and cost estimates (MoPE, 2016). The Second NDC (2020) introduced specific sectoral milestones such as a 15,000 MW clean energy target, increased forest cover, and 25% adoption of private EVs (MoFE, 2020). With the ambitious target set by the Second NDC (2020) for private EV sales by 2025, EV imports increased to more than 75,000 units since 2020, demonstrating 70% compounded annual growth rate (Jha et al., 2025). This is driven by favorable customs tariffs, expanding charging infrastructure, and rising fuel prices, resulting in significant promotion of the use of private EVs, as targeted to 95% by 2035 in NDC 3.0. However, inconsistent fiscal policies such as fluctuating customs, clean infrastructure investment fees, and a shift from motor power-based to value-based import taxation set by Nepal's 2026 EV budget (MoF, 2026), and persistent technical, infrastructural, and financial barriers hinder the progress (Jha et al., 2025).

Table 7: Nepal's climate commitments and energy sector targets

Feature	INDC (2016)	First NDC (2016)	Second NDC (2020)	Third NDC (2025)
Time period	2025	2025	2025–2030	2025–2035
Mitigation targets	Non-quantified (sectoral targets without quantified GHG reductions): • 12,000 MW hydropower by 2030 • Maintain 40% forest cover • Promote electric rail, fuel tax, and bicycles	• Continuation of INDC • No quantified GHG targets	Partially quantified: • 15,000 MW clean energy by 2030 (5,000 MW unconditional) • 90% public transport electric by 2030 • 25% private EVs by 2025* • Maintain 45% forest cover • Wastewater treatment targets	Fully quantified, sectoral pathways: • 28,500 MW clean energy by 2035 • 95% private EVs by 2035 • Electrify 50 km public transit corridors by 2030 • Industrial decarbonization methane reduction in waste • Wastewater treatment expansion
Finance needs	• No cost estimates • Fully conditional on external support	• No cost estimates • Dependent on bilateral/multilateral grants	• USD 33 billion by 2030 • 88% conditional (25 billion USD) • 12% unconditional (3.4 billion USD)	• USD 73.7 billion by 2035 • 85% conditional • 15% domestic/unconditional • Structured climate finance planning, carbon taxes, public-private partnership, and climate budget tagging

(Sources: MoPE, 2016; MoFE, 2020; MoFE, 2025b)

**The Second NDC targets designated for 2025 have transitioned into baseline indicators for the NDC 3.0 (2025–2035)*

The target has been significantly scaled further in NDC 3.0 (2025), which establishes a fully quantified pathway extending to 2035, targeting a near-total shift (95%) to private EVs and a massive 28,500 MW of clean energy (MoFE, 2025b). This strategic shift is accompanied by a more rigorous approach to adaptation, moving from general frameworks to mainstream resilience in all local governments, and a transparent financial roadmap (NPC, 2024b; MoFE, 2025b). The projected cost has risen from unquantified figures to a staggering USD 73.7 billion by 2035, with a steady domestic commitment of roughly 15%, while

remaining primarily dependent on international climate finance to bridge the remaining 85% gap (MoFE, 2025b).

4.1 Energy sector development and SDGs

Early NDCs focused on development-linked mitigation actions without quantified emission reductions (MoPE, 2016). The Second NDC (2020) introduced measurable sectoral benchmarks such as specific targets for EV sales and clean energy capacity (MoFE, 2020). The NDC 3.0 represents Nepal's first comprehensive GHG reduction target and formal net-zero timeline, aligned with post-global stock take (GST) ambitions and the net-zero scenario 2045 (MoFE, 2025b). Nepal's mitigation strategy is closely linked to energy policy, emphasizing expansion of hydropower generation, electrification of transport and industry, and promotion of clean cooking energy. These measures are consistent with national energy planning documents and NDC implementation frameworks (NPC, 2024b).

Nepal's GHG emissions are very small in absolute and per-capita terms, but are increasing with economic growth and the modernization of the energy mix (MoFE, 2021). Forestry continues to play a critical role in maintaining net-sink status, provided the 46.08% forest cover mandate is upheld (MoF, 2026). The shift from action-based to economy-wide NDC targets reflects improved national statistical and reporting capacity, moving toward Tier 2 and Tier 3 emission factor modeling (NSO, 2025). Ultimately, energy sector transformation is central to achieving both SDG 7 and SDG 13 targets (NPC, 2024b).

Table 8: Energy and climate action aligned with SDG targets

SDGs	Indicator	National evidence
SDG 7	Installed renewable electricity capacity	15,000 MW target by 2030; approximately 28,500 MW identified project pipeline (planned capacity)
SDG 7	Share of clean energy in total demand	15% by 2030
SDG 7	Electrification of transport	EV sales targets (NDC-2 onward)
SDG 13	Total GHG emissions	Approximately 54 MtCO ₂ -eq (projected emissions around 2030 under BAU/reference scenario, NDC 3.0 estimates)
SDG 13	NDC mitigation target	26.8% below BAU by 2035
SDG 13	Net-zero commitment	Net-zero emissions by 2045
SDG 13	Transparency reporting	First BTR submitted in 2025

(Source: GoN, 2020; MoFE, 2025b)

The strategies outlined in Nepal's NDC 3.0 are intrinsically linked to the UN SDGs, specifically targeting the intersection of energy security and climate action. Table 2 shows alignment of Nepal's national energy and climate targets with SDG 7 and SDG 13 and reflects a combination of ambitious energy targets and climate commitments. The alignment of Nepal's energy strategies with SDGs underscores a transition toward a more resilient and low-carbon economy. By prioritizing a nationwide shift toward electrification, Nepal directly advances SDG 7 (affordable and clean energy) through a reduced dependence on imported fossil fuel markets in favor of domestic hydropower. Nepal has set a target of 15,000 MW of renewable electricity capacity by 2030 (NPC, 2024b), while a larger pipeline of approximately 28,500 MW has been identified, representing potential future development rather than committed capacity (WECS, 2024).

This systemic change simultaneously supports SDG 13 (climate action), as the resulting decline in energy sector CO₂ emissions is essential for meeting the nation's 2045 net-zero targets and mitigating the local environmental impacts of fuel combustion (MoFE, 2025b). The replacement of petroleum and coal with renewable alternatives in the transport and industrial sectors promotes SDG 12 (responsible consumption

and production), ensuring that its path toward economic graduation is built upon a sustainable model that minimizes the national carbon footprint and enhances energy sovereignty (WECS, 2024). Additionally, the country targets to achieve 15% clean energy in total energy demand, alongside efforts to promote EV adoption through evolving NDC policies.

From a climate perspective, Nepal's emissions are projected to reach approximately 54 Mt CO₂-eq by 2030 under the BAU scenario, which serves as the baseline for mitigation efforts. Against this trajectory, Nepal has committed to a 26.8% emissions reduction below BAU by 2035, with a long-term goal of achieving net-zero emissions by 2045, and has strengthened transparency by submitting its first BTR report in 2025.

5. Conclusion

Nepal stands at a critical turning point, seeking to accelerate economic growth while strengthening its resilience to climate change. As the country prepares for its graduation from LDC, energy has transitioned from a basic utility to an economic resource. The evidence presented throughout this chapter visualizes that energy is the fundamental factor driving socioeconomic development as well as the primary factor responsible for determining the environmental impact. Historically, traditional biomass has been the dominant energy resource of Nepal, which is now shifting towards a modern hydropower-based economy. With increasing energy demands, Nepal has been able to achieve a remarkable 45% reduction in energy intensity since 1990 as evidence of decoupling of economic output from energy consumption through efficiency gains, promotion of alternative energy technologies, and expanded hydropower generation. The energy sector remains the most rapidly growing source of GHG emissions. Though Nepal's electricity generation is mostly carbon-neutral due to hydro energy production, there have been increasing emissions as a result of high dependency on imported fossil fuels for transportation and industrial sectors. These scenarios demonstrate the high costs of carbon associated with rapid urbanization and industrial recovery that are heavily reliant on coal-based manufacturing and petroleum-based transportation, which govern the emissions profile, put public health at risk, cause urban heat island effects, and accelerate the Himalayan glacier melt.

To address these structural imbalances, Nepal's NDC 3.0 proposes an ambitious, data-driven framework to address the current imbalances. With its commitments toward reducing emissions by 26.8% below BAU levels by 2035 and increasing the clean energy capacity to 28,500 MW, Nepal is targeting a fundamental structural shift toward net-zero energy by 2045. The feasibility of this vision is greatly dependent on overcoming the gap of USD 73.7 billion in finance, with about 85% of the funds expected from international support. Thus, strategic priorities must now focus on accelerating the economy by substituting industrial coal and imported oil with domestic hydropower surplus. Strengthening climate finance mechanisms through carbon taxation and public-private partnerships is important to achieve the target. Ultimately, the success of Nepal in achieving the environmental outcomes promised through such policies would depend on its ability to mobilize international finance and domestic institutional capacity to appreciate its clean energy-led development pathway.

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Glossary

Business-as-Usual (BAU): A projected emissions or consumption scenario that assumes no new policy interventions. It is used as a baseline against which emission-reduction targets are measured.

Consumption-Based Emissions: Greenhouse gas emissions attributed to a country based on the goods, services, and energy consumed by its residents, including emissions embodied in imported products.

Energy Intensity: The amount of energy required to produce one unit of economic output, usually measured in relation to gross domestic product (GDP). It is commonly used as an indicator of energy efficiency.

Energy Mix (Energy Matrix): The composition and relative share of different energy sources, such as biomass, fossil fuels, hydropower, solar, wind, and other renewable sources, in a country's total energy supply or consumption.

Greenhouse Gas (GHG) Emissions: The release of heat-trapping gases, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), primarily from activities such as fossil-fuel combustion, agriculture, industry, and land-use change.

Load-Shedding: Planned and rotational interruptions in electricity supply implemented when electricity demand exceeds the available generation or distribution capacity.

Nationally Determined Contribution (NDC): A country's climate action plan submitted under the Paris Agreement, outlining its commitments, targets, and strategies for reducing greenhouse gas emissions and adapting to climate change.

Net-Zero Emissions: A state in which the amount of greenhouse gases emitted is balanced by an equivalent amount removed from the atmosphere, resulting in no net increase in atmospheric emissions.

Territorial Emissions: Greenhouse gas emissions physically released within a country's national borders, regardless of where the goods or services associated with those emissions are ultimately consumed.

Total Energy Supply (TES): The total amount of energy available within a country from all sources, generally calculated by considering domestic energy production and imports, while accounting for exports and changes in energy stocks.

CHAPTER: VIII

Environmental Impact Assessment (EIA) practices in Nepal

Deep Narayan Shah

Central Department of Environmental Science, Tribhuvan University

Email: dnshah@cdes.edu.np

Summary

Environmental Impact Assessment (EIA) in Nepal has evolved into an important instrument for integrating environmental considerations into development planning. Since the National Environmental Impact Assessment Guidelines 1993 and the subsequent Environment Protection Act and Rules, the country has established a comprehensive legal and institutional framework. The Environment Protection Act 2019 and Environment Protection Rules 2020 further strengthened this framework through a tiered system of Brief Environmental Study, Initial Environmental Examination, and Environmental Impact Assessment, alongside provisions addressing climate change, biodiversity, hazardous waste, enforcement, and federal responsibilities. More than 500 EIA reports have been approved, demonstrating the growing institutionalization of environmental assessment. Despite this progress, the current status of EIA practice reveals a substantial gap between regulatory requirements and implementation. EIA is widely applied across hydropower, roads, forestry, mining, water resources, industry, tourism, urban development, waste management, agriculture, health, and infrastructure. However, monitoring and enforcement remain weak, mitigation measures are frequently inadequately implemented, and cumulative, induced, long-term, and ecosystem-level impacts are often overlooked. Public participation is also frequently procedural rather than meaningful. The quality and credibility of EIA reports remain major concerns. Reports sometimes contain generic or copied material, inadequate baseline information, factual inaccuracies, weak alternative analysis, and insufficient site-specific assessment. Limited technical capacity, inexperienced practitioners, inadequate review mechanisms, resource constraints, and political pressure further compromise the process. Improvement therefore requires stronger post-approval monitoring, consistent enforcement, greater accountability of consultants and project proponents, and enhanced technical capacity within regulatory institutions. EIA should be initiated early enough to influence project design and alternatives, rather than functioning as a procedural approval requirement. Meaningful public participation, consideration of cumulative impacts and valued ecosystem components, stronger inter-agency coordination, and integration of free, prior and informed consent can further strengthen the system. These reforms are essential for transforming EIA from a largely procedural mechanism into an effective instrument for sustainable and environmentally responsible development.

Keywords: Environmental Governance; Environmental Impact Assessment; Nepal; Public Participation; Sustainable Development

1. Introduction

In the 21st century, environmental degradation has emerged as one of the most critical global challenges that are largely driven by rapid industrialization, urbanization and increasing demand for natural resources (Tyagi et al., 2014). Although development activities are necessary for economic growth and improving the livelihoods of human well-being, they adversely create a significant impact on the environment, including deforestation, biodiversity loss, pollution and climate change (Goldsmith, 1984). The infrastructure

development such as hydropower projects, road construction and urban expansion in developing countries like Nepal has been growing rapidly due to which there has been a significant pressure on the natural ecosystems. In this context, Environmental Impact Assessment (EIA) has become an essential tool for promoting sustainable development. It is a scientific method of determining the possible environmental consequences of an intended project before implementation. It aims to ensure that environmental considerations are integrated into decision-making processes, thereby minimizing negative impacts while enhancing positive outcomes (Morgan, 2012). By doing so, EIA helps strike a balance between development needs and environmental conservation.

Nepal, characterized by its diverse geography (Figure 1), rich biodiversity, and fragile ecosystems, faces unique environmental challenges. The country is highly vulnerable to environmental degradation due to factors such as unplanned development, weak regulatory enforcement, and limited technical capacity (Chhetri & Shakya, 2016). Recognizing the importance of environmental protection, the Government of Nepal has established legal and institutional frameworks to regulate development activities through EIA. Policies such as the Environment Protection Act (EPA) and Environment Protection Rules (EPR) have made it mandatory for certain projects to undergo environmental assessment before approval and implementation (Bhatt & Khanal, 2009). Despite the existence of these frameworks, the effective implementation of EIA in Nepal continues to be constrained by challenges such as inadequate monitoring, limited public participation, political influence, and the poor quality of EIA reports (Aryal et al., 2020). These issues highlight the need for a critical examination of the current status of EIA practice in the country, including its legal provisions, processes, and implementation challenges. Accordingly, this chapter provides a comprehensive overview of Environmental Impact Assessment in Nepal by discussing its concept, historical evolution, legal and institutional frameworks, procedural steps, and the major challenges.

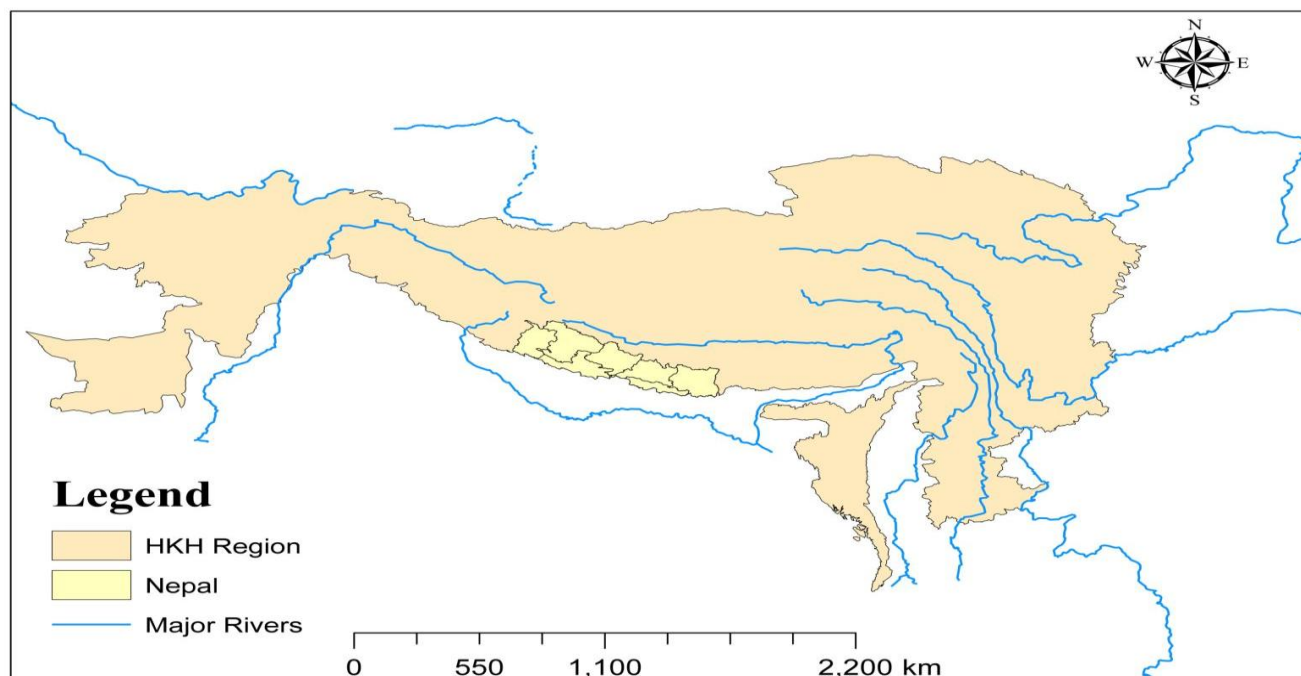


Figure 1: Map showing location of Nepal and HKH Regions

2. Concept of EIA

EIA is a systematic process used to identify, predict, and evaluate the potential environmental impacts of proposed development projects before they are carried out (Ortolano & Shepherd, 1995). It serves as a decision-making tool that helps planners, developers, and policymakers incorporate environmental considerations into project planning and implementation (Morgan, 2012). It is considered to be one of the successful policy innovations of the twentieth century (Sadler, 1996) as well as one of the effective tools (Bilgin, 2015) for the protection of the environment. The primary objective of EIA is to ensure that development activities are environmentally sound and sustainable, reducing detrimental effects while enhancing potential benefits (Clark, 1984). EIA involves a comprehensive analysis of various environmental components, including physical, biological, and socio-economic aspects (Bowd et al., 2015). The physical environment includes factors such as air, water, soil, and climate, while the biological environment focuses on flora, fauna, and ecosystems (Slootweg & Kolhoff, 2003). The socio-economic environment considers the effects of projects on human populations, livelihoods, culture, and public health (Pellizzoni, 1992). By assessing these components, EIA provides a holistic understanding of how a proposed project may affect the environment and society. One of the key features of EIA is its predictive nature. It not only identifies existing environmental conditions but also forecasts the likely changes that may occur as a result of project implementation. These impacts can be classified into various types, such as positive and negative impacts, direct and indirect impacts, and short-term and long-term impacts (Silsilah & Gandhimathi, 2023). For example, a hydropower project may generate positive impacts such as electricity production and employment opportunities, while also causing negative impacts like habitat destruction and displacement of local communities (Botelho et al., 2017).

Another important aspect of EIA is the identification of mitigation measures. These are strategies designed to avoid, reduce, or compensate for adverse environmental impacts. Mitigation measures may include changes in project design, adoption of environmentally friendly technologies, or implementation of conservation programs (Marshall, 2001). In addition, EIA promotes the consideration of alternative project options, including alternative sites, designs, and technologies, to identify the most environmentally suitable option (Ding, 2008). Public participation is also a crucial component of the EIA process. It ensures that the concerns and opinions of affected communities and stakeholders are taken into account during decision-making. This not only enhances transparency but also improves the quality and acceptability of development projects (Glucker et al., 2013). Furthermore, EIA is guided by key principles such as sustainability, the precautionary principle, and intergenerational equity, which emphasize the responsible use of natural resources for the benefit of present and future generations (Hundloe, 2021). Overall, Environmental Impact Assessment plays a vital role in promoting environmentally responsible development. By integrating environmental considerations into planning and decision-making processes, EIA helps to balance trade-offs; minimize the environmental risks as well as help mitigate the negative impacts of a project (Paudel et al., 2025) and thus, support sustainable development goals.

3. History and Evolution of EIA

The concept of EIA originated as a response to the growing environmental concerns associated with growing population, rapid industrialization and large-scale development projects in the mid-20th century. Prior to the introduction of EIA, development decisions were primarily based on economic and technical considerations, often neglecting their environmental consequences (Caldwell, 1988). As environmental degradation became more evident, the need for a systematic approach to evaluate the environmental

implications of development activities gained global attention. The formal introduction of EIA can be traced back to the United States with the enactment of the National Environmental Policy Act (NEPA) in 1969. NEPA made it mandatory for federal agencies to assess the environmental impacts of major projects before their implementation (Ortolano & Shepherd, 1995). This marked a significant milestone in environmental governance and set a precedent for other countries to adopt similar practices. Following this, EIA was gradually incorporated into environmental policies and legal frameworks across the world, particularly after the 1972 Stockholm Conference on the Human Environment and the 1992 Rio Earth Summit, which emphasized sustainable development and environmental protection (Kasurinen et al., 2023). 191 out of 193 UN member states had adopted some form of EIA in law or treaties by 2011 (Morgan, 2012).

In the context of Nepal, the evolution of EIA is relatively recent but has progressed significantly over the past few decades. Before the 1990s, there was no formal mechanism for assessing the environmental impacts of development projects in the country. However, increasing awareness of environmental issues and the need to manage natural resources sustainably led to the introduction of environmental assessment practices. The first major step towards institutionalizing EIA in Nepal was the formulation of the National Environmental Impact Assessment Guidelines (NEIAG) in 1993. These guidelines provided a basic framework for conducting environmental assessments and marked the beginning of formal EIA practices in the country. Subsequently, the Government of Nepal enacted the Environment Protection Act (EPA) in 1997 and the Environment Protection Rules (EPR) in 1997, which made EIA and Initial Environmental Examination (IEE) legally mandatory for certain categories of development projects (Bhatt & Khanal, 2009). Over time, Nepal has made efforts to strengthen its environmental governance system. The Environment Protection Act was revised in 2019 (2076 B.S.), and the updated Environment Protection Rules were introduced in 2020 (2077 B.S.).

A new category for project level environmental assessment called as the Brief Environmental Study (BES) was introduced by the EPA, 2019. These legal instruments provide clearer provisions regarding the screening, approval, and monitoring of EIA processes. They also define the roles and responsibilities of various government agencies involved in environmental management. Despite these advancements, the implementation of EIA in Nepal has faced several challenges, including limited technical capacity, weak enforcement mechanisms, and political influences. Nevertheless, the evolution of EIA in Nepal reflects a growing recognition of the importance of integrating environmental considerations into development planning (Aryal, 2023). The history and evolution of EIA demonstrate a global shift towards more sustainable development practices. From its origins in the United States to its adoption in Nepal, EIA has become an essential tool for minimizing environmental impacts and promoting responsible development.

4. Legal and Policy Framework of EIA in Nepal

The legal and policy framework of EIA in Nepal provides the foundation for integrating environmental considerations into development planning and decision-making. Over the years, the Government of Nepal has established various laws, policies, and guidelines to regulate development activities and minimize their adverse environmental impacts. These legal instruments ensure that projects with potential environmental consequences undergo proper assessment before implementation. The principal legislation governing EIA in Nepal is the EPA, 2019 (2076 B.S.), which serves as the primary legal framework for environmental management in the country. The Act mandates that certain categories of development projects must conduct either an EIA or an IEE prior to approval. It emphasizes the identification, prediction, and mitigation of environmental impacts to ensure that development activities are environmentally sustainable (Aryal et al.,

2020). Supporting the Act are the EPR, 2020 (2077 B.S.), which provide detailed procedures for conducting environmental assessments.

The Rules classify projects based on their scale, nature, and potential impacts, requiring large-scale projects such as hydropower, highways, and industrial developments to undergo a full EIA, while smaller projects may require only an IEE or a BES. They also outline key stages of the assessment process, including screening, scoping, public consultation, report preparation, approval, and monitoring (Bhatt & Khanal, 2009). The revised EPA 2019 replaced the earlier 1997 Act with the objective of modernizing environmental governance in line with Nepal's 2015 Constitution and federal structure. The updated framework introduced several significant improvements, including the expansion of its scope to address contemporary environmental issues such as climate change, carbon trading, hazardous waste management, and biodiversity conservation. It also aligned environmental governance across federal, provincial, and local levels, ensuring clearer distribution of responsibilities. Furthermore, the Act introduced a tiered system of environmental studies, requiring projects to undertake a BES, IEE or EIA depending on their scale and potential impacts (Aryal, 2023).

In addition, the revised framework strengthened enforcement mechanisms by introducing stricter penalties for non-compliance, incorporating the polluter pays principle, and establishing an Environmental Fund to support environmental protection and restoration activities. The EPR 2020 further detailed procedural requirements and enhanced compliance monitoring through the involvement of environmental inspectors. Subsequent amendments to the Rules have also updated project classification criteria, making the system more responsive to emerging environmental challenges (Dangi et al., 2015). Beyond the EPA and EPR, the NEIAG, 1993 continue to play an important role in guiding the preparation and evaluation of EIA reports, ensuring consistency and standardization. Several sectoral laws further support the EIA framework. For example, the Forest Act, 2019 regulates forest resource management, the National Parks and Wildlife Conservation Act, 1973 focuses on biodiversity protection (Chaudhary et al., 2024), and the Local Government Operation Act, 2017 empowers local governments to participate in environmental management and monitoring. Moreover, the Constitution of Nepal (2015) guarantees the right to a clean and healthy environment as a fundamental right, thereby strengthening the legal basis for environmental protection (Adhikari, 2024).

Despite the existence of a comprehensive legal framework, challenges remain in terms of effective implementation and enforcement. Weak monitoring mechanisms/ non-compliance to mitigation measures (Ghimire et al., 2021), limited technical capacity, and inadequate institutional coordination often reduce the effectiveness of EIA in practice. Nevertheless, the legal and policy framework of EIA in Nepal represents a significant step toward achieving sustainable development by integrating environmental considerations into development planning. Nepal has developed a relatively strong legal and institutional framework for Environmental Impact Assessment. However, its success depends largely on effective implementation, continuous monitoring, and periodic updates to address emerging environmental issues.

5. EIA Process and Practices in Nepal

The Environmental Impact Assessment process in Nepal is a systematic and step-by-step procedure designed to evaluate the potential environmental impacts of proposed development projects before their implementation. The process is guided by the EPA (2019) and EPR (2020), which outline the necessary stages and requirements. The main objective of this process is to ensure that environmental considerations

are integrated into project cycle, thereby minimizing adverse impacts and promoting sustainable development.

The first step in the EIA process is screening. Screening determines whether a proposed project requires a full EIA or a less detailed IEE or BES. This decision is based on the fixed list of project type and scale rather than an analysis of characteristics of each project, project site or the identification of significant impacts (Lima et al., 2015). The screening is done as specified in the Environment Protection Rules (Schedule 1 of the EPR, 2020). Large-scale and high-impact projects such as hydropower plants, highways, and industrial operations typically require a full EIA. The second step is scoping, which involves identifying the key environmental issues and impacts that need to be studied in detail. During this stage, the major concerns related to the project are outlined, and the boundaries of the study are defined. Scoping helps to focus the assessment on the most significant environmental aspects, saving time and resources (Aryal et al., 2020). Scoping is mandatory for EIA only and IEE and BES don't require to follow this step. Following scoping, the Terms of Reference (ToR) are prepared. The ToR is a detailed document that outlines the methodology, scope, and specific issues to be addressed in the EIA study. It is submitted to the relevant authority, usually the Ministry of Forests and Environment, for approval. Only after the ToR is approved, the detailed EIA study can proceed. The next stage is the baseline study, which involves collecting data on the existing environmental conditions of the project area following the data requirement and methodology mentioned in approved ToR. This includes information on physical aspects such as air quality, water resources, soil conditions, and climate, as well as biological aspects like flora and fauna. Socio-economic conditions, including local communities, livelihoods, and cultural practices/heritages are also assessed. The baseline study serves as a reference point for evaluating future environmental changes (Bhatt & Khanal, 2009). Once the baseline data is collected, the process moves to impact identification and prediction. In this stage, potential environmental impacts of the project are identified and analyzed. These impacts may be positive or negative, direct or indirect, reversible or irreversible and short-term or long-term. Various scientific methods and tools are used to predict the magnitude and significance of these impacts. After identifying the impacts, mitigation measures are proposed to avoid, minimize/mitigate, or compensate for negative effects. These measures may include changes in project design, adoption of environmentally friendly practices/technologies, or implementation of environmental management plans. The goal is to reduce the overall environmental footprint of the project (Aryal, 2023). Public participation is another important step in the EIA process. Public hearings and consultations are conducted to gather the opinions and concerns of local communities and stakeholders who may be affected by the project. This ensures participatory approach of affected people, transparency and inclusiveness in decision-making and helps improve the quality of the EIA report.

The findings of the assessment are then compiled into an EIA report, which includes all relevant information such as baseline conditions, identified/predicted impacts, mitigation measures, and environmental management plans. Alternative Analysis is an important component of EIA. The US NEPA considers alternative analysis as the heart to the assessment processes (Smith, 2006). Alternatives in terms of project selection, design, project site, construction materials, time schedule as well as no action alternatives are believed to be examined for the augmentation of the beneficial and mitigation of the adverse impacts. EIA report is then submitted to the concerned authority for review and approval. The review process evaluates the adequacy, accuracy and overall quality of the report before granting permission for project implementation. Finally, monitoring and evaluation are conducted after project approval to ensure that the proposed mitigation measures are effectively implemented and that environmental standards are maintained

(Dangi et al., 2015). Regular monitoring helps the effective implementation of environmental management plan and to identify any unforeseen impacts and allows for corrective actions to be taken if necessary.

6. Thematic areas of EIA practices in Nepal

In Nepal, EIA is applied across a wide range of development sectors as specified in the EPR (2020). These include key sectors such as energy, forestry, mining, roads, water resources and irrigation, industry, tourism, housing and urban development, waste management, agriculture, health, and other infrastructure development projects. The inclusion of multiple sectors ensures that environmental considerations are integrated into diverse development activities, thereby minimizing adverse impacts and promoting sustainable development. Studies show that most EIAs in Nepal are concentrated in the water resources and energy sectors, followed by road and forestry projects, while the mining sector has the fewest. Additionally, Kathmandu records the highest number of EIA-approved projects, reflecting the concentration of development activities in the region (Joshi, 2017).

6.1 Energy Sector

The energy sector, particularly hydropower development, represents the most prominent area where EIA is extensively practiced in Nepal. Given the country's vast hydropower potential and increasing demand for electricity, numerous large-scale hydropower and transmission line projects have been developed, making this sector a primary focus of environmental assessment. Under this sector, hydropower projects with more than 5 MW capacity requires an EIA (Yadav, 2026). Major hydropower projects such as the Upper Tamakoshi Hydropower Project, Arun III Hydropower Project, and Kali Gandaki 'A' Hydropower Project have undergone comprehensive EIA studies prior to their implementation. These EIAs typically involve detailed baseline assessments of river hydrology, aquatic biodiversity, forest resources, and socio-economic conditions of affected communities. Particular attention is given to issues such as alteration of natural river flow, impacts on fish migration, sediment transport, and displacement of local populations. In practice, EIA reports in the energy sector are generally well-prepared and technically detailed, often including Environmental Management Plans (EMPs) and mitigation strategies (Paudel et al., 2025). For instance, in projects like Indrawati-3 hydropower project, mitigation measures such as afforestation programs, compensation for affected households, and controlled water release have been proposed to reduce environmental impacts (Ghimire et al., 2021). However, despite these provisions, the effectiveness of implementation remains a significant concern.

The major environmental impacts associated with hydropower development include changes in river ecosystems, habitat fragmentation, loss of biodiversity, and socio-economic impacts such as displacement and changes in local livelihoods. In many cases, cumulative impacts of multiple hydropower projects within the same river basin are not adequately assessed, leading to long-term ecological consequences (Gaudel, 2015). A critical example of weak implementation of EIA provisions in Nepal's hydropower sector can be observed in the case of the Modi Khola basin. Although Hydropower Development Policy, 2058 (2001) require hydropower projects to release such quantum of water which is higher of either at least ten per cent of the minimum monthly average discharge of the river/stream or the minimum required quantum as identified in the environmental impact assessment study report, studies have found that compliance is extremely poor. Research conducted on the Modi Khola, where multiple hydropower projects are concentrated within a small watershed, revealed that no water was being released downstream in several cases. Furthermore, field findings indicated that even project engineers were unaware of EIA requirements

and mitigation measures (Dangol & Uprety, 2019). This situation reflects not only weak monitoring and enforcement but also highlights the issue of cumulative environmental impacts, where multiple projects within the same river system significantly degrade aquatic ecosystems. Furthermore, challenges in this sector include weak monitoring and enforcement mechanisms, political and economic pressure to expedite projects, and limited public participation. Although public hearings are conducted as part of the EIA process, they are sometimes treated as procedural requirements rather than meaningful platforms for community engagement (Gaudel, 2015).

6.2 Transportation infrastructure Sector

The construction/expansion of road among the transportation sector is one of the most rapidly expanding development sectors in Nepal, and it constitutes a major area of EIA application. With increasing demand for connectivity and economic integration, numerous large-scale road projects such as the Mid-Hill Highway, Kathmandu-Tarai Fast Track, and rural road expansion programs have been implemented, many of which require comprehensive EIA studies. EIA practices in the road sector focus on assessing environmental impacts related to slope stability, changes in natural drainage system, landslide risks, deforestation, habitat fragmentation, soil erosion, and impacts on local communities. Baseline studies include geological assessments, vegetation analysis, and socio-economic surveys. Mitigation measures typically involve bioengineering techniques, slope stabilization, proper drainage systems, and reforestation programs (Paudel & Henry, 2024). Despite the preparation of detailed EIA reports, implementation remains a major concern. Road construction in hilly and mountainous regions has frequently resulted in increased soil erosion and landslides, sedimentation of rivers, and destruction of natural habitats.

In many cases, contractors do not strictly follow environmental guidelines or environmental management plan of the EIA reports, and monitoring by authorities is limited. The environmental impacts of road development are particularly severe in fragile mountainous ecosystems. Improper road alignment, unplanned excavation, and lack of slope protection measures contribute to environmental degradation. Additionally, road expansion often leads to increased human encroachment, deforestation, and changes in land use patterns (Merz et al., 2006). A notable example highlighting the gap between EIA provisions and actual implementation can be observed in the Mugling-Pokhara Highway expansion project. In addition to it, the expansion of roads across biodiversity-rich regions has created significant conservation challenges. Roadways pose risk to the movement of local wildlife when they pass through the protected areas (Selvan, 2011). The studies in Chitwan National Park, revealed increased conflict during road expansion (Lamichhane et al., 2018). The IEE conducted in 2019 had identified air pollution, particularly dust emissions from construction activities, as a key environmental impact and proposed mitigation measures such as regular water sprinkling and air quality monitoring. However, field observations and local reports indicate that these measures have been poorly implemented. Residents living along the highway have reported severe dust pollution, leading to worsening respiratory health conditions. Despite repeated complaints to authorities, effective mitigation actions were delayed, forcing local communities to protest and demand compliance. This case clearly illustrates the weak enforcement of environmental management plans and the gap between EIA commitments and on-ground practice in Nepal's road sector (Bhusal, 2022). Key challenges in this sector include weak enforcement of environmental regulations, lack of coordination between agencies, and prioritization of rapid construction over environmental sustainability. Public participation is often limited, and local concerns are not adequately addressed (Paudel & Henry, 2024).

Therefore, while EIA is widely practiced in the road sector, its effectiveness is constrained by poor implementation and monitoring.

6.3 Forestry Sector

The forestry sector plays a crucial role in Nepal's environmental management, and EIA is applied to projects involving forest land use, deforestation, and resource extraction. Many development projects, including hydropower and road construction, require clearance of forest areas, thereby triggering the need for environmental assessment under forestry-related regulations. EIA practices in this sector emphasize biodiversity conservation, ecosystem services, and wildlife habitat protection. Baseline studies often include detailed assessments of forest composition, species diversity, and ecological significance of the affected area. Mitigation measures typically involve compensatory afforestation, biodiversity conservation programs, and wildlife management plans. However, implementation of these measures remains inconsistent. While compensatory plantation programs are commonly proposed, their survival rates and long-term effectiveness are often questionable. Illegal logging, forest encroachment, and inadequate monitoring further undermine conservation efforts. Environmental impacts in this sector include loss of forest cover, habitat fragmentation, and decline in biodiversity. These impacts are particularly critical in ecologically sensitive areas, where even small disturbances can have significant consequences. Furthermore, the conversion of forest land for development purposes often leads to long-term ecological imbalance. Challenges in the forestry sector include allocation of adequate budget for the conservation measures, weak institutional coordination, lack of proper monitoring, and conflicts between development and conservation priorities. Although policies emphasize sustainable forest management, implementation gaps continue to limit the effectiveness of EIA in this sector.

6.4 Mining Sector

The mining sector in Nepal involves the extraction of limestone, sand, gravel, and other minerals, with a primary focus on limestone quarrying due to the growing demand from the cement industry. Major mining activities requiring EIA are concentrated in districts such as Udayapur, Sindhuli, Makwanpur, Palpa, Dang, Pyuthan, and Dhankuta. Although the number of EIA studies in this sector is relatively low compared to others, mining activities generate significant localized environmental impacts, making environmental assessment essential. EIA practices in this sector typically focus on changes in land use pattern and land degradation, water and air pollution, and impacts on surrounding ecosystems. Baseline studies include geological assessments, water resource evaluation, and analysis of nearby settlements, while mitigation measures involve controlled extraction, site rehabilitation, dust suppression, and proper waste management (DGM, 2022). However, in practice, many mining activities, particularly riverbed extraction, are conducted informally or with limited regulatory oversight, often bypassing EIA requirements. Monitoring by authorities remains weak, and enforcement mechanisms are not effectively implemented.

The approval process itself can be lengthy, often taking six months to a year, while political pressure has at times led to the over-extraction and relaxation of environmental regulations, especially for construction materials such as stone, sand, and gravel. In some instances, extraction activities have been permitted in sensitive areas, including riverbeds, conservation zones, and even national parks, without proper EIA compliance, despite opposition from environmental experts (Shahi, 2016). The environmental impacts of such practices include riverbank erosion, lowering of groundwater levels, habitat destruction, and landscape degradation. Unregulated extraction further increases the risk of flooding, change in river morphology,

sediment transport and damage to infrastructure. These issues highlight key challenges in the sector, including weak regulatory enforcement, illegal mining activities, strict monitoring and limited institutional capacity. Consequently, despite the presence of EIA requirements, their practical effectiveness in the mining sector remains significantly constrained (Shrestha, 2019).

6.5 Water resources and Irrigation Sector

The water resources and irrigation sector plays a vital role in Nepal's agricultural economy and rural livelihoods, involving projects such as dams, irrigation canals, diversion structures, and water supply systems. EIA in this sector focus on hydrological changes, water availability, soil conditions, and impacts on aquatic ecosystems and downstream communities. Baseline studies typically assess river hydrology and flow patterns, groundwater levels, water use rights and agricultural dependency on water resources, while mitigation measures include controlled water distribution, canal lining, and soil management practices. A notable example demonstrating the effectiveness of EIA in the irrigation sector is the Babai Irrigation Project in Bardiya district. Initially, the Department of Irrigation proposed clearing approximately 1,150 hectares of forest land for canal construction. However, following the requirement to conduct an EIA, the project plan was significantly modified, and approval was granted for clearing only 22 hectares (Bhusal, 2022). In practice, however, implementation of EIA recommendations remains inconsistent. Many irrigation projects alter natural water flow, leading to issues such as waterlogging, reduced downstream supply, and conflicts among water users. In some cases, insufficient consideration is given to cumulative impacts, particularly where multiple water diversion projects exist within the same basin. Monitoring mechanisms are often weak, and local participation in decision-making is limited. Environmental impacts associated with this sector include degradation of aquatic habitats, changes in sediment flow, water sharing related conflicts and long-term soil fertility issues. Despite the importance of EIA in ensuring sustainable water use, challenges such as poor coordination among agencies, limited technical capacity, and weak enforcement continue to hinder effective implementation.

6.6 Industry Sector

The industrial sector in Nepal includes cement factories, brick kilns, manufacturing plants, and other processing industries, many of which require EIAs due to their potential environmental impacts. EIAs in this sector primarily focus on air pollution, water contamination, solid waste generation, and energy consumption. Baseline studies assess existing environmental conditions, including air, water quality and noise level while mitigation measures involve installation of pollution control technologies, wastewater treatment systems, and proper waste disposal mechanisms. Despite these provisions, compliance with EIA recommendations is often weak. Many industries operate without fully implementing pollution control measures, resulting in significant environmental degradation. Brick kilns, for example, are major contributors to air pollution in urban and peri-urban areas, while cement industries generate dust and emissions that affect surrounding communities. Monitoring and enforcement by regulatory authorities are limited, and industrial operators may prioritize cost reduction over environmental compliance. As a result, environmental impacts such as air quality deterioration, water pollution, occupational health and safety risk and health risks for nearby populations persist. These challenges highlight the gap between EIA requirements and actual environmental management practices within Nepal's industrial sector.

6.7 Tourism Sector

Tourism is a key economic sector in Nepal, with development activities including hotels, resorts, trekking infrastructure, and facilities in ecologically sensitive regions. EIAs are required for tourism projects, particularly those located in protected areas and high-altitude ecosystems. EIAs in this sector focus on waste management, water resource use, biodiversity conservation, and impacts on natural landscapes. While EIA reports often propose sustainable and environment-friendly tourism practices, implementation remains inconsistent. Popular tourist destinations experience increasing environmental pressure due to high visitor numbers, leading to issues such as solid waste accumulation, water scarcity, and degradation of fragile ecosystems. In mountainous regions, inadequate waste management systems have resulted in pollution along trekking routes and near settlements. Although conservation areas have management plans, enforcement of EIA recommendations is often weak, and coordination among stakeholders is limited. Balancing economic benefits from tourism with environmental sustainability remains a major challenge, highlighting the need for stronger implementation of EIA measures in this sector.

6.8 Residence, Building, Town Development and Urban Development Sector

Rapid urbanization in Nepal has significantly increased the need for EIA in housing and urban development projects. Large-scale housing complexes, land development initiatives, and urban infrastructure projects require EIA to assess impacts on land use, drainage systems, waste management, water supply/sewerage management and air quality. EIA practices in this sector include analysis of land transformation, population density, and infrastructure capacity, with mitigation measures focusing on proper urban planning, waste disposal systems, and water supply and sewerage management. However, implementation is often weak, particularly in rapidly growing urban areas such as Kathmandu Valley. Unplanned urban expansion has led to environmental issues such as water scarcity, air pollution, poor drainage, sewage treatment and increased solid waste generation. In many cases, EIA requirements are either bypassed or inadequately enforced, allowing developments to proceed without proper environmental safeguards (Shrestha & Pradhan, 2009). These challenges underscore the limitations of EIA in managing the environmental impacts of urban growth in Nepal.

6.9 Waste Management Sector

The waste management sector includes projects such as landfill sites, waste treatment plants, and sewage management systems, all of which require EIAs due to their potential environmental and public health impacts. EIAs in this sector focus on waste segregation, transfer and disposal methods, leachate management, air pollution, and risks to nearby communities. Although EIA reports propose measures such as proper landfill design, waste segregation, transfer and treatment systems, implementation is often inadequate. Landfill sites frequently face issues such as poor design and management, lack of proper operation and maintenance practices, and strong opposition from local communities in absence of grievance redress mechanism. In some cases, environmental safeguards are not fully implemented, leading to groundwater contamination and air pollution. Institutional weaknesses, lack of technical capacity, and insufficient public engagement further complicate effective waste management (Dangi et al., 2017). As a result, despite the presence of EIA requirements, environmental and health risks associated with waste management projects remain significant in Nepal.

6.10 Agriculture Sector

The agriculture sector involves large-scale farming projects, irrigation expansion, and agro-based industries that may require EIAs. EIAs in this sector focus on soil quality, water use, pesticide and fertilizer application, and impacts on biodiversity. Baseline studies assess existing agricultural practices and environmental conditions, while mitigation measures include sustainable farming techniques, controlled use of chemicals, and soil conservation practices. However, implementation of these measures is often limited, particularly in rural areas where monitoring is weak. Environmental impacts associated with agriculture include soil degradation, water pollution from chemical runoff, impact on public health from pesticide use and loss of biodiversity. The lack of awareness among farmers and limited institutional support further hinder effective implementation of EIA recommendations. This highlights the need for stronger integration of environmental considerations into agricultural development practices.

6.11 Health Sector

Healthcare infrastructure projects, including hospitals, laboratories, and medical facilities, require EIAs due to concerns related to medical waste management and public health risks. EIAs in this sector focus on waste disposal, sanitation systems, and potential environmental contamination. Although guidelines for medical waste management exist, implementation remains inconsistent. Many healthcare facilities lack proper waste treatment systems, leading to improper disposal of hazardous materials. This poses risks to both the environment and public health. Challenges in this sector include limited infrastructure, low priority in health care waste management, weak monitoring, and lack of awareness regarding environmental standards. As a result, EIA recommendations are not always effectively implemented, reducing their overall impact on improving environmental management in healthcare projects.

6.12 Infrastructure

Other infrastructure projects, including airports, communication systems, and large public facilities, also require EIAs due to their wide-ranging environmental impacts. EIAs in this sector assess issues such as land use change and change in drainage pattern, sound pollution, air quality, and ecological disturbance. While EIA reports provide mitigation measures such as noise control, drainage management, site restoration, environmental monitoring, and land management strategies, implementation is often inconsistent. Large infrastructure projects may proceed with limited adherence to environmental safeguards, particularly during construction phases. A prominent example illustrating the challenges of EIA implementation in Nepal's infrastructure sector is the proposed Nijgadh International Airport project in Bara district. The EIA for the project was approved despite significant concerns, including the proposed clearing of approximately 2.4 million trees in one of Nepal's remaining subtropical forests. The approval process was reportedly rushed, with limited time allocated for reviewing the extensive technical documentation, and the report itself contained notable flaws, including factual inconsistencies and lack of comparative analysis of alternative sites. These shortcomings raised serious questions about the credibility and rigor of the EIA process. Public criticism and media reports led to legal challenges, and in 2022, the Supreme Court directed the government to halt the project and restart the EIA process (Bhusal, 2022). This case highlights the influence of political

pressure, inadequate data collection and question on their accuracy, lack of alternative analysis, poor environmental management plan, weak review mechanisms, and the gap between procedural compliance and meaningful environmental protection in Nepal's EIA system.

7. Sector-Specific Environmental Laws

In addition to the general EIA framework, Nepal has several sector-specific laws that incorporate environmental assessment requirements and interact with the broader EIA system. For instance, the Electricity Act, 1992 and the Electricity Regulatory Commission Act, 2017 require project developers to comply with environmental standards, including EIA, as a prerequisite for obtaining licenses. Similarly, the National Parks and Wildlife Conservation Act, 1973 regulates activities within and around protected areas, linking them to EIA requirements. The Forest Act, 2019 also mandates environmental clearance, including EIA where necessary, for projects affecting forest land. Together, these overlapping legal provisions create a complex and multi-layered regulatory framework that project proponents must navigate during the EIA approval process (Yadav, 2026).

8. Post EIA Implementation and Monitoring in Nepal

Once an EIA is approved in Nepal, it signifies the transition from the assessment phase to the implementation phase of a development project. The approval granted by the Ministry of Forests and Environment (MoFE) provides legal clearance for the project to proceed, provided that the proponent complies with the conditions outlined in the approved EIA report and relevant provisions of the EPA, 2019. A key requirement following approval is the implementation of the Environmental Management Plan (EMP), which includes mitigation measures designed to minimize adverse impacts on the environment and local communities. Project proponents are obligated to carry out these measures throughout the project lifecycle. In addition, proponents must conduct periodic self-monitoring and submit compliance reports, typically every six months, to the relevant authorities such as the Ministry or the Department of Environment. These reports are intended to track environmental performance and ensure adherence to the approved mitigation measures (Yadav, 2026).

Environmental auditing is another important component of the post-approval process. Unlike the EIA, which is conducted prior to project implementation, environmental audits are carried out after project completion often within two years to evaluate whether the predicted impacts align with actual outcomes and to assess compliance with the EMP. The approved project is also subject to regulatory oversight by government agencies, and local communities have the right to raise concerns if environmental safeguards are not properly implemented. This reflects an effort to incorporate accountability and public participation in environmental governance (Rimal, 2024). However, several challenges persist in the post-approval phase.

If there are significant changes in the project's scale, design, location, or technology, a Supplementary EIA is required. Moreover, failure to comply with the approved EMP can result in penalties, including fines, suspension of the project, or revocation of approval under the Environment Protection Act, 2019. Failure to comply with EIA requirements, either by implementing projects without approval or violating approved conditions, can result in strict penalties. These include fines of up to NPR 5 million, suspension or closure of the project, and liability for environmental restoration and compensation. In cases of continued non-compliance, legal action may be taken, including cancellation of project approval and potential criminal liability. These provisions apply to both unauthorized project execution and failure to implement prescribed mitigation measures (Republica, 2019). Despite these provisions, the effectiveness of post-EIA implementation in Nepal remains a concern. In practice, many projects fail to fully implement mitigation measures, and monitoring by authorities is often limited. This gap between approval and actual implementation reduces the effectiveness of EIAs as a tool for environmental protection and sustainable development.

9. Quality of Reports

The quality of EIA reports in Nepal is a crucial factor influencing the overall effectiveness of the environmental governance system. The Ministry of Forests and Environment (MoFE) serves as the primary authority responsible for granting EIA approval, while the Department of Environment (DoEnv) plays a central role in reviewing and processing EIA applications. The DoEnv coordinates with other relevant government agencies and stakeholders to assess and monitor the environmental implications of proposed projects. Sector-specific line ministries are involved in the approval process of Initial Environmental Examination Reports. Since the implementation of the EIA system, more than 500 EIA reports have been approved, with the majority of approvals occurring during the past decade (Table 01). This reflects the growing scale of development activities and the increasing reliance on environmental assessment as a regulatory tool.

In Nepal, EIA reports are generally prepared by independent private consultancy firms on behalf of project proponents. The EPR 2020 outline the procedural and technical requirements for EIA preparation, including the involvement of a multidisciplinary team of at least five specialists, as specified in Schedule 13, and adherence to the report format prescribed in Schedule 12. Despite these provisions, the quality of EIA reports has been widely questioned due to several systemic issues.

Table 9: Sector-wise approved Environmental Impact Assessment (EIA) reports in Nepal since fiscal year 2072/073 (source: MoFE)

SN	Sectors (Based on the Schedule 1, 2 & 3 of EPR, 2077)	Total EIA Reports approved in the following years										Sector- wise Total
		2072/073	073/074	074/075	075/076	076/077	077/078	078/079	079/080	080/081	081/082	
1	Forest Sector	5	5	3	1	2		1		1		18
2	Health Sector	1	2	1			2	3	7	5	3	24
3	Education Sector	1			2	6	2	5		1	1	18
4	Tourism Sector	3	3	5	3	8	13	10	3	4	3	55
5	Transportation Infrastructure	6	8	13	5	10	18	11	11	8	4	94
6	Energy, water resources and irrigation	13	9	10	14	33	18	19	10	24	6	156
7	Drinking water sector		1		1							2
8	Residence, Building, Town Development and Urban Development Sector	1			2	1	2	3	4	3	3	19
9	Waste management sector	1					1	1	1			4
10	Industry sector	4	5	1	1	4	6	3		2		26
11	Mining sector					1					1	2
12	Agriculture Sector						1					1
13	Agri-industry Sector											
14	Others											
Total (Year wise)		35	33	33	29	65	63	56 Incl – 6 SEIA	36	48	21	419

One of the most prominent concerns is the widespread practice of copying and pasting content from previously prepared reports, resulting in generic and non-site-specific assessments. Even large-scale projects have been affected by such practices. For instance, the EIA report of the Nijgadh International Airport project was found to contain sections copied from a hydropower project, raising serious concerns about the credibility and rigor of the assessment process. Such issues indicate a lack of originality and technical diligence in report preparation (Joshi, 2022). Another major issue is the presence of inadequate, inaccurate, inconsistent and misleading information within EIA reports.

In some cases, ecological and environmental claims lack scientific validity. For example, the EIA report of the Sangu Khola Hydropower Project identified the presence of fishing cats in an area where experts argue the species cannot survive due to unsuitable climatic conditions. Experts have attributed such inaccuracies to the involvement of inexperienced practitioners in the preparation process (Kantipur TV HD, 2021). It has been observed that project proponents often hire less experienced or newly graduated individuals to minimize costs, which compromises the technical quality and reliability of the reports (Joshi, 2022). Furthermore, a critical component of EIA, the analysis of project alternatives is frequently overlooked or inadequately addressed. Instead of presenting a comprehensive comparison of alternative sites, designs, or technologies, many reports include only brief and superficial discussions. This limitation is further compounded by the fact that EIAs are often conducted at a late stage of project development, after key decisions regarding project location and design have already been finalized (Shah, 2019). As a result, the EIA process becomes more of a procedural requirement rather than an effective decision-making tool. The review and approval process itself also affects the quality of EIA reports. Limited technical capacity and engagement of multidisciplinary study team, time and resource constraints, and administrative or political pressures can lead to insufficient scrutiny of complex EIA documents. Consequently, some projects receive approval despite significant gaps in analysis and documentation. Although the EPR 2020 provides provisions to blacklist consultancy firms for up to five years if they fail to meet required standards, the extent of enforcement of such measures remains unclear, raising concerns about accountability and quality control. Limited budget, weak technical rigor, lack of experienced professionals, insufficient review mechanisms, and limited enforcement collectively undermine the effectiveness of EIA as a tool for environmental protection and sustainable development.

10. Challenges and Limitations of EIA in Nepal

Despite the establishment of a comprehensive legal and institutional framework, the implementation of EIA in Nepal faces numerous challenges that limit its effectiveness as a tool for sustainable development. One of the most critical issues is the significant gap between EIA provisions and their actual implementation on

the ground. Although EIA reports often include detailed mitigation measures, these are frequently not carried out during project execution. For instance, hydropower projects are required to maintain minimum environmental flow; however, studies have shown widespread non-compliance, with little to no water being released downstream in several cases (Paudel et al., 2025). Weak monitoring and enforcement mechanisms further exacerbate this issue. Government agencies responsible for overseeing EIA compliance often lack sufficient technical capacity, resources, and coordination. Research indicates that only a small proportion of approved projects are regularly monitored, allowing many developers to bypass environmental commitments without consequence. This lack of accountability reduces the effectiveness of the entire EIA system (Joshi, 2017). Another major challenge is the poor quality of EIA reports. In many cases, assessments are prepared hastily, with insufficient data, lack of site-specific analysis, and even factual inaccuracies. The Nijgadh International Airport project serves as a prominent example, where the EIA report was criticized for errors and lack of alternative analysis, raising concerns about the credibility of the review process (Patela & Shrestha, 2022). Such shortcomings undermine the reliability of EIA as a decision-making tool.

Political interference and pressure from development-oriented agencies also pose significant limitations. Large infrastructure projects are often prioritized for economic or strategic reasons, leading to rushed approvals and compromised environmental standards. This is evident in cases where projects have been approved despite significant environmental risks or without thorough review of EIA documents. Public participation, although legally required, is often limited in practice. Participation aligns with the concept of "pseudo-participation" (Murombo, 2008) as it's often carried out merely to meet legal obligations, making it superficial. Consultations are frequently conducted as formalities, with minimal incorporation of local concerns into project design and decision-making (Adhikari & Shrestha, 2025). As a result, affected communities may face adverse environmental and health impacts, such as dust pollution from road construction projects, without effective mitigation.

Additionally, there is a lack of consideration of valued ecosystem component (VEC), cumulative, induced, unanticipated and long-term environmental impacts. Many EIAs focus only on individual projects without assessing the combined or induced effects of multiple developments within the same region or ecosystem. This is particularly problematic in river basins where several hydropower projects operate simultaneously, leading to significant ecological degradation. Institutional weaknesses, including overlapping legal provisions and poor inter-agency coordination, further complicate the EIA process. Multiple sectoral laws require environmental clearance, creating a complex regulatory environment that can lead to delays, inconsistencies, and confusion among project proponents (Rimal, 2024). Overall, these challenges indicate that while Nepal has made significant progress in establishing an EIA framework, its practical effectiveness

remains limited. Addressing these issues requires strengthening monitoring and enforcement mechanisms, improving the quality of EIA reports, enhancing public participation, and ensuring that environmental considerations are genuinely integrated into development planning and project cycle rather than treated as procedural requirements.

11. Conclusion

EIA in Nepal has evolved significantly since its initial introduction through the NEIAG 1993, and its formal legal enforcement under the EPA, 1997 and EPR, 1997. Over time, the system has expanded, with more than 500 EIA reports approved by the Ministry of Forests and Environment, reflecting Nepal's increasing reliance on environmental assessment as a key regulatory tool for development projects. Despite this progress, the effectiveness of the EIA system remains limited due to persistent structural and implementation challenges. Monitoring, evaluation, and environmental auditing mechanisms are notably weak, resulting in poor oversight of approved projects. In many cases, mitigation measures outlined in EIA reports are either partially implemented or completely ignored, undermining the core objective of minimizing environmental impacts. Furthermore, issues related to the quality of human resources, including the involvement of inexperienced practitioners and lack of technical expertise, continue to affect the credibility and scientific rigor of EIA reports. Recent practices also highlight growing concerns regarding procedural weaknesses, including rushed approvals, inadequate review processes, and increasing pressure from development priorities. These trends suggest that, while the procedural framework of EIA exists, its practical implementation remains inconsistent and often ineffective.

In conclusion, although Nepal has established a comprehensive legal and institutional framework for EIA, there is a clear gap between policy and practice. Strengthening monitoring and enforcement, improving the quality and accountability of EIA preparation, and enhancing the public engagement and institutional capacity are critical for ensuring that EIAs serve their intended purpose. Furthermore, consideration of cumulative and induced environmental impacts and integration of valued ecosystem components (VECs) as well as free prior informed consent (FPIC) can be crucial to enhance the overall effectiveness of the EIA process in Nepal. Without such reforms, EIA remains as a procedural requirement rather than an effective instrument for achieving sustainable and environmentally responsible development in Nepal.

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Glossary

Baseline study: The collection of data on existing environmental, biological, and socio-economic conditions in a project area, used as a reference point for evaluating future changes caused by the project.

Brief Environmental Study (BES): The least detailed of Nepal's three-tiered environmental assessment instruments, required for smaller-scale projects that fall below the threshold for an IEE or EIA.

Cumulative impact: The combined environmental effect of multiple projects or activities within the same area or river basin, which may be significant even when each individual project's impact appears minor.

Environmental Impact Assessment (EIA): A systematic process for identifying, predicting, and evaluating the likely environmental impacts of a proposed development project before it is implemented.

Environmental Management Plan (EMP): A document setting out the mitigation measures, monitoring arrangements, and institutional responsibilities needed to manage a project's environmental impacts during construction and operation.

Initial Environmental Examination (IEE): A mid-level environmental assessment instrument in Nepal's tiered system, required for projects of moderate scale and impact that do not require a full EIA.

Mitigation measures: Actions proposed to avoid, minimize, or compensate for the adverse environmental impacts identified during an assessment, such as design changes, compensation, or environmentally friendly technologies.

Scoping: The stage of the EIA process, mandatory only for full EIAs, in which the key environmental issues and impacts to be studied in detail are identified and the boundaries of the assessment are defined.

Screening: The first step in the EIA process, which determines whether a proposed project requires a full EIA, an IEE, or a BES, based on the project's type and scale.

Terms of Reference (ToR): A document, prepared after scoping and approved by the relevant authority, that outlines the methodology, scope, and specific issues to be addressed in an EIA study.

CHAPTER: IX

Climate Change and Disaster Risk in Nepal

Sudeep Thakuri

Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal

Email: sudeep.thakuri@cdes.tu.edu.np

Summary

Nepal is facing an increasing risk of climate hazards and becoming one of the world's most vulnerable mountain economies due to its topography, monsoon climate, and sensitive cryosphere. Warming temperatures, melting glaciers, changing precipitation patterns, and increasing extreme events are exacerbating the occurrence of floods, landslides, droughts, and glacial lake outburst floods (GLOFs), resulting in compound and cascading effects across multiple sectors and ecosystems. Disaster data (2018–2024) show a strong upward trend in climate hazards. A total of 32,375 disasters were reported in the period. These led to 3,672 fatalities, 446 people missing and 11,752 injured. In terms of physical impacts, 57,271 houses and 43,168 infrastructure units were damaged or destroyed, as well as 18,336 livestock loss. The economic loss from the impact of disasters was estimated at NPR 23.60 billion (~US\$175 million) in six years. Fires (19,534 events) and landslides (2,881 events) are the most frequent hazards, among others. The death toll is also highest from landslides (878 deaths), followed by fires (619), thunderstorms (477), drowning (346), and floods (260), suggesting a multi-hazard risk landscape influenced by climatic and socio-environmental factors. This evidence demonstrates a rise in disaster risk and impacts, as a result of climate change, environmental degradation and socio-economic vulnerability. It shows that climate-informed disaster risk reduction, enhanced monitoring and ecosystem-based adaptation are vital for minimizing future risk in Nepal. The results also have valuable lessons for other high mountain areas exposed to climate-induced disasters.

Keywords: Adaptation; Flood; Hazards; Landslide; Vulnerability

1. Introduction

Mountain regions are among the world's most at-risk regions in the face of climate-induced disaster (Kohler & Maselli, 2009; Mishra et al., 2019; Thakuri et al., 2020). Nepal Himalaya is a critical vulnerability hotspot because of its active tectonic setting, fragile and steep topography, monsoonal climate, and climate-sensitive cryosphere (Nyaupane, 2022; MoFE, 2025). Warming temperatures, glacier melt and shifts in rain and snow are contributing to more frequent and intense hydro-meteorological and glacial hazards including floods, landslides, droughts, avalanches, and glacial lake outburst floods (GLOFs). Along with this, increasing vulnerability is leading to an increasing trend in disaster losses. Nepal's climate is changing rapidly and unequally, due to high-altitude gradients, the monsoon, and the effects of global warming. Recent studies and observational records reveal Nepal's warming trend is greater than the global average, with high variability in both temperature and precipitation (Thakuri et al., 2019; IPCC, 2021; DHM, 2024a, 2024b). In addition to gradual long-term changes, the climate is increasingly characterized by more frequent and

intense extreme events, which are becoming major drivers of local climate variability and associated impacts.

Nepal, a landlocked Himalayan country with an area of 147,516 km², spans from the Terai plains at some 60 m elevation to the High Himalaya, with the highest peak, Mount Everest, at 8,849 m. This combination of extreme relief, unstable geology and steep slopes makes Nepal highly vulnerable to various natural hazards. Nepal, despite its limited contribution to global greenhouse gas (GHG) emissions (0.1% in recent years, or 41–59 Mt CO₂-equivalent, and per capita emissions of 1.3–2.0 tonnes) is among the most vulnerable nations to climate change. The Central (Nepal) Himalaya, the region of Mount Everest, known as the "Third Pole" (Moore & Semple, 2004), is the water tower for millions of people. It is home to vast glaciers, deep valleys, diverse ecosystems and rapidly flowing rivers, which are highly sensitive to climate. As the atmosphere warms, largely due to GHG emissions from fossil-fuel burning and deforestation, it can carry more moisture, contributing to heavier rainfall. According to the Clausius–Clapeyron relationship, the moisture-holding capacity of the atmosphere increases by approximately 7% for every 1 °C rise in temperature, enhancing the potential for more intense rainfall and increasing flood risk (Trenberth et al., 2003; Held & Soden, 2006; IPCC, 2021).

Human-caused warming has become a key driver of disaster risk, driving glacier melt, extreme rainfall events, changes in the water cycle, and shifts in the frequency, intensity and distribution of hazards (Adhikari et al., 2021; IPCC, 2021). Warming temperatures have led to increased glacier melt and subsequently increasing the size and number of glacial lakes, raising concerns of GLOF risks in the downstream regions (Khadka et al., 2023; Bhandari et al., 2025). Heavy monsoon rainfall triggers landslides across Nepal's mountainous terrain, sometimes blocking rivers and setting off a chain of compounding hazards that devastate local communities. These sudden events compound further with slow-onset threats, such as ecosystem degradation, seasonal droughts, and biodiversity loss, as well as seismic hazards in this geologically active region. Increasing impacts from climate-related disasters are being observed in Nepal, with both economic and non-economic losses increasing. The social and economic effects are significant, impacting infrastructure, livelihoods, ecosystems and human well-being.

Disasters in Nepal are determined not only by physical hazards, but also by exposure and socio-economic vulnerability. Nepal has consistently been one of the most affected countries by climate change; for instance, it ranked 4th in the Germanwatch Climate Risk Index (CRI) in 2017. Though Nepal is ranked 69th in the CRI 2025 (1993–2022) due to methodological adjustments and temporal variations, but risks are still considerable. For example, Nepal continues to have a climate-sensitive economy. The agricultural sector accounts for 25–27% of the national gross domestic products (GDP) (recently estimated at 25.16% for FY2024/25) and provides employment for a large proportion of the population (traditionally around 69%, though this is changing due to diversification). This renders the economy more vulnerable to temperature rise, erratic precipitation and extreme events. Further, climate change also exacerbates inequality as vulnerable groups, such as women, indigenous people, rural communities and the disabled, are disproportionately impacted.

This chapter provides an overview of climate change, disaster risk, vulnerability, and adaptation in Nepal, drawing on the most recent national data and policy documents, including the State of the Climate of Nepal 2024 (DHM, 2024a), the Nepal Disaster Report 2024 (MOHA, 2024), the Update of Climate Change Study of Nepal (DHM, 2024b), the Nationally Determined Contribution (NDC3.0, 2025), and the National Adaptation Plan 2021–2050 (NAP, 2021), alongside relevant research literature. It examines observed climatic trends and future projections, the drivers and sectoral impacts of climate change, disaster data (including recent glacial lake outburst floods), and mitigation, adaptation, and institutional responses. Using an integrated framework that links climate drivers, hazard formation, exposure, vulnerability, and disaster risk, the chapter synthesizes quantitative data to shed light on mountain-specific hazards and broaden understanding of climate impacts across Nepal's diverse mountain regions.

2. Drivers of Climate Change and Risk Formation

Climate change, GHG emissions, and disaster risk reduction (DRR) are interlinked with causal and feedback mechanisms (Figure 1). Climate change is largely driven by human GHG emissions, primarily carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), from energy production, deforestation, agricultural and industrial activities. Higher levels of these gases result in global warming, changes in precipitation patterns, and increased variability.

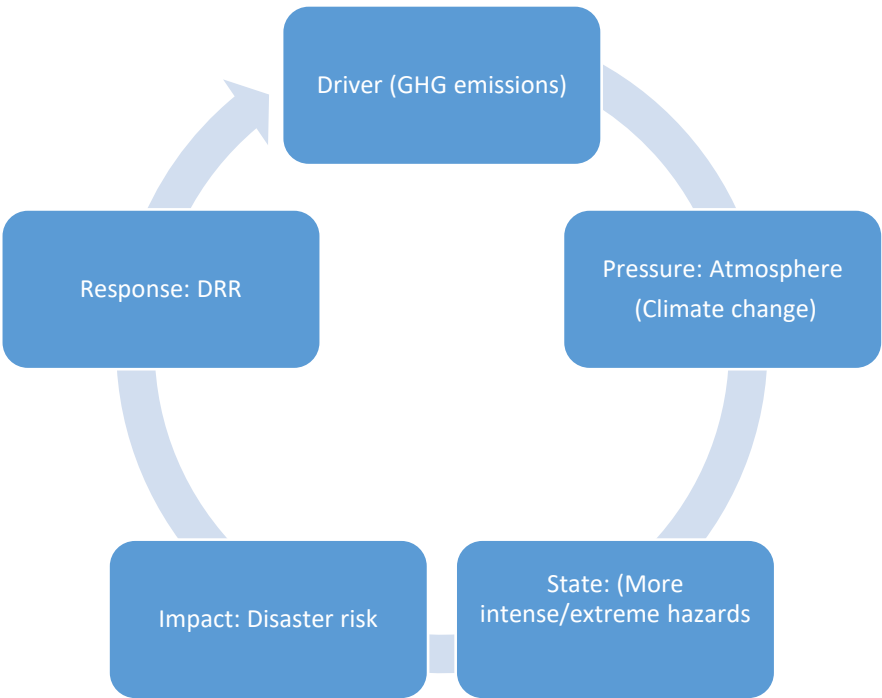


Figure 1: Causal chain: Driver, pressure, state, impact, and response (DPSIR) model of climate change and disaster risk relations

Climate change is a "threat multiplier", by changing the characteristics (intensity, frequency, magnitude, duration, and spatial distribution) of hydro-meteorological and geological hazards (floods, drought,

heatwaves, landslides). The changing characteristics of hazards due to climate change leads to increased risk of disasters, especially in vulnerable countries such as Nepal (Figure 2).

Nepal's contribution to global GHG emissions is miniscule. The latest estimates suggest that Nepal accounts for roughly 0.05% of global CO₂ emissions with total emissions of around 18.78 million tonnes (MtCO₂) and per capita CO₂ emissions of 0.63 tonnes in 2024 (Friedlingstein et al., 2026; Our World in Data, 2026). Despite the very small share, Nepal is extremely vulnerable to climate change.

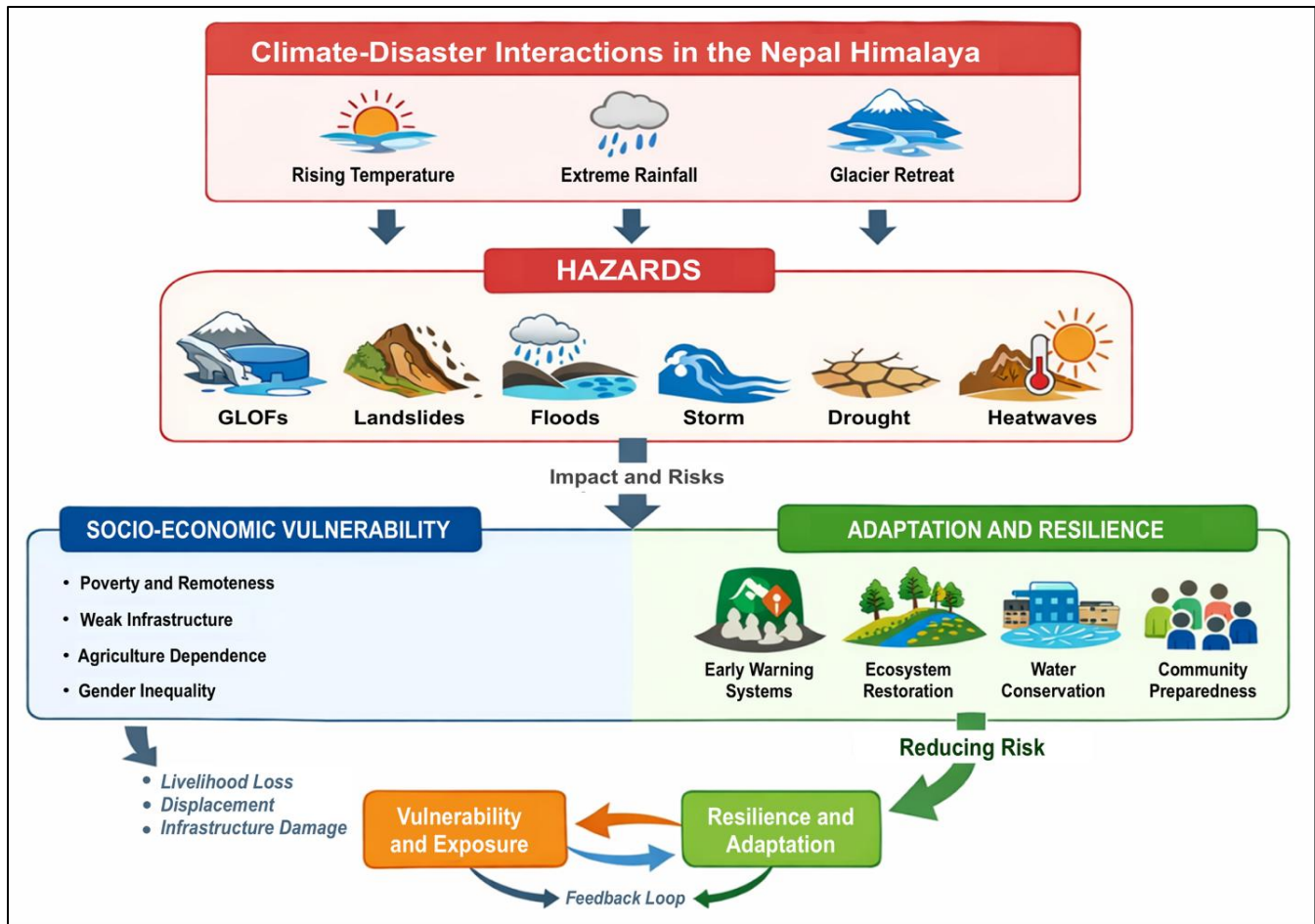


Figure 2: Conceptual framework for climate change and disaster risk in the Nepal Himalaya: It shows how primary climate drivers (temperature rise, precipitation variability, and glacier retreat) generate multiple hazards (GLOFs, landslides, floods, droughts, and heatwaves). These hazards interact with exposure (population and assets in hazard zones) and vulnerability factors (socio-economic conditions, livelihood dependence on climate-sensitive sectors, and limited adaptive capacity) that drive the overall risk. The model incorporates feedback loops showing how adaptation and resilience-building measures (early warning systems, nature-based solutions, policy interventions) can substantially reduce risk and enhance long-term climate-resilient development (adapted from UNDRR, 2015; IPCC, 2022)

2.1 Climate Drivers and Hazard Modification

Increasing temperatures, altered precipitation trends (stronger monsoon rains and weakened winter rains), and rapid glacier mass loss directly exacerbate processes of hazard formation (Figure 2). These changes affect river flows, slope stability, and the cryosphere (glaciers, ice and snow), further elevating risks of floods, landslides, and GLOFs. These include extreme rainfall events causing flash floods and landslides, increased glacier melt, causing the formation and expansion of glacial lakes, thereby increasing the risks of

GLOFs, and more frequent heatwaves, droughts and avalanches. These biophysical changes are combined with high socio-economic vulnerability in Nepal, where many people are highly dependent on rain-fed agriculture, inhabit hazard-prone steep slopes and lack sufficient resources to cope and recover.

2.2 Kaya identity components for GHG emission drivers

The Kaya Identity (Kaya & Yokoburi, 1997; Wang et al., 2019) provides a structured approach to understand the drivers of GHG emissions, particularly CO₂, by representing emissions in terms of population, economic activity, energy intensity and carbon intensity. It can be expressed as: **CO₂ = (Population) × (GDP/Population) × (Energy/GDP) × (Emissions/Energy)**. This identity offers a useful framework to understand the impact of demographic, economic and technological factors on emissions.

Globally, population growth continues to be a major driver of GHG emissions, with the global population estimated at around 8.3 billion in 2026, and is expected to surpass 10 billion by 2060, plateau at 10.3 billion in the 2080s and then start to decline (Statista, 2026). The National Population and Housing Census of 2021 found that the population in Nepal was 29.19 million. The population growth rate has also substantially decreased to around 0.92–0.93% annually, compared to 1.35% in 2011, the lowest growth rate in eight decades. However, the population growth is still driving the demand for more goods and services, which in turn drives energy consumption and emissions.

Economic growth also contributes to emissions. GDP growth in Nepal was approximately 3.7% in 2024, showing a growth in economic activity and energy consumption, but Nepal's carbon intensity is quite low. Carbon intensity in 2024 was around 0.11 kg CO₂ per dollar of GDP which is less when compared to the global average of 0.16. Over the period 1990–2024, Nepal's average carbon intensity was 0.07 kg CO₂ per dollar of GDP, ranging from 0.03 kg CO₂ per dollar (minimum) in 1990 to 0.13 kg CO₂ per dollar (maximum) in 2020 (World Bank, 2025). This shows that Nepal has a low share of global emissions, lower than 0.05% of total CO₂ emissions.

Recent years have seen improvement in energy intensity, indicative of energy efficiency in the economy. Energy intensity in Nepal remained at the level of 0.27–0.29 (in the appropriate units) from FY 2075/76 to 2078/79, but dropped to about 0.11 GJ per NPR 1,000 of value added in FY 2079/80, suggesting improved efficiency and/or lower energy inputs (WECS, 2024). There are also improvements in sectors, such as a reduction in residential energy consumption from 13.3 GJ per capita to 11.09 GJ per capita during the period.

3. Observed Trends and Future Projection of Climate

Past and future changes show a trend towards higher variability, with more intense extreme events such as extreme rainfall and floods. These trends are linked with an increase in disaster losses and uncertainty in water availability and hazard occurrence.

3.1 Temperature Trends

The historical record shows a distinct warming over Nepal, with greater warming of maximum (daytime) temperature relative to minimum (nighttime) temperature. Using 58 meteorological stations (1976–2015), maximum temperature has increased by +0.045 °C per year, while minimum temperature has increased by +0.009 °C per year, causing diurnal temperature range (DTR) to increase by +0.034 °C per year (Thakuri et al., 2019). This trend is in contrast to the global trend of higher night-time warming.

Other studies by the Department of Hydrology and Meteorology, Nepal (DHM, 2017) show even greater rates of increase in the annual maximum temperature (+0.056 °C per year in 1971–2014), further suggesting the dominance of daytime warming (DHM, 2017). Another important characteristic of warming in Nepal is elevation-dependent warming (EDW), with warming at higher elevations (up to ~2,500 m) being greater than lowlands (Thakuri et al., 2019). While data are limited in the higher regions above 3,000–5,000 m, evidence shows that high mountain areas are warming at a higher rate than the global average, a feature known as "mountain amplification" (Salerno et al., 2015; IPCC, 2021). In the High Himalaya, rates of warming were 0.06–0.08 °C/year between 1970 and 2020, with greater increases in winter (Bhandari et al., 2025).

Recent data also reveal an increase in warming. DHM (2024a) reports that the maximum temperatures were normal to above normal in most parts of Nepal and minimum temperatures were the highest since 1981 in many southern parts. Nepal faced persistent and severe heatwaves, with 50 extremely hot days (>40 °C) mainly in the lower Himalayas. Heatwave conditions lasted for 5-17 consecutive days, mainly in Lumbini, Sudurpaschim and Madhesh Provinces. Maximum temperatures were above normal from April to December, with minimum temperatures above normal in all months except February. These findings indicate the pervasive and worsening extreme heat in recent years.

3.2 Precipitation Patterns and Variability

Nepal's rainfall is highly seasonal, with the South Asian monsoon accounting for about 80% of the annual rainfall, but in recent years, precipitation has become more variable. This was seen in 2024, when annual precipitation was 111.1% of the 1991–2020 average, with a very wet monsoon (122% of average) and dry winter (19.8% of average, one of the driest on record) (DHM, 2024a; Table 1).

Monsoon patterns are changing too. In 2024, the monsoon onset was on 10 June (three days earlier than normal) and its withdrawal on 12 October (10 days later than normal), extending the monsoon duration to 125 days, 13 days longer than average. These changes in monsoon onset and withdrawal can affect agriculture, water resource planning and disaster management.

Rainfall spatial variability persists due to Nepal's diverse topography. While the country receives more than 3,000 mm of rainfall annually in some isolated parts of central and eastern Nepal (e.g., Lumle in Kaski received 4,572.7 mm), regions of the northern trans-Himalaya (Karnali and northwest Gandaki) receive less than 800 mm. This steep gradient is responsible for the contrasting hydrology across short distances.

Beyond seasonal variations, there is evidence of intensifying rainfall. Heavy rains are increasing in intensity (Talchabhadel et al., 2022), occurring in short time-frames, resulting in flash flooding and landslides potential (Adhikari et al., 2021). Conversely, periods with no rainfall are extending, leading to drought, especially in rain-fed farming areas (Bookhagen et al., 2021).

3.3 Extreme Events and Climate Variability

Nepal's weather and climate are increasingly being shaped by extreme events. This year, 49 meteorological stations witnessed new extreme 24-hour rainfall, including a national record-breaking 624.0 mm in Dodhara (Kanchanpur) on 8 July (previously 516.2 mm). Similarly, 14 stations recorded extreme daily maximum temperatures, with a new national high of 45.2 °C in Tikapur (DHM, 2024a).

The most significant event was the heavy rainfall on 28 September 2024, which recorded more than 320 mm of rainfall across 25 stations in 14 districts (largest event in the last 54 years). This event led to flooding and landslides, and caused 244 deaths across the country. Attribution analyses indicate that the likelihood

of such extreme rainfall events increased by about 70% and intensity by about 10% due to climate change, offering compelling evidence of the impact of global warming on disasters.

Table 10: Key 2024 Climate Anomalies (DHM Data, Relative to 1991–2020 Normal) (adapted from DHM, 2024a)

Parameter	Value / Anomaly	Notable Records / Highlights
Annual Precipitation	111.1% of normal	49 new 24-hr records; national max 624 mm (Dodhara, 8 Jul)
Monsoon Precipitation	122% of normal	Early onset, extended duration
Winter Precipitation	19.8% of normal	One of the driest on record
Max Temperature	Above normal (most areas)	14 new daily records; 50 hot days (>40 °C)
Min Temperature	Highest since 1981 in many areas	Above normal in south
Heatwave Episodes	Multiple (5–17 days)	11 DHM bulletins issued

3.4 Future Climate Projection

Downscaled projections (DHM, 2024b) from CMIP6 models, under SSP2-4.5 and SSP5-8.5 scenarios, suggest ongoing and faster warming in Nepal, with a rise in precipitation variability. The average annual temperature is projected to increase by about 2.4–4.3 °C by the end of the century (2080s) compared to 1981–2010. This warming is greater in the High Himalaya, where winter temperatures could rise by as much as ~7 °C under the high-emission SSP5-8.5 scenario. Maximum and minimum temperatures are expected to rise, with greater warming in the winter.

Precipitation is projected to increase by 7-37% on an annual scale, but with large spatial and temporal variability. Monsoon precipitation is likely to increase (+16–43%), whereas winter precipitation is likely to decrease (-11 to -16%) over the region, suggesting an increase in seasonal extremes. Precipitation indices associated with extremes are also expected to rise, including very wet days (R95ptot: +85 to +485 mm) and extremely wet days (R99ptot: +52 to +347 mm), as well as warm spell duration (WSDI: +122 to +256 days). Moreover, the number of consecutive dry days (CDD) is also projected to increase in some areas, indicating increased flood and drought risks.

There remains significant spatial variability in precipitation change. The currently relatively dry northern trans-Himalaya (e.g., Mustang) could see a precipitation increases of up to ~110% under high-emission scenarios, but the uncertainty in precipitation projections is larger than for temperature, especially at smaller scales.

Over the short term, increased glacier melt is likely to lead to higher river discharge, especially in the dry season, but as glaciers melt, future water yields will decrease. This shift will affect hydropower production (Shrestha et al., 2016), irrigation practices and downstream ecosystems, requiring flexible water resource management approaches.

Table 11: Projected Annual Temperature and Precipitation Changes (2080s vs. 1981–2010 Baseline, Ensemble Average) (adapted from DHM Update of Climate Change Study of Nepal; DHM, 2024b)

Scenario	Annual Temp Change (°C)	Annual Precip Change (%)	Key Seasonal Notes (Monsoon/Winter)
SSP2-4.5	+2.4 to +3.6	+7 to +25	Monsoon +16–30%; Winter -11 to -14%
SSP5-8.5	+3.2 to +4.3	+15 to +37	Monsoon +25–43%; Winter -13 to -16%

4. Human-Induced Drivers of Risk

The vulnerability in Nepal is shaped by a range of human factors, such as poverty, unplanned urbanisation in areas prone to hazards, poor infrastructure development, deforestation, land-use changes, and low

adaptive capacity. These factors increase vulnerability and ultimately risks of disasters in a mountainous context.

Apart from climate change, factors such as rapid urbanisation and infrastructure development, especially uncontrolled road building and slope cutting, have played a major role in the escalating disasters in Nepal (McAdoo et al., 2018; Sudmeier-Rieux et al., 2019). Unplanned urban development and infrastructure growth has modified the landscape and destabilised vulnerable hill slopes, leading to landslides and erosion (Adhikari et al., 2022). For instance, in the Kathmandu Valley, buildings and infrastructure have increased (urban expansion) by about 368.06% in the last three decades (Devkota et al., 2023) at the expense of agricultural land and other open areas. This has altered natural drainage patterns and decreased the soil's ability to absorb water, resulting in increased runoff and flood risk (Lamichhane et al., 2025). Additionally, this deforestation has caused soil erosion and sedimentation, impairing soil structure and its capacity to infiltrate water, exacerbating the flood risks.

5. Trends and Impacts of Disasters: Key Sectors and Vulnerability

5.1 Observed and projected impacts (Loss and damage)

Climate-related disasters are resulting in damage and losses. In 2024, an individual flood event resulted in NPR 46.68 billion in losses, mostly to infrastructure. Landslides and floods destroyed over 30 hydropower projects (NPR 8.5 billion). Climate damages average 0.08% of GDP per annum ($\approx$ NPR 2.78 billion) in Nepal, but they can exceed 2% during extreme climate events.

A study on the impacts of climate change in Nepal for the period 1971–2025 shows a rising trend in both economic and non-economic losses. The majority of losses (75%) are to infrastructure, with agriculture (18%), livestock (4%) and food storage (3%) also heavily impacted. Non-economic losses are also significant, with an average of 647 lives lost per year, mass population displacement, loss of cultural assets, local knowledge systems and ecosystem services. Looking ahead, without proper mitigation and adaptation, the economic losses could rise to around 2.2% of GDP by 2050 and 9.9% by 2100.

5.2 Disaster Profile and Latest Statistics (2018–2024)

In Nepal, hydro-meteorological disasters account for around 91% of the total disaster incidents. A total of 32,375 disaster events were recorded, with an upward trend, from 2018 to 2024. The most frequent hazards include fires (19,534 events), landslides (2,881), thunderbolts (1,699), and floods (927) (MoHA, 2024). These incidents resulted in 2,996 fatalities with 446 missing and 11,752 injured (excluding earthquakes and road accidents). The greatest number of people were killed by landslides (878), fires (593) and thunderbolts (477). There were NPR 23.60 billion in economic losses, 74.7% (NPR 17.63 billion) of which were fires. A total of 57,271 houses and 43,168 infrastructure units were destroyed, with 18,336 livestock lost.

Growing losses has been observed in the recent disaster events. Floods and landslides in September 2024 led to 249 deaths, 178 injuries, displaced approximately 11,000 families and resulted in USD 345 million losses. A 2024 GLOF in Thame Valley of Everest region (16 August 2024) also highlights increasing cryospheric risks. The cascading GLOF caused an estimated economic loss of US\$6.18 million within Khumbu Pasang Lhamu Rural Municipality, destroying private houses, lodges, a primary school, agricultural land, and trekking infrastructure, while displacing 135 people and causing riverbank erosion extending more than 50 km downstream (Khadka et al., 2026).

Table 12: Major Disaster Statistics (17 Jul 2018–16 Jul 2024) (adapted from Nepal Disaster Report 2024; MoHA, 2024)

Hazard	Incidents	Deaths	Economic Loss (NPR million)	Notes
Fire	19,534	593	17,630	74.7% of total economic loss
Landslide	2,881	878	797	Deadliest per event
Thunderbolt	1,699	477	—	Rising in Terai/hills
Flood	927	260	Significant	High infrastructure damage
Total	32,375	2,996 (excl. EQ/road)	23,600	Increasing trend

5.3 Hydrological Changes

Nepal's hydrological regimes are undergoing significant transformation as rising temperatures, glacier retreat, and changing precipitation patterns alter the timing and magnitude of river flows (Shrestha et al., 2016; Bajracharya et al., 2018). Warming has accelerated glacier and snow melt while modifying precipitation regimes, leading to fundamental changes in runoff generation across Himalayan river basins. Climate projections indicate substantial changes in basin hydrology. In the Kaligandaki River Basin, average annual precipitation is projected to increase by up to 26%, resulting in increases of more than 50% in river discharge and water yield and up to 90% in snowmelt by the 2090s under the RCP8.5 scenarios (Bajracharya et al., 2018). Similarly, process-based modelling in the Langtang River Basin (2008–2018) shows that recent increases in temperature and precipitation have enhanced runoff under current glacier conditions. However, continued glacier shrinkage is projected to reduce total annual streamflow in the future, marking the onset of "peak water", whereby glacier melt temporarily increases river discharge before declining as glacier storage is depleted (Pradhananga et al., 2024).

The hydrological response also varies with elevation. In the Upper Koshi Basin, runoff below approximately 4,000 m is increasingly becoming rainfall-dominated rather than snowmelt-driven, indicating a transition from a cryosphere-dominated to a rainfall-dominated hydrological system (Xiang et al., 2024). At higher elevations (>5,000 m), although warming is relatively moderated, changes in snow accumulation and melt continue to alter the timing and seasonality of streamflow.

These changes are reshaping seasonal flow regimes across Nepal. Both observations and modelling indicate that monsoon peak flows are increasing because of intensified precipitation, whereas pre-monsoon and winter baseflows are declining owing to reduced snow storage and groundwater recharge. Consequently, annual flow variability is increasing, with more frequent high-flow events during the monsoon and reduced low flows during the dry season. Hydrological modelling further demonstrates that Himalayan catchments are highly sensitive to precipitation variability, such that even modest increases in extreme rainfall can produce disproportionately large increases in runoff and sediment yield because of the region's steep terrain and unstable slopes (Bajracharya et al., 2018; Pradhananga et al., 2024).

These hydrological changes have important implications for Nepal's water resources and hydropower sector. Projected changes in temperature and precipitation are expected to alter river discharge and hydropower generation, with annual energy production at the Upper Tamakoshi Hydropower Project projected to vary from –7.6% to +15.8%, while the risk of production shortfalls could increase to 13.4% relative to the design baseline (Shrestha et al., 2016). These findings emphasize the need to incorporate

climate uncertainty into hydropower planning, infrastructure design, and reservoir operation to ensure long-term energy security.

5.4 Cryospheric Changes (Glaciers, Snow, and Glacial Lakes)

5.4.1 Glaciers

Accelerated glacial retreat, permafrost degradation, and changing river processes are major cryospheric and hydrologic processes involved in hazard development in the Nepal Himalaya (Thakuri et al., 2020). Accelerated glacial melt leads to the growth of glacial lakes, enhancing the risk of GLOF and flooding. It also alters river flow characteristics and sediment transport, affecting flood behaviour and slope stability. Nepal has witnessed an acceleration in glacier retreat with the current rates during 2011-2020 around 65% higher than during the previous decade (DHM, 2024b). The findings reveal that glaciers are responding with a differential change in glacier area (-1 to $-5 \text{ km}^2 \text{ yr}^{-1}$), negative mass balance (-0.3 to $-0.8 \text{ m w.e. yr}^{-1}$), reduction in ice volume ($-4.29 \text{ km}^3 \text{ yr}^{-1}$) and a rise in the equilibrium line of altitude (ELA $\sim 20.66 \text{ m decade}^{-1}$). The cumulative loss in ice mass (-128.84 km^3) of the country has contributed to sea level rise (0.32 mm) in the last 30 years (Khadka et al., 2023).

5.4.2 Snow cover

The snow cover in the Nepal Himalaya is consistently decreasing, with the rising trend in the snowline elevation, mainly influenced by the warming trend and precipitation changes. Remote sensing studies using satellite data (MODIS and Landsat) show a statistically significant decline in snow cover (Khadka et al., 2020). Winter snow cover across Nepal showed an overall declining trend during 2003–2018, with the western region experiencing the largest reduction ($-127.39 \text{ km}^2 \text{ yr}^{-1}$), while the snow line altitude shifted upward by 33.3 m yr^{-1} in western and central Nepal and 66.7 m yr^{-1} in eastern Nepal, indicating a significant response of the cryosphere to climate change. In the Langtang Basin, the snow-covered area has declined from $\sim 200 \text{ km}^2$ (1988) to $\sim 128 \text{ km}^2$ (2024) with a reduction rate of about -3.7 km^2 per year and the snowline is rising (2.2 m per year) (Pradhananga et al., 2025). This suggests diminishing water storage capacity and increasing water variability.

At larger scales, MODIS analyses reveal that snow cover in the Himalaya is highly seasonal and inter-annually variable, with peaks in late winter and spring, and a minimum in the monsoon (Shrestha & Joshi, 2009). Recent regional studies also confirm the effect of elevation on snow loss, with more rapid reductions at lower and mid-elevation areas due to increased temperatures and more rainfall instead of snow (Tauqir et al., 2025). These trends are supported by increased winter "snow drought" and decreased snow persistence across High Mountain Asia in recent years, impacting on meltwater runoff and seasonal river flows.

5.4.3 Glacial Lakes

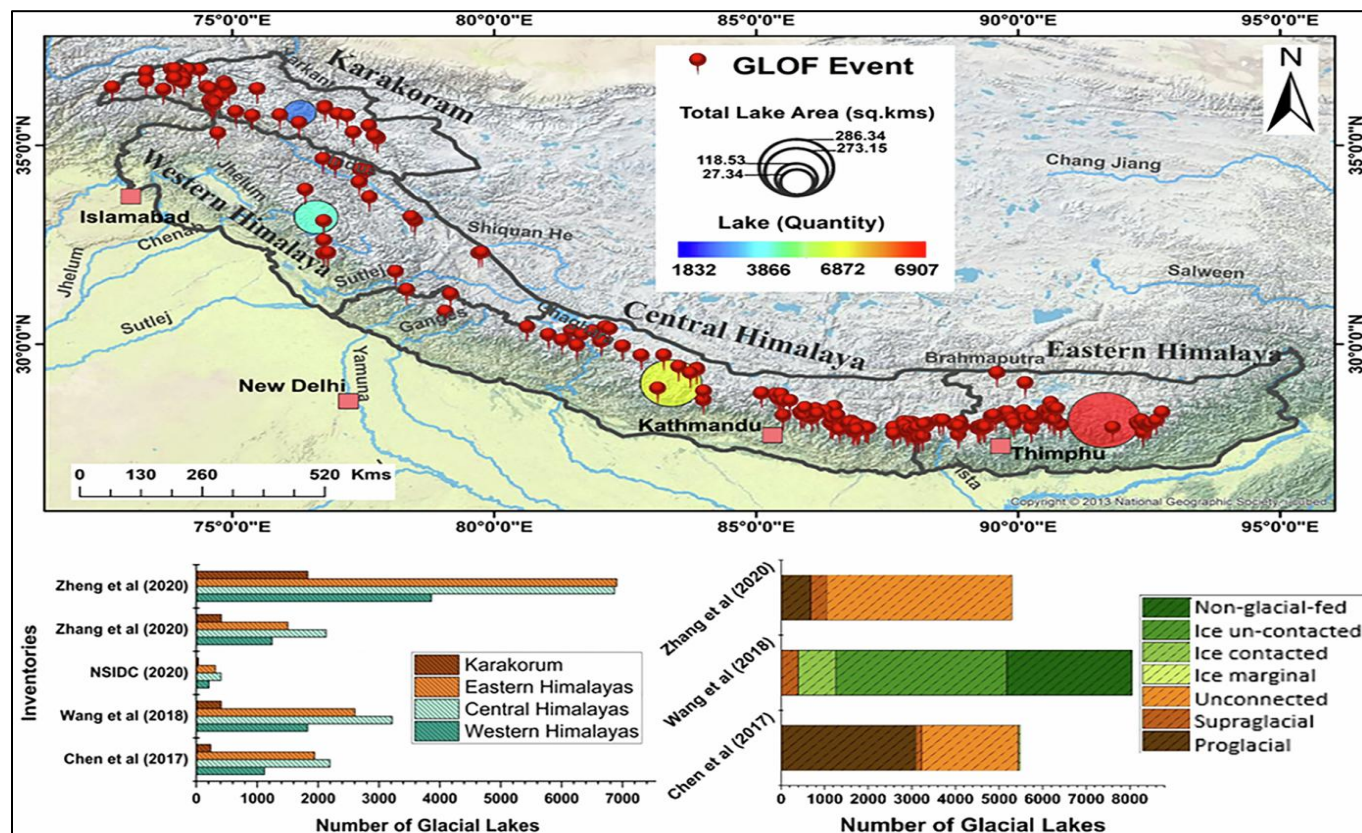


Figure 3: Spatial distribution of glacial lakes and documented past GLOF events across the H-K region (Rather et al., 2026). Glacial Lakes and GLOF Events Across the Himalaya (Regional context for Nepal). The map shows lake quantity and total lake area, with Nepal (central Himalaya) hosting thousands of glacial lakes

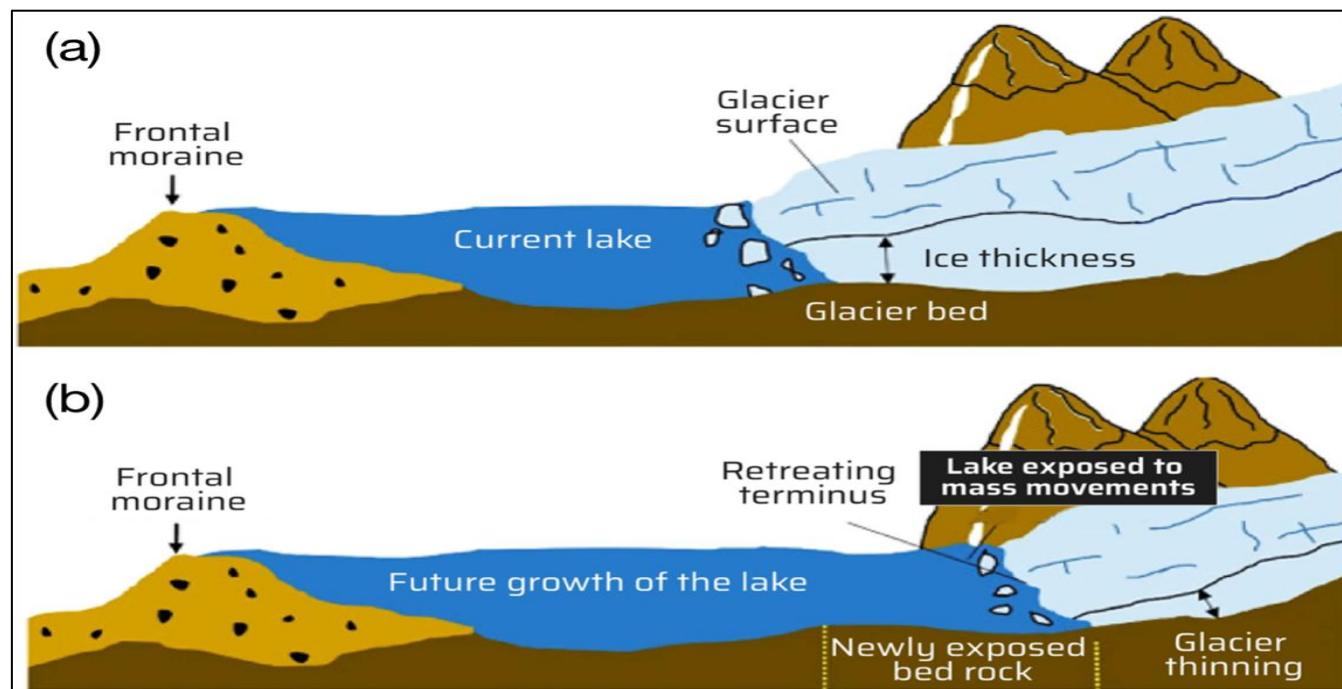


Figure 4: Process of glacial lake expansion: (a) shows current lake conditions; (b) illustrates how glacier retreat exposes new areas, increasing outburst potential

Nepal has more than 2,000 glacial lakes with identified 47 dangerous glacial lakes, 21 in Nepal and the rest in Tibetan China, but connected to Nepal (Bajracharya et al., 2020). Khadka et al. (2018) reported 1541 glacial lakes (size larger than 0.36 hectare) in 2017, an increase from 606 in 1977 in Nepal. The study further revealed that the surface area of the glacial lakes has increased from 55.53 km² to 80.95 km² in the same period, with above 181% increase in number and 82% increase in surface area. Increased glacial melt water due to rising temperatures increase the hydrostatic pressure on the moraine dam and increase the risk of catastrophic rupturing (Khanal et al., 2015; Bhandari et al., 2025; Figure 4). Nepal is highly vulnerable to GLOF events and have documented 45 confirmed (reported and unreported) historical GLOF events from 39 glacial lakes in Nepal (34 moraine-dammed, 4 ice-dammed, and 1 bedrock-dammed) (Khadka et al., 2023). After updating the GLOFs for 2024 and 2025, the number has reached to 42 (Table 4).

Table 13: List of reliable reported and unreported (UR) GLOF events in Nepal. The unreported GLOF events are those events that were not documented previously and were identified using geomorphological evidence and high-resolution satellite imagery (updated list from Khadka et al., 2023)

SN	Lake name	Latitude	Longitude	Altitude (m)	Dam type	Sub-basin	GLOF Date	Mechanism
1	Chubung	27.8769	86.4606	4557	Moraine	Tama Koshi	1991-12-07	Breach
2	Langmale Lake	27.8136	87.1395	4790	Moraine	Arun	2017-04-20	Overtopping
3	Lhonak lake	27.829351	88.037622	-	Moraine	Tamor	1921	Unknown
4	Nagma Pokhari	27.8695	87.8663	4916	Moraine	Tamor	1980-06-23	Breach
5	Dig Tsho	27.8745	86.5864	4378	Moraine	Dudh Koshi	1985-04-08, 25-04-15	Breach, over topping
6	Tam Pokhari/ Sabai Tsho	27.7434	86.8449	4372	Moraine	Dudh Koshi	1998-09-03	breach
7	Nare Lake	27.8295	86.8368	4724	Moraine	Dudh Koshi	03-09-77	breach
8	Unknown	27.988793	86.811476	-	Ice	Dudhkoshi	16-07-17	Unknown
9	Unknown	30.267	81.47408	-	Ice	Humla	2004, 2006, 2007, 2008, 23-06-09, 30-06-11	Tunneling
10	Thyanbo, or Ngole	27.827734	86.573630	4718	Moraine	Thame	16-08-24	Cascading/breach
11	Unnamed-UR	29.288086	83.820157	5900	Ice	Mustang	08-07-25	Unknown
12	Unnamed-UR	30.241676	81.468793	5300	Moraine	Limi, Humla	15-05-25	Themokarst
13	Water pocket	27.585963	88.027139	-	Ice	Tamor	1986	Unknown
14	Unnamed-UR	27.8835	87.8298	5114	Moraine	Tamor	n/a	Unknown
15	Unnamed-UR	27.8349	88.0787	5645	Moraine	Tamor	n/a	Unknown
16	Unnamed-UR	27.8158	87.7492	4910	Moraine	Tamor	n/a	Unknown
17	Unnamed-UR	27.7827	87.9362	4847	Moraine	Tamor	n/a	Unknown
18	Unnamed-UR	27.7248	87.9367	4983	Moraine	Tamor	n/a	Unknown
19	Unnamed-UR	27.7047	87.8952	4640	Moraine	Tamor	n/a	Unknown
20	Unnamed-UR	27.6948	87.8934	4575	Moraine	Tamor	n/a	Unknown
21	Unnamed-UR	27.672	87.6299	4874	Moraine	Tamor	n/a	Unknown
22	Unnamed-UR	30.0296	81.2939	5136	Moraine	West Seti	n/a	Unknown
23	Unnamed-UR	28.8156	83.1198	5139	Moraine	Bheri	n/a	Unknown
24	Unnamed-UR	29.994	82.044	4716	Moraine	Humla	n/a	Unknown
25	Unnamed-UR	29.8749	82.4511	5285	Bedrock	Humla	n/a	Unknown
26	Unnamed-UR	30.1588	81.0344	4655	Moraine	Mahakali	n/a	Unknown
27	Unnamed-UR	28.7445	83.997	4911	Moraine	Marsyangdi	n/a	Unknown
28	Unnamed-UR	29.1969	83.7423	5806	Moraine	Kali Gandaki	n/a	Unknown
29	Unknown	27.7926	86.8439	5309	Moraine	Dudh Koshi	n/a	Unknown
30	Unknown	27.9549	86.7759	5015	Moraine	Dudh Koshi	n/a	Unknown
31	Unnamed-UR	27.9518	86.7779	5012	Moraine	Dudh Koshi	n/a	Unknown
32	Unnamed-UR	27.9357	86.8132	4917	Moraine	Dudh Koshi	n/a	Unknown
33	Unnamed-UR	27.9205	86.7452	4883	Moraine	Dudh Koshi	n/a	Unknown
34	Unnamed-UR	27.8101	86.9568	5541	Moraine	Dudh Koshi	n/a	Unknown
35	Unnamed-UR	27.7918	86.955	5353	Moraine	Dudh Koshi	n/a	Unknown
36	Unnamed-UR	27.7812	86.5898	5065	Moraine	Dudh Koshi	n/a	Unknown
37	Unnamed-UR	27.754	86.9438	4943	Moraine	Dudh Koshi	n/a	Unknown
38	Unnamed-UR	27.737	86.8722	4733	Moraine	Dudh Koshi	n/a	Unknown
39	Unknown	27.769867	87.874966	-	Moraine	Tamor	n/a	Unknown
40	Unknown	27.766255	88.026638	-	Moraine	Tamor	n/a	Unknown
41	Unnamed-UR	27.8018	87.1283	4613	Moraine	Arun	n/a	Unknown
42	Unknown	27.90556	86.89083	-	Ice	Dudhkoshi	n/a	Unknown

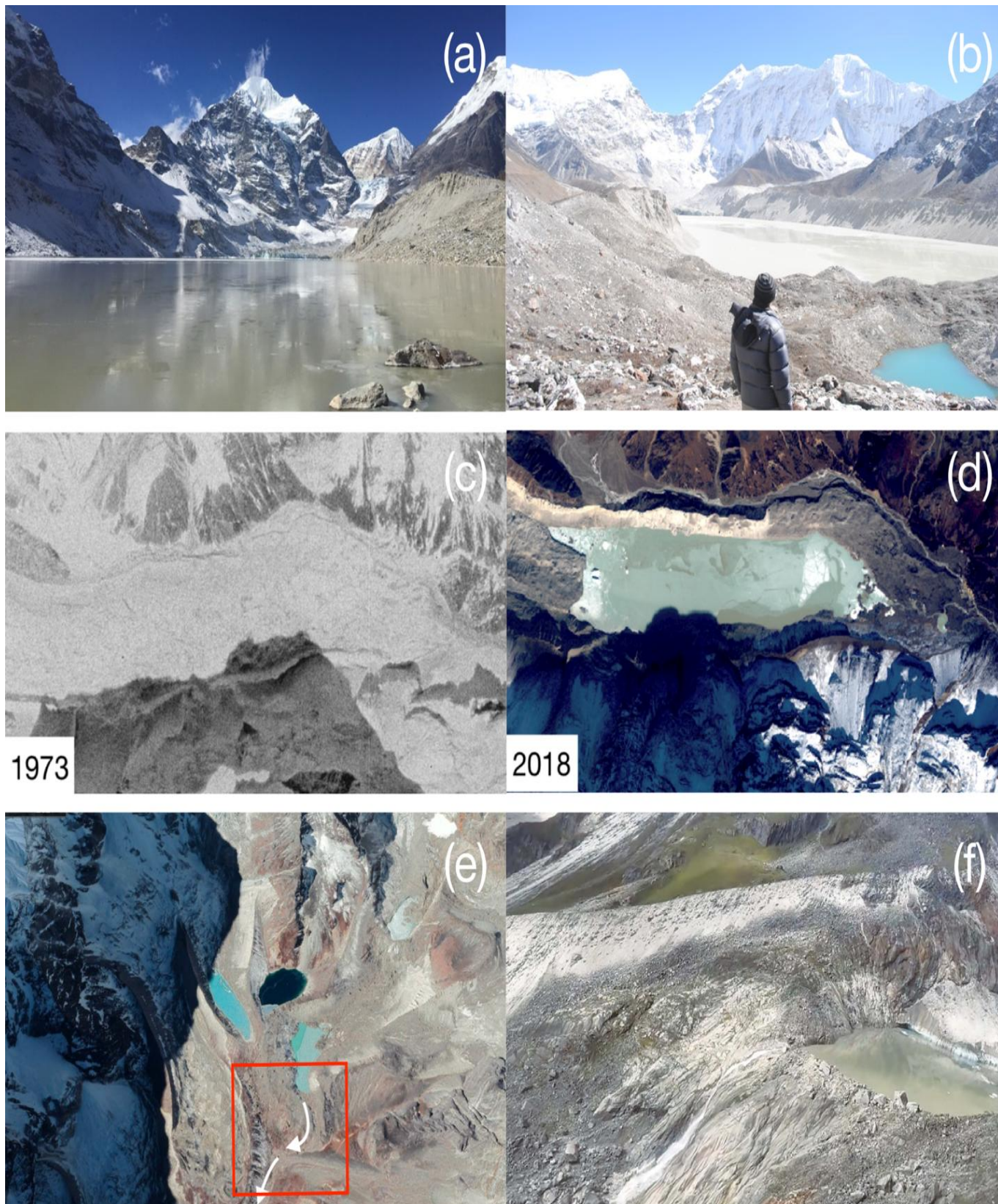


Figure 4: Glacial lakes: a) Lower Barun glacial lake, b) Imja Tsho glacial lake, c-d) Lower Barun glacial lake expansion from 1973 (corona image) to 2018 (Google Earth Image). Satellite imagery demonstrates increased lake surface area. e) a satellite view of Thame Khola GLOF 2017 (Google Earth image; Solukhumbu District). The red-highlighted area in an image (e) shows the breached lake and flood path that devastated downstream villages on 16 August 2024 (Thame flood). f) Thame GLOF Site – Post-Event Aerial View. This image captures the moraine breach and drained lake area following the 2024 event (Google photo)

Different triggers and conditioning factors (Figure 6), such as lake area, expansion rate, glacier and lake proximity, dam characteristics, landslide avalanche and rockfall potentials, earthquake, are important for GLOF susceptibility (Zhang et al., 2024; Khadka et al., 2021; Westoby et al., 2014; Richardson & Reynolds, 2000). Nepal has witnessed some devastating GLOFs. Examples include the 1985 Dig Tsho GLOF, and more recent events in Thame, Rolwaling and Langtang, which have had major downstream effects on infrastructure, farming, and livelihoods (Bhandari et al., 2025; Pandey, 2024). They are mostly found in the Everest region (Khadka et al., 2021).

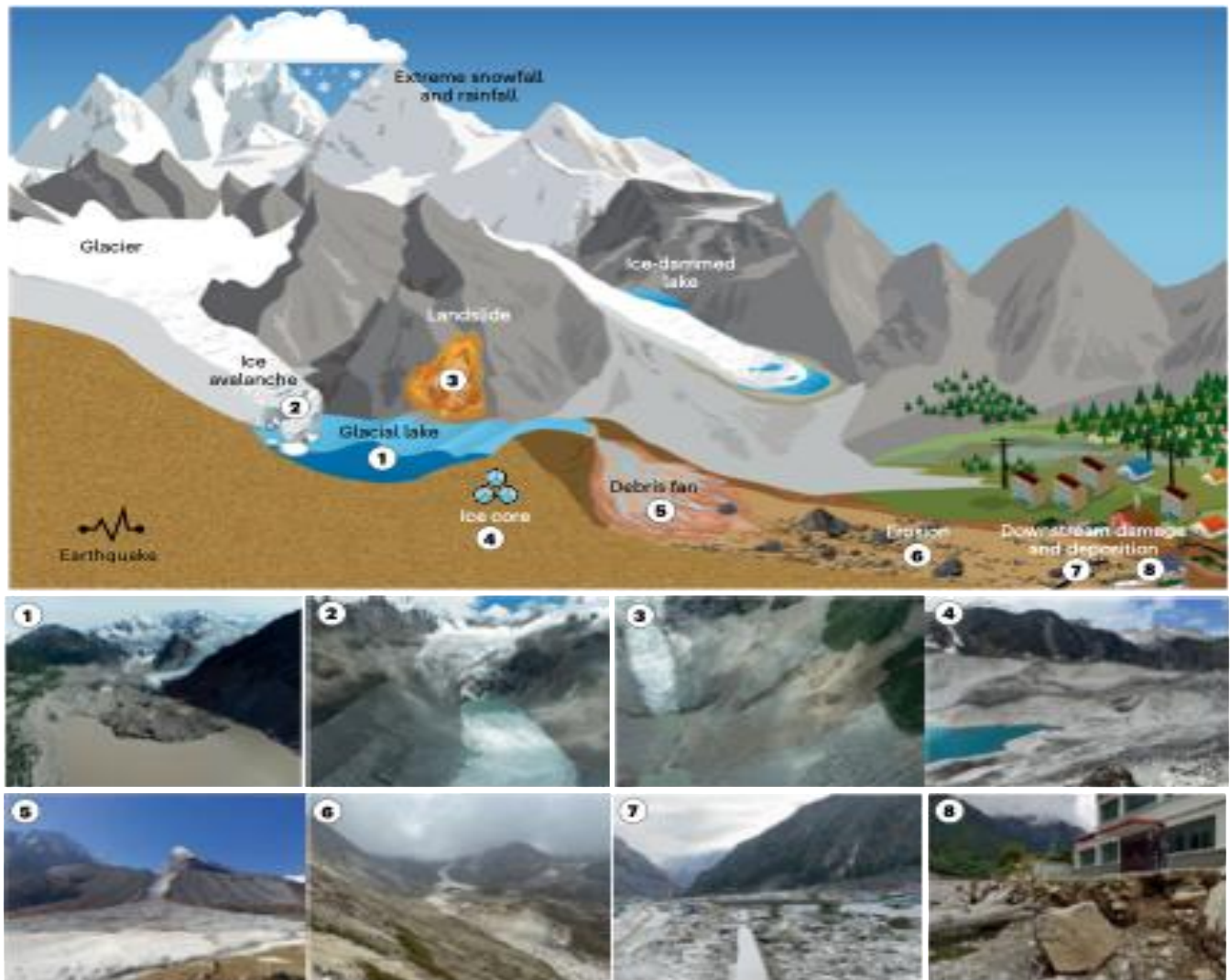


Figure 5: Triggers and mechanisms of GLOFs: The hazard chain, from triggering factors to glacial lake outburst, downstream impacts and damage, and corresponding photographs (1–8). Understanding the triggers and mechanisms of GLOFs and flood modelling practices can improve hazard mitigation (adopted from Zhang et al., 2024)

Rounce et al. (2017) explores the GLOF risk, hazard, and downstream impacts by the major basins of Nepal and reports 3, 3, 5 lakes of “very high risk” and 16, 11, and 4 lakes of “high risk” in the Koshi, Gandaki, and Karnali basins, respectively. Settlements downstream of GLOF-prone lakes, particularly in Sankhuwasabha, Solukhumbu, Dolakha, Rasuwa, Gorkha, Lamjung, Manang, Mustang, Dolpa, Mugu, and Humla districts, are highly vulnerable to GLOFs due to ongoing development of infrastructure, and dependence on river flow for irrigation and hydropower (Shrestha et al., 2016). Lack of early warning

system, rugged terrain and limited funds further exacerbate vulnerability and make disaster management difficult (Adhikari et al., 2021).

5.5 Landslides and Climate-Induced Slope Instability

Nepal is the home of one of the most common and destructive natural hazards: landslides (Figure 6). These result from the interaction of steep slope, weak geology, deforestation, glacial hazards, and extreme rainfall events, which are all being influenced by climate change (Thakuri et al., 2020; Adhikari et al., 2022). Harvey et al. (2025), using a database of 117 landslide inventories for Nepal released between 2010 and 2021, found a nationwide areal density of 0.05 landslides per km², corresponding to 6000 landslides in the country. The Nepal Disaster Risk Reduction Portal (<http://drrportal.gov.np>; 2011 to August 2025) indicates 4,629 landslides, which have killed 1906 people, injured 1591, and led to losses of more than NRs 20.66 billion. The rate of landslide incidents has accelerated dramatically – from 0.85 per 1,000 km² in 2011 to 3.36 in 2023, and a staggering 6.82 in 2024. Eastern Nepal witnessed heavy rains and flooding and landslides in 2025. As of early October 2025, at least 47–52 people have been killed, most of them by landslides, especially in Ilam district where dozens have lost their lives. A UN situation update reported **51 fatalities, 47 injuries, and several missing persons** during the same period, highlighting the severity of rainfall-induced slope failures (UN OCHA, 2025).

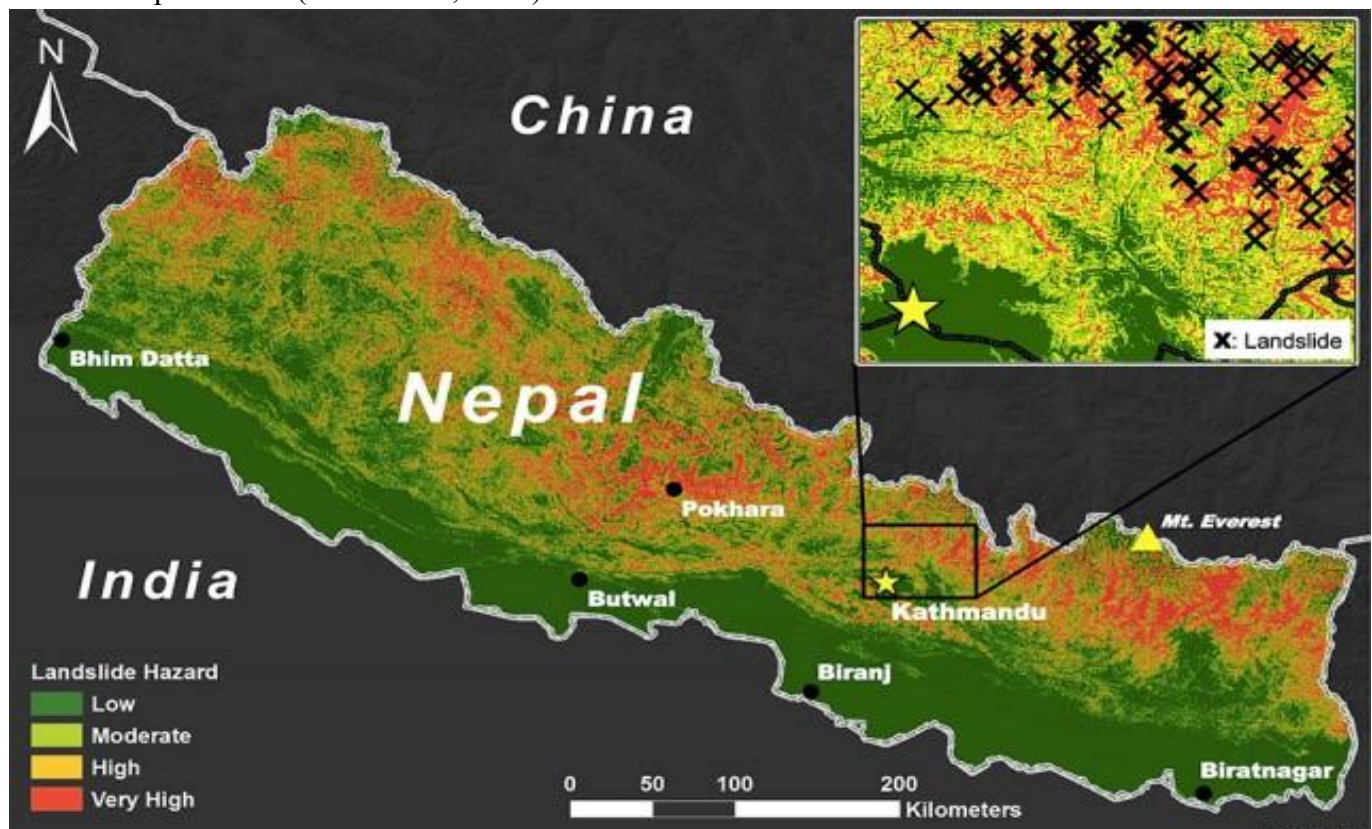


Figure 6: Landslide hazard map of Nepal (Source: The Yale Himalaya Initiative 2016; <https://blogs.agu.org/landslideblog/2016/03/24/the-yale-himalaya-initiative-1/>)

From a long-term perspective, landslides were the deadliest natural hazard in 2024–2025 in Nepal, with 351 lives lost and more than 1,000 landslide events in a year alone. Likewise, by mid-July 2024, at least 135 people had been killed in 38 fatal landslides, showing the seasonal trends (Petley, 2024). Severe rains in September 2024 alone resulted in about 250 deaths from floods and landslides (Lamichhane et al., 2025). Historical data also reveals an increasing trend: since 2011 more than 4,600 landslides have caused

approximately 1,900 fatalities in Nepal, while historically (since 1968), over 6,000 people have been killed in more than 1,400 fatal landslides. These figures suggest landslides continue to be one of Nepal's most common and deadly natural hazards, exacerbated by climate change, vulnerable geology, and poorly managed development.

One of the examples of large and deadliest landslide was the 2014 Sunkoshi landslide in Sindhupalchok District on August 2, 2014 (Ye & Chen, 2017; Ao et al., 2020; Yagi et al., 2020). The Sunkoshi landslide was triggered by heavy monsoon rain fall and underlying deep-seated slope instability, resulting in a devastating disaster. The slope failure involved a deep-seated mass of about 7.4 million m³ of debris which, travelling at an estimated speed of 60–70 m s⁻¹, completely blocked the Sunkoshi River in minutes to form a 3 km long and 46.7 m deep barrier lake upstream of the blockage. The landslide resulted in 156 people death, destroyed dozens of homes, damaged the Arniko Highway (a major international trade route between Nepal and China), and amplified the risk of a catastrophic flood downstream due to the river damming. It took more than 45 days for Nepal Army engineers to cut a safe drainage channel to de-water the lake (International Consortium on Landslides, 2014; Lamichhane et al., 2021).

5.6 Flooding and Hydrological Extremes

In recent years, flooding and other hydrological extremes show a significant escalation in magnitude, frequency and consequences during the monsoonal period in Nepal. A recent study of the September 2024 extreme event, indicates that the extreme rainfall caused extreme river flooding in the Kathmandu Valley, resulting in more than 36 deaths and significant economic losses, highlighting the vulnerability of urban catchments (Lamichhane et al., 2025). Related studies report that the same event brought 240–322 mm of rain in two days, causing over 50 lives lost in Kathmandu Valley alone and at least 192 across the country, showcasing the extent of river overflow and floodplain inundation (Talchabhadel et al., 2025).

Nationwide assessments also reveal the 2024 floods have led to more than 300 lives lost and significant infrastructure damage of NPR 17 billion, representing one of the worst hydrological events of the last few decades. Hydrologic extremes are also experiencing increasing economic losses. A 2025 loss-and-damage assessment estimates USD 346 million damage from just three days of flooding in September, 2024 (PRC, 2025).

Longer-term hydrologic research shows that extreme flood events are more frequent and intense in Nepal's rivers due to climate change, urban development, and land use change (Bhattarai et al., 2024). Future projections indicate that monsoon rainfall may become more variable and extreme with a warming climate, increasing the risk of extreme riverine flooding in Nepal (OECD, 2025). These studies collectively show an increasing trend of severe riverine floods associated with compound hydro-meteorological hazards.

5.7 Drought and Water Scarcity in Mountain and Mid-Hill Areas

The monsoon may dominate the water cycle of Nepal, but drought is an equally important, albeit opposite, climate-related hazard, especially in the rain shadow areas of the mid hills and southwest Terai. Drought significantly reduced cereal crop yields in Nepal, with drought frequency increasing after 2000 by 13%, 6%, and 7% for summer maize and by 12.5%, 7.5%, and 8% for winter wheat in the western, central, and eastern regions, respectively; the strongest yield impacts occurred during the sowing stage of summer maize and the growing stage of winter wheat (Hamal et al., 2020). Recent dry years and water scarcity in Nepal suggests a "creeping" drought linked with rainfall variability and groundwater loss. A 2025 ICIMOD study of the country's breadbasket, Madhesh Province, reveals widespread 30–50% precipitation deficit during

the 2025 monsoon, after a dry winter, resulting in a severe hydrologic drought. This has led to a substantial decline in groundwater levels, with more than 30% of boreholes drying out and widespread water scarcity for drinking in critical districts like Mahottari, Dhanusha, and Siraha (Shrestha et al., 2025). The drought also severely affected agriculture: the monsoon started late, with only ~52% of rice transplantation done compared to more than 90% in average years, which could indicate large yield losses.

National-level evaluations estimate up to 450,000 metric tons of rice ($\approx 10\%$ of national production) could be lost, jeopardising food security and rural livelihoods (Shrestha et al., 2025). Other peer-reviewed and policy-focused studies also point out that groundwater depletion, variable rainfall, and late monsoons are exacerbating household water security stress in Nepal, particularly in the densely populated Terai (Bista et al. 2024). Recent research indicates that droughts are increasingly frequent and intense in Nepal, with knock-on effects on food security, water resources and socio-economic well-being (Sharma et al., 2023; Talchabhadel et al., 2023). Future droughts in Nepal are projected to become longer and more severe under climate change, with mean drought duration increasing from 4.93 months (historical) to 10.8 months and drought severity intensifying from -6.80 to -15.98 under the high-emission SSP585 scenario during 2020–2100 (Sharma et al., 2021). While not as visible as floods and landslides, drought has significant impacts on food security and rural livelihoods in Nepal. Impact includes diminished agricultural productivity, livestock stress and heightened migration. Vulnerable mountain households adapt by changing crops, planting schedules and seasonal labour migration (Nepal et al., 2021) in response to these challenges.

5.8 Heatwaves, Public Health, and Emerging Climate Hazards

New evidence demonstrates the increasing severity of heatwaves and other new climate-sensitive health hazards in Nepal, with discernible impacts on health and mortality, morbidity, and health institutions. A recent study shows that between 2002 and 2010, Nepal witnessed 25 known heatwave events, which resulted in 25 deaths and at least 280 people affected, though longer-term studies estimate 35 heat-related deaths from 1991 to 2021. While these numbers may seem low, researchers stress that underreporting is common due to poor health surveillance practices, and the actual impacts may be greater (Sharma et al., 2025). At the local scale, 61.2% of urban households surveyed suffered from heat-related illnesses (e.g., heat stroke, headaches, dehydration) in one warm season, underscoring the impact on morbidity (Bhatta & Pahari, 2020).

Average summer temperatures in the Kathmandu Valley are increasing ($35\text{--}38^\circ\text{C}$) resulting in heat stress for urban residents, and heatwaves in the Terai region have led to increased hospital admissions and healthcare system pressures (Awale, 2025). New climate-related hazards are also emerging, such as the spread of mosquito-borne diseases such as dengue to the hills and growing heat-related occupational hazards for workers. Urban heat islands, ventilation, and health system challenges are exacerbating heatwaves. These studies point to a clear pattern of increasing frequency, intensity and health impacts of heatwaves in Nepal, with flow-on effects to urban infrastructure, productivity and human health.

5.9 Socio-Ecological Vulnerability and Differential Impacts

Impacts from climate related disasters are not equal for all. The poorest, most remote, and poorly serviced areas, with insecure land tenure, are the most vulnerable in the Nepal Himalaya. Recent research shows that socio-ecological vulnerability in Nepal is both pervasive and uneven, with significant regional, livelihood and social differences. One 2025 study estimates that more than 10 million Nepalis are impacted by climate

hazards such as flooding, drought and landslides, highlighting widespread impacts on ecosystems and people (Ghimire et al., 2025).

At the household level, studies in the Nepali Himalaya (360 household surveys) show "very high" levels of social-ecological vulnerability across all ecological zones due to high exposure and low adaptive capacity, especially among resource-poor households (Pandey & Bardsley, 2015). Impacts are highly variable by socio-economic class. A study in the middle hills (Gentle et al., 2014) demonstrates that different classes will have different vulnerabilities that will affect overall risk, but poor and very poor households are much more vulnerable than other classes because they have fewer livelihood options and lower resilience.

More recent 2026 research also highlights the structural nature of vulnerability, with women, the elderly, low-caste groups, and rural groups disproportionately affected, with limited resources, mobility and power. There are also spatial variations: the mountain is threatened by glaciers, the hills by soil erosion and the Terai by flooding (Magar, 2026). Rural women are disproportionately vulnerable to disasters because of their care responsibilities and lack of access to adaptive resources. Mountain districts like Solukhumbu, Sankhuwasabha, Rasuwa and Sindhupalchok have many settlements on alluvial fans and riverbanks, which are susceptible to flood and debris flows. A lack of access to early warning systems, transportation and restrictions on diversification are further factors of exposure and vulnerability. Families relying on subsistence farming, or seasonal tourism (e.g., trekking) are particularly affected by climate impacts that affect their livelihoods.

6. Policy Response (Mitigation, Adaptation, and DRR)

Nepal's climate change and disaster risk policies adopt an integrated approach of mitigation, adaptation and DRR, in line with international commitments like the Intergovernmental Panel on Climate Change risk framework and the Sendai Framework for Disaster Risk Reduction. Because 91% of disasters in Nepal are related to hydro-meteorological hazards, climate change adaptation (CCA) and DRR must be integrated for effective risk management.

6.1 Mitigation Commitments and Pathways

Nepal has relatively low GHG emissions compared to the global average; however, GHG emissions are expected to grow under a BAU scenario. From a baseline of 28,166 GgCO₂-eq in 2011, emissions are expected to rise to 51,781 GgCO₂-eq by 2030 and 62,056 GgCO₂-eq by 2035. In response, Nepal's Nationally Determined Contribution (NDC3.0) commits to reducing emissions by 17.12% (8,867 GgCO₂-eq) by 2030 and 26.79% (16,628 GgCO₂-eq) by 2035 relative to BAU levels (MoFE, 2025). Notably, 96-97% of these are subject to international climate finance and technology support. Nepal has also pledged to reach net-zero CO₂ emissions by 2045 under its Long-term Decarbonization Strategy (LTDS) (GoN, 2021a).

Mitigation priorities include multi-sectors such as energy, agriculture, forestry and other land use (AFOLU), waste and industrial processes. Mitigation measures include increasing renewable energy capacity to 28,500 MW by 2035, electric mobility promotion (targeting 90-95% battery electric vehicle (BEV) sales), forest cover maintenance at, or above 46%, and waste management. The cost of mitigation actions is estimated to be USD 73.74 billion, of which only 14.68% is currently viewed as unconditional, implying a high level of international support (MoFE, 2025).

6.2 Adaptation and Resilience Building

Adaptation is a key focus for Nepal due to vulnerability to climate change-related risks. National strategies such as the National Adaptation Programme of Action (NAPA), National Adaptation Plan (NAP 2021-2050; GoN, 2021b) and NDC3.0 prioritise resilience building in critical sectors such as water resources, agriculture, infrastructure, and disaster management (MoFE, 2025).

Key adaptation actions include risk reduction from GLOFs, multi-hazard early warning systems (MHEWS), and climate-resilient infrastructure. A significant project funded by the Green Climate Fund (USD 36.1 million) aims raise institutional capacity of the DHM in DRR, to reduce water levels of high-risk glacial lakes (e.g., Thulagi, Lower Barun, Lumding Tsho and Hongu-2), improve monitoring, bank stabilization through reforestation, and build community resilience. This initiative will reach over 2.2 million people in high-risk mountain areas.

Nature-based measures (ecosystem-based adaptation - EbA) are increasingly important strategies with multiple benefits. Forestry projects, reforestation for slope stability and wetland conservation lower vulnerability to hazards and improve ecosystem services like water and soil conservation. These activities also provide co-benefits of mitigation through carbon storage.

6.3 Disaster Risk Reduction (DRR) Measures

Nepal's DRR measures are a mix of structural and non-structural measures that reduce the impacts of hazards and increase preparedness. Structural measures include slope stabilization, flood control measures, and GLOF risk mitigation through controlled lake drawdown, strengthening of moraine dams and retention structures (Wang et al., 2025). Non-structural measures include hazard mapping and land-use planning, early warning systems, community awareness raising and preparedness planning.

Nepal has advanced the MHEWS for major river basins and vulnerable mountain regions, but there are constraints in achieving real-time monitoring, especially in remote high-altitude areas with limited meteorological and hydrological monitoring stations (Talchabhadel et al., 2022), and gaps in communication due to ambiguities in the roles and responsibilities of agencies at all three levels of government (Bhandari, 2025).

6.4 Governance and Institutional Framework

Nepal's disaster and climate governance is based on the Disaster Risk Reduction and Management (DRRM) Act (2017), the Local Government Operation Act (2017), and the National DRR Policy (2018) accompanied by the Strategic Action Plan (2018–2030). These policies complement federal, provincial and local government structures outlined in the Constitution.

The Ministry of Forests and Environment, Department of Hydrology and Meteorology (DHM) and the National Disaster Risk Reduction and Management Authority (NDRRMA), as well as provincial and local disaster committees are key institutions responsible for DRR and DRM. Every one of the 753 local governments is required to develop and implement disaster risk reduction and climate adaptation plans, with national-level guidelines and frameworks providing support (GoN, 2021b).

Despite progress in governance, there are still issues of effective implementation. Governance structures are often fragmented, with overlapping responsibilities for climate adaptation and DRR, leading to coordination and resource allocation inefficiencies. Lack of data (especially in the high mountains) limits evidence-based approaches and local governments often lack capacity to understand climate change information and undertake risk reduction activities (GoN, 2021b; MoFE, 2025).

6.5 Integration, Synergies, and Remaining Challenges

An important policy challenge in Nepal is to integrate mitigation, adaptation and DRR into an integrated risk management framework. There are considerable synergies between these areas. For instance, ecosystem-based measures, land management and infrastructure all reduce emissions, boost adaptive capacity, and reduce risk. These "triple dividend" approaches are increasingly highlighted in international and national approaches.

The barriers for effective implementation remain. Scarcity of resources, reliance on external aid, lack of monitoring infrastructure at high altitudes, and institutional coordination are key barriers to implementation (UNDP Nepal, 2019). Similarly, poorly planned mitigation actions, such as large-scale land-use changes without safeguards, can also increase vulnerability.

7. Disaster Risk Framework

The concept of disaster risk in Nepal is defined by the relationship of hazard, exposure and vulnerability: $\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability}$. This equation emphasizes that disasters are not only products of extreme events, but are manifestations of interactions between physical and socio-economic processes. Climate change plays a significant modifying role in this equation by changing the characteristics of hazards (intensity, frequency, duration, spatial extent), and interacting with exposure, while vulnerability exacerbates the risk and *vice-versa*. In the steep, geologically vulnerable and climate-sensitive region of the Nepal Himalaya, these effects are especially acute.

One characteristic of climate change risks in mountain regions is the growing incidence of cascading and compound hazards. Cascading disasters are not stand-alone events, but are a series of interconnected events where one hazard triggers another (Sharma et al., 2023; Talchabhadel et al., 2023). For example, heavy monsoon rainfall can trigger landslides, which can block rivers and create lakes. Ultimately, the failure of such dams can cause downstream flooding and debris flow, exacerbating impacts in multiple sectors and regions. These cascading effects make it difficult to forecast, react and recover. This complexity highlights the importance of shifting from reactive disaster management to anticipatory risk governance that emphasizes preparedness, prevention, and forward-looking planning across multiple hazards.

These processes are evident in Nepal. The 2014 Jure (Sunkoshi) landslide, caused by rainfall, dammed the Sunkoshi River, forming a temporary lake and 156 lives were lost (Yagi et al., 2020). More recent disasters, such as the 2021 Melamchi flood and the 2024 Thame GLOF, show how changes in the cryosphere (glaciers and glacial lakes) can trigger a complex chain of hazards, including landslides, river blockage and flooding. While early warning and emergency interventions have mitigated potential impacts in some instances, these examples underline the complexities of climate risks (Pandey, 2024).

To better understand these interactions, this chapter presents an integrated climate-disaster resilience framework, which integrates six key elements: (i) climate drivers, (ii) hazard formation, (iii) exposure, (iv) vulnerability, (v) adaptive capacity and (vi) resilience outcomes. The foundation is climate drivers, such as rising temperatures, precipitation variability, glacier melting, and extreme events. These trigger and amplify hazard formation, such as floods, landslides, droughts, heatwaves, and GLOFs. Hazard formation is the physical expression of climate change. Hazards in Nepal are intricately linked. Drought, for instance, can weaken soil, making it more prone to landslides during the next monsoon, and glacier melt can feed into expanding glacial lakes that can cause flooding downstream. These connections emphasize the importance of shifting focus from single hazards to multi-hazard approaches.

Risk is also determined by exposure and vulnerability. Exposure is geographically distributed, reflecting population and infrastructure settlement, and natural resource dependence. Mountain regions in districts like Solukhumbu, Mustang and Sankhuwasabha are highly exposed to glacial lake outbursts and landslides, while the low-lying Terai areas are more vulnerable to flooding. Vulnerability depends on socio-economic and institutional factors such as poverty, geographical isolation, lack of access to services and institutions, and social inequalities (gender and marginalisation). These affect the ability of people to predict, respond, cope and adapt to disasters.

Adaptive capacity plays a key role in the risk model. It includes both formal (e.g. early warning systems, disaster preparedness, and robust infrastructure) and informal (e.g., local knowledge and coping strategies) adaptation measures. In Nepal, local adaptation strategies such as slope protection through reforestation, water harvesting, and migration from high-risk zones help to mitigate risk, but monitoring, data collection, and inter-institutional coordination in high-altitude areas can be improved to enhance these measures.

Despite recent policy advancements, disaster risk management in Nepal has historically been more reactive than proactive, with greater emphasis on disaster response and post-disaster recovery than on hazard preparedness and risk prevention. As climate-related hazards become more frequent and interconnected, this approach is increasingly insufficient. Strengthening hazard preparedness through comprehensive risk assessment, multi-hazard early warning systems, risk-informed land-use planning, resilient infrastructure, regular preparedness drills, and community-based disaster preparedness should become a priority to reduce disaster losses before hazardous events occur (UNDRR, 2015; GoN, 2017; IPCC, 2022).

The aim of the framework is to improve resilience outcomes, which are measured as the capacity of systems, communities and institutions to sustain, recover and adapt to climatic and disaster shocks. Appropriate management of climate drivers, hazards and vulnerabilities can help decrease fatalities, safeguard infrastructure and livelihoods, and enable sustainable development. Critically, the framework also acknowledges the links between climate change and disasters. Floods and wildfires, for example, can mobilise carbon, thus exacerbating GHG emissions and climate change. Conversely, integrated climate change mitigation, adaptation and DRR measures can create "triple dividends". For instance, ecosystem-based approaches such as reforestation and good land management practices lower vulnerability to hazards, improve livelihoods, and sequester carbon.

This holistic thinking is evident in Nepal's policy landscape. Recent national policies, including the Disaster Risk Reduction and Management Act (2017), the National Adaptation Plan (2021–2050) and the Nationally Determined Contributions (NDC3.0), recognize the importance of shifting from reactive disaster response toward proactive disaster risk reduction through preparedness, prevention, early warning systems, and risk-informed planning (GoN, 2017; MoFE, 2025; UNDRR, 2015). MHEWS, Local Adaptation Plans of Action (LAPAs; GoN, 2019), and post-disaster recovery measures under the "Build Back Better" principle also translate this perspective.

Looking ahead, strengthening climate–disaster resilience in Nepal requires a strategic shift from a predominantly response- and recovery-oriented approach towards proactive disaster risk reduction that prioritizes hazard preparedness, prevention, and risk-informed planning (UNDRR, 2015; IPCC, 2022). This includes enhancing high-altitude monitoring and forecasting, expanding multi-hazard early warning

systems, integrating climate risk into land-use and infrastructure planning, promoting community-based preparedness and regular emergency exercises, implementing ecosystem-based adaptation, and addressing the underlying social and economic drivers of vulnerability. Such investments are generally more cost-effective than post-disaster recovery and are essential for reducing future climate risks in the Nepal Himalaya.

8. Conclusions

Nepal's climate is warming, becoming more variable and extreme, with significant consequences for disaster risk and development. Warming temperatures, changing precipitation, and declining cryosphere are changing the risk landscape across the Nepal Himalaya, exacerbating the natural hazards such as floods, landslides, droughts, glacial lake outburst floods, and heatwaves. These changing hazards, coupled with socio-economic vulnerabilities and high mountain ecosystems, lead to multifaceted and cascading disaster risks, as illustrated by recent disasters and long-term trends, but there are also important challenges. Lack of local capacity and investment and governance fragmentation limit the effective roll-out of climate adaptation and disaster risk reduction. Key statistical deficits, such as country-specific emission factors, lack of high-resolution hazard assessments, poor integration of hydro-meteorological and loss data, and underreporting of non-economic losses (including mental health and cultural heritage) hinder informed policy-making. Although economic losses are around 0.08% of GDP each year, extreme events can result in disproportionate impacts, revealing systemic vulnerability despite low emissions.

There is a path forward to overcome these challenges. Improving climate and disaster data platforms, connecting data from the Department of Hydrology and Meteorology with disaster loss records and sectoral assessments, will be crucial. Expanding multi-hazard early warning systems, adopting climate-smart infrastructure and nature-based solutions can reduce vulnerabilities. Local capacity building, inclusive and equitable approaches, and international climate finance mobilisation will also be critical in meeting national adaptation and mitigation targets. In conclusion, Nepal's resilience path is a science-based, community-oriented and integrated approach to climate and disaster risk reduction. This approach will not only help Nepal meet national targets, such as net-zero emissions by 2045, but will also offer insights to other mountain regions vulnerable to climate change around the world.

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Glossary

Adaptation: The process of adjusting practices, systems, or policies to reduce vulnerability and cope with the actual or expected impacts of climate change.

Carbon intensity: The amount of carbon dioxide (CO₂) emitted for each unit of economic activity or energy produced. It indicates how much carbon is released to produce a given amount of goods, services, or energy.

Climate-induced disaster: A disaster event, such as a flood, landslide, drought, or glacial lake outburst, whose frequency or severity is influenced or worsened by climate change.

DRR (Disaster Risk Reduction): The systematic effort to analyze and reduce the causes of disasters through policies, planning, and practices that lower vulnerability and exposure to hazards.

Energy intensity: The amount of energy used to produce one unit of economic output, commonly used as an indicator of an economy's energy efficiency.

EWS (Early Warning System): A set of monitoring, communication, and response mechanisms designed to warn communities of an approaching hazard in time to take protective action.

GHGs (Greenhouse Gases): Gases such as carbon dioxide, methane, and nitrous oxide that trap heat in the atmosphere and contribute to global warming.

Glaciers: Large, slow-moving masses of ice formed from accumulated snow, found in high mountain and polar regions, which are highly sensitive to changes in temperature.

GLOF (Glacial Lake Outburst Flood): A sudden release of water from a glacial lake, often triggered by the failure of a moraine or ice dam, capable of causing catastrophic downstream flooding.

Mitigation: Actions taken to reduce or prevent the emission of greenhouse gases in order to limit the extent of future climate change.

Resilience: The capacity of a system, community, or society to withstand, absorb, and recover from the effects of a hazard or disaster in a timely and efficient manner.

CHAPTER: X

Environmental Governance in Nepal

Ramesh Raj Pant

Central Department of Environmental Science, Tribhuvan University, Kirtipur, Nepal

Email: rpant@cdes.edu.np

Summary

Environmental governance is the set of laws, policies, strategies, institutions, frameworks and practices through which government and societies manage their environment and natural resources sustainably. It ensures that development is sustainable, ecosystems are protected, and communities have a strong voice in decision-making. It is fundamental for sustaining ecological integrity, livelihoods and resilience across diverse landscapes. In Nepal, challenges such as rainfall pattern and intensity, flash flood induced disasters, pollution, unsustainable use of resources, watershed degradation, deforestation, biodiversity loss and the decline of ecosystem services are driven by complex and interlinked factors including global climate change. Fragmented policies and strategies, overlapping mandates and weak institutional coordination exacerbate these pressures, underscoring the need for integrated responses across legislative, policy and institutional domains. In this chapter, the governance framework of Nepal is analyzed through a nexus perspective, highlighting the interplay of laws, policies, strategies and institutions in shaping environmental management and institutional effectiveness. This work is based on the systematic review of published research articles and official documents using content analysis issued by federal, provincial and local governments and other concerned national and international organizations and institutions. These documents were assessed for relevance, coherence and implementation capacity of the concerned organizations/institutions in terms of policy, strategy and legislation. The analysis extends beyond formal institutions to include perspectives from government agencies, academia, civil society and local leadership across pollution control, watershed management, forestry, biodiversity conservation and disaster risk reduction, including climate change issues. Findings highlight notable progress in environmental governance, including the introduction of recent legislation such as the constitutional provisions as a fundamental right to recent Carbon Trading Regulation (2025 AD), which signals Nepal's engagement with global climate finance mechanisms. However, persistent gaps remain for example coordination is weak, mandates often overlap and conceptual integration of environmental governance across sectors is limited. These shortcomings hinder effective policy implementation and long-term sustainability. Marginalized households and communities, in particular, face constrained access to water and other natural resources due to restrictive provisions within policies and practices. The study underscores the urgent need for a harmonized governance framework that bridges policy, legislation and institutional functions. Such a

framework must be adaptive, inclusive and resilient-capable of aligning with Nepal's international commitments and national ambitions with ground realities, empowering communities and ensuring that environmental governance in Nepal contributes meaningfully to both ecological sustainability, sustained economic growth and social equity.

Keywords: Constitution; Environmental Governance; Institutions; International commitments; Sustainability

1. Introduction

Environmental governance is foundational for ensuring ecological integrity, human well-being and climate resilience, particularly across fragile Himalayan landscapes. Key environmental sectors such as forest and biodiversity conservation, pollution control and disaster risk reduction represent critical ecological processes and embody the dynamic relationships between nature and society. Governance frameworks provide integrated approaches to environmental planning by aligning ecological functions with social values for economic sustainability and embedding legislation, policies and institutions into coherent systems. Globally, degradation of terrestrial, freshwater and marine systems remains alarming, with accelerating biodiversity loss and ecosystem decline under the context of global climate change. In Nepal, fragile mountain ecosystems are particularly vulnerable to degradation due to both natural and anthropogenic drivers, posing serious threats to human and ecosystem health (Regmi & Bhandari, 2013).

Governance entails interactions among diverse actors and institutions over shared environmental concerns, including the management of common-pool resources (Acharya et al., 2015; Shrestha & Paudel, 2022). Environmental governance thus refers to the laws, policies and institutions through which societies regulate ecosystems and associated services (Upreti & Shrestha, 2021). International frameworks such as the Stockholm Conference (1972) and the Rio Declaration (1992) advanced policy responses by embedding environmental concerns into global environmental initiatives, while also promoting eco-centric critiques, climate research, ecosystem payment schemes and principles such as “Polluter Pays” (Ojha et al., 2019; Mishra & Prasai, 2025). In Nepal, environmental governance has been closely linked with natural resource management, climate vulnerability, pollution control, disaster risk reduction and socio-economic development, a trajectory that began with the establishment of Chitwan National Park in 1973. The Constitution of Nepal (2015), Article 30 (1) enshrines the fundamental right of citizens to live in a clean and healthy environment and embeds devolution of authority across three tiers of government. Yet, persistent gaps remain between legislative provisions, policy aspirations and institutional implementation with fragmented mandates and weak coordination complicating effective governance to accomplish the motive of actual governance (Paudel & Khatri, 2023; Nepal et al., 2025).

This study examines the environmental governance of Nepal through three interconnected policy questions. First, it considers which legislations and policies currently define the country's institutional landscape and regulatory priorities. Then it explores how these frameworks have shaped institutional mechanisms across federal, provincial and local governments, drawing attention to gaps and challenges in coordination, enforcement and capacity. Finally, it assesses to what extent existing legal arrangements align with community aspirations and resilience needs under changing environmental contexts and climate stress. Together, these research questions guide the study's dual objectives to: (i) examine how legislation, policies and institutional frameworks influence the design/creation and effectiveness of environmental governance,

and (ii) evaluate how governance mechanisms contribute to strengthening environmental and community resilience in Nepal.

2. Materials and Methods

This study employs a qualitative research design to analyze the status and role of legislation, policies, strategies and institutions in shaping environmental governance and community resilience in Nepal. A qualitative approach is particularly suited to governance research, as it enables in-depth exploration of textual frameworks, institutional arrangements and community practices rather than relying solely on quantitative indicators. Similar methodological strategies have been adopted in recent studies of Nepal's environmental governance, including assessments and explorations of governance integration with green economy strategies (Mishra & Prasai, 2025).

2.1 Approach

This study adopts a documentary and literature-based review, synthesizing constitutional provisions, legislative acts, regulations, national policies, strategies, institutional frameworks, judicial decisions and scholarly papers to assess how governance mechanisms support environmental and community resilience, including international commitments of Nepal. The review focuses on the formal structures with local community practices, drawing on policy documents, institutional reports, community-level records and judicial decisions. Methodologically, text mining identified key discourse on environmental governance-covering climate change, ecosystem services, pollution and conservation while a PRISMA-based protocol guided the systematic search, screening and selection of scientific literature and policy documents. This integrated framework ensures analytical rigor and provides a robust basis for evaluating governance effectiveness, coherence and resilience outcomes.

2.2 Data Sources and Analysis

This review draws on a diverse set of resources encompassing constitutional provisions, legislative acts, regulations, national policies, strategies, institutional frameworks, reports, judicial decisions and international commitments. Foundational legal instruments include the Constitution of Nepal (2015), the Environment Protection Act (2019), Forest Act (2019), Water Resources Act (1992) and the Disaster Risk Reduction and Management Act (2017). Complementary regulations such as the Environmental Protection Regulation (2020) and the Carbon Trading Regulation (2025) provide operational guidelines. Policy frameworks reviewed comprise the Climate Change Policy (2019), the National Adaptation Plan (NAP), and Local Adaptation Plans of Action (LAPA), 16th Periodic Plan (2024-2029), etc., which collectively articulate Nepal's strategic priorities for climate resilience and environmental management. Institutional sources include reports from the Ministry of Agriculture, Forest and Environment, the National Disaster Risk Reduction and Management Authority (NDRRMA), and community forestry programs. Community Forestry User Group reports provide insights into grassroots governance and implementation practices (Acharya et al., 2015; Shrestha & Paudel, 2022). Judicial decisions on environmental rights and climate justice were examined to highlight the judiciary's evolving role in enforcing constitutional mandates. At the international level, Nepal's commitments under frameworks such as the Paris Agreement (2015) and SDG contextualize national governance within global environmental and climate regimes, illustrating how international collaboration translates into resilience outcomes at the national scale.

Procedurally, the study employed a triangulation approach to ensure both breadth and depth of analysis, consistent with prior qualitative governance studies in Nepal (Regmi & Bhandari, 2013; Nepal et al., 2025).

A systems-thinking perspective guides the analysis, recognizing governance as a dynamic interaction among laws, policies, institutions and communities rather than a linear process.

To examine governance practices in Nepal, this study adopts a multi-pillar framework to analyze environmental governance, focusing on five interrelated domains: Environmental Pollution (EP), Climate Change (CC), Natural Resource Management (NRM), Disaster Risk Reduction and Management (DRRM), and Cross-Cutting Issues (CCI). Each domain is examined through its legislative foundation, policy instruments, and institutional arrangements, while cross-cutting themes such as decentralization, inclusivity, equity, institutional coordination, ethics, justice, and indigenous knowledge highlight the multidimensional nature of resilience at the community level.

3. Results and Discussion

3.1 Environmental Governance

Nepal, a landlocked country situated in the central Himalayas of South Asia, covers an area of 147, 181 km², with elevations ranging from approximately 60 m above mean sea level (amsl) in the southern Terai to 8,848.86 m amsl at the summit of Mount Everest. This geographic diversity creates distinct climatic zones and tremendous ecological and social variability (Acharya et al., 2015; Shrestha & Paudel, 2022). Despite this rich, natural heritage, Nepal's ecosystem remains highly vulnerable to climate change, land degradation and increasing anthropogenic pressures, which threaten the structure and functioning of critical ecosystem services, particularly those provided by mountain ecosystems (Regmi & Bhandari, 2013). Climate change has intensified hazards such as glacial lake outburst floods (GLOFs), landslides and flash floods with cascading impacts on hydropower and livelihoods, is a matter of serious concern in Nepal (Tiwari et al., 2025).

Both terrestrial and aquatic ecological systems of Nepal illustrate multiple challenges vividly for their sustainability. For instance, with over 6,000 rivers, the country harnesses only a fraction of its water potential but major urban based aquatic ecosystem are highly polluted due to various anthropogenic activities. The environmental sustainability is deeply influenced by Nepal's unique geography, which creates both opportunities and vulnerabilities: rich biodiversity, abundant water resources and community-driven practices provide resilience, yet recurrent disasters and ecological degradation undermine sustainability. These realities underscore the need for integrated governance frameworks that balance conservation and development, empower local institutions and ensure accountability in managing natural resources. Thus, the existing legal frameworks are approaching "adaptation turning points" necessitating adaptive strategies integrated into national policy (Ojha et al., 2019).

Thus, the environmental governance is shaped by a governance system that operates through laws, policies and institutions including community-based mechanisms that emphasize participatory approaches such as community forestry and local level watershed and water sources protection practices in Nepal. It is anchored in legislation, which establishes accountability and coherence while policies translate legal mandates into strategic priorities for institutions (Mishra & Prasai, 2025). The environmental governance cycle including problem identification, formulation, implementation and evaluation ensures adaptive responses to evolving environmental issues and challenges (Jordan & Lenschow, 2010). Both formal institutions (ministries, regulators) and informal ones (community groups, indigenous systems of water sources protection) help people work together and integrate their efforts for environmental and community resilience. They diffuse accountability, allocate tasks and manage conflicts, shaping the operational framework of environmental governance (Acharya et al., 2015; Shrestha & Paudel, 2022).

Decentralized and community-based environmental institutions are particularly critical, empowering local actors and fostering adaptive practices that sustain resilience and equity (Regmi & Bhandari, 2013; Upreti & Shrestha, 2021). This institutional dimension underscores that governance is not merely compliance-driven but also about enabling adaptive, inclusive and sustainable management of environmental systems (Ojha et al., 2019). Thus, the framework situates the governance within a comparative and integrative lens, highlighting how legislation, policies and institutions interact to shape environmental and societal resilience outcomes (Figure 1). While these initiatives have strengthened grassroots stewardship, persistent challenges such as pollution, climate-induced disasters and unsustainable resource exploitation demand stronger coordination, enforcement and resilience-building measures. The results highlight interdependencies of different aspects such as pollution control policies influence water resource management; climate adaptation strategies shape disaster preparedness and response; and community forestry links ecological conservation with livelihoods. Such interconnections reveal both synergies and fragmentation, consistent with findings that overlapping mandates and weak coordination remain persistent challenges in Nepal’s governance landscape (Nepal et al., 2025). The core aspects of environmental governance are discussed in following sections:

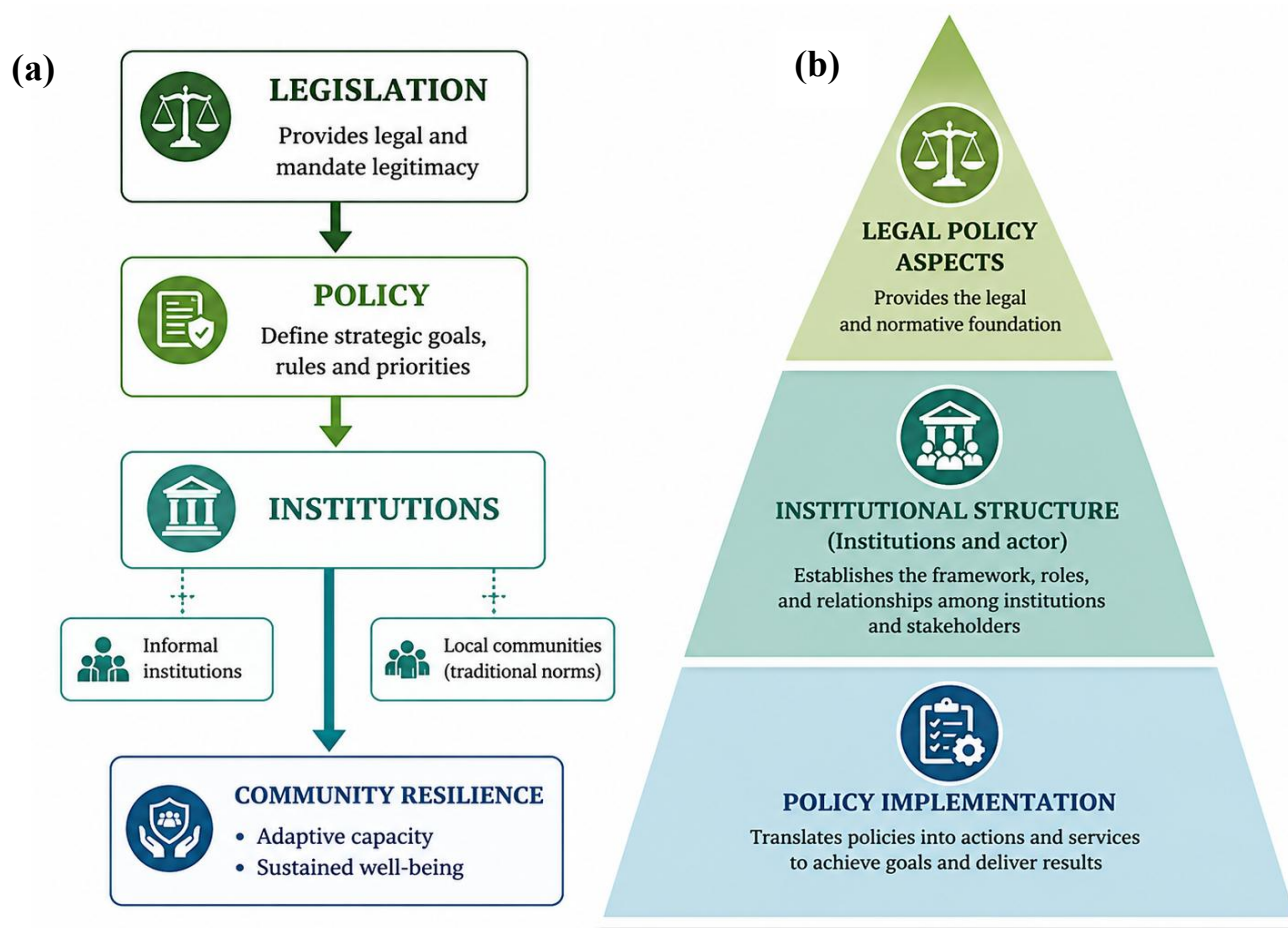


Figure 1: (a) Governance framework environmental sustainability and (b) Policy framework triangle

3.2 Constitutional Provisions

The country has made notable progress in embedding environmental governance within its constitutional and policy frameworks. After the promulgation of the Constitution of Nepal (2015), the country adopted a

federal democratic system with three tiers of government: the federal government, seven provinces and 753 local levels. The Constitution of Nepal (2015) enshrines the right to a clean and healthy environment as a fundamental right, reflecting a strong normative commitment to sustainability. Decentralization reforms have empowered local governments to integrate environmental concerns into planning and service delivery, while community forestry programs have become internationally recognized models of participatory resource management (Acharya et al., 2015; Shrestha & Paudel, 2022).

Article 30 of the Constitution of Nepal explicitly guarantees the Right to a Clean Environment. In the Article, Clause (1) secures every citizen's entitlement to live in a clean and healthy environment; Clause (2) provides compensation for individuals adversely affected by environmental degradation; and Clause (3) requires a balance between environmental protection and national development. Additionally, Article 35 (4) provides the rights of water and sanitation. Collectively, these constitutional provisions impose binding legal obligations upon the state to safeguard environmental rights, ensure restitution for harm and harmonize economic progress with ecological sustainability, thereby embedding environmental justice within the governance framework of Nepal.

Under the Directive Principles, Policies and Obligations of the State outlined in Part 4 of the Constitution of Nepal. Article 51(g) sets comprehensive policies for the protection, promotion, and sustainable use of natural resources. It emphasizes safeguarding resources based on national interest and intergenerational equity, while granting priority rights to local communities in governance. The article promotes multipurpose water resource development with public participation, expansion of renewable energy for reliable and affordable supply, and sustainable irrigation alongside river management to control water-induced disasters. It also mandates conservation of forests, wildlife, biodiversity and vegetation while minimizing environmental risks from development activities. Importantly, sustainability principles such as the polluter pays, precautionary principle and prior informed consent are adopted to ensure accountability. Furthermore, disaster risk management is prioritized through early warning systems, preparedness, rescue, relief and rehabilitation measures. Collectively, these provisions embed ecological stewardship, community participation and sustainable development into the constitutional governance framework of Nepal.

Article 57 of the Constitution, together with Schedules 5 to 9, defines and distributes the rights and powers among these three levels of government. Additionally, Nepal's executive, legislative and judiciary are all actively engaged in advancing environmental sustainability, though their effectiveness varies. At the national level, Federal Powers under Schedule 5 include the formulation of environmental legislation, acts, regulations, policies, strategies, institutions and provisions related to international commitments. Provincial Powers under Schedule 6 focus on provincial environmental governance and resource management, while Concurrent Powers under Schedule 7 assign shared responsibilities between federal and provincial governments. At the grassroots, Local Powers under Schedule 8 emphasize planning, implementation and monitoring of environmental services and Concurrent Powers under Schedule 9 require coordination across all three tiers of the governments (Table 1).

The executive branch drives policy formulation and international commitments, the legislature provides the legal foundation and the judiciary enforces constitutional rights through landmark decisions on environmental justice. Together, these institutions form the environmental governance system that is evolving but continues to face challenges in enforcement, coordination and balancing development imperatives with environmental protection (Upreti & Shrestha, 2021; Paudel & Khatri, 2023).

Despite these constitutional achievements, significant governance gaps persist. Environmental governance in Nepal is often fragmented, with overlapping mandates across ministries, weak enforcement of legislation

and limited coordination among federal, provincial and local institutions (Tiwari et al., 2025). For example, pollution control policies exist but remain poorly implemented in urban areas, climate change adaptation frameworks are ambitious yet constrained by financial and technical capacity, natural resource management has been successful in community forestry but less effective in water governance and disaster risk reduction has improved institutionally but struggles with cross-sectoral integration. This fragmentation undermines the transformative potential of governance and restricts communities from building resilience in a holistic manner, highlighting the urgent need for stronger coherence, enforcement and collaboration across all three tiers of government (Pant et al., 2026).

Table 1: The major constitutional provisions as per Article 57, Schedule 5-9

Schedule	Constitutional Provision
5. Federal jurisdiction	7. International boundary rivers 11. Policies relating to conservation and multiple use of water resources 27. National and international environment management, national parks, wildlife reserves, and wetlands, national forest policies, carbon services 29. Land use policies, human settlement, development policies, tourism policies, environment adaptation
6. Provincial jurisdiction	7. State-level electricity, irrigation, and water supply services and navigation 19. Use of forests and waters and management of environment within the state
7. Concurrent (Federal & State) jurisdiction	13. State boundary river, waterways, environment protection, biodiversity 23. Utilization of forests, mountains, and forest conservation
8. Local jurisdiction	10. Local market management and environment protection 11. Irrigation 19. Water supply, small hydro-power projects, alternative energy 21. Protection of watersheds, wildlife, mines and minerals
9. Concurrent (Federal, State & Local) jurisdiction	5. Services such as electricity, water supply and irrigation 6. Service fees, charges, penalties and royalties from natural resources 7. Forests, wildlife, birds, water uses, environment, ecology and biodiversity 14. Royalties from natural resources

3.3 Environmental Protection Act and Regulations

The latest Environment Protection Act (EPA) enacted in 2019 and Environment Protection Regulation (EPR) in 2020 of Nepal represents a landmark in environmental legislation, providing the overarching legal foundation for pollution control, sustainable development, biodiversity conservation and climate change management. Guided by the Constitution of Nepal (2015), which enshrines the right to a clean and healthy environment under Article 30, the Act provides the environmental governance of Nepal by introducing the polluter-pays principle, mandating brief environmental studies (BES), initial environmental examinations (IEE) and environmental impact assessments (EIA) and requiring compensation for environmental damage. It also integrates climate change into development planning, establishes mechanisms for carbon trading and emphasizes community participation in environmental management. Despite these advances, it has been noted that enforcement capacity remains weak, particularly in high-risk mountain regions, and urban areas where air and water pollution are most acute (Nepal et al., 2018; Acharya, 2024; ActionAid Nepal, 2025).

The Act is structured into several chapters. Chapter 2 requires proponents of development projects to conduct environmental studies, with public hearings, scoping and environmental audits as mandatory components. Chapter 3 sets standards for pollution control, bans harmful substances and empowers

inspectors to monitor compliance. Chapter 4 addresses climate change, mandating adaptation plans for vulnerable groups, emission monitoring and integration of climate risk into planning. Chapter 5 protects national heritage and establishes environmental protection areas, while Chapter 6 introduces fines and compensation mechanisms, with penalties depending on the severity of violations. Finally, Chapter 7 emphasizes traditional knowledge, annual reporting and periodic assessment of implementation (Table 2).

Table 2: The major legal provisions as per Environmental Protection Act (2019)

Chapter	Articles	Major Provisions
Chapter 1 Preliminary	Articles 1-2	Title, commencement and definitions of the terms
Chapter 2 Environmental Study	Articles 3-14	Mandatory environmental study reports (BES, IEE, EIA), approval process, public hearings, scoping, analysis of alternative, standards, strategic environmental analysis, environmental management plan, supplementary EIA, post-implementation environmental examination, power to prevent unauthorized projects, government-led environmental studies, power of the Government of Nepal or Provincial Government to make environmental study
Chapter 3 Control of Pollution	Articles 15-22	Pollution control standards, prohibition of harmful activities, regulation of hazardous substances (import/export/management), establishment of laboratories, sample collection, pollution control certificates, appointment and duties of environmental inspectors, powers of the environmental inspector, penalties for non-compliance
Chapter 4 Provisions Relating to Climate Change	Articles 23-28	Provide public information on climate change, preparation of adaptation plan, power to carry out acts of mitigation, impacts from climate change and risk management, power to determine technical standards, power to participate in carbon trade
Chapter 5 Provisions Relating to Protection of National Heritages and Environment Protection Areas	Articles 29-34	Protection of national heritages, special provision relating to environment protection areas, establishment and operation of fund, an environmental protection and climate change management national council chaired by the Prime Minister, functions, duties and powers of the Council
Chapter 6 Fine and Compensation	Articles 35-37	Fine, penalties, compensation, public participation, transparency, if a party who is not satisfied with the fine imposed may make an appeal within thirty-five days to the concerned District Court if such fine is imposed by the Local Level and to the concerned High Court if it is imposed by other body or authority of the Government of Nepal or Provincial Government.
Chapter 7 Miscellaneous Provisions	Articles 38-47	Miscellaneous provisions including environmental plans, delegation of authority and rule-making powers of the Government of Nepal, power to issue order, power to frame guidelines, procedures and standards, assessment as to implementation of the Act, repeal and saving.

To operate the provisions of EPA, the EPR and Carbon Trading Regulation (CTR, 2025) were enacted. While the EPA sets broad principles, EPR and CTR translate them into actionable procedures and standards. For instance, EPR specifies the process for conducting BES, IEE, and EIA, including scoping, public hearings, report submission and approval mechanisms at federal, provincial and local levels, while CTR sets the detail provisions and procedures of trading mechanisms. The EPR also establishes pollution control standards for air, water and noise, and outlines compliance monitoring through inspectors and laboratories. Similarly, hazardous waste management is strengthened, with bans on harmful imports and requirements for producers to bear disposal costs. The EPR also details procedures for declaring

environmental protection areas, managing restoration and involving local communities in benefit-sharing. Enforcement provisions include fines, blacklisting of violators and compensation mechanisms for victims of environmental harm.

On climate change, the CTR provides guidance for integrating adaptation and mitigation into development planning, monitoring greenhouse gas emissions and enabling participation in domestic and international carbon trading.

3.4 Environmental Policies, Plans and Strategies

National Environmental Policy

The **National Environment Policy (2019)** of Nepal was introduced to tackle pressing environmental challenges arising from rapid urbanization and industrialization and other environmental issues. Its key objectives include promoting sustainable development, strengthening environmental governance, conserving natural resources and mitigating climate change impacts. The policy emphasizes mainstreaming environmental concerns into national development plans, fostering multi-sectoral collaboration and enhancing monitoring and enforcement mechanisms. It highlights the importance of public participation, equitable access to resources and balancing economic growth with ecological sustainability. Effective implementation requires investment in research, capacity development and clearly defined responsibilities across the federal, provincial and local governments ensuring that all tiers of governance contribute to building a resilient and sustainable future for Nepal.

Periodic Plans

Nepal's environmental policy trajectory reflects a gradual but significant transformation from resource-extraction priorities to environmental and social resilience and integrated sustainability. The periodic plans can be divided into following four categories:

a) Early phase (Plans 1-4)

Environmental concerns were marginal with policies focused on forest resources utilization for agriculture, resettlement and basic forest management. Governance was rudimentary and largely oriented toward development infrastructure.

b) Mid phase (Plans 5-7)

Influenced by global environmental movements such as the 1972 Stockholm Conference, ecological balance and pollution control entered policy discourse. This period introduced watershed management, population control and the first commitments to EIA, laying the groundwork for institutional exploration.

c) Transition phase (Plans 8-9)

The Rio Earth Summit (1992) shaped Nepal's eighth periodic development plan, which firmly integrated sustainable development into national planning. Legal and institutional foundations were established, including the Environment Protection Act (1997), EIA guidelines, and the establishment of the Ministry of Population and Environment. The Ninth Plan expanded biodiversity conservation, pollution control and community forestry, marking a shift toward participatory governance.

d) Mature phase (Plans 10-16)

Environmental governance became fully integrated with poverty reduction, disaster risk reduction, climate adaptation and alignment with the SDGs. Plans emphasized resilience, climate-adaptive hydropower, renewable energy, and post-earthquake reconstruction. The Fifteenth Plan (2019-2024) mainstreamed climate adaptation at local levels, while the Sixteenth Plan represents Nepal's highest environmental commitment to date. In the Sixteenth Plan (2024/2025-2028/2029), Chapter 13

prioritized biodiversity, climate change and green economy strategies including sustainable forest management, biodiversity conservation, pollution control, climate risk reduction, local adaptability, access to international climate finance and institutional capacity development. This evolution demonstrates Nepal's shift from extraction-oriented planning to a holistic governance framework that integrates ecological sustainability, social equity and economic transformation.

Environmental Strategies and Guidelines

Environmental strategies and guidelines are essential instruments for translating sustainability principles into actionable policies and practices. They provide a structured approach to managing natural resources, reducing pollution and ensuring ecological balance while supporting economic and social development. Strategies outline long-term visions, such as integrating environmental concerns into national planning, fostering resilience against climate change and promoting inclusive participation. Guidelines, on the other hand, serve as operational manuals that define procedures, standards and responsibilities for implementation at the federal, provincial, and local government levels. Together, they form the backbone of environmental governance, ensuring that development activities are conducted responsibly and that environmental safeguards are consistently applied across sectors and regions.

a) Environmental and Social Management Framework (2023)

This framework provides a comprehensive approach to managing environmental and social risks in development projects. It emphasizes safeguards, stakeholder engagement and grievance redress mechanisms. Importantly, it assigns responsibilities across federal, provincial, and local governments, ensuring coordinated implementation and monitoring.

b) National Environmental Impact Assessment Guideline (1993)

As Nepal's pioneering guideline for EIAs, it established procedures for project-level environmental assessments. It outlines scoping, baseline studies, impact prediction, mitigation measures, and reporting requirements. The guideline remains foundational, guiding ministries, and authorities in evaluating development projects to minimize adverse environmental and social impacts.

3.5 Sectorial Environmental Governance

Environmental Pollution (EP)

Nepal has developed a layered legal framework to address pollution, combining constitutional guarantees, umbrella legislation and sector-specific acts, regulations and policies. For instance, EPA (2019) and the EPR (2020), Nepal has introduced the polluter-pays principle, mandate environmental studies (EIA, IEE, BES), and establish compensation mechanisms for victims of pollution. The Regulation operationalizes these provisions, setting standards for pollution control, hazardous waste management and climate integration. These frameworks provide targeted measures for air, water, solid waste, pesticides, chemicals and noise management. Some of the major provisions are briefly highlighted below:

a) Air Pollution

Nepal's National Air Quality Management Policy (2019), the Action Plan (2017) and recent National Ambient Air Quality Standard of Nepal, 2026 set emission standards for vehicles, industries, and brick kilns. Air quality monitoring stations in Kathmandu and other urban centers provide real-time data, consistently showing alarming levels of PM2.5 and PM10 (Chauhan & Shrestha, 2022). Despite several policy frameworks, and legal provisions, the enforcement remains weak. Unmanaged construction dust, poorly regulated brick kilns, and rising vehicular emissions continue to drive urban air pollution, posing serious risks to public health and environmental integrity.

b) Water and Sanitation

The National Water Supply and Sanitation Act (2020) guarantees universal access to safe drinking water and sanitation, mandates wastewater treatment and promotes climate-resilient WASH infrastructure. Complementing this, the National Water Resources Policy (2020) adopts integrated water resource management, prioritizing drinking water, irrigation and hydropower. However, untreated sewage and industrial effluents still pollute rivers and streams, exposing enforcement gaps and undermining the effectiveness of these policies.

c) Solid Waste Management

The Solid Waste Management Act (2011, amended 2017), the Solid Waste Management Rules (2013), and the Hazardous Materials and Waste Management Regulation (2020) provide Nepal's legal foundation for waste governance. The Solid Waste Management National Policy (2022) emphasizes segregation at source, landfill management, recycling industries and bans on disposal into rivers and public spaces. Municipalities are tasked with implementation, but limited capacity and resources hinder effectiveness. The policy also promotes the 3R approach (Reduce, Reuse, Recycle), citizen participation and public-private partnerships, aiming for zero waste to landfill by 2030.

d) Pesticides and Chemicals

The Pesticide Management Act (2019) regulates the import, sale and use of pesticides, requiring registration, labeling and safe disposal. It promotes integrated pest management to reduce chemical dependency in agriculture. Hazardous substances are further controlled under the EPR (2020), which restrict imports and mandate producer responsibility for waste. Soil pollution is indirectly addressed through land-use policies and agricultural regulations that encourage sustainable practices and reduced reliance on chemical inputs.

e) Noise Pollution

Noise standards are embedded within the EPA (2019) and EPR (2020), regulating industrial and vehicular noise levels. However, enforcement remains limited, and urban centers continue to experience excessive noise from traffic, construction and unregulated commercial activities, affecting both public health and quality of life.

Climate Change (CC)

Nepal does not yet have a standalone Climate Change Act, but climate provisions are embedded within broader environmental legislation and policies such as EPA (2019), the EPR (2020), the CTR (2025) and the National Climate Change Policy (2019). Together, these frameworks provide the legal and policy foundation for climate action, linking adaptation, mitigation and resilience with environmental governance system of Nepal. They also ensure that climate concerns are integrated into development planning across federal, provincial and local levels of the governments.

The National Climate Change Policy organizes climate action into major domains such as agriculture and food security, forest, biodiversity and watershed conservation, water resources and energy, rural and urban habitats, industry, transport and physical infrastructure, tourism and cultural heritage, health, drinking water and sanitation and disaster risk reduction and management. These are complemented by cross-cutting priorities such as gender equality and social inclusion, livelihoods and good governance, awareness raising and capacity development, research and technology expansion, and climate finance management. Together,

they provide a holistic framework that integrates ecological sustainability, social justice, and resilience, ensuring Nepal's climate governance is inclusive and future-oriented.

It mainstreams climate adaptation across all tiers of governance and mandates that 80% of climate finance be allocated at the local level, ensuring resources reach vulnerable communities. The policy emphasizes climate justice, biodiversity conservation, pollution control and public participation, while promoting inclusive and sustainable development pathways. By embedding adaptation and mitigation into national planning, it strengthens Nepal's ability to respond to climate risks while safeguarding ecosystems and livelihoods.

Nepal has also advanced a series of strategies and action plans that complement this policy. The National Adaptation Program of Action (NAPA, 2010) identified urgent adaptation priorities, while the Local Adaptation Plans of Action (LAPA, 2011) institutionalized community-level adaptation planning. Building on these, the National Adaptation Plan (NAP, 2021–2050) provides a long-term vision, outlining 64 priority programs across 12 sectors and guiding access to international climate finance. Nepal's National Biodiversity Strategy and Action Plan (NBSAP) 2026–2030 is the government's latest framework to conserve biodiversity, align with the Kunming–Montreal Global Biodiversity Framework, and integrate climate resilience, livelihoods, and governance into conservation policy.

Nepal submitted its first NDC in October 2016, the second in December 2020, and the third (NDC 3.0) in May 2025. These submissions progressively increased ambition in mitigation, adaptation, and financing, aligning with the Paris Agreement and global climate goals. These expanded renewable energy, electric mobility and clean cooking technologies, while reinforcing climate-resilient agriculture and forest-based emission reduction goals.

The CTR (2025) represents a significant milestone, providing Nepal with a legal framework for domestic and international carbon markets. It authorizes the Ministry to approve, monitor, and regulate carbon trading projects, enabling participation in bilateral agreements, non-market projects, and result-based financing mechanisms. The regulation encourages private sector and community involvement, supports access to international climate finance, and requires robust MRV (Monitoring, Reporting, Verification) systems to ensure the credibility of carbon credits. Together with the updated NDCs and the long-term NAP, this regulation positions Nepal to leverage carbon markets while advancing low-carbon development pathways.

Natural Resources Management (NRM)

Nepal's Constitution of 2015 treats natural resources including water, forests, land, minerals, and biodiversity as national assets under state ownership, mandating their sustainable and equitable use for present and future generations. The directive principles emphasize intergenerational equity, climate change mitigation, and ecological stewardship. Federalism distributes responsibilities across three tiers of government, supported by the Natural Resources and Fiscal Commission (Article 250), which ensures revenue sharing and dispute resolution among federal, provincial, and local authorities.

Forests remain central to Nepal's environmental governance. The Forest Act (2019) provides a comprehensive framework for sustainable forest management, categorizing forests into government-managed, community, leasehold, partnership, religious, and protection forests. It promotes biodiversity conservation, watershed protection, carbon sequestration, and community participation. Importantly, it institutionalizes Community Forest User Groups (CFUGs) as autonomous entities with rights to manage and benefit from local forests. Complementary instruments such as the National Forest Policy

(2019) and the Forestry Sector Strategy (2016-2025) expand community forestry, introduce REDD+ financing, and emphasize climate response, ensuring forests contribute to both livelihoods and global carbon reduction goals.

Water resources are equally vital, with the Water Resources Act (1992) establishing state ownership and enabling user associations for irrigation, drinking water, and hydropower. The National Water Resources Policy (2020) adopts integrated water resource management, prioritizing drinking water, irrigation, and energy production. More recently, the National Drinking Water and Sanitation Policy (2080 B.S.) commit to universal access, climate-resilient WASH infrastructure, and community-managed systems. Complementary frameworks such as the National Wetland Policy (2012) embed ecosystem protection and integrated water management, recognizing wetlands as critical for biodiversity, disaster resilience, and livelihoods.

Soil and land management are guided by the National Land Use Policy (2015), which introduced scientific land classification, zoning, and disaster risk reduction measures. Constitutional provisions under Article 51(d) emphasize soil conservation, prevention of land degradation, and sustainable agriculture. Land-use frameworks integrate urban planning, food security and climate resilience, ensuring that development does not compromise ecological balance. Similarly, mineral resources are constitutionally recognized as state property, with revenue shared across governance tiers (Article 60). Mining activities require environmental assessments under the EPA (2019), ensuring minimal ecological impact, while policies emphasize regulated extraction, equitable benefit sharing, and integration with local development priorities.

Biodiversity and wetlands are safeguarded through the National Biodiversity Strategy and Action Plan, which provided a strategic framework for conservation and equitable benefit sharing, fulfilling Nepal's obligations under the Convention on Biological Diversity (CBD, 1992). The National Ramsar Strategy and Action Plan (2018-2024) guides wetland conservation and wise use, aligning Nepal with Ramsar Convention commitments. These frameworks focus on ecological integrity, community participation and integration into climate adaptation and disaster risk reduction. Supporting instruments such as the Soil and Watershed Conservation Act (1982), the Guidelines for Development Activities in the Chure Conservation Area (2020), and the Forest Regulation (2022) further strengthen ecosystem protection. Collectively, these policies and laws establish a holistic approach to natural resource management, balancing conservation with development, and ensuring resilience in the face of climate change.

Disaster Risk Reduction and Management (DRRM)

Nepal is highly vulnerable to recurrent disasters such as earthquakes, floods, landslides, hailstones, heat and cold waves, thunderstorms, GLOFs, epidemics and fires. Recognizing these risks, the country has progressively shifted from fragmented, response-focused disaster laws to a comprehensive resilience-oriented framework. This transition aligns with global commitments such as the Sendai Framework for Disaster Risk Reduction (2015-2030), which emphasizes risk reduction, preparedness, and resilience. Over the past decade, Nepal has institutionalized disaster governance, integrating climate adaptation, community participation, and multi-hazard preparedness into national development planning.

The Disaster Risk Reduction and Management Act (2017) marked a turning point by replacing earlier fragmented laws with a unified legal framework. It defines disaster management as a continuous process encompassing risk reduction, preparedness, response and recovery. The Act classifies disasters into natural and non-natural categories and establishes a multi-tier institutional structure, including the National Council for DRRM chaired by the Prime Minister, the Executive Committee led by the Minister of Home Affairs,

and the National Disaster Risk Reduction and Management Authority (NDRRMA) as the central implementing body. It also introduced a Disaster Management Fund to finance rescue, relief, rehabilitation, and reconstruction, prioritizing vulnerable groups such as women, children, the elderly, and marginalized communities. The DRRM Regulation (2019) operationalized the Act, mandating risk-sensitive land-use planning, contingency strategies, early warning systems, and transparent fund mobilization, while embedding the principle of “Build Back Better” in recovery. Importantly, at the local level in Nepal, DRRM is legally mandated by the DRRM Act 2017 and its Regulation 2019, which require municipalities and rural municipalities to establish disaster management committees, prepare risk-sensitive land-use plans, and implement community-based preparedness and response mechanisms.

The National Disaster Risk Reduction Policy (2018) provides strategic direction for mainstreaming DRR into development planning, emphasizing risk assessment, early warning, and community-based preparedness. The National Disaster Risk Reduction Strategic Action Plan (2018-2030) offers a long-term roadmap aligned with Sendai priorities, focusing on governance, management of disaster related statistics (pre, during and post disaster related data) resilience of critical infrastructure, and community empowerment. Earlier milestones such as the National Strategy for Disaster Risk Management (2009) laid the foundation for integrated disaster management, while climate-linked frameworks like the National Adaptation Program of Action (2010) and Local Adaptation Plans of Action (2011) institutionalized community-level resilience planning. More recently, the National Climate Change Policy (2019) has integrated DRR with climate adaptation, recognizing the increasing risks of floods, landslides and droughts driven by climate change.

Nepal has also strengthened operational mechanisms to support implementation. The National Emergency Operation Center (NEOC) functions as the hub for disaster information, early warning and coordination, disseminating alerts to vulnerable communities. Risk-sensitive land-use planning has been integrated into urban development to minimize exposure to hazards, while Community-Based Disaster Risk Management (CBDRM) initiatives promote local ownership of preparedness and response. Citizen-led efforts, such as air quality monitoring, water testing and early flood warning, demonstrate the potential of participatory approaches in strengthening accountability. Modern disaster information systems now employ GIS, remote sensing, and hazard mapping to support evidence-based decision-making, ensuring that risk knowledge informs planning and response.

In recent years, Nepal has advanced multi-hazard preparedness by embedding resilience into national development priorities. The National Disaster Risk Reduction Policy (2018) and subsequent action plans emphasize reducing mortality, minimizing economic losses, and protecting infrastructure. The NDRRMA has expanded its role in coordinating federal, provincial, and local governments, while new initiatives focus on climate-induced hazards such as GLOFs and droughts. Integration of DRR with climate finance, technology development, and community participation reflects Nepal’s commitment to building a disaster-resilient society. Collectively, these frameworks demonstrate a shift toward proactive governance, where disaster risk reduction is not only about emergency response but also about safeguarding livelihoods, ecosystems and long-term sustainable development.

Local governments often lack resources, technical expertise, and clear mandates, constraining their ability to implement risk reduction measures. Community preparedness has emerged as a critical driver of resilience, with local committees, NGOs, and community-based organizations mobilizing for early warning, evacuation drills, and recovery. Examples include river basin level flood management, community-led flood

preparedness in Terai and earthquake drills in Kathmandu schools, showing how grassroots action complements national frameworks.

Cross Cutting Issues (CCI)

The environmental governance framework of Nepal increasingly emphasizes cross-cutting themes such as local governance and decentralization, data management, inclusivity, institutional coordination, judicial interventions and green economy linkages. These dimensions ensure that legislation and policies translate into transformative outcomes rather than remaining fragmented or symbolic. A wide range of complementary policies including the National Petroleum and Natural Gas Policy (2014), National Energy Policy (2019), National Land Use Policy (2019), the National Integrated Strategies Plan (2025–2043) and the Local Government Operation Act (2017) reinforce sustainability by embedding environmental concerns into energy, land use and development planning.

The Constitution of Nepal 2015 devolved substantial authority to provincial and local governments, creating opportunities for localized environmental governance. Local governments are mandated to integrate environmental concerns into development planning, manage natural resources and implement climate adaptation and disaster preparedness. Decentralization has empowered municipalities to tailor policies to local contexts, but capacity gaps and resource constraints remain (Pant et al., 2026). Effective local governance is therefore a critical catalyst of resilience, ensuring that national frameworks translate into community-level action and that climate finance reaches vulnerable populations.

Inclusivity is another cornerstone of resilience. The community forestry and local adaptation planning demonstrate the importance of engaging women, marginalized groups and indigenous communities in Nepal. Women's participation in CFUGs has improved equity and resource management outcomes, while indigenous knowledge in water management, agriculture and disaster preparedness provides valuable insights that complement scientific approaches. However, barriers such as elite capture and socio-cultural hierarchies persist. Strengthening inclusivity ensures that governance frameworks are socially just, equitable and resilient, while aligning with the SDGs.

Institutional coordination and judicial interventions also play pivotal roles. Institutional fragmentation overlaps between ministries, unclear mandates and weak coordination mechanisms undermines effectiveness. Stronger institutional synergy is essential to integrate pollution control, climate adaptation, resource management and disaster preparedness. Nepal's judiciary has acted as a governance actor, with Supreme Court rulings reinforcing environmental rights and climate justice. These interventions highlight the importance of accountability and the rule of law in bridging enforcement gaps and ensuring that environmental governance is not only policy-driven but also rights-based.

Nepal's environmental governance is also increasingly linked to green economy strategies. Policies promoting renewable energy, eco-tourism, sustainable agriculture and electric mobility illustrate how governance can simultaneously address environmental challenges and livelihood needs. Recent strategies such as the National Urban Development Strategy (2017), the Biomass Energy Strategy (2017) and the National Action Plan for Electric Mobility (2018) promote cleaner technologies, sustainable urban growth and circular economy practices. Integrating green economy approaches reduces dependency on unsustainable practices and creates new opportunities for communities. Financing and institutional alignment remain barriers, but strengthening these linkages ensures that governance contributes not only to resilience but also to long-term sustainable development. Collectively, these frameworks demonstrate

Nepal's shift from sectoral approaches to integrated, participatory and forward-looking governance, situating resilience within both national priorities and global commitments.

3.6 Environmental Standards of Nepal

Nepal has progressively developed a range of environmental standards to safeguard public health, ecosystems and sustainable development. The National Drinking Water Quality Standard (2022) sets safe limits for pH, arsenic, turbidity and coliforms, ensuring potable water quality across the country. Complementing this, the Surface Water Quality Standards for Industrial Effluents (2012) regulate pollutants such as coliforms, chloride and heavy metals, protecting rivers and lakes from contamination. These frameworks are vital in Nepalese context where water resources and their quality are both fragile and essential for livelihoods, agriculture and hydropower.

Air quality management is guided by the National Ambient Air Quality Standard (2026), which updates permissible thresholds for PM_{2.5}, PM₁₀, SO₂, NO₂ and CO reflecting growing concerns about urban air pollution and aligning Nepal with international benchmarks. Earlier standards from 2012 provided the foundation for monitoring, while the Air Quality Management Plan for Kathmandu (2019) outlined strategies to tackle vehicular emissions, brick kilns and construction dust. Noise pollution is addressed through the National Ambient Sound Quality Standard (2012), which specifies limits by zone 75 dB(A) in industrial areas, 65 dB(A) in commercial zones, 55 dB(A) in urban residential areas, and 50 dB(A) in protected or silent zones helping to mitigate health and social impacts in rapidly urbanizing regions.

Agricultural and chemical safety is regulated by the Pesticide Management Act (2019), which requires registration, licensing, and compliance with labeling and formulation standards. It promotes integrated pest management to reduce chemical dependency and protect human health, crops, and ecosystems. Industrial pollution is controlled by effluent standards that limit discharges of suspended solids, pH, and heavy metals into surface waters. The Petroleum Storage and Handling Standards (2018) further safeguard communities and ecosystems by regulating hazardous materials.

Beyond pollution control, Nepal has introduced broader ecosystem safeguards. The Ecological Protection Standard (2019) under the National Environmental Policy sets criteria for biodiversity conservation and ecosystem integrity. Together, these standards form a multi-sectoral framework that integrates water, air, noise, chemical and industrial regulation. While enforcement challenges persist particularly due to limited technical capacity and weak monitoring at the local level these standards remain critical tools for protecting health, ecosystems, and resilience in Nepal's fragile Himalayan context.

Ultimately, Nepal's environmental standards illustrate a shift toward integrated governance, where sectoral thresholds are linked to broader sustainability goals. By aligning with international conventions and updating standards to reflect emerging risks, Nepal demonstrates its commitment to climate resilience, biodiversity conservation, and the SDGs. Strengthening enforcement, expanding monitoring networks, and empowering local governments will be essential to ensure that these standards translate into tangible improvements in environmental quality and community well-being.

3.7 Environmental Institutions

Nepal's institutional landscape for environmental governance and disaster resilience is complex, multi-layered and evolving stage. At the core are ministries such as the Ministry of Agriculture, Forest and Environment (MoAFE), the Ministry of Energy, Water Resources and Irrigation (MoEWRI), which oversee agriculture, forests, biodiversity, water and energy respectively. The Department of Hydrology and Meteorology (DHM) of Nepal was restructured in 2026 to strengthen basin-level offices, integrate climate

services, and modernize forecasting systems. The new structure emphasizes decentralization with field offices in major river basins and enhanced disaster risk reduction capacity.

The Alternative Energy Promotion Centre (AEPCC) advances renewable energy. Semi-governmental bodies like the National Trust for Nature Conservation (NTNC) and regional institutions such as ICIMOD strengthen conservation and research. High-level councils ensure inter-ministerial coordination: The National Environment Protection Council, chaired by the Prime Minister, provides strategic guidance; the Climate Change Council oversees compliance with UNFCCC commitments; and the National Disaster Risk Reduction and Management Council (NDRRMC) integrates sustainability into disaster resilience planning. The NDRRMA serves as the lead institution for disaster governance, coordinating with ministries, provincial governments, and local disaster committees. These committees prepare contingency plans, conduct drills, and mobilize communities during emergencies. The NEOC functions as the hub for disaster information and early warning, while modern technologies such as GIS, remote sensing, open AI and hazard mapping are increasingly used to support evidence-based decision-making. International organizations and NGOs complement these efforts by providing capacity-building, financing, and technical expertise. Despite these arrangements, coordination gaps persist, particularly at different level of governments, leading to duplication of efforts and delays in response.

Community-based governance innovations illustrate both strengths and challenges. Nepal's community forestry model is globally recognized as a participatory success. CFUGs have regenerated degraded forests, improved biodiversity, and generated income through forest-based enterprises, while fostering social inclusion by involving women and marginalized groups in decision-making. Watershed management initiatives have similarly reduced soil erosion and enhanced water availability, demonstrating resilience benefits. Yet tensions arise when communities prioritize income generation over conservation, or when elite capture undermines equitable benefit-sharing. Water governance faces parallel challenges, with conflicts over allocation, weak enforcement and limited integration of watershed management into broader development planning. It is argued that stronger institutional coordination across forestry, water, and agriculture is needed to achieve holistic resource governance (Pant et al., 2026).

3.8 Community Stewardship

Community stewardship has become a cornerstone of environmental governance in Nepal, offering a participatory model that balances environmental protection with livelihood security. A prominent example is Nepal's Community Forestry program. Also, the Buffer Zone Management around national parks integrates conservation with community welfare by sharing tourism revenue and supporting anti-poaching patrols. These approaches demonstrate that governance rooted in community participation generates resilience outcomes that extend beyond ecological conservation to encompass livelihoods, equity and social cohesion. By embedding stewardship within local institutions, these approaches have strengthened participatory environmental governance and contributed to both ecological management and community livelihoods, although challenges related to equity, participation, and institutional capacity remain (SACEP, 2021; Laudari et al., 2024).

Additionally, the indigenous traditions across Nepal provide powerful examples of ecological stewardship rooted in cultural wisdom. The Sithi Nakha festival, celebrated by the Newar community, involves cleaning stone spouts, ponds and canals before the monsoon, reinforcing water conservation as both a spiritual and communal duty. In the hilly districts of Sudurpashchim regions, the practice of Naula (springs) protection safeguards natural water sources, ensuring reliable drinking water sources and strengthening resilience

against climate variability. Similarly, the Singi Nawa tradition among Sherpa communities prohibits tree cutting without collective permission, protecting fragile mountain forests. There are several such practices that highlight that environmental stewardship in Nepal is not only about modern policies but also about ancestral wisdom, rituals and discipline. By respecting sacred species, seasonal cycles and communal rules, indigenous communities contribute to environmental protection and biodiversity conservation while fostering social cohesion and cultural continuity. Such practices illustrate how cultural identity and ecological responsibility can be mutually reinforcing (Pant et al., 2026).

Citizen-led campaigns and grassroots projects are emerging as powerful tools for accountability. Local initiatives generate valuable data, raise awareness and pressure institutions to act. NGOs and INGOs in Nepal contribute to environmental protection and resilience by combining grassroots action, research, advocacy, and global partnerships. Groups like APEC-Nepal and AEPN promote awareness and cultural values in conservation, while CEN advances clean energy and climate solutions. CONCERN and Discover Nepal link education and eco-tourism to sustainability. Research bodies such as IHC-Nepal, TMI, and the Rhododendron Research Project strengthen biodiversity knowledge. Advocacy groups like INHURED International and NEFEJ raise awareness and influence policy, while conservation INGOs such as IUCN Nepal and WWF Nepal provide technical expertise and funding. Community-based initiatives like NRCT and ENPHO focus on river health, sanitation, and disaster preparedness. Together, they enhance biodiversity conservation, climate resilience, and community empowerment. Embedding such participatory efforts within formal governance structures could significantly strengthen enforcement, improve resilience and foster a culture of shared responsibility for environmental protection.

3.9 International Commitments of Nepal

Globally, environmental governance has evolved as a multidimensional concept linking ecological sustainability, social equity and institutional accountability. International frameworks provide guiding principles for countries like Nepal to align national strategies with global commitments. The SDGs emphasize integrated approaches to poverty reduction, environmental protection and resilience building. The Paris Agreement (2015) calls for climate action through NDCs, adaptation planning and low-carbon development pathways. Similarly, the Sendai Framework for Disaster Risk Reduction (2015-2030) highlights the importance of governance, institutions and community participation in reducing disaster risks. Collectively, these frameworks stress that legislation, policies and institutions are not merely administrative tools but catalysts that enable societies to withstand shocks and adapt to long-term environmental change (Ojha et al., 2019; Shrestha & Bhandari, 2021).

Nepal’s participation in major environment-related international conventions demonstrates its commitment to global environmental governance and resilience. By joining agreements such as the CBD, CITES, and the Ramsar Convention, Nepal safeguards biodiversity, wetlands, and endangered species. Engagement in frameworks like the UNFCCC, Vienna Convention, and Montreal Protocol strengthens climate action and ozone protection. Conventions such as the Basel Convention and Stockholm Convention on POPs help Nepal address hazardous waste and chemical pollution. Meanwhile, several treaties on pollution, outer space, and world heritage highlight Nepal’s broader role in safeguarding ecosystems, cultural heritage, and global commons (Table 3). Collectively, these conventions provide Nepal with legal frameworks, technical support, and international cooperation that reinforce its environmental protection, sustainable resource management, and climate resilience.

Table 3: Nepal’s Commitments to Major International Environmental Legislations

Treaty/Convention	Adoption	Nepal Party	Entry into Force	Key Features
Ramsar Convention	1971	1988	1988	Wetlands conservation and wise use.
Stockholm Conference	1972	Participated	1972	First global environment conference; basis for UNEP.
World Heritage Convention	1972	1978	1978	Protects cultural & natural heritage sites.
CITES	1973	1975	1975	Controls trade in endangered species.
Vienna Convention	1985	1994	1994	Ozone layer protection framework.
Montreal Protocol	1987	1994	1994	Phase-out of ozone-depleting substances.
Basel Convention	1989	1997	1997	Control of hazardous waste movement/disposal.
Convention on Biological Diversity	1992	1994	1994	Biodiversity conservation, sustainable use, benefit sharing.
UNFCCC	1992	1994	1994	Climate change mitigation/adaptation.
Rio Declaration	1992	1992	1992	Principles of sustainable development.
UNCCD	1994	1997	1997	Combat desertification, drought resilience.
Kyoto Protocol	1997	2005	2005	Binding GHG reduction targets.
Rotterdam Convention	1998	2007	2007	Prior informed consent for hazardous chemicals/pesticides.
Cartagena Protocol on Biosafety	2000	2001	2001	Safe handling of GMOs.
Stockholm Convention	2001	2004	2004	Elimination of persistent organic pollutants.
Nagoya Protocol	2010	2014	2014	Access and benefit-sharing of genetic resources.
Minamata Convention	2013	2017	2017	Mercury reduction/elimination.
Paris Agreement	2015	2016	2016	Global climate action, NDC commitments.
SDGs	2015	2015	2015	17 goals for sustainable development.
Kunming-Montreal Biodiversity Framework	2022	2022	2022	Global biodiversity targets to 2030.

Nepal's environmental and disaster governance demonstrates significant progress in legislation, institutional clarity and participatory approaches, but persistent challenges remain in coordination, implementation, equity and local capacity (Pant et al., 2026). Ministries and specialized agencies provide technical leadership, councils ensure strategic oversight, and institutions act as catalysts of resilience. Academia and the education sector also play important roles, with universities shaping policy research and embedding environmental education into curricula. Integrating indigenous knowledge, participatory governance and inclusivity into institutional design enhances resilience outcomes. Ultimately, Nepal's governance system illustrates that resilience is most effective when communities are empowered, institutions are synergized and policies are forward-looking. The success of community forestry demonstrates the transformative potential of participatory governance, but scaling such models across water, agriculture and disaster management requires stronger integration, inclusivity and sustained investment. By bridging institutional gaps and empowering local action, Nepal can ensure that its governance frameworks not only address immediate environmental challenges but also build long-term resilience in its fragile Himalayan context.

4. Conclusions

Nepal's environmental governance has evolved into a progressively comprehensive system that integrates constitutional mandates, legislative frameworks, and institutional arrangements. The Constitution of Nepal, 2015 enshrines the right to a clean and healthy environment, establishing sustainability as a guiding principle of national development. Building on this foundation, the Environment Protection Act 2019 and Environment Protection Regulation 2020 consolidated fragmented sectoral policies into a unified legal framework covering biodiversity, pollution control, climate change, and resource management. Complementary strategies such as the Climate Change Policy 2019 and the Carbon Trading Regulation 2025 have expanded Nepal's capacity to address adaptation, mitigation and market-based climate action. Institutionally, agencies including the Ministry of Agriculture, Forest and Environment and the National Disaster Risk Reduction and Management Authority have enhanced coordination, among all stakeholders including provincial and local governments, while community-based organizations such as Community Forest User Groups and water user associations have demonstrated the transformative potential of participatory governance. Nepal's alignment with global frameworks the Paris Agreement, the Sendai Framework, and the Sustainable Development Goals further underscores its commitment to integrate and forward-looking environmental governance.

Despite these achievements, Nepal continues to face persistent challenges in translating policy ambition into effective policy implementation. Implementation gaps are evident due to limited technical expertise, inadequate financial resources and weak enforcement capacity, particularly at provincial and local levels. Institutional overlaps between ministries and agencies often result in duplication, inefficiency, and fragmented accountability. Coordination across federal, provincial and local tiers remains uneven, limiting the effectiveness of decentralized governance. Moreover, stronger integration of climate adaptation with disaster risk reduction, water governance and natural resource management is urgently needed to address interconnected vulnerabilities. Equity and inclusion remain pressing concerns, as marginalized groups often face barriers to meaningful participation in adaptation planning and benefit-sharing. Sustaining early warning systems, adopting modern technologies, and ensuring long-term financing require consistent institutional commitment. Balancing economic growth with ecological sustainability continues to be a central governance dilemma, highlighting the need for stronger accountability, monitoring, and adaptive policy mechanisms. Thus, Nepal's environmental governance requires urgent attention to bridge persistent implementation gaps caused by limited technical and financial capacity. Institutional overlaps across federal, provincial and local agencies must be streamlined to avoid duplication and inefficiency. Stronger integration of environmental assessment with developmental activities is essential, alongside ensuring equity and inclusion for vulnerable groups. To achieve this, government bodies should prioritize empowering local institutions and recruiting more environmental and climate experts and skilled human resources within ministries and related organizations.

Finally, Nepal's environmental governance shows strong constitutional and policy ambition, but resilience depends on closing implementation gaps. Building synergy across institutions, empowering local governments, and strengthening grassroots groups like CFUGs and water user associations are essential. Long-term sustainability requires domestic financing, skilled capacity, and equitable participation of vulnerable communities. Ultimately, Nepal must integrate pollution control, climate change, natural resource management, and disaster risk reduction into a coherent, inclusive framework to achieve lasting environmental protection and resilience.

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Glossary

Environmental Governance: The system of laws, policies, institutions, and practices that regulate how societies manage natural resources and ecosystems sustainably.

Sustainability: The principle of meeting present needs without compromising the ability of future generations to meet theirs, balancing ecology, economy, and society.

Decentralization: Transfer of authority and responsibility from central to provincial and local governments, enabling community participation in environmental management.

Polluter Pays Principle: A legal concept requiring those who cause pollution to bear the costs of managing and mitigating its impacts.

Climate Change Adaptation: Strategies and actions taken to reduce vulnerability and enhance resilience against climate-related risks such as floods, landslides, and droughts.

Carbon Trading: A market-based mechanism allowing countries or organizations to buy and sell carbon credits to offset greenhouse gas emissions.

Community Forestry: A participatory approach where local user groups manage forests, ensuring conservation, livelihood benefits, and equitable resource use.

Environmental Assessment: A formal study required before development projects to evaluate potential environmental effects and propose mitigation measures.

Disaster Risk Reduction: Policies and practices aimed at minimizing vulnerabilities and disaster impacts through preparedness, mitigation, and resilience building.

Ecosystem Services: Benefits humans derive from nature, such as clean water, fertile soil, biodiversity, and climate regulation.



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