KINGDOM OF CAMBODIA

NATION RELIGION KING

NATIONAL CLIMATE REPORT

PART II

CLIMATE CHANGE IMPACTS, VULNERABILITY ASSESSMENT AND ADAPTATION

January 2026

National Climate Report

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FOREWORD

Building on the peace and political stability achieved under the leadership of **Samdech Akka Moha Sena Padei Techo Hun Sen**, President of the Senate, and guided by the **Pentagonal Strategy – Phase I** under the leadership of **Samdech Moha Borvor Tipadei Hun Maneth**, Prime Minister of the Royal Government of Cambodia, the country stands at a pivotal moment in its journey toward sustainable and climate-resilient development. Cambodia recognizes that environmental degradation and climate change are transboundary challenges that require collective action, as well as strengthened regional and global cooperation under multilateral frameworks, including the United Nations Framework Convention on Climate Change (UNFCCC).

In this context, the **Cambodia National Climate Report (NCR)** represents a major milestone in advancing national climate action and fulfilling Cambodia's international commitments on climate change adaptation under the UNFCCC and the Paris Agreement. The NCR directly supports Cambodia's efforts to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change, in line with **Article 7 of the Paris Agreement** and the **Global Goal on Adaptation (GGA)**.

The NCR is structured in two complementary parts: **Part I: Physical Science Basis**, and **Part II: Climate Change Impacts, Vulnerability Assessment, and Adaptation**. Together, these documents present the most up-to-date and comprehensive scientific evidence on climate change in Cambodia, drawing on global, regional, and national data. By providing robust, credible, and policy-relevant information, the NCR serves as a foundational knowledge resource for government officials, policymakers, planners, and practitioners, enabling informed and evidence-based decision-making.

Importantly, the NCR directly supports the formulation and implementation of Cambodia's **National Adaptation Plan (NAP)** and its climate reporting obligations under the UNFCCC, including the Biennial Transparency Report (BTR). It informs climate risk assessments, identifies sectoral and geographic vulnerabilities, and strengthens the evidence base for prioritizing adaptation actions and investments. Through this, the NCR enhances the integration of climate science into national planning processes and aligns adaptation measures with broader socio-economic development objectives.

The NCR is also a strategic resource for advancing Cambodia's national climate frameworks, including **Nationally Determined Contributions (NDCs 3.0)**, the **Cambodia Climate Change Strategic Plan 2024–2033 (CCCSP)**, and the **Circular Strategy on Environment 2023–2028**. These frameworks emphasize robust, inclusive, and locally grounded adaptation strategies. In alignment with NDCs 3.0, **NCR Part II** places particular emphasis on priority adaptation measures that are critical to Cambodia's safety, resilience, and long-term development as climate risks intensify. It provides in-depth analysis of adaptation priorities, institutional and governance responses, and good practices, supported by illustrative case studies from Cambodia and relevant international experiences.

Furthermore, NCR Part II assesses current adaptation actions and provides forward-looking recommendations to guide future policy development and investment. These recommendations support the implementation of the **CCCSP 2024–2033** and align with key national development strategies, including the Royal Government's **Pentagonal**

Strategy (Growth, Employment, Equity, Efficiency, and Sustainability) and the Ministry of Environment's **Circular Strategy on Environment** (Clean, Green, and Sustainable). The focus on adaptation and good governance reflects the three strategic outcomes of the CCCSP and reinforces Cambodia's commitment to climate-resilient development pathways.

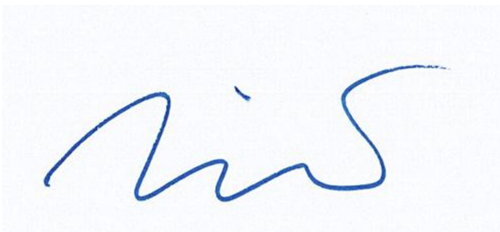
The NCR Part II also builds upon the data and analysis presented in Cambodia's **First Biennial Transparency Report (BTR1)** under the Paris Agreement, further advancing work on climate change impacts, adaptation, mitigation, and governance. It highlights adaptation measures already implemented, as well as those still required to achieve the level of adaptation ambition articulated under Article 7 of the Paris Agreement and Cambodia's long-term resilience goals.

This work has been made possible through the financial support of the **Green Climate Fund (GCF)**, reflecting Cambodia's strong engagement with GCF initiatives to scale up adaptation finance, strengthen institutional capacity, and support climate-resilient development at national and subnational levels. Implementation support provided by the **United Nations Office for Project Services (UNOPS)** has been instrumental in ensuring effective coordination and delivery.

I would like to express my sincere appreciation to the Ministry of Environment's Management Team and the General Directorate of Policy and Strategy (GDPS) for their leadership and coordination, as well as to the Technical Working Group on Climate Change (TWGCC), line ministries, academia, development partners, the private sector, and community stakeholders for their valuable contributions.

Our efforts must now continue with renewed determination. Realizing the vision set forth in this report will require sustained partnerships and strengthened support, particularly in climate finance, capacity development, climate science and knowledge sharing, and technology transfer, toward a shared goal of climate-resilient and low-emission development.

I sincerely hope that the NCR serves as a valuable resource for all climate stakeholders in Cambodia and beyond, and that the knowledge and insights contained within this report will guide impactful and enduring climate action for present and future generations.



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Secretary of State

ACKNOWLEDGEMENT

The development of the National Climate Report (NCR) was supported by the Green Climate Fund (GCF) under the Preparatory Readiness Programme through the United Nations Office for Project Services (UNOPS), as part of a broader process of cooperation with the Ministry of Environment / National Council for Sustainable Development (NCSD), the General Directorate of Policy and Strategy, and the Department of Climate Change (DCC) in Cambodia.

The Ministry of Environment, through the General Directorate of Policy and Strategy, extends its sincere appreciation to: **H.E. Dr. EANG Sophalleth**, Minister of Environment and Chair of the NCSD; **H.E. Dr. CHUOP Paris**, Secretary of State and Chair of the Technical Working Group on Climate Change (TWGCC); **H.E. Dr. PHEAV Sovuthy**, Under Secretary of State and Chair of the Project Steering Committee; **H.E. SUM Thy**, Director General of the General Directorate of Policy and Strategy (GDPS) for valuable guidance. Special thanks to **H.E. Dr. HENG Chanthoeun**, Deputy Director General of GDPS and NAP National Project Director; **H.E. MENG Monyrak**, Deputy Director General of GDPS and National Project Director; **Mr. SUM Cheat**, Deputy Director of the Department of Climate Change and NAP National Project Manager; **Mr. LEANG Sophal**, Deputy Director of the Department of Climate Change and National Project Manager; and the NAP Project Coordination Team of GDPS for technical inputs.

We extend our heartfelt gratitude to the Royal University of Phnom Penh, the Royal University of Agriculture, the Institute of Technology of Cambodia, and the Prek Leap National Institute of Agriculture for their technical intribution and cooperation.

Profound thanks are also extended to the members of the Technical Working Group on Climate Change from line ministries including MoE, MAFF, MoWRAM, MoP, MoT, MEE, MISTI, MOWA, MRD, MoIn, MPWT, MoH, MoEYS, MEF, MLMUPC, MFA&IC, MoI, NCDM, and CDC; provincial departments; communities; concerned development partners such as UNDP, FAO, and UNOPS; as well as NGOs and the private sector for their credible and valuable inputs, comments, and suggestions.

Finally, our deepest gratitude goes to peer reviewers for their valuable comments and suggestions, which greatly contributed to the revision and finalization of this report.

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LIST OF ABBREVIATIONS

AA	:	Anticipatory Actions
ACs	:	Agricultural Cooperatives
ADB	:	Asian Development Bank
AfDB	:	African Development Bank
AR5	:	Fifth Assessment Report of IPCC
BAU	:	Business As Usual
BRAWS	:	Building Resilience in Agricultural and Water Sectors
CBA	:	Community-Based Adaptation
CBNRM	:	Community-Based Natural Resource Management
CBT	:	Community-Based Tourism
CCCA	:	Cambodia Climate Change Alliance
CCCSP	:	Cambodia Climate Change Strategic Plan
CCDR	:	Country Climate and Development Report
CCKP	:	Climate Change Knowledge Portal
CCSP	:	Climate Change Strategic Plan
CDMRH	:	Cambodia Disaster Management Reference Handbook
CDPs	:	Commune Development Plans
CDRI	:	Cambodia Development Research Institute
CEGIM	:	Climate Economic Growth Impact Model
CES	:	Circulating and Ecological Sphere
CF	:	Community Forest
CFE-DM	:	Center for Excellence in Disaster Management
CGE	:	Computable General Equilibrium Model
CI	:	Conservation International
CICAS	:	Cambodia Inter-Censal Agriculture Survey
CLMD	:	Cambodia Lower Mekong Delta
CMIP	:	Coupled Model Inter-comparison Project
CRD	:	Climate Resilient Development
CREWS	:	Climate Risk & Early Warning Systems
CRF	:	Climate Resilience Framework
CSA	:	Climate-Smart Agriculture
CSCP	:	Cambodian Seagrass Conversation Project
CSM	:	Crop Simulation Models
CSOs	:	Civil Society Organizations
CSR	:	Corporate Social Responsibility
CVAA	:	Climate Vulnerability and Adaptation Assessment
DCC	:	Department of Climate Change
DDPs	:	District Development Plans
DERs	:	Distributed Energy Resources
DGE	:	Department of Green Economy
DO	:	Dissolved Oxygen
DRMKC	:	Disaster Risk Management Knowledge Centre
DRR	:	Disaster Risk Reduction
DST	:	Department of Science and Technology
EAC	:	Electricity Authority of Cambodia
EAS	:	Emergency Alert System
EbA	:	Ecosystem-based Adaptation
EC	:	Electrical Conductivity

EIB	:	European Investment Bank
ELP	:	Environmental Literacy Program
ENSO	:	El Nino-Southern Oscillation
EU	:	European Union
EW4All	:	Early Warning for All
EWS	:	Early Warning System
FAO	:	Food and Agriculture Organization
FFI	:	Fauna and Flora International
FGDs	:	Focus Group Discussions
FRDP	:	Framework for Resilient Development in the Pacific
FWI	:	Fire Weather Index
FWUC	:	Farmer Water User Community
GACSA	:	Global Alliance for Climate-Smart Agriculture
GCF	:	Green Climate Fund
GCM	:	General Circulation Models
GDP	:	Gross Domestic Product
GDPS	:	General Directorate of Policy and Strategy
GEDSI	:	Gender Equity, Disability and Social Inclusion
GEF	:	Global Environment Facility
GFDRR	:	Global Facility for Disaster Reduction and Recovery
GGA	:	Global Goal on Adaptation
GHG	:	Greenhouse Gas
GIS	:	Geographic Information Systems
GSSD	:	General Secretariat of the National Council for Sustainable Development
HAB	:	Harmful Algal Blooms
IAEA	:	International Atomic Energy Agency
IAMS	:	Integrated Assessment Models
ICZM	:	Integrated Coastal Zone Management
IDMC	:	Internal Displacement Monitoring Centre
IEA	:	Integrated Ecosystem Assessment
IEA	:	International Energy Agency
ILO	:	International Labour Organization
IMF	:	International Monetary Fund
INFORM	:	Index for Risk Management
IOM	:	International Organization for Migration
IoT	:	Internet of Things
IPCC	:	Intergovernmental Panel on Climate Change
ITC	:	Information and Communication Technology
IUCN	:	International Union for Conservation of Nature
IWRM	:	Integrated Water Resources Management
LDC	:	Least Developed Countries
LDCF	:	Least Developed Countries Fund
LULC	:	Land Use and Land Change
M	:	Meters
MA	:	Millennium Ecosystem Assessment
MAFF	:	Ministry of Agriculture, Forestry and Fisheries
MCC	:	Marine Conservation Cambodia
MEF	:	Ministry of Economy and Finance
MEL	:	Monitoring, Evaluation and Learning
MoE	:	Ministry of Environment
MoH	:	Ministry of Health

MOWRAM	:	Ministry of Water Resources and Meteorology
MRC	:	Mekong River Commission
MRE	:	Monitoring, Reporting, and Evaluation
MSMEs	:	Micro, Small, and Medium Enterprises
NAP	:	National Adaptation Plan
NAPAs	:	National Adaptation Programmes of Actions
NASA	:	National Aeronautics and Space Agency
NbS	:	Nature-based Solution
NBSAP	:	National Biodiversity Strategies and Action Plan
NCCC	:	National Climate Change Committee
NCDM	:	National Committee for Disaster Management
NCSD	:	National Council for Sustainable Development
NDCs	:	Nationally Determined Contributions
NGOs	:	Non-Governmental Organizations
NIS	:	National Institute of Statistics
NSDP	:	National Strategic Development Plan
OTEC	:	Ocean Thermal Energy Conversion
PE	:	Partial Equilibrium Models
PFERNA	:	Post-Flood Early Recovery Needs Assessment
PLNIA	:	Prek Leap National Institute of Agriculture
PPP	:	Public-Private Partnership
PPWSA	:	Phnom Penh Water Supply Authority
PSNP	:	Productive Safety Net Programme
PWWs	:	Public Water Works
R&D	:	Research and Development
RCP	:	Representative Concentration Pathway
REDD+	:	Reducing Emissions from Deforestation and Forest Degradation
RGC	:	Royal Government of Cambodia
RPSP	:	Readiness and Preparatory Support Programme
SDGs	:	Sustainable Development Goals
SEACAR	:	Southeast Asia Climate Adaptation and Resilience
SEZs	:	Special Economic Zones
SIPS	:	System Integrity Protection Schemes
SMEs	:	Small and Medium Enterprises
SNC	:	Second National Communication
SPCR	:	Strategic Program for Climate Resilience
SPEI	:	Standard Precipitation Evapotranspiration Index
SRSP	:	Shock-Responsive Social Protection
SRWSA	:	Siem Reap Water Supply Authority
UDL	:	Universal Design for Learning
UNDP	:	United Nations Development Programme
UNDRR	:	United Nations Office for Disaster Risk Reduction
UNEP	:	United Nations Environment Programme
UNESCO	:	United Nations Educational, Scientific and Cultural Organization
UNFCCC	:	United Nations Framework Convention on Climate Change
UNICEF	:	United Nations Children's Fund
UNISDR	:	United Nations International Strategy for Disaster
UNOPS	:	United Nations Office for Project Services
USAID	:	United States Agency for International Development
UWSP	:	Urban Water Supply Project
WASH	:	Water, Sanitation, and Hygiene

WAT4CAM	:	Water Resource Management and Agro-Ecological Transition in Cambodia
WB	:	World Bank
WEA	:	Wild Earth Allies
WHO	:	World Health Organization
WtE	:	Waste-to-Energy
WUE	:	Water Use Efficiency
WWF	:	World Wildlife Fund
WWT	:	Wildfowl and Wetlands Trust

EXECUTIVE SUMMARY

The National Climate Report (NCR) Part 2, *titled "Climate Change Impact, Vulnerability Assessment and Adaptation"*, aims to strengthen institutional and scientific capacity in Cambodia for formulating and implementing national, sectoral, and sub-national strategies and actions related to climate change adaptation, mitigation and good governance. The objectives of Part II are to review and assess the current state of Cambodia 's ecosystem and human systems; conduct vulnerability and exposure assessment for both of ecosystems and people; provide an overview of observed impacts and risks to both ecosystems and communities; provide an overviewed of observed climate change impacts and associated risks; conduct an in-depth review of Cambodia's adaptation, mitigation, governance, and adaptive capacity; assess climate-resilient development pathways; and provide recommendations to reduce the pressures and negative impacts of climate change by: strengthening agricultural resilience; enhancing water resource management; developing climate-resilient infrastructure; promoting sustainable forestry and land use; building institutional and community capacity; raising public awareness, and implementing adaptation measures in coastal zones to prevent soil erosion and saltwater intrusion.

The data/information for NCR Part II comes from the authors' relevant research, as well as from both primary and secondary sources, including academic journal articles, government publications, development partners' reports, and other relevant documents. This section of the NCR provides actionable recommendations for future research, policymakers, practitioners, development partners and other stakeholders involved in climate adaptation efforts. Part II of the NCR is structured into seven chapters as follows:

Chapter 1 provides an overview of Cambodia's current and projected exposure and sensitivities of climate change vulnerability, the sectoral impacts of climate change, and corresponding adaptation measures. Climate change poses significant threats to agriculture productivity, livelihoods, health, and economic development, particularly for impoverished rural communities that dependent on natural resources in areas flood and droughts. In terms of climate change impacts and vulnerability, the most affected sectors include agriculture, water resources, forestry, infrastructure, coastal zones, ecosystems, and human health. Seasonal floods and droughts frequently affect Cambodia, and these challenges are exacerbated by limited adaptive capacity, poor infrastructure, and inadequate institutional capacity in planning, policy development and budget allocation for sub-national level to effective respond to the impacts of climate change. Cambodia is one of countries that ranks high on global climate risk indices, indicating severe risks from extreme weather events such as floods, droughts, intense storms, heatwaves, water scarcity and seawater intrusion. These challenges pose significant threats to poverty reduction and sustainable development. In the future, these exposures are expected to intensify, particularly an increased natural disaster. To address these impacts, adaptation and mitigation measures are urgently required both national and sub-national levels. In alignment with the Global Goal on Adaptation (GGA) under the Paris Agreement, a framework consists of 11 global targets has been established to achieve by 2030. Seven of these targets focus on adaptation actions within specific thematic areas: agriculture, food, biodiversity, water resources, health, infrastructure, coastal zones and ecotourism, poverty reduction, and the preservation of cultural heritage. The Chapter 1 recommends strengthening agricultural resilience, particularly the improvement of irrigation system;

and enhancing water resource management to better cope with climate-related events such as floods and droughts; Improving infrastructure development; Promoting sustainable forestry and land use; and Capacity building and awareness raising on climate change and adaptation.

Chapter 2 presents updated knowledge on Cambodia's existing ecosystems and human systems, along with future directions for research related to the country's natural environment. Cambodia's ecosystems are rich and diverse, encompassing natural resources such as forests, fisheries, and comprising various habitats that support a wide range of plant and animal species, including wetlands, freshwater ecosystems, and marine and coastal ecosystems. The human systems addressed include air quality, weather conditions, access to water and food production, health, livelihood, and communities, urban areas, key infrastructure, and other vital economic sectors. In response to these risks, the country is prioritizing infrastructure development by promoting sustainable, resilient urban planning and transitioning to a low-carbon economy to enhance climate resilience and support its Sustainable Development Goals (SDGs). Key areas of concern include the limited comprehensive data on biodiversity loss in coastal ecosystems and the impacts on critical water resources such as the Tonle Sap Lake and Mekong River. Moreover, the socio-economic effects of climate vulnerability on agriculture and fisheries, as well as the implications of rising temperatures on labor productivity, remain insufficiently studies. Future research should prioritize integrated ecosystem assessments, the development of effective adaptation strategies for vulnerable communities, and measures to mitigate the impacts of heat stress on workers. Strengthening climate resilience through informed policy frameworks, efficient information dissemination, and enhancing public awareness are essential for addressing these challenges and developing effective strategies to mitigate climate change impacts on Cambodia's economy and ecosystems.

Chapter 3 assesses the vulnerability and exposure of ecosystems and people to climate change. It primarily draws on the Intergovernmental Panel on Climate Change (IPCC), Fifth and Sixth Assessment Reports (AR5 and AR6), which provide a framework for evaluating future climate change risks and vulnerabilities. Human--caused climate change is driving widespread and rapid changes across the atmosphere, oceans, cryosphere, and biosphere, affecting weather and climate extremes globally with severe consequences. These impacts include the increased frequency and intensity of heatwaves, heavy precipitation, droughts, and wildfires, all of which contribute to ecosystem degradation and pose significant threats to biodiversity. Climate change has numerous impacts on terrestrial ecosystems, including shifts in species distribution, changes in phenology, the spread of invasive species, alterations in biomass and carbon stocks, increased wildfires, and loss of habitat and biodiversity. These changes can lead to reduction in forest cover and modifications in ecosystem structure, resulting in biodiversity loss and altered ecosystem services. In coastal ecosystems, climate change affects marine biodiversity and productivity, marine biogeochemistry, estuaries, mangroves, and seagrass, and coral reef integrity. Similarly, impacts on water resources and freshwater ecosystems include water quality and quantity (both surface and groundwater), freshwater biodiversity, wetlands, and urban water management. In Cambodia, these effects are compounded by the loss of forests, habitat loss, and pollution, leading to significant biodiversity decline, increased risks to local livelihoods, especially among indigenous communities, and heightened vulnerability to soil erosion, flooding, and water quality degradation. Future studies should prioritize understanding ecosystem vulnerabilities, such as biodiversity loss, habitat degradation, and soil erosion, particularly in sensitive areas like the Tonle Sap Lake and the coastal zones. They should also incorporate economic modeling to predict climate-related impacts on GDP and assess adaptation strategies; address health and social risks for vulnerable populations; and support the development of integrated policy frameworks and community-based adaptation. These efforts are essential to inform effective and holistic responses to the escalating challenges of climate change in Cambodia.

Chapter 4 focuses on the observed impacts and risks to Cambodia's ecosystems. As highlighted throughout the report, Cambodia has diverse and fragile ecosystems which face significant threats from climate change, environmental degradation, human activities, posing serious risk to biodiversity, local communities, and ecological health. The country has experienced alarming rates of forests loss and habitat loss, leading to decline in biodiversity within habitats. Land Use Change and Forestry are among the greatest threats to the Cambodia's ecosystem and biodiversity. Coastal ecosystems, including mangrove forests, seagrass beds, and coral reef, are also at risk, as Cambodia's vital freshwater resources. These coastal and freshwater resources are vital for Cambodia's food security and the economy, particularly the unique Tonle Sap watershed region. This Chapter highlights the need for further research to better understand ecosystem vulnerabilities, along with the development of improved climate projections and economic modeling based on those projections. In terms of policy development and implementation, the Chapter recommends using enhanced climate data to establish a comprehensive framework for future climate action. It also emphasizes the important of strengthening cross-sectoral cooperation, improving the integration of climate research into policymaking, and increasing community engagement in both research and policy processes.

Chapter 5 presents the observed impact of climate change on the human systems, offering a comprehensive understanding of its effects, assessing vulnerability and risk factors, and providing policy recommendations for adaptation. Rising temperatures, shifting precipitation patterns, and more frequent extreme weather events threaten food security, public health, migration patterns, and economic development. These impacts of climate change are far-reaching, affecting human health, livelihoods, communities, and vulnerable groups, and exacerbating existing social and economic inequalities. The most vulnerable populations, including low-income groups, women, children, persons with disabilities, the elderly, and indigenous communities; are disproportionately affected due to limited resources and adaptive capacities. Addressing these challenges require the implementation of targeted policies, inclusive community engagement, and equitable adaptation measures aimed at reducing risks and building long-term resilience. Furthermore, the increasing frequency of extreme weather events, such as storms, floods, droughts and heat waves, have caused substantial damage to transportation networks, energy systems, and water resources infrastructure, particularly in low-lying areas. This has led to a growing financial burden for repairing and maintenance, particularly in regions with aging or inadequately designed infrastructure. To safeguard infrastructure and ensure long-term social and economic stability, it is essential to align infrastructure planning with sustainable urban development strategies at both national and sub-national levels. This includes integrating climate resilience concepts—such as nature-based solutions and effective gray infrastructure designs, along with the use of sustainable materials—into all stages of planning and development.

Chapter 6 presents Cambodia's adaptation governance and assessment of its adaptive capacity. Adapting to climate change is essential to protect communities, ecosystems, and the economies from the increasingly severe impacts of climate change. To reduce vulnerability and enhance resilience, it is crucial to implement measures such as upgrading infrastructure, adopting climate-resilient agricultural practices, and establishing early warning systems. Effective adaptation requires the active engagement of both government and broad range of stakeholders, who play vital roles in, decision-making, resource mobilization, and the implementation of strategies at various levels. These stakeholders include government line ministries and institutions, local communities, the private sector, non-governmental organizations, development partners and international partners, all of whom bring diverse expertise, resources, and perspectives to the adaptation process. While Cambodia is working to develop a robust policy framework for environmental protection and climate change adaptation, significant obstacles remain in the effective implementation of these policies and securing the necessary financial and technical resources. In addition, the institutional capacity is limited, with a lack of integrated governance structures and inadequate coordination between the national, sub-national, and local levels, these barrier factors affect the execution of adaptation measures. Challenges also persist in the availability and quality of data. In fact, accurate climate data and vulnerability assessments are limited, making it difficult to design targeted and effective strategies. To address these obstacles, it is essential to strengthen institutional frameworks, enhance resource mobilization, and improve data and information systems. This includes training for journalist and media professional on climate change impacts and adaptation, and as well as fostering stronger coordination across all sectors and levels of the government institutions and key stakeholders.

Chapter 7 explores the current state and future of climate-resilient development in Cambodia and emphasize the importance and benefits of implementing measures and strategies to improve the transitions in key sectors. It focuses on sectors such as energy, physical infrastructure, and key industries where adaptation efforts will be crucial. The Chapter also highlights the role of Nature-based Solutions (NbS) in enhancing climate resilience and adaptation, featuring case studies of NbS initiatives that have already been implemented in Cambodia and globally. This Chapter also addresses planning and social policy in key sectors that are vital for building climate resilience. These include social protection systems, and disaster risk management, health services, climate change education, cultural and heritage preservation, communication systems, and inclusive policies that promote gender equality, disability rights, and social inclusion. The Chapter also emphasizes the importance of climate data management to support decision-maker and policy development. It highlights that climate change poses a serious risk to the achievement of the Cambodia Sustainable Development Goals (CSDGs). Without careful planning and targeted adaptation measures across these sectors, Cambodia's progress toward sustainable development could be significantly undermined. Strengthening social policies and planning processes and its implementation, will be essential to ensure that vulnerable populations are protected and that development remains inclusive and resilient in the face of climate challenges.

CHAPTER 1
INTRODUCTION

1.1 Overview

Cambodia is one of the most disaster-prone countries in Southeast Asia, affected by floods, droughts, intense storms, and heatwaves on a seasonal basis. Cambodia is vulnerable to climate change because it is a developing, predominantly agrarian country, with nearly 80 percent of the population living in rural areas. While development in Cambodia has been rapid in recent years, the country is still limited by weak adaptive capacity, poor infrastructure, and limited institutions, which exacerbate the country's vulnerability to climate variability and change (WB and ADB, 2021). Cambodia is located in the tropics, where hot and humid climates create very favorable conditions for growing a wide variety of crops. Agriculture is a key economic pillar, contributing 22 percent to the country's GDP in 2022 and employing 2.6 million people in the agricultural sector, however it is a highly climate vulnerable sector (MAFF, 2022).

Cambodia is among the countries most vulnerable to climate change, ranking 46th out of 163 countries on the Children's Climate Risk Index, which highlights the high risk faced by its population—particularly children—due to extreme weather events, water scarcity, river flooding, and vector-borne diseases (UNICEFF, 2024). This vulnerability is exacerbated by the fact that a large proportion of Cambodians depend on agriculture for their livelihoods and reside in flood-prone areas, making them especially susceptible to climate-related shocks (WB, 2023). Additionally, Cambodia is ranked 140th out of 181 countries on the ND-GAIN Index, reflecting its significant exposure to climate change impacts and limited readiness to adapt, as the country's economy and social systems are highly dependent on climate-sensitive sectors such as agriculture, water resources, and fisheries (WB and ADB, 2021). These challenges threaten not only economic development and poverty alleviation efforts but also the health and wellbeing of millions, especially children, underscoring the urgent need for strengthened resilience and adaptation measures (UNICEFF, 2024).

While 76 percent of the people in Cambodia lives in rural areas, the country is rapidly becoming more urbanized. Approximately 49 percent of the workforce is employed in agriculture and fishing, which together account for 25 percent of the nation's GDP. The two fastest-growing sectors of the economy are industry and services. Due to its high exposure and vulnerability, Cambodia faces significant risk from both flood and drought-related disasters (Oudry, 2016) The national poverty rate and the rate of undernourishment remain high, at 15 percent (WB and ADB, 2021). Additionally, there is considerable reliance on natural resources, and the large-scale changes in the Mekong River's dynamics are expected.

According to Cambodia Climate Change Strategic Plan (CCCSP 2014-2023), the Royal Government of Cambodia (RGC) is committed to pursuing sustainable development that enhances the standard of living for its citizens and ensures a higher quality of life. Poverty reduction is the top objective of national development. Therefore, the nation's efforts to combat climate change cannot be separated from its attempts to expand the economy and reduce poverty.

People are severely impacted by climate change, especially the impoverished in rural areas who rely heavily on natural resources that are expected to be significantly affected. Due to their high poverty rates, households engaged in agriculture are particularly vulnerable to the effects of climate change. In order to demonstrate its commitment to mitigation and adaptation actions, Cambodia submitted its Intended Nationally Determined Contribution (INDC) in 2015 and its updated NDC in December 2020 and achieved NDC 3.0 in 2025. In order to maintain strategic coherence in addressing a broad range of climate change concerns related to adaptation, greenhouse gas abatement, and low-carbon development, these documents create synergies with existing government programs.

As part of its response to climate change, Cambodia has actively collaborated with the Green Climate Fund (GCF) through the Ministry of Environment's General Directorate of Policy and Strategy (GDPS).

1.2 Objective and Scope

1.2.1 Objective

The general objective of this report is to strengthen institutional and scientific capacity in Cambodia for formulating and implementing national, sectoral, and subnational climate change adaptation strategies and actions. The primary objectives of NCR Part II, “Climate Change Impacts, Vulnerability Assessment and Adaptation,” are:

- Review and assess the current Cambodia ecosystem and human systems;
- Conduct vulnerability assessment and exposure of ecosystems and people;
- Provide an overview of observed impacts and risks to both ecosystems and human systems;
- Conduct in-depth review of the Cambodian adaptation governance and adaptive capacity assessment; and
- Assess climate-resilient development and provide recommendations to reduce pressures and negative impacts caused by climate change by strengthening agricultural resilience, enhancing water resource management, developing infrastructure, promoting sustainable forestry and land use, and building capacity and raising awareness, supported by case studies from Cambodia as well as other countries.

1.2.2 Scope

This report focuses on assessment of current and projected future vulnerabilities to climate change in Cambodia and how Cambodia can adapt to current and projected changes and impacts. The goal of the report is to deepen knowledge about the effects of climate change at the national, regional, and global levels. The report also seeks to explore connections in expanding and diverse areas, including ongoing adaptation activities, policy, strategy, and planning.

This report takes as a starting place the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), which covered the expansion of human settlements, security, and livelihoods, and the human dimensions of climate change. The IPPC report focuses on climate change as a challenge in managing and reducing risk, as well as capitalizing on opportunities; and the interconnectedness of climate change impacts with a focus on risk, appreciating the multi-stressor context of the risks of climate change and approaches for solutions. This report focused on the secondary data gathering from national, regional, and global contexts, particularly in Cambodia, related to climate change impact, vulnerability assessment, and adaptation, in priority sectors as agriculture, water resources, forest ecosystem, infrastructure, human health, and coastal zones. Accordingly, Part II uses the gathered evidence to guide policymakers and stakeholders in creating informed, effective climate strategies and emphasizes how this knowledge fosters collaboration and innovation to build Cambodia's resilience and support sustainable development aligned with global climate goals.

Therefore, its scope is to cover the current Cambodia ecosystem and human system; vulnerability assessment and exposure of ecosystems and people; observed impact and risk on ecosystem; observed impact and risk on human system; Cambodia adaptation governance and adaptive capacity assessment; and climate resilient development.

1.3 Methods and Approach

In this chapter, data were collected from existing resources, including academic journal articles, reports, and relevant documents. Some were the original works of the authors. Collected documents have been synthesized and analyzed to obtain good and acceptable content. The major sources of data were gathered from the following published documents and reviews:

- Academic journal articles
- National Adaptation Plan 2017
- Synthesis Report of IPCC: Summary for Policymakers 2023
- Fifth and Sixth Assessment Report (AR5 and AR6) by the IPCC
- Pentagonal Strategy Phase I
- Other related documents

1.4 Current and Future Exposure and Sensitivities

1.4.1 Conceptual Relationship of Vulnerability

The IPCC defines vulnerability as the susceptibility of a species, system, or resource to the adverse effects of climate change and other stressors (Schneider, 2007). Vulnerability comprises three elements: exposure, sensitivity, and adaptive capacity, as has shown in Figure 1.1.

a. Exposure

Exposure refers to the level of contact or proximity that an individual or group has with a factor as well as the degree to which exposure impacts on their health. For instance, rising temperatures might make outdoor environments more appealing, which may unintentionally expose people to greater climate-related risks such as intense heat, mosquitoes, and contaminated water.

b. Sensitivity

Sensitivity in IPCC usage is defined as the extent to which a system is affected by climate variability and change, either positively or negatively. It can also be described as the fraction of a population that is more susceptible to the effects of climate change due to specific physiological or social traits, or as the varying degrees to which different members of the population may be impacted by climate change. Populations who are particularly vulnerable to effects of climate change include women, children, the elderly, people with disabilities, and indigenous and rural communities who rely directly on ecosystems for livelihoods and daily survival.

c. Adaptive Capacity

The IPCC defines adaptive capacity as a system's capacity to respond to possible harms, such as climate fluctuation and change. Adaptive capacity depends on a range of characteristics such as income, infrastructural access, skills, education, knowledge, and managerial abilities (McCarthy, 2001).

Climate change vulnerability assessments are essential for understanding how different systems are affected by climate variability and change. This framework helps identify who or what is vulnerable, where vulnerabilities exist, and how systems can adapt to mitigate risks. As shown in Figure 1, Cambodia has six main sectors that are vulnerable to climate change impact that can pose significant risks to its most marginalized communities. Hence, adaptation strategies are essential to mitigate these effects and enhance resilience. AR5 introduced a climate risk framework that combines hazard, exposure, and vulnerability to define risk (shown in figure 1).

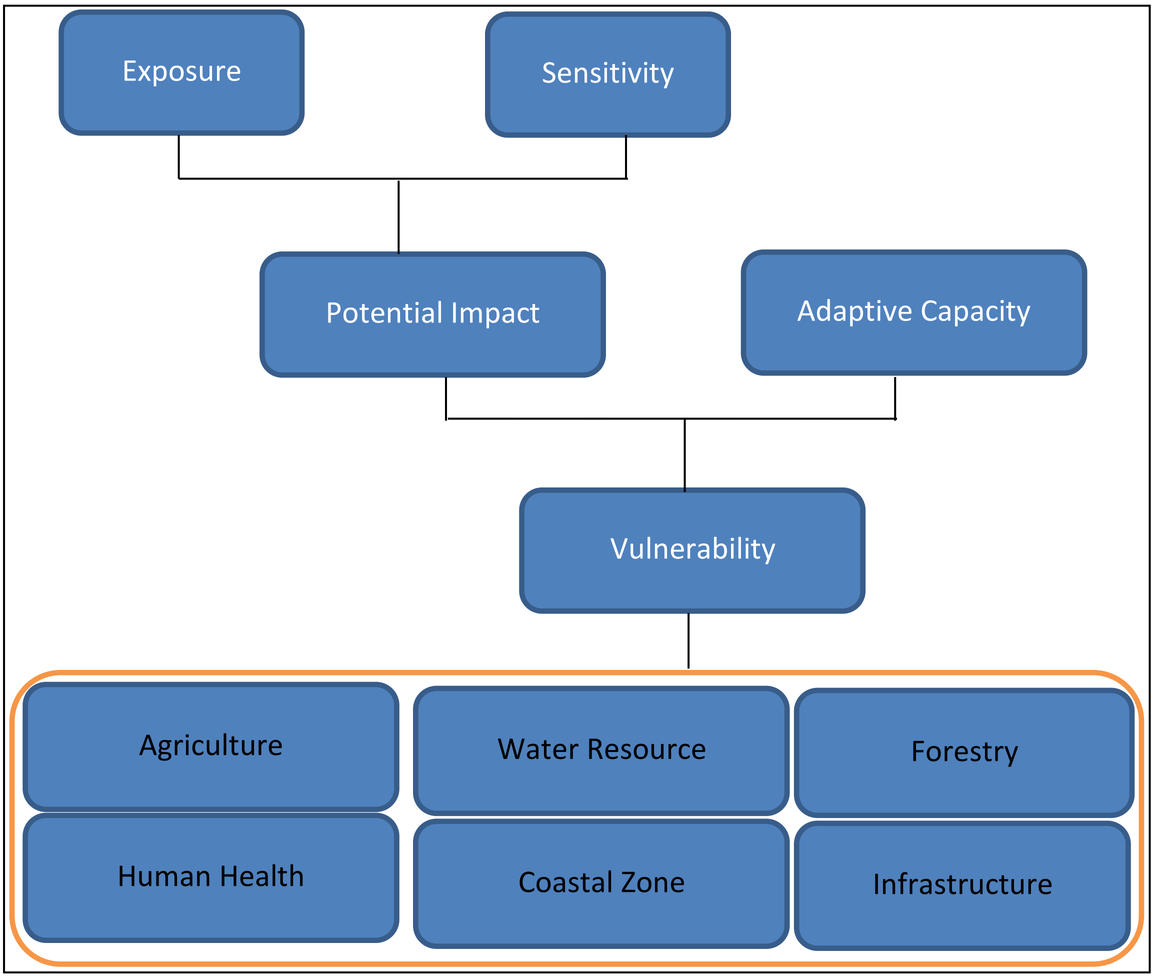


Figure 1: Vulnerability Assessment Framework.
Source: NAP Process (GSSD, 2017).

1.4.2 Country Risks

Risk calculation takes into account exposure to hazards, vulnerability, and capacity to cope. Addressing all of these elements is important in reducing and mitigating disaster risk. Various indices emphasize structural or institutional risk, while others emphasize hazards or losses (human and economic). Regardless of emphasis, disaster risk calculations use some form of the equation (Fitzgibbon and Crosskey, 2013):

Disaster Risk = (Hazard × Vulnerability)/ Capacity

The INFORM Risk Index measures the risk of humanitarian crises and disasters in 191 countries (CDMRH, 2024). The INFORM model is based on the standard dimensions of risk: Hazards and Exposure, Vulnerability, and Lack of Coping Capacity. The first dimension measures the natural and human hazards that pose the risk (CDMRH, 2024). The second and third dimensions cover population factors that can mitigate against or exacerbate the risk. The vulnerability dimension considers the strength of individuals and households relative to a crisis while the Lack of Coping Capacity dimension considers factors of institutional strength (European Commission-DRMKC, n.d.).

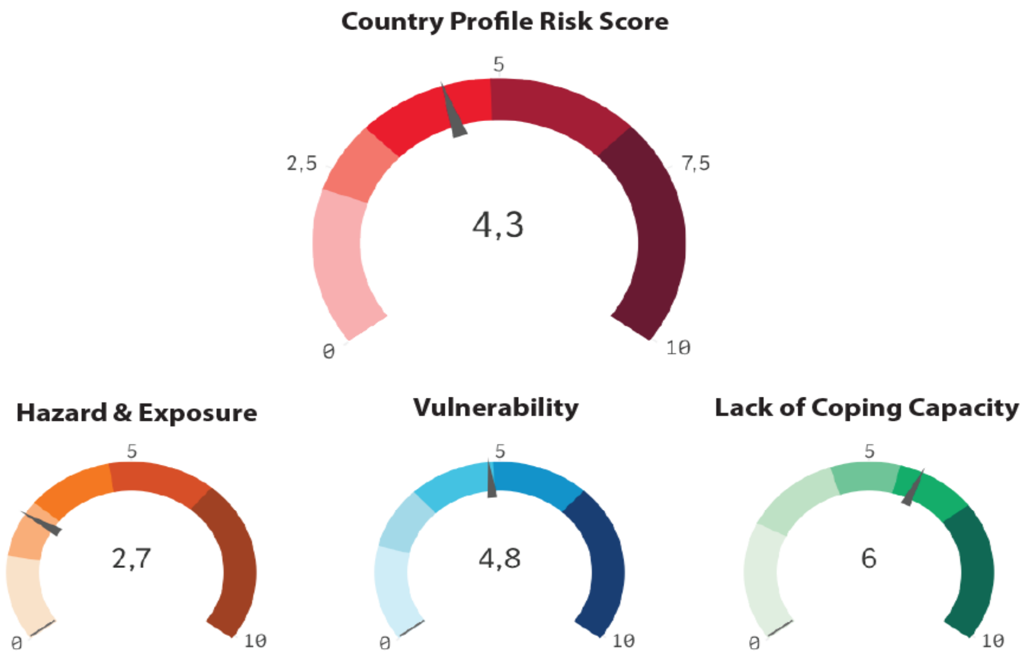


Figure 2: INFORM Risk Index, Cambodia 2024.
Source: (CDMRH, 2024)

Based on each dimension, type, and component of risk, as well as the overall risk score, INFORM ranks each country on a scale from 1 to 10, with 1 being the lowest and 10 being the highest. According to Figure 2, the overall risk score is 4.3/10, which categorizes the country as medium risk according to INFORM, ranking it as the 58th most at-risk country in the index.

The Hazards and Exposure dimension score takes into account a combination of both natural and human hazards, and Cambodia rated 2.7/10, or 80th of 191 countries. The vulnerability dimension score was 4.8/10 or 56th of 191, and the Lack of Coping Capacity dimension score was 6.9/10 or 42nd of 191. Physical exposure to River Flooding at 8.7/10, was the greatest threat in the Hazards and Exposure dimension, with Development and Deprivation measuring at a 6.5/10, making it highest in the vulnerability dimension, and DRR rated 6.8/10, the highest score in the Lack of Coping Capacity dimension.

1.4.3 Current Exposure and Sensitivities

Cambodia faces high disaster risk levels driven particularly by its exposure to flood hazards. This country has extremely high exposure to flooding (ranked joint 4th), including riverine and flash flooding (CDMRH, 2024). Cambodia also has some limited exposure to tropical cyclones and their associated hazards. The country's drought exposure is slightly lower, but is still of significant concern, as highlighted by the severe drought of 2015–2017 (WB and ADB, 2021). Cambodia's overall ranking on the INFORM risk index is somewhat exacerbated by its lack of coping capacity and to a lesser extent by the vulnerability of the population (Figure1.2).

A. Sector-Specific Analysis

Cambodia is currently facing a number of exposures and sensitivities that have had negative impacts on the key sectors such as ecosystems, freshwater resources, coastal system and low-lying area, agriculture, fisheries, livestock, and human health.

a. Ecosystems

Increased flooding, droughts, and extreme weather events have threatened both natural ecosystems and human livelihoods. For instance, nearly 45 percent of Cambodia's natural wetland areas have been lost, exacerbating the risks of flooding and drought. The degradation of wetlands significantly affects biodiversity, particularly species that rely on these habitats for survival (WB and ADB, 2021; WB, 2023).

b. Freshwater Resources

Cambodia experiences frequent floods and droughts that disrupt water availability and quality, which are crucial for agriculture, fisheries, and the drinking water supply. The Water Resources Adaptation Guide highlighted that the country deals with excessive water during the wet season and insufficient water during dry periods, which is compounded by increasing pollution levels in urban areas (NCSD and MoE, 2019). Climate change exacerbates these issues by altering precipitation patterns and increasing average temperatures, which affects both surface and groundwater (NCSD and MoE, 2019; ADB, 2021).

c. Coastal Systems and Low-lying Areas

Coastal zones and low-lying areas are highly exposed and sensitive to climate change impacts. The combination of rising sea levels, increased storm intensity, economic dependence on vulnerable sectors, and socioeconomic challenges creates a precarious situation for local communities (FAO, 2023). Seasonal storms are particularly detrimental to poorer families in regions like Kep and Kampot, where they disrupt agricultural activities and threaten food security (NCSD, 2017).

d. Agriculture, Fisheries, and Livestock

The agricultural sector is particularly sensitive to climate variability, with historical data indicating that flooding and drought have caused significant production losses—62 percent due to flooding and 36 percent due to drought (NCSD, 2017). The fisheries sector contributes significantly to Cambodia's economy and food security. Over 6 million people are involved in fisheries, which account for 8-10 percent of GDP (SEAFDEC, 2022). However, declining fish stocks due to climate change and overfishing are leading to increased fish prices for consumers and reduced incomes for fishermen. This impacts the livelihoods of rural communities that rely heavily on fish as a primary protein source (IFRC, 2024). At the same time, the livestock sector has faced significant challenges on the health and productivity caused by the outbreak of infectious disease, such as Avian Influenza A (H5N1). There have been 72 reported cases of human infection, with a case fatality ratio of approximately 59.7 percent (WHO, 2024).

e. Human Health

Cambodia is highly susceptible to climate-related health risks in the form of increasing outbreaks of waterborne diseases and vector-borne diseases like dengue fever and malaria. Additionally, health infrastructure is also at risk from flooding, storms and other climate-related events, which lead to damage that compromises service delivery and increases health inequalities (WB, 2024). A report conducted by USAID indicated that climate change significantly impacts concerning infectious diseases like tuberculosis (TB), with a reported increase in case notifications from 21,589 in 2021 to 32,772 in 2022 (USAID, 2024).

Climate change may be increasing the risk of water- and vector-borne diseases and the likelihood of epidemics. Droughts, rains, and floods are linked with an increased risk of outbreaks of diseases, including diarrhea, cholera, dengue, malaria, and respiratory tract infections, putting additional strain on local health services. High temperatures also drive vector-borne diseases such as dengue (WHO, 2024).

B. Hazard-Specific Analysis

As mentioned above, Cambodia experiences nearly all types of hydrometeorological hazards, including floods, droughts, heavy storms, typhoons, and lightning strikes. In addition, disease outbreaks (such as cholera, malaria, and dengue), fires, technological hazards, and climate change impacts can trigger disasters (UNDRR, 2019). Floods and droughts are recognized by the RGC as major drivers of poverty (WB, 2024).

a. Flood

There are significant risks associated with flooding in Cambodia. Flooding occurs frequently during the wettest months of the monsoon season, from July to October. These are often caused by prolonged or intense rainfall, rising river levels, and inadequate or obstructed drainage systems. According to data from the International Disaster Database, there were 20 significant floods between 2000 and 2024 that affected over 11 million people and resulted in damages of USD 1.2 billion (WB, 2024). In 2022, 16 out of 25 provinces experienced floods by August (WB, 2023).

Floods are particularly dangerous in heavily populated urban areas like Phnom Penh, as they can lead to costly infrastructure damage, fatalities, and loss of livelihoods. In rural areas, the annual flooding of the Mekong River Delta, which occurs from August to November, is crucial for the livelihoods of farming and fishing communities in Cambodia. Thus, changes in flooding patterns due to climate change may adversely affect these livelihoods. Notably, flooding patterns are worsening (WB, 2023).

Approximately, 80 percent of Cambodia’s territory is covered by the Mekong River and Tonlé Sap basins, seasonal flooding is the most common and frequent emergency event in Cambodia. While the flooding does have a cumulative, beneficial impact on agriculture-based livelihoods as it increases soil moisture and fertility, floods also cause loss of lives, homes, and livelihoods in already fragile communities. Riverine flooding and flash flooding are the most common hazards, and major events occur approximately every five years (UNDRR, 2019).

b. Landslides and Riverbank Collapse

In Cambodia, landslides and riverbank collapses have resulted in fatalities and the destruction of homes and other infrastructure, including transportation, electricity, and health systems. Climate change is expected to increase the likelihood of landslides occurring. Landslides occur in areas with porous soil and high soil moisture content and usually follow prolonged heavy rainfall. The populations and built-up areas in Koh Kong, Battambang, and Kampong Chhnang are particularly exposed to landslide hazards (WB, 2023). According to GFDRR, the highest landslide risks are found in the provinces of Koh Kong and Pursat, indicating that these areas have rainfall patterns, terrain slope, geology, soil, land cover, and potentially earthquakes that make localized landslides a frequent hazard. In 2023, a significant flood in Pursat caused damage to 2,785 homes, eight highways, six sewers, and triggered six landslides (CDMRH, 2024).

Regarding riverbank collapse, approximately 86 percent of Cambodia’s total area lies within the Mekong River Basin (Tha et al., 2024). Riverbank collapse along the Mekong occurs with some frequency and damages homes. Human activity, such as sand dredging, is contributing to riverbank erosion and riverbank collapse (ODC, 2023).

c. Sea-level Rise

While Cambodia has limited coastline, increasing sea levels pose a concern to coastal towns. Sea-level anomalies of 200 mm are evident in CCKP data from 1993 to 2015, with maximum elevations of 250 mm noted close to Koh Kong's shore. According to the 2014, Cambodia Climate Change Strategic Plan (CCCSP), sea levels are expected to increase by more than half a meter by 2090, which might submerge 25,000 hectares (ha) of land and cause thousands of people to evacuate. Sea-level rises might imperil marine coastal communities already facing storm surges, high tides, beach erosion, and seawater intrusion. Low-lying places, such as towns, seaports, beach resorts, coastal fisheries, and mangrove forests, may be impacted by this (WB, 2023).

As indicated in Part I, in coastal regions such as Koh Kong, Preah Sihanouk, Kampot, and Kep, exposure to sea-level rise leads to coastal erosion, saltwater intrusion, and ecosystem damage. Human activities like unregulated development, excessive sand mining, and deforestation worsen coastal erosion by weakening natural defenses. Rising sea levels increase the frequency and severity of coastal flooding from storm surges and high tides, while coastal land loss is evident, as seen in Botum Sakor district’s 10.1 percent area reduction in the early 1990s. Saltwater intrusion threatens freshwater supplies, harming agriculture and livelihoods, while coastal ecosystems such as mangroves, coral reefs, seagrass beds—of which Cambodia has about 33,814 hectares with only 11 percent managed—in key provinces are under increasing threat. Socio-economic impacts are profound, as fisheries and agriculture-dependent communities face challenges from ecosystem degradation and reduced freshwater availability due to altered rainfall patterns, increased droughts, and groundwater depletion, with Koh Kong province notably at risk of worsening saltwater intrusion and freshwater stress.

d. Drought

In Cambodia, drought is characterized by loss of water sources that coincides with the early end or delayed start of rainy season rainfall. The southeastern regions of the country, particularly Pailin, are the most exposed to drought driven by rainfall variability. According to drought impact reports in Cambodia during the period 1980-2019, there were drought events in almost every year. Phnom Penh, Svay Rieng, Prey Veng, and Pailin are severely affected every 5-6 years, with more than 30 percent of cropland experiencing drought stress (WB, 2023). One of the most drought-prone regions in the nation is Svay Rieng, which has suffered financial losses from crop failure, medical issues, and environmental harm. In the Tonle Sap Lake region, a drought in 2019 destroyed over 70,000 hectares of rice fields which impacted the national food supply. In total, there were four significant droughts that impacted about 4 million people in Cambodia between 2000 and 2024 (WB, 2023).

e. Extreme Heat Weather Events

Cambodia already experiences high temperatures, with 64 days per year when the maximum temperature surpasses 35°C. It is expected that under all future climate scenarios, the number of days with a heat index over 35°C will rise. According to Thirumalai et al. (2017), The El Niño Southern Oscillation (ENSO) contributed 49 percent of the extreme temperatures that occurred in April 2016 in Southeast Asia, whereas climate change was responsible for 29 percent of the same temperatures. Additionally, the increased frequency and intensity of heat waves has been noted recently (UNICEFF, 2022). The region saw a strong El Niño event in 2015–2016, which contributed to the worst drought Cambodia has seen in 50 years, with temperatures reaching an all-time high of 42.6°C. Higher temperatures and humidity values will result in increased heat stress, which will regularly surpass safe levels for humans and biodiversity (WB and ADB, 2021).

f. Wildfire

Many areas in Cambodia are thought to be highly vulnerable to wildfires, and predicted drops in precipitation and increases in rainfall unpredictability may make matters worse. The majority of Cambodian regions outside of the southwest are classified as "in very high danger" by the Fire Weather Index (FWI), while some parts are classified as "in extreme danger." The forested area surrounding the Tonle Sap Lake witnessed lower water levels between April 1 and July 1, 2021, and 45 high-confidence fire alerts were issued there, based on National Aeronautics and Space Administration (NASA) satellite data. Due to the common practice of swidden or slash-and-burn agriculture in Southeast Asia, where small-scale subsistence farmers start fires in forested regions, increasing the risk of forest fires, Cambodia's forests have drastically diminished in recent decades (NASA, 2018). Moreover, as temperatures increase, the risk of forest fire rises, which can significantly disrupt people’s daily lives. The Department of Forestry and Environmental Science at Prek Leap National Institute of Agriculture (PLNIA) is implementing a five-year project (2023–2027) titled “Collaborative Forest Landscape Governance Towards a Resilient and Sustainable Future.” This initiative is a joint effort among four countries—Cambodia, Thailand, Indonesia, and the Philippines, with the Philippines serving as the lead country. As part of the project’s activities, focus group discussions (FGDs) were conducted in 2024 with diverse stakeholders, including local authorities, community members, and representatives from both national levels and sub-national within the forestry and environment sectors. These discussions, held in the Tonle Sap Watershed area of Baribour District, Kampong Chhnang Province, revealed significant challenges facing the region. Participants reported that forest and flooded forest fires have led to habitat loss for people, health problems, reduced incomes, and negative impacts on both animal habitats and fish populations in the Tonle Sap zone. In addition to fire, the area is also affected by floods and droughts. Flooding has resulted in the loss of people's homes and environmental degradation, while drought has contributed to health issues, water shortages, illnesses among livestock, disruptions to the food chain, and decreased income for local residents. The main causes of wildfire are human activities combined with the hot and dry weather which is the consequence of climate change (IFAW, 2024). These include swidden or slash-and-burn agriculture, farmers setting fires in the dry season in open lands close to forests to promote grass growth to feeding cattle, setting of fires underneath Dipterocarp trees to obtain higher yield of resin, setting of fires to trap wildlife during poaching or chase away bees to collect honey, and fires causes by carelessly discarded lit cigarettes or cooking fires left unattended.

g. Cyclones and Tropical Storms

In Cambodia, cyclones constitute a persistent climatic threat; increased rainfall and predicted wind speeds could make the population and infrastructure more vulnerable. In the past, residences, public infrastructure, crops, and cattle have all suffered losses due to cyclones and tropical storms, which have also resulted in injuries and deaths. The country-wide cyclone risk is classified as "high" by the Global Facility for Disaster Reduction and Recovery (GFDRR), with the exception of the provinces of Preah Sihanouk, Kampong Speu, and Kampong Chhnang, which are classified as medium risk. A 20 percent probability of potentially harmful wind speeds throughout the following ten years is classified as high danger. Eight storms overall between 2000 and 2023 were registered in the International Disaster Database, with about 1 million people affected.

More particularly, the 2009 Ketsana and 2013 Haiyan typhoons affected lives and livelihoods in Cambodia. Notably, the Ketsana Typhoon caused USD 132 million in economic damage and affected about 1.4 percent of the population of Cambodia. The Mekong River's water level rose by 0.5 m in April 2022 as a result of an extraordinary rainfall event that occurred during the dry season, according to a study released by the National Committee for Disaster Management (NCDM). More storms in June 2022 led to flooding, severely damaging homes and farmland in the Sre Russey Commune, Thala Parivat District, Stung Treng province. Tropical cyclones strike Cambodia six times every year on average. They have been known to deliver death and destruction, especially in Svay Rieng and Kampot where 230 hectares of agricultural land is considered highly exposed to annual cyclonic storms (WB, 2023).

1.4.4 Future Exposure and Sensitivities

Cambodia is highly vulnerable to climate change, facing significant exposure and sensitivity due to its geographical and socio-economic conditions. The country ranks among the most affected globally, with various assessments highlighting its susceptibility to climate-related risks. Projections indicate that Cambodia could experience a temperature increase of approximately 3.1°C by the 2090s under high emissions scenarios. This rise will likely lead to more extreme heat days, significantly impacting outdoor laborers and urban populations (WB, 2024). Additionally, the frequency of extreme weather events is expected to increase, with projections suggesting that millions more people will be exposed to river flooding by the 2040s if no action is taken (WB and ADB, 2021).

A. Sector-Specific Analysis

Future exposures and sensitivities in many sectors are similar to the current exposures and sensitives mentioned above. The primary future exposure-sensitivity will be floods and droughts that significantly affect key sectors in Cambodia, including ecosystems and biodiversity; freshwater resources; coastal systems and low-lying areas; agriculture, fisheries, livestock; and human health.

a. Ecosystem and Biodiversity

Cambodia's ecosystems and biodiversity are highly exposed and sensitive to future climate change impacts, including rising temperatures, altered flood regimes, and coastal degradation. These changes threaten ecosystem services, species diversity, and the livelihoods of communities dependent on natural resources. Adaptation strategies focusing on ecosystem-based approaches and sustainable management of natural resources are critical to enhancing resilience (GSSD, 2017; WB and ADB, 2021) Climate change will exacerbate forest degradation through increased erosion from heavy rainfall and altered soil water availability, directly affecting forest productivity. This degradation not only impacts biodiversity but also diminishes the ecosystem services that forests provide (NBSAP, 2016). In coastal zones, increasing habitat stressors, such as salinity intrusion, will threaten marine and coastal biodiversity (NBSAP, 2016) For example, Kep province is increasingly exposed to climate-related risks, including sea-level rise and saline intrusion, which degrade mangrove forests and marine biodiversity. These ecosystems provide crucial services for environmental protection and community livelihoods but are vulnerable to climate-induced changes (NCSD, 2020). Moreover, Cambodia's biodiversity hotspots, including protected areas like Kep National Park, face risks from climate variability and extreme events. The degradation of habitats due to changing climate conditions threatens species diversity and ecosystem resilience (NCSD, 2020).

b. Freshwater Resources

Changes in rainfall patterns and increased evaporation rates due to higher temperatures will affect water availability in Cambodia. This will complicate the management of water resources critical for agriculture and human consumption, further stressing ecosystems that depend on stable water conditions (NCSD, 2017). Climate change is projected to intensify the frequency and severity of extreme weather events, including floods and droughts, which are already prevalent in Cambodia. This variability leads to too much water during the wet season and insufficient supply during the dry season, complicating water management efforts (NCSD, 2019; Sam and Pech, 2015). Moreover, predictions indicate that climate change will alter the hydrological regime of the Mekong River and Tonle Sap, which are crucial for agriculture and fisheries. For instance, there may be changes in seasonal rainfall distribution, with longer dry seasons and shorter, more intense wet seasons likely causing higher drought risks in agricultural areas (UNDP, 2019).

According to the data from Part I, from 1979 to 2023, Cambodia experienced significant variability in seasonal rainfall distribution, with increases in some areas like the western highlands and coastal plain and decreases or mixed trends in regions such as the eastern highlands and plains, indicating a shift toward more irregular rainfall patterns. These changes coincided with documented droughts linked to El Niño events, causing severe agricultural damage, food, and water shortages. Notably, prolonged droughts lasting over 12 months impacted multiple provinces, including vital agricultural zones, with the 2016 El Niño-related drought affecting 18 provinces and 2.5 million people. Additionally, trends in rainfall extremes show increasing lengths of consecutive dry days alongside stronger single-day precipitation events in certain locations, resulting in water scarcity during extended dry periods and intensified flooding during wet seasons, thereby elevating drought risks for agriculture dependent on consistent rainfall.

c. Coastal Zones and Low-lying Areas

Coastal regions are projected to experience a sea-level rise of more than half a meter by 2090, which could inundate approximately 25,000 hectares and displace thousands of residents (WB, 2024). The northernmost coastal areas are particularly at risk from storm surges associated with cyclones and tsunamis, although the overall exposure is lower compared to other Southeast Asian nations (WB and ADB, 2021). Recent La Niña events have resulted in widespread flooding, exacerbating vulnerabilities in these regions (ADB, 2021).

d. Agriculture, Fisheries, and Livestock

The Projections indicate increased temperatures and altered precipitation patterns, leading to more frequent and intense flooding and droughts. This will lead to impacts on the agricultural, fisheries, and livestock sectors, which will likely impact food security.

By 2050, agricultural areas are projected to experience higher risks of droughts and floods, severely affecting crop productivity and leading to substantial economic losses, with GDP reduction of nearly 10 percent (ADB, 2021). For instance, wet season rice yields could decrease by up to 70 percent under high emission scenarios, while dry season rice yields may drop by 40 percent (NCSD, 2017).

Regarding the fishery sector, changes in the Mekong River's hydrology due to climate change can lead to boom-and-bust cycles in fish catch. This variability threatens the stability of fish populations, with some years yielding high catches followed by severe shortages (World Fish, 2012). The expected increase in droughts and floods further complicates this situation, affecting both capture fisheries and aquaculture (Wessling, 2020).

Similarly, for the livestock, projections suggest that average temperatures in Cambodia could rise by approximately 3.1°C by the 2090s under high emissions scenarios, which will exacerbate heat stress in livestock, leading to higher susceptibility to diseases and reduced productivity (ADB, 2022).

e. Human Health

With rising temperatures and an increase in extreme weather events such as floods, droughts, and heatwaves affecting health outcomes, these changes have led to a rise in climate-sensitive diseases, including:

- Vector-borne diseases: Diseases like malaria and dengue fever are expected to increase due to changing rainfall patterns and higher temperatures, which affect the breeding cycles of disease-carrying insects (WHO, 2021; WB, 2024).
- Waterborne diseases: Flooding and heavy rainfall can contaminate water supplies, leading to outbreaks of diseases such as cholera and diarrhea (WB, 2024).
- Malnutrition: Climate-related disruptions in agriculture threaten food security, contributing to malnutrition, particularly among children (WB, 2024).

The Cambodian health system is already under strain due to these climate impacts, which exacerbate existing vulnerabilities such as poverty and inadequate healthcare infrastructure (Ministry of Health, 2019). Future projections indicate that without adequate intervention, the incidence of climate-sensitive diseases could rise significantly. For instance, diarrheal disease incidence among children may increase by up to 19 percent due to climate change impacts. The number of high heat index days is expected to rise dramatically, posing additional risks for heat-related illnesses among outdoor laborers and urban populations (WB, 2024).

B. Hazard-Specific Analysis

According to IPCC AR6, rising sea levels, heat waves and the frequency and severity of flooding are all expected to increase with climate change. The IPCC uses Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) are two types of scenarios used in climate change research to project future climate outcomes and socio-economic conditions. RCPs are climate scenarios that describe possible trajectories of greenhouse gas concentrations in the atmosphere. Each RCP is named after its level of radiative forcing (measured in watts per square meter, W/m^2) expected by the year 2100. SSPs are narratives describing different plausible socio-economic futures that influence greenhouse gas emissions and climate change. They incorporate factors such as population growth, economic development, technology, governance, and environmental policies. There are five main SSPs: SSP1 (a sustainable development pathway with low challenges to mitigation and adaptation), SSP2 (middle-of-the-road development), and SSP3 (a fragmented world with regional rivalry and high challenges).

According to climate projections, heat stress in Cambodia is expected to drastically worsen. Daily average temperatures will increase by 0.9–1.7 degrees Celsius under RCP2.6–8.5 scenarios by 2040–2059 when compared to the baseline of 1986–2005 (WB and ADB, 2021). Under various scenarios, the predicted number of days with a Wet Bulb Global Temperature—a measure of heat and humidity combined—above 30°C might rise by about 4–7 percent by the middle of the century. Drought estimates are still highly uncertain, but the risk profile's emissions pathways all show an increase in the median yearly probability of droughts from 4 percent to 9 percent (WB and ADB, 2021).

a. Flood and Landslide

Climate forecasts suggest that the intensity of precipitation events will rise, including rainfall exceeding 10 mm, maximum five-day precipitation, and extreme wet-day precipitation (MIMURA, 2013). Therefore, rainfall in Cambodia may become more erratic, increasing the risk of floods and landslides. The average biggest one-day precipitation is anticipated to reach over 100 mm during October in Kep (97.4 mm) and Kampot (95.3 mm) by 2020–2039 under the SSP3-7.0 scenario, which is a signal of both a flood danger and landslide risk. The five-day cumulative rainfall indicator can also be used to identify places that are saturated with water, which raises the risk of landslides and flooding due to the gradual loss of slope stability. In September in Pailin, the maximum five-day total rainfall is expected to reach more than 243 mm on average by 2020–2039 and 267 mm by 2040–2059 (WB, 2024). Sea level rise may also have profound effects along Cambodia's coastlines, particularly in the provinces of Koh Kong and Preah Sihanouk. With sea levels expected to increase by at least 19 cm in all climate change scenarios by the middle of the century, this region is most at risk. Under high-emission scenarios, sea levels might rise by 40 to 80 cm.

b. Drought

Variability in rainfall causes frequent droughts in Cambodia, with more than 30 percent of cropland experiencing drought stress every five-to-six years in the most exposed provinces (Phnom Penh, Svay Rieng, Prey Veng and Pailin) (WB, 2023). Future fluctuations in precipitation, as indicated by drought estimates, could further undermine Cambodia's food systems. The high humidity in Cambodia, combined with expected increases in rainfall variability, will affect the Standard Precipitation Evapotranspiration Index (SPEI), which predicts slightly positive values in the future and a positive water balance (indicating wetter conditions), particularly in the northwest region.

c. Cyclones and Tropical Storms

Projections indicate that the frequency and intensity of tropical cyclones affecting Cambodia may rise in the coming decades. Research suggests that areas along the Cambodian coastline could experience storm surges and extreme weather conditions previously unseen, driven by shifts in cyclone tracks and increased sea temperatures (Wood et al., 2023). In Cambodia, rising sea surface temperatures—specifically those exceeding 28.2°C—are linked to a higher occurrence of super storms, greater cyclone intensity, and consequently, increased damage (WB, 2024). Moreover, by 2050, sections of Cambodia's coastline are expected to see a dramatic increase in exposure to storm surge levels of 2.5 meters or greater. This poses significant risks to low-lying coastal communities, necessitating urgent adaptations in coastal flood management strategies (Wood et al., 2023).

1.5 Current and Future Vulnerabilities

Current vulnerability refers to the known risks based on current climate variability, while future vulnerability refers to the potential and known risks based on climatic changes. Both types of vulnerability assessments are important for understanding the magnitude and distribution of potential impacts and for identifying appropriate adaptation measures (Adom, 2024).

According to the Climate Modeling Report in 2016, the mean monthly temperature in Cambodia is expected to rise by 0.013^{o}C to 0.036^{o}C year by 2099, depending on the location, with higher rates at low latitudes. This tendency is consistent with the country's historical trend of rising temperatures (WB and ADB, 2021; WB, 2024). A rise in temperature will likely impact agricultural output. The International Rice Research Institute states that for every degree Celsius increase in the growing-season minimum (night) temperature during the dry season, rice yield decreased by 10 percent (WB and ADB, 2021). Mekong Adaptation and Resilience to Climate Change (Mekong ARCC) showed that during the rainy season, rainfall will increase in higher elevation regions, but during the dry season, it will decrease. This could negatively impact Cambodia's coffee and rubber industries (ADB, 2021).

Even if temperature increases stay within the 2°C threshold, the Ministry of Economy and Finance and the National Council for Sustainable Development project that the effects of climate change might lower Cambodia's projected GDP by over 10 percent by 2050 (United Nation Cambodia, 2021). As a result of shifting and less predictable rainfall patterns, extreme weather events including tropical storms, floods, and droughts are becoming more often and severe. The industries most affected include forests, infrastructure, agriculture, and human health. The most vulnerable - children, women, individuals with disabilities, the elderly, and socially marginalized groups, such as migratory communities, will be the most affected (WHO, 2024).

1.5.1 Future Vulnerability of Ecosystem

The past, present, and future development of human society will have a significant impact on how vulnerable ecosystems are to climate change in the future. These factors include overall unsustainable production and consumption, growing demographic pressures, and ongoing unsustainable use and management of land, ocean, and water resources (IPCC, 2022). The future vulnerability of ecosystems will likely manifest through:

- Increased rates of species extinction as habitat loss accelerates;
- Greater instability in ecosystem services due to climate-induced changes; and
- A shift in species composition and functional types within ecosystems as they respond to changing environmental conditions.

In summary, the future vulnerability of ecosystems is a complex interplay of climate change, land use alterations, and nutrient loading. Effective assessments of ecological vulnerability are crucial for prioritizing conservation actions and mitigating adverse impacts on biodiversity and ecosystem services.

1.5.2 Future Vulnerability in Cambodia

Cambodia faces significant vulnerabilities due to climate change, with various provinces experiencing different degrees of risk. The following sections outline the key factors contributing to vulnerability across several regions. The CVAA project (The Climate Vulnerability and Adaptation Assessment project) was a comprehensive climate vulnerability and adaptation study conducted by a multidisciplinary team led by Geoff Wright under NIRAS and UrbanLogic. Using climate models, hydrological data, existing plans, and strong stakeholder engagement, the project assessed climate risks for four Cambodian cities (Battambang, Kampot, Kratie, and Chhlong) and proposed context-specific, multi-sectoral adaptation options. These options are intended to integrate with broader urban development projects, strengthening institutional capacity and resilience while also promoting sustainable urban growth. The CVAA study indicated the result of future climate vulnerability and risk in four areas, Battambang, Kampot, Kratie, and Chhlong (Wright, 2020). The section below outlines those vulnerabilities and risks.

a. Battambang

The Climate Vulnerability and Adaptation Assessment project indicates that under the RCP 2.6 scenario, Battambang's climate is expected to remain relatively stable from 2019 to 2050, meaning that natural hazards like floods and droughts are unlikely to worsen significantly. Conversely, in the RCP 8.5 scenario, both the average maximum and minimum temperatures are projected to increase by approximately 1.6 degrees Celsius, rising from 23.6 to 25.2 degrees Celsius. Additionally, annual rainfall is anticipated to grow from 1,318 mm in 2019 to 1,619 mm by 2050, leading to more frequent and intense droughts and floods. The study concludes that climate change will primarily expose Battambang to risks such as flooding and riverbank erosion (Wright, 2020).

Table 1: Hazard-vulnerability-risk analysis for Battambang.

Hazard	Δ Impact		Vulnerability	Risk	
	RCP 2.6	RCP 8.5		RCP 2.6	RCP 8.5

Primary hazard					
Flood	Low	Hight	Medium	Medium	High
Typhoon	Nil	Low	Medium	Nil	Low
Storm Surge	Nil	Nil	Nil	Nil	Nil
Sea Level Rise	Nil	Nil	Nil	Nil	Nil
Droughts	Low	Medium	Medium	Low	Medium
Fires	Low	Low	Medium	Low	Low
Secondary hazards					
Water shortages	Low	Medium	Medium	Low	Medium
Food shortages	Low	Low	Medium	Low	Low
Health problems	Low	Medium	Medium	Low	Medium
Riverbank erosion	Low	Medium	High	Medium	High

Source: (Wright, 2020)

b. Kampot

Table 2: Hazard-vulnerability risk analysis for Kampot.

Hazard	Δ Impact		Vulnerability	Risk	
	RCP 2.6	RCP 8.5		RCP 2.6	RCP 8.5
Primary hazard					
Flood	Medium	High	Medium	Medium	High
Typhoon	Nil	Low	Medium	Nil	Low
Storm Surge	Low	High	High	Medium	Extreme
Sea Level Rise	Medium	High	High	High	Extreme
Droughts	Low	Medium	Medium	Low	Medium
Fires	Low	Low	Medium	Low	Low
Secondary hazards					
Water shortages	Low	Medium	Medium	Low	Medium
Food shortages	Low	Low	Medium	Low	Low
Health problems	Low	Medium	Medium	Low	Medium
Riverbank erosion	Low	Medium	Medium	Low	Medium

Source: (Wright, 2020)

The RCP 2.6 scenario from the climate change vulnerability and adaptation assessment project indicates that Kampot Town's climate is not expected to undergo significant changes from 2019 to 2050, suggesting that natural hazards such as droughts and floods will not substantially worsen. In contrast, the RCP 8.5 scenario forecasts notable increases in both rainfall and temperature for Kampot during the same period. Specifically, the average maximum temperature is anticipated to rise by 1.5°C, increasing from 31.3°C to 32.8°C. By 2050, average annual rainfall is projected to exceed 250 mm, rising from 2502 mm to 2750 mm. These climatic shifts could result in more frequent and intense monsoon storms and flooding along the Gulf of Thailand and Cambodia's coastline. Additionally, global sea levels are also expected to rise (Wright, 2020).

c. Kratie

The RCP 2.6 scenario from the Climate Vulnerability and Adaptation Assessment project indicates that Kratie Town's climate is expected to remain relatively stable from 2019 to 2050, suggesting that natural disasters such as droughts and floods will not significantly intensify. In contrast, the RCP 8.5 scenario predicts an increase in the average maximum temperature by about 1.7°C (from 33.2°C to 34.9°C) and a rise in the average minimum temperature by approximately 1.5°C (from 23.5°C to 25.0°C). Annual rainfall is projected to increase from 1684 mm in 2019 to 1884 mm by 2050, which is likely to lead to more frequent and severe flooding and drought conditions. The analysis concludes that flooding poses the greatest risk influenced by climate change in Kratie (Wright, 2020).

Table 3: Hazard-vulnerability-risk analysis for Kratie.

Hazard	Δ Impact		Vulnerability	Risk	
	RCP 2.6	RCP 8.5		RCP 2.6	RCP 8.5
Primary hazard					
Flood	Medium	High	Medium	Medium	High
Typhoon	Low	Medium	Medium	Low	Medium
Storm Surge	Nil	Nil	Nil	Nil	Nil
Sea Level Rise	Nil	Nil	Nil	Nil	Nil
Droughts	Low	High	Low	Low	Medium
Fires	Low	Low	Medium	Low	Low
Secondary hazards					
Water shortages	Low	Medium	Medium	Low	Medium
Food shortages	Low	Low	Medium	Low	Low
Health problems	Low	Medium	Medium	Low	Medium
Riverbank erosion	Medium	High	Medium	Medium	High

Source: (Wright, 2020)

d. Chhlong

The Climate Vulnerability and Adaptation Assessment project, utilizing RCP 2.6 and RCP 8.5 scenarios, revealed that the geographical closeness of Chhlong and Kratie, along with the impacts of climate-related hazards, leads to similar climate change predictions for both towns. However, Chhlong, being smaller in size, is evaluated to be more susceptible to certain secondary effects. As a result, in various scenarios, Chhlong may face more severe hazards. Additionally, due to its lower population density compared to Kratie, the projected increase in average maximum temperatures for Chhlong is likely to be less significant (Wright, 2020).

Table 4: Hazard-vulnerability-risk analysis for Chhlong.

Hazard	Δ Impact		Vulnerability	Risk	
	RCP 2.6	RCP 8.5		RCP 2.6	RCP 8.5
Primary hazard					
Flood	Low	High	High	Low	Extreme
Typhoon	Low	Medium	Medium	Low	Medium
Storm Surge	Nil	Nil	Nil	Nil	Nil
Sea Level Rise	Nil	Nil	Nil	Nil	Nil
Droughts	Low	Medium	Medium	Low	Medium
Fires	Low	Low	Low	Low	Low
Secondary hazards					
Water shortages	Low	Medium	Medium	Low	Medium
Food shortages	Low	Low	High	Low	Medium
Health problems	Low	Medium	Medium	Low	Medium
Riverbank erosion	Low	Medium	High	Low	High

Source: (Wright, 2020)

In overall, the future vulnerabilities of provinces around Cambodia are closely tied to their geographic characteristics, socioeconomic conditions, and the anticipated impacts of climate change. Addressing these vulnerabilities requires comprehensive adaptation strategies that consider both environmental and social factors to enhance resilience among affected populations.

1.6 Adaptation

The world is already experiencing changes in average temperature, shifts in the seasons, an increasing frequency of extreme weather events, and slow onset events. A slow onset event is an environmental or climate-related phenomenon that develops gradually over an extended period and can cause progressive changes that accumulate severe, often irreversible impacts on ecosystems and human systems. Sea level rise is a prime example where ocean levels gradually increase over decades due to climate change, threatening coastal ecosystems and human settlements. The faster the climate changes and the longer adaptation efforts are put off, the more difficult and expensive responding to climate change will be. Adaptation refers to actions taken at the individual, local, regional, and national levels to reduce risks from today's changed climate conditions and to prepare for impacts from additional changes projected for the future (Wuebbles et al., 2017).

Adaptation measures can vary widely based on the specific circumstances of a community, business, organization, country, or region. There is no uniform solution; adaptation strategies may include constructing flood barriers, implementing early warning systems for cyclones, transitioning to drought-resistant agricultural practices, and rethinking communication frameworks, business processes, and government policies. Numerous nations and communities are already making efforts to create resilient societies and economies. Nevertheless, increased action and ambition are essential to effectively manage risks both now and in the future (UNFCCC, 2019).

Successful adaptation relies not only on government initiatives but also on the ongoing and active involvement of various stakeholders. This includes local communities, national and regional bodies, multilateral and international organizations, as well as the public and private sectors, civil society, and other relevant participants. Additionally, effective knowledge management is crucial. The parties involved in the UNFCCC and the Paris Agreement acknowledge that adaptation presents a global challenge that encompasses local, subnational, national, regional, and international aspects (UNFCCC, 2022).

1.6.1 Adaptation Strategies

In 2023, the World Bank reported that many adaptation strategies must be implemented at the local level, making rural communities and cities essential players in this process (WB, 2023). These strategies include adopting regenerative agriculture and cultivating drought-tolerant crop varieties, improving water storage and utilization, managing land to reduce the risk of wildfires, and strengthening defenses against extreme weather events such as floods and heat waves (UNDP, 2024). Climate projections indicate that Cambodia's vulnerability to heat stress and flooding may worsen in the future. In the absence of appropriate adaptation and mitigation strategies, the effects of climate change may result in a reduction of Cambodia's GDP by 9 percent by 2050 and raise the country's poverty rate by up to 6 percent by 2040 (WB, 2023). Agriculture, water resources, coastal zones, infrastructure, ecology and forestry, and human health are priority sectors that are most vulnerable to climate change. Adaptation measures must be more specifically targeted towards communities and locations that are not receiving protection or services in order to decrease susceptibility to climate change.

Estimates based on models including Integrated Assessment Models (IAMS), Computable General Equilibrium Models (CGE), Partial Equilibrium Models (PE), Structural an Statistical Models and Meta Analysis, indicated that well-designed adaptation strategies could prevent at least half of the potential GDP losses due to climate change (IPCC-AR6; Dwortzan, 2025). Climate adaptation refers to adjusting systems, practices, and policies to reduce potential damage or take advantage of opportunities arising from climate change (UNFCCC, 2022). Although these adaptation measures can help reduce many of the negative effects of climate change, they cannot entirely reverse its far-reaching impacts. Both the public and private sectors can adopt various strategies from this Country Climate and Development Report (CCDR) to lessen the consequences of climate change.

1.6.2 Global Goal on Adaptation

The Global Goal on Adaptation (GGA) in the Paris Agreement aims to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change, within the broader goal to limit global average temperature increase to well below 2^{o}C (Hussein, 2024).

As different regions experience climate change differently as a result of differences in factors like geography, economic resources, infrastructure, social conditions, health, and capacity to adapt, the GGA is meant to enable adaptation actions that are timely, scalable, and specific and encourage solutions that consider both local contexts and the particular needs of vulnerable people.

The GGA aims to address this shortfall by providing a clear framework and targets that can guide global adaptation efforts and enhance support for adaptation in developing nations (Hussein, 2024). The GGA framework includes 11 global targets to be achieved by 2030. Seven of these targets focus on adaptation action in specific areas: water, health, biodiversity, food, infrastructure, poverty, and heritage. The remaining four targets address the adaptation cycle: climate risk and vulnerability assessments, planning, implementation, monitoring, evaluation and learning. These four targets for the adaptation cycle include:

- Impact, vulnerability and risk assessment: By 2030, all Parties will have conducted assessments of climate hazards, climate change impacts, and exposure to risks and vulnerabilities, using the results to inform their national adaptation plans, policy instruments, and planning processes and/or strategies. Furthermore, by 2027, all Parties will have established systemic observation to gather climate data, as well as multi-hazard early warning systems and climate information services to support risk reduction.
- Planning: By 2030, all Parties will have developed country-driven, gender-responsive, participatory, and fully transparent national adaptation plans, policy instruments, and planning processes, and have integrated adaptation into all relevant strategies and plans.
- Implementation: By 2030, all Parties will have made progress in implementing their national adaptation plans, policies, and strategies, and will have reduced the social and economic impacts of key climate hazards.

- Monitoring, evaluation and learning (MEL): By 2030, all Parties will have designed, established, and operationalized systems for monitoring, evaluation, and learning for their national adaptation efforts, and will have built institutional capacity to fully implement these systems.

1.6.3 Adaptation in Cambodia

The Royal Government of Cambodia is committed to combating climate change and advancing a climate-resilient, low-carbon, sustainable development path, and aspires to achieve net-zero emissions by 2050. As a party to the United Nations Framework Convention on Climate Change, Cambodia ratified the Paris Agreement and outlined Nationally Determined Contributions (NDCs) that set mitigation targets, adaptation actions, and climate policies aligned with national priorities (USAID, 2024). In addition to the NDCs, Cambodia has a number of documents that address climate change adaptation, including Cambodia Climate Change Strategic Plan (CCCSP) 2024-2033, National Adaptation Plan Process in Cambodia, National Adaptation Plan: Communication Strategy, National Adaptation Plan Financing Framework and Implementation Plan, and Cambodia's Third National Communication, as well as the Master Plan on Gender and Climate Change (2018-2030).

Furthermore, Cambodia has implemented a sector-specific adaptation strategies, such as improving agricultural resilience, reforesting natural land, establishing home gardens, training farmers on climate forecasting, training farmers on how to plant paddies with more resilient varieties, supporting renewable energy generation and distribution, promoting energy efficiency measures, promoting climate-smart agricultural technologies, promoting low-carbon agro-processing, and promoting piped clean water infrastructure.

The Cambodia Climate Change Strategic Plan (CCCSP) 2014-2023, outlined 8 strategic objectives along with detailed strategies. The 8 strategic objectives are:

- Promote climate resilience through improving food, water, and energy security;
- Reduce vulnerability of sectors, regions, gender, and health to climate change impacts;
- Ensure climate resilience of critical ecosystems (Tonle Sap Lake, Mekong River, coastal ecosystems, highlands, etc.), biodiversity, protected areas, and cultural heritage sites;
- Promote low-carbon planning and technologies to support sustainable development of the country;
- Improve capacities, knowledge and awareness for climate change responses;
- Promote adaptive social protection and participatory approaches in reducing loss and damage;
- Strengthening institutions and coordination frameworks for national climate change responses; and
- Strengthen collaboration and active participation in regional and global climate change processes.

Adaptation measures often generate co-benefits. For example, in the long run, adaptation measures can reduce future vulnerabilities due to climate change and drought. Afforestation helps reduce land degradation and increases soil-water availability during drought and also creates a carbon sink that helps mitigate global warming. The implementation of adaptation measures requires services, knowledge, and resources, and therefore creates market opportunities for the providers. For example, the development of wastewater treatment infrastructure and transportation networks are required to facilitate the use of wastewater for agriculture during drought. By and large, the policies, measures and development activities taken toward drought adaptation can help achieve long-term sustainable development goals (UNDRR, 2020). For example, in the case of drought adaptation illustrating the benefit of adaptation action in three key dimensions of sustainable development. Drought adaptation can propel three dividends bringing about economic, social and environmental benefits, as shown in Figure 3 (Tanner et al., 2015). Adaptation measures not only help avoid losses caused by drought, proving to be economically beneficial in the short-term, but enhance resilience and future risk reduction, long-term benefits which are reflected in the social and environmental sectors.

Figure 3: Triple Dividends: Economic, Social and Environmental Benefits of Drought.
Source: (WRI, 2022)

1.6.4 Challenges and Gaps

Despite the progress, several challenges remain in addressing climate change in Cambodia:

- **Limited Financial Resources:** Securing sufficient funding, especially in rural areas, remains a significant challenge for implementing large-scale adaptation measures.
- **Capacity and Knowledge Gaps:** Additional capacity building is needed at the local level to ensure communities can effectively adopt and maintain adaptation measures.

- **Coordination Across Agencies:** Enhanced coordination among government agencies and sectors is essential for a more unified and integrated approach to climate adaptation.
- **Monitoring and Evaluation:** Robust systems are required to monitor and evaluate the effectiveness of adaptation plans and policies.

The fourth Study on Understanding Public Perceptions of Climate Change in Cambodia (KAP4) presents comprehensive findings on Cambodians' knowledge, attitudes, and practices regarding climate change (NCSD and MoE, 2024). The key findings can be summarized as follows:

Box 1.1: Key findings on climate change knowledge, attitudes, and practices based on a recent study (KAP4) of NCSD and MoE (NCSD and MoE, 2024)

1. Perceptions of Climate Change and Environmental Changes

- Most Cambodians perceive that climate change is happening in Cambodia, with noticeable changes in weather patterns, natural resources, and the environment. There is widespread recognition of resource availability changes, such as water and forest resources declining or being degraded.
- Loss of trees is the most commonly perceived driver of climate change, indicating strong awareness of deforestation's role in environmental degradation.

2. Knowledge and Awareness

- Familiarity with terms like "climate change" and "global warming" is relatively high among the population, reflecting growing public awareness.
- Despite this, understanding of the complex causes and impacts of climate change varies by region and educational attainment.

3. Attitudes Towards Climate Change

- Cambodians generally have a positive attitude towards addressing climate change, showing concern about its impacts on health, livelihoods, and natural resources.
- There is a willingness to engage in both individual and community actions to mitigate and adapt to climate change.

4. Practices and Adaptation Measures

- Moderate levels of preparedness for extreme weather events are reported, with many individuals and communities taking practical steps to respond to climate-related changes.
- Adaptation actions include changes in livelihoods and lifestyles, such as adjusting agricultural practices and managing water and food shortages.
- Community-level actions are increasingly common, with positive attitudes toward collective efforts to address environmental challenges.

5. Barriers and Enablers to Adaptation

- Key barriers to climate change adaptation include limited resources, lack of information, and infrastructural challenges.
- Enablers for adaptation include community engagement, access to information, and institutional support, which help facilitate adaptive actions.
- Gender roles and norms influence how individuals take action, with specific challenges and opportunities identified for women and men in climate adaptation.

6. Media and Communication

- Media consumption habits show that television, radio, and increasingly, mobile phones and the internet are important sources of information on climate change.
- Trusted and accessible communication channels are critical for raising awareness and promoting climate adaptation practices.

7. Socioeconomic Context

- Most Cambodians report improvements in their quality of life, with strong values placed on health and education, which are linked to environmental concerns.
- Income status and educational levels influence perceptions and responses to climate change, highlighting the need for targeted communication and support strategies.

8. Recommendations and Strategic Directions

- The study emphasizes the importance of enhancing public knowledge, strengthening community resilience, and improving institutional responses to climate change. It advocates for gender-sensitive approaches, better communication strategies, and multi-sectoral collaboration to support sustainable climate action in Cambodia.
- This study provides a detailed and nuanced understanding of how Cambodians perceive and respond to climate change, offering valuable insights for policymakers, practitioners, and stakeholders engaged in climate adaptation and sustainable development in Cambodia.

1.6.5 Recommendations

Based on the information and projections regarding current and future exposure, sensitivity, and vulnerability, Cambodia is facing and will continue to face rising temperatures, along with increased floods and droughts, which heavily impact priority sectors in Cambodia including ecosystems and biodiversity, freshwater resources, coastal systems and low-lying areas, agriculture, fisheries, livestock, and human health. Therefore, the government, private sector, and relevant technical institutions play a crucial role in addressing these impacts. Below are some key recommendations to reduce pressure and negative impacts caused by climate change:

a. Strengthening Agricultural Resilience

- **Diversification of Crops:** Encourage farmers to diversify their crops to reduce dependency on rain-fed rice, which is highly vulnerable to climate variability. This can help mitigate risks associated with droughts and floods.
- **Improving Irrigation Systems:** Rehabilitation of existing irrigation schemes is crucial, as nearly 80 percent currently require upgrades. Investment in efficient water management technologies can enhance resilience against changing rainfall patterns.
- **Climate-Smart Agriculture:** Implement practices that improve soil health and water retention, such as agroforestry and conservation tillage, to adapt to extreme weather events.

Strengthening agricultural resilience in Cambodia involves adapting farming practices and technologies to better withstand climate change impacts like droughts, floods, and erratic rainfall. This includes promoting climate-smart agriculture practices, diversifying crops, improving water management, and providing farmers with tools and support for accessing innovative financing and technologies. Box 1.2 provides examples relevant to agricultural practices to adapt to climate change in Cambodia and other countries in Asia.

Box 1.2: Case studies on strengthened agricultural resilience in Cambodia and other countries

- In 2024, the Prek Leap National Institute of Agriculture (PLNIA), in collaboration with the International Atomic Energy Agency (IAEA), launched a project aimed at improving cotton varieties to enhance resilience to climate change. The main objective of this initiative is to develop drought-tolerant, high-yield cotton seeds, which are essential for boosting domestic cotton production. This effort is particularly significant as Cambodia's textile industry is a cornerstone of the national economy, accounting for approximately 70 percent of total exports and playing a vital role in economic growth through the export of garment products (GIZ, 2022). By strengthening local cotton production, the project seeks to support the textile sector's raw material needs, reduce reliance on imports, and further solidify Cambodia's position as a prominent textile and apparel supplier in the global market.
- In Cambodia, the Meanchey Agricultural Service Cooperative (MASC) project has successfully promoted crop diversification among smallholder farmers. By introducing new

crops such as melons, yellow watermelon, bell peppers, cherry tomatoes, and onions, MASC helped members increase their incomes by 91 percent. This diversification reduced dependency on rain-fed rice and improved resilience to climate variability, while also expanding market opportunities and enhancing food security (Asian Farmers Association, 2024).

- In Haryana, India, farmers are reducing their reliance on water-intensive rice by shifting to crops like millets (bajra, jowar), pulses, mustard, maize, and potato. These alternatives require less irrigation, improve soil health, and offer better resilience to droughts and groundwater depletion. The transition is supported by targeted government schemes and market incentives (CGIAR, 2023).
- In Tramkak District, Takeo province, rice farmers reported adapting to climate change by altering crop cycles and constructing wetlands to manage irregular rainfall and water shortages. However, the study also highlighted the need for further improvements in irrigation infrastructure to support broader resilience (Born, 2021).
- In Cambodia, climate-smart agriculture practices have been implemented through projects that focus on soil health and water retention. For example, the use of cover crops, organic fertilizers, and improved pasture cropping for cattle has been promoted in cashew and pepper plantations. These practices, supported by training and demonstration plots, have reached over 200 farmers, including women and indigenous groups, and have shown positive impacts on soil fertility and resilience to extreme weather (CCCA3-Climate Smart Farming Project).
- Ecosystem-based adaptation strategies in rice farming, such as the Integrated Rice Resilience Model, have been piloted in Cambodia. These approaches combine climate-resilient rice varieties, eco-agriculture, and landscape restoration to create more sustainable and resilient rice production systems. The holistic approach addresses both agricultural productivity and the health of surrounding ecosystems, enhancing adaptation to climate extremes (United Nations Program, 2023).

b. Enhancing Water Resource Management

- **Integrated Water Resource Management (IWRM):** Develop comprehensive strategies that consider the interconnectedness of water resources, agriculture, and ecosystems. This includes managing the Mekong River and Tonle Sap Lake systems to balance agricultural needs with ecological sustainability.
- **Flood and Drought Management Plans:** Establish early warning systems and community-based disaster risk reduction plans to prepare for extreme weather events, ensuring that vulnerable populations have access to timely information and resources.

Enhancing water resource management in Cambodia involves strengthening existing institutions, updating policies, investing in infrastructure, and promoting collaboration, particularly with regional partners like China. The focus is on building resilience to climate change impacts, improving water supply, and supporting agricultural productivity. Box 1.3 illustrates examples to enhance water resource management in Cambodia. These examples illustrate Cambodia's ongoing commitment to integrated, climate-adaptive, and community-centered water resource management, particularly in the Mekong and Tonle Sap systems.

Box 1.3: Examples of enhanced water resource management in Cambodia

- Stung Sen Pilot Basin Project: The Stung Sen basin, the largest catchment of the Tonle Sap Lake, has served as a pilot for IWRM in Cambodia. This project addresses access to drinking water, water for agriculture (especially rice cultivation), and the management of flooding and drought. It involves building local capacity, creating inter-institutional river basin

- committees, and promoting stakeholder participation to ensure integrated and sustainable management of water resources (OiEau, 2023; INBO, 2024).
- Cambodia Integrated Water Resources Management Project (IWRMP): Supported by international partners like the Asian Development Bank and the Asian Infrastructure Investment Bank, this project targets the Pursat and Sangker River Basins. It aims to strengthen planning and coordination capacities, increase dry season irrigation water availability, and improve flood control and drainage facilities. The project's three main components are: (1) strengthening river basin management committees, (2) expanding irrigation infrastructure, and (3) reducing flood risks through better drainage and flood-control systems (ADB, 2024).
- Early Warning Systems and Community-Based Disaster Risk Reduction: The IWRMP includes the installation and upgrading of water monitoring stations and the development of flood and drought forecasting and warning systems. These systems are designed to provide timely information to vulnerable communities, enabling them to prepare for extreme weather events. Training for river basin committees and local authorities is also part of the project to ensure effective use and dissemination of early warning information (ADB, 2024).

c. Infrastructure Development

- **Resilient Infrastructure Standards:** Upgrade infrastructure, particularly in health and education sectors, to withstand climate impacts. This includes building flood-resistant roads and facilities that can endure extreme weather conditions.
- **Urban Planning:** Implement zoning regulations that prevent development in flood-prone areas, reducing the risk of displacement and economic loss during severe weather events.

Upgrading infrastructure to withstand climate impacts is increasingly critical, especially for vital sectors like health and education. Climate-resilient infrastructure is planned, designed, built, and operated to anticipate, prepare for, and adapt to changing climate conditions. Box 1.4 provides examples of resilient infrastructure development.

Box 1.4: Examples of resilient infrastructure development from other countries

- New York City's East Side Coastal Resiliency Project: The project is a major urban flood protection initiative designed to protect Manhattan's Lower East Side from coastal flooding and rising sea levels. It includes building flood-resistant barriers, elevating parks, and upgrading critical infrastructure to withstand future climate impacts. This project demonstrates how urban infrastructure, including public facilities and transportation networks, can be upgraded to meet new resilience standards in the face of extreme weather (Climate Adaptation Platform, 2024).
- Flood-Resistant Housing in Pakistan: Architect Yasmeen Lari's flood-resistant housing uses bamboo and elevated designs to protect against floodwaters. These affordable homes are built with local materials and designed to endure extreme weather, providing a model for resilient residential infrastructure in flood-prone regions (Morrison, 2025).
- China's Sponge Cities Initiative: Several Chinese cities have adopted the "sponge city" model, which integrates permeable pavements, green roofs, and rain gardens to absorb and reuse rainwater. This approach reduces urban flood risk, prevents waterlogging, and enhances groundwater recharge. It exemplifies how urban planning and zoning can be used to manage stormwater and prevent development in high-risk flood zones (Morrison, 2025).
- Gravity Smart Campus, Somerset, UK: This mixed-use development incorporates advanced drainage and water attenuation systems that exceed standard requirements, addressing future climate strain on infrastructure. The project's urban planning strategy includes zoning for biodiversity and sustainable energy, ensuring the site remains resilient to flooding and extreme weather events (Carluccio, 2023).

d. Promoting Sustainable Forestry and Land Use

- **Reforestation Initiatives:** Launch programs aimed at restoring degraded forests and enhancing biodiversity, which can help sequester carbon and protect watersheds.
- **Community Forestry Management:** Empower local communities to manage forest resources sustainably, which can provide livelihoods while promoting conservation efforts.

Promoting sustainable forestry and land use involves balancing human needs with environmental preservation through practices like selective logging, replanting, and habitat restoration, while also leveraging technology and collaboration. Sustainable forestry focuses on preserving biodiversity, maintaining ecosystem functions, and ensuring long-term forest health, while sustainable land use aims to manage resources responsibly for both current and future generations. Box 1.5 represents case studies in Cambodia as well as in other countries promoting sustainable forestry and land use.

Box 1.5: Case studies on promoting sustainable forestry and land use in Cambodia and other countries

Cambodia: Forest and Landscape Restoration Mechanism

- Since 2016, FAO and RECOFTC have supported Cambodia's Community Forestry (CF) initiative by providing technical training and funding to local communities in Kampong Thom, Siem Reap, Preah Vihear. The project focuses on restoring over 52 hectares of degraded land across five pilot sites. Project's activities include replanting native species, restoring ecosystem services, and building community capacity for sustainable management. The project has improved environmental conditions and boosted community livelihoods, demonstrating the effectiveness of linking restoration with local empowerment (FAO, 2021).

Cambodia: Community Forestry Livelihood Case Studies

- Eight case studies in various Cambodian provinces highlight different CF models, such as resin-based CF in Stung Treng, ecotourism-based CF in Siem Reap, and bamboo-based CF in Kampong Speu. These projects have contributed to local food security, income generation, and policy development. However, economic returns remain modest, indicating the need for further support and policy refinement (SEARCA, 2019).

South Korea: National Reforestation Success

- South Korea is one of only four countries, and the only former developing country, to succeed in rehabilitating its forests following World War ll. Despite devastation of South Korea's forests due to continuous occupations and war, the country successfully transformed its denuded lands into rich forests in less than half a century, thanks to strong policies and focused implementation. This makes South Korea's unique experience timely for other countries looking to implement sustainable forestry initiatives, execute wildfire management, and promote national reforestation, including community forestry (UNDP, 2019).

Myanmar: Participatory Community Forestry

- Myanmar, having lost significant forest cover, is now prioritizing restoration through participatory community forestry programs. These include seedling production, tree planting, forest patrols, and sustainable harvesting of forest products. This country is partnering with South Korea and UNDP for knowledge transfer, policy advice, and funding, aiming to replicate Korea's success (UNDP, 2019).

e. Capacity Building and Awareness Raising

- **Training Programs:** Develop training for local authorities and communities on climate adaptation strategies, ensuring they have the knowledge to implement effective measures at the grassroots level.
- **Public Awareness Campaigns:** Increase awareness about climate change impacts and adaptive practices among the general population, particularly targeting vulnerable groups such as women, children, and marginalized communities.

Capacity building and awareness raising are crucial for effective climate action, particularly in developing countries, and involve strengthening individuals, organizations, and systems to address climate change. This includes providing education, training, and raising public awareness about the impacts of climate change and the need for adaptation and mitigation efforts. Box 1.6 highlights some examples about the training and awareness raising to local authorities and community in Cambodia.

Box 1.6: Examples of training and awareness raising to local authorities and communities in Cambodia

- The Cambodia Climate Change Alliance (CCCA) has organized technical training workshops, such as "Climate Change Vulnerability, Impact and Adaptation Assessment" held in Phnom Penh in 2018, aimed at strengthening the technical capacity of local government and agricultural officers to assess climate vulnerabilities and develop adaptation strategies (CCCA/GSSD, 2018).
- The Royal University of Agriculture and the Ministry of Environment, with support from UNDP and other partners, have developed and implemented training modules specifically designed for extension officers and local government officials to build capacity for climate-resilient agriculture and local climate action planning (CCCA/GSSD, 2018; APAN, 2013).
- Civil Society Organizations (CSOs) in Cambodia actively engage in awareness raising and capacity building at the community level, focusing on vulnerable populations including women, children, and marginalized groups, to help them manage climate risks and promote local ownership of adaptation measures (MoE and NCSD, 2018).
- National and subnational governments, with support from development partners, are working to enhance public access to climate data and information, and to integrate climate risk assessment into local development planning processes. This includes efforts to raise awareness among communities and local authorities about novel climate risks and adaptation options, fostering participatory and inclusive approaches to climate resilience (WB, 2024).

CHAPTER 2
CURRENT CAMBODIA ECOSYSTEM AND HUMAN SYSTEM

2.1 Introduction

2.1.1 Overview

Cambodia is renowned for its rich biodiversity and natural resource, including the world's largest freshwater fish and significant tiger populations. This area, characterized by diverse ecosystems including forests, rivers, grasslands, and wetlands, supports an array of flora and fauna, with new species being discovered regularly (WWF, 2021). Approximately 80 percent of the 300 million people in the Greater Mekong rely on these ecosystems for essential goods and services such as food, clean water, and materials for shelter and clothing (GMS, 2024). Furthermore, Cambodia contains the largest contiguous block of natural forest on the Asian mainland and is part of the Indo-Burma Biodiversity Hotspot, and is home to 1.6 percent of globally threatened species on the IUCN Red List

(NCSD, 2023). The country's biodiversity is crucial for ecosystem services that sustain life and are particularly vital for vulnerable populations, including indigenous communities who depend on these resources for their livelihoods (NCSD, 2016). In response to these challenges, Cambodia has implemented various policies aimed at conserving its biological wealth.

Cambodia's rich biodiversity can be categorized into four primary ecological regions: Eastern Indochina moist forests (also referred to as Annamite Range moist forests), Cardamom Mountains moist forests, Central Indochina dry forests, and the Mekong freshwater eco-region (John 2017; NBSAP 2019). The Eastern Indochina moist forests support a diverse array of wildlife, including 134 species of endemic and near-endemic mammals and 525 bird species, yet over 50 percent of these forests have been lost to logging and firewood collection. The Cardamom Mountains moist forests are among Cambodia's most biodiverse areas, housing over 100 mammal species, including significant populations of elephants, alongside 450 bird species. The region is generally well-protected, although illegal logging remains a concern. The Central Indochina dry forests consist of sparse woodlands with 167 mammal species, predominantly threatened mega herbivores, and over 500 bird species, facing threats primarily from land clearing for settlement. Lastly, the Mekong freshwater ecoregion boasts a remarkable habitat diversity that includes wetlands and grasslands, supporting at least 212 mammal species, around 850 to 1200 fish species, 240 reptile species, and over 2,000 plant species; however, this region is severely impacted by hydroelectric dam constructions, sand mining, and overfishing. Collectively, these regions illustrate Cambodia's ecological wealth while highlighting the urgent need for conservation efforts amidst ongoing environmental pressures.

2.1.2 Objectives and Scope

Building on the assessment of current and projected climate change vulnerabilities outlined in Chapter 1, this chapter focuses on the current ecosystem and human system in Cambodia. It aims to identify the diverse ecosystems existing in Cambodia, such as terrestrial, coastal, and marine, and water and freshwater ecosystems, as well as the key issues relevant to the existing human system. Understanding these ecosystems and human dynamics is essential for addressing the impacts of climate change and informing effective adaptation strategies. The objectives of this chapter are to:

- Describe the existing ecosystem in the whole country, highlighting the important ecosystems and the specific biodiversity in each ecosystem.
- Describe the existing human system and discuss the main relevant sectors such as water access and food production, cities and key infrastructure, health, livelihoods, and communities.
- Provide an overview of the country's economy and key economic sectors.
- Briefly discuss the main challenges and opportunities facing key economic sectors in the context of climate change.
- Identify the knowledge gaps to provide directions for future study on ecosystems and human system.

2.1.3 Method and Approach

This chapter was prepared based on the authors' relevant works, which were primary data for this section of the report, and secondary data, which were reviewed from existing literature, including academic journal articles, government and development partners' reports, and other relevant documents. The gathered information has been synthesized and analyzed to obtain good and reliable content.

The main documents consulted include:

- Royal Government of Cambodia: Pentagonal Strategy - Phase I
- Cambodian NBSAP 2016
- Cambodia Fifth National Report to the Convention on Biological Diversity 2014
- Ministry of Environment 2023: Cambodia Forest Cover 2018
- Reports and publications from internationally recognized NGOs working on Cambodian ecosystem, biodiversity, and natural resources such as Fauna & Flora International (FFI), Wild Earth Allies (WEA), and Marine Conservation Cambodia (MCC).

2.2 Update on Existing Ecosystem

The Pentagon Strategy Phase I of the 7th Legislation of the Royal Government of Cambodia highlighted sustainable management of natural resources and ensuring environmental sustainability and readiness in responding to climate change. In the National Biodiversity Strategy and Action Plan, Cambodia envisions that by 2050, Cambodia's biodiversity and ecosystem services will be valued, conserved, restored where necessary, wisely used, and managed to ensure equitable economic prosperity and improved quality of life for all citizens in the country.

Cambodia's ecosystem is rich and diverse, with many different habitats that support a wide range of animal and plant species, including forests, wetlands, freshwater ecosystems, and marine and coastal ecosystems. Every ecosystem provides habitat for plants, animals, and microorganisms, which each have a function in the ecosystem. The World Resources Institute calls ecosystems "the productive engines of the planet, providing us with everything from the water we drink to the food we eat and the fiber we use for clothing, paper or wood for construction" (GMS, 2024).

2.2.1 Terrestrial Forest and Biodiversity

Cambodia has several forest regions. In 2023, Cardamom National Park became Cambodia's largest protected area, covering nearly one million hectares. The Central Cardamom Mountain landscape is considered one of the most species-rich ecoregions in Cambodia and is home to more than 500 animal species, including over 50 species on the IUCN's red list of threatened species (Global Conservation , 2024).

The Royal Government of Cambodia's Fifth National Report to the Convention on Biological Diversity (2014) recognized that Cambodian forests are predominantly dominated by the Dipterocarpaceae, Leguminosae, Lythraceae, and Fagaceae families, with some areas also featuring Pinaceae, Podocarpaceae, or bamboo. The flora at lower altitudes is characteristic of the Indochinese floristic province, contrasting with that of the Chinese, Indo-Burma, and Indo-Malayan provinces, while the flora at higher altitudes shares affinities with those of the Indo-Malayan region.

The report also indicated that, to monitor the country's various forests, the Forestry Administration conducted periodic forest cover assessments in 1993, 1997, 2002, 2006, and 2010. These assessments classified forests into categories of evergreen, semi-evergreen, deciduous, and other types. As a result, the forest area in 2010 was estimated at 10,363,789 ha, or 57.07 percent of the country's total land area. This area comprises deciduous forests (24.68 percent of the country's land area), evergreen forests (19.27 percent), and semi-evergreen forests (7.02 percent) (FAO, 2020). The 2010 forest cover assessment also revealed that forest cover had been lost at an average annual rate of 0.5 percent of land area between 2002 and 2010 (ODC, 2016). In response, the government has established 60 percent of the country's area as forests as a Millennium Development Goal and a priority of the National Forest Programme.

From 1965 through 2018, Cambodia conducted 8 national forest cover assessments. The assessment was made at different stages for 27 years, showing that the forest cover has declined by 26.18 percent compared to the overall country area. The reasons for this decline include civil war, population increase, need of land for agricultural production, and other key factors (MoE, 2018; MoE, 2023). According to the national forest cover assessment in 2018, Cambodia's forest covers an area of 8,510,807 ha, equivalent to 46.86 percent of the country's total land area. Compared to the assessment statistics in 2016, there was a decrease of about 1.28 percent, from 48.14 percent to 46.86 percent.

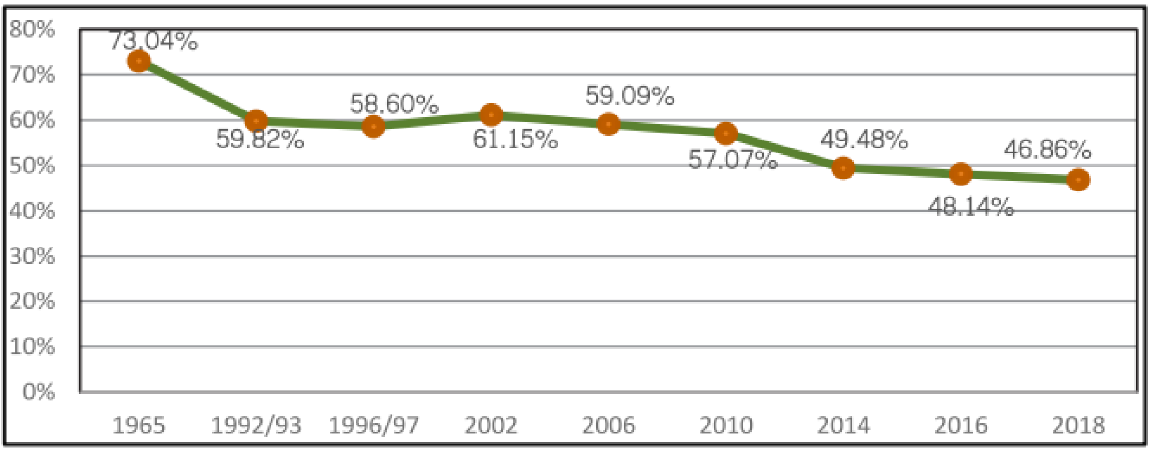


Figure 4: Graphic: the rate of variation in forest cover resource from 1965 to 2018.
Source: MoE, 2023.

The Royal Government of Cambodia continues to strengthen its collaboration with international and national development partners, as well as conservation organizations, demonstrating its commitment to sustainable forest management and biodiversity conservation through various programs, including the National Forest Programme implemented by the Forestry Administration, along with other guidelines, regulations, and laws. These achievements, along with a case study on Protected Areas & Economic Land Concessions, are highlighted in the Fifth National Report to the Convention on Biological Diversity.

2.2.2 Marine Coastal Ecosystems

The coastline of Cambodia extends along the northeastern shore of the Gulf of Thailand between the Thai and Vietnamese borders for approximately 435 km, covering an area of 17,237 km^{2}, as shown in Figure 5 (PEMSEA and MoE, 2019; MoE, 2005). The coast consists of estuaries, bays, and approximately 64 islands (PEMSEA and MoE, 2019). Over the last two decades, infrastructure (i.e. roads, ports, and coastal resorts) in these areas has been developed and people have migrated from inland areas to coastal areas for economic opportunity reasons (Rizvi and Singer, 2011). Although the land use map shows natural forest covering most parts of the coastal zone, this is projected to change rapidly due to human activities and unsustainable development (Pao, 2018). Within this marine area, important coral reefs, seagrass, and mangrove habitats can be found, either fringing the multitude of islands or, as in the case of seagrass, along sheltered areas of the mainland (Rizvi and Singer, 2011). The health and productivity of these habitats are crucial for a diverse and functional marine environment and the livelihoods of the many people who rely on them. Aquatic resources constitute the largest proportion of protein sources for Cambodians, comprising 76 percent of the nation's annual protein intake (IFREDI, 2013). Therefore, intact, healthy, and productive marine ecosystems are vital for the continuation of Cambodian societal resource prioritization (Fisheries Administration, 2023). Cambodian coastal and marine ecosystems, including mangrove forests, coral reefs, seagrass beds, salt marshes, and estuaries, are all extremely important to Cambodia's economic development as well as to the livelihoods of the local communities (FAO, 2019).

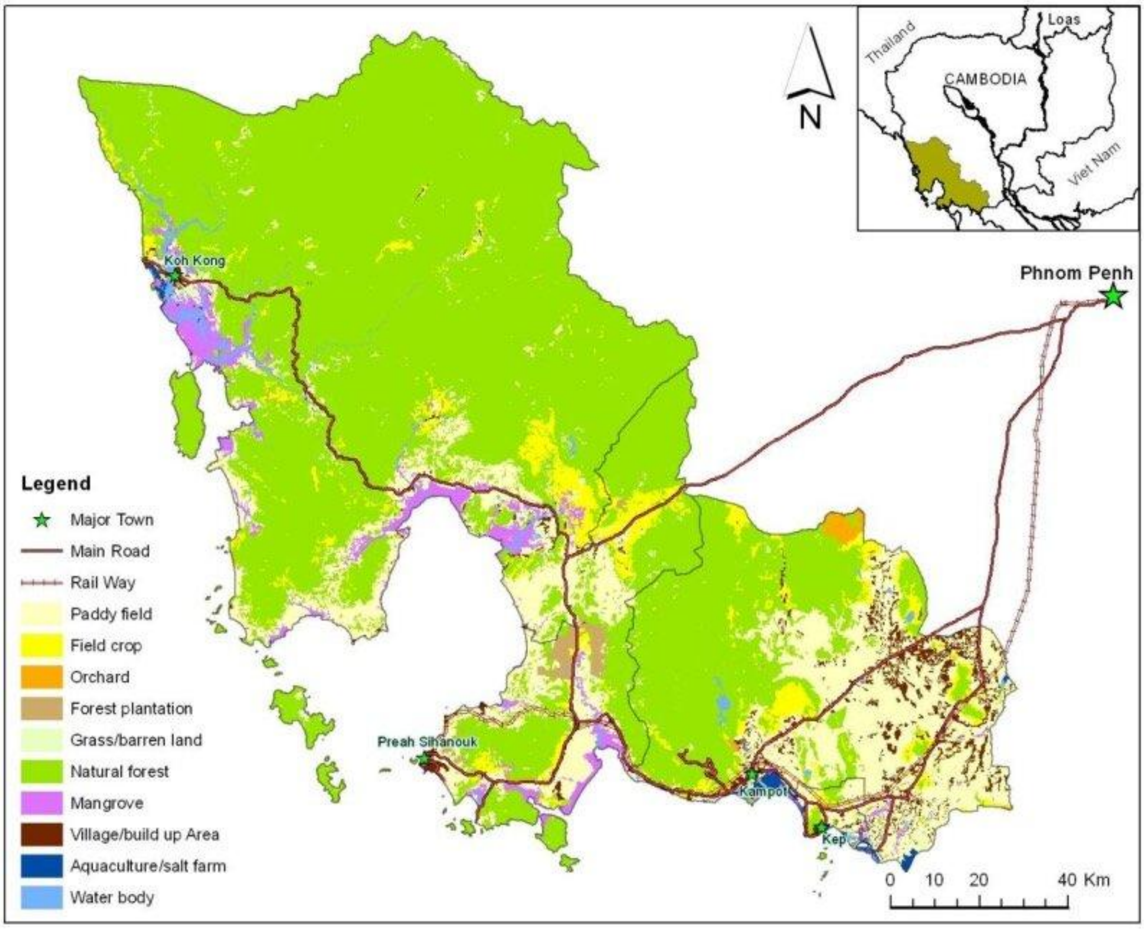


Figure 5: Map Showing Land Use in the Coastal Zone of Cambodia in 2011.
Source: MoE, 2013.

a. Mangrove Forests

Cambodia's mangrove forests, particularly in the Peam Krasop Wildlife Sanctuary and the adjacent Koh Kapik Ramsar site, represent one of the largest and most biodiverse mangrove ecosystems in mainland Southeast Asia. The Peam Krasop Wildlife Sanctuary covers approximately 23,750 hectares, while the Koh Kapik Ramsar site adds another 12,000 hectares, making them critical areas for conservation efforts in Cambodia. Recent surveys highlighted their ecological significance, revealed a staggering diversity of species, and emphasized the urgent need for conservation efforts (Munoz et al., 2024).

Mangrove forests provide ecosystem services to protect the coast against tsunamis and cyclones, climate conditions, flooding, protection for carbon sequestration, and shelter for biodiversity. A comprehensive survey conducted by Fauna & Flora International, in collaboration with the Cambodian Ministry of Environment, identified over 700 species within these mangrove areas (Munoz et al., 2024). This includes a wide variety of wildlife such as:

- Mammals: Critically endangered Sunda pangolin, endangered long-tailed macaque, hairy-nosed otter, and large-spotted civet.
- Fish: 74 species of juvenile fish, many of which are vital for local fisheries.
- Birds: 157 bird species recorded, including 15 that are listed as Near Threatened to Endangered on the IUCN Red List.

The survey underscores the role of mangroves as crucial habitats that support both terrestrial and marine life. They serve as breeding grounds for fish and provide essential ecosystem services such as carbon sequestration and coastal protection against erosion and flooding (Munoz et al., 2024).

b. Coral Reefs

Cambodia's coral reefs, located primarily along the Gulf of Thailand, are a vital part of the country's marine ecosystems. These reefs contribute significantly to biodiversity, coastal protection, and local economies through fisheries and tourism. Coral ecosystems are characterized by a rich variety of species, including numerous fish, invertebrates, and coral types, which provide essential habitats for marine life and serve as breeding grounds for many species (SCS SAP, 2021). Among the 750,000 ha of coral reef identified in the South China Sea, around 2,807 ha are located in coastal waters of Cambodia. There are more than 200 coral reef species that occur in Cambodia. Significant coral reef sites include Prek Ampil (953 ha), Koh Sdach archipelago (529 ha), and Koh Rong archipelago (468 ha) (SCS SAP, 2021).

Recently, scientists observed a rare and significant event of mass coral spawning at the Koh Rong Archipelago in southwest Cambodia. This is the second consecutive year (2024 and 2025) that conservationists witnessed this synchronized release of coral eggs and sperm, a natural reproductive event that usually happens once a year under specific environmental cues like water temperature and moon phases. Conservationists from Fauna & Flora’s marine team in Cambodia witnessed the spectacular show during the first week of March 2024. This momentous event is living proof that Cambodia’s coral reefs remain healthy despite the severe pressures from climate change, pollution and coastal development (Munoz, 2024).

However, according to a threat index used by (Rizvi and Singer, 2011), 90 percent of coral reefs in Cambodia are classified as being at high risk, while the remaining 10 percent are classified as being at very high risk. Strong protection and management efforts need to be undertaken to avoid their disappearance in the near future. The absence of recent information regarding the extent, health, and diversity of the coral reefs in Kampot province needs to be addressed to maximize the conservation and management initiatives (WEA and MCC, 2020).

c. Seagrass

Seagrass meadows are essential ecosystems located along the coastal regions of Cambodia, particularly in Kampot, Kep, and the Koh Rong Archipelago. These habitats are crucial for marine biodiversity, offering vital ecosystem services such as providing nursery grounds for fish, enhancing water quality, and safeguarding coastlines against erosion and flooding.

Cambodia boasts some of the largest seagrass beds in Southeast Asia, with approximately 32,492 hectares identified in areas like Kampot and Kep (Fisheries Administration, 2023). More than 12 species of seagrass have been recorded, with the most diverse meadows found in these provinces. The health of these ecosystems is vital for local fisheries and the livelihoods of coastal communities (MCC, 2025).

Research indicates that seagrass meadows in Cambodia have faced significant declines. For example, the largest seagrass meadow near Kampot and Kep has reportedly decreased by as much as 50 percent since previous assessments, with similar reductions observed in the Koh Rong Archipelago. Globally, seagrass meadows are estimated to decline by about 7 percent annually, underscoring an urgent need for conservation initiatives (Fisheries Administration, 2023; MCC, 2025). The decline is attributed to intense pressures from various anthropogenic activities. Destructive fishing practices such as bottom trawling severely impact seagrass beds by removing biomass and increasing sedimentation, which diminishes light availability necessary for photosynthesis. Coastal development also exacerbates habitat degradation through heightened nutrient runoff and sedimentation. Furthermore, environmental changes like rising sea surface temperatures and ocean acidification pose additional threats to these ecosystems (Fisheries Administration, 2023; MCC, 2025)

In conclusion, the situation of seagrass meadows in Cambodia is critical, with significant declines attributed to various human-induced pressures. Conservation projects like the CSCP (Cambodian Seagrass Conservation Project) are essential for reversing these trends and safeguarding the ecological functions that seagrasses provide. Ongoing monitoring and effective management strategies will be vital for the future health of Cambodia's coastal ecosystems.

2.2.3 Wetlands and Freshwater Ecosystems

Wetlands are defined as "areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Ramsar, 2016). To be considered a wetland, an area must have hydrology that results in wet or flooded soils, soils that are dominated by anaerobic processes, and biota, particularly rooted vascular plants, that are adapted to life in flooded, anaerobic environments (Cherry, 2011).

Cambodia's freshwater wetlands cover more than 30 percent of the total land area (see Figure 6) (Vathan and Phnom, 2003). The freshwater hydrology of Cambodia is dominated by the Mekong River and Tonle Sap River and Great Lake system (Kosal, 2004). Other important freshwater wetland areas include the seasonally inundated grassland of Boeung Prek Lapouv. In addition, numerous other smaller wetlands are found in the country in the form of streams, ponds, freshwater swamps, and marshes (Vathana and Penh, 2003). Many of these wetlands make a significant contribution to human well-being and biodiversity but are not being actively managed and may be under threat, which will lead to their degradation or loss (Blackham and Avent, 2019). Wetlands provide a diverse range of ecosystem services that are essential for human well-being and the environment (Table 5). Some of these services, or functions, include protecting and improving water quality, providing fish and wildlife habitats, storing floodwater, and maintaining surface water flow during dry periods. These valuable functions are the result of the unique natural characteristics of wetlands (EPA, 2024).

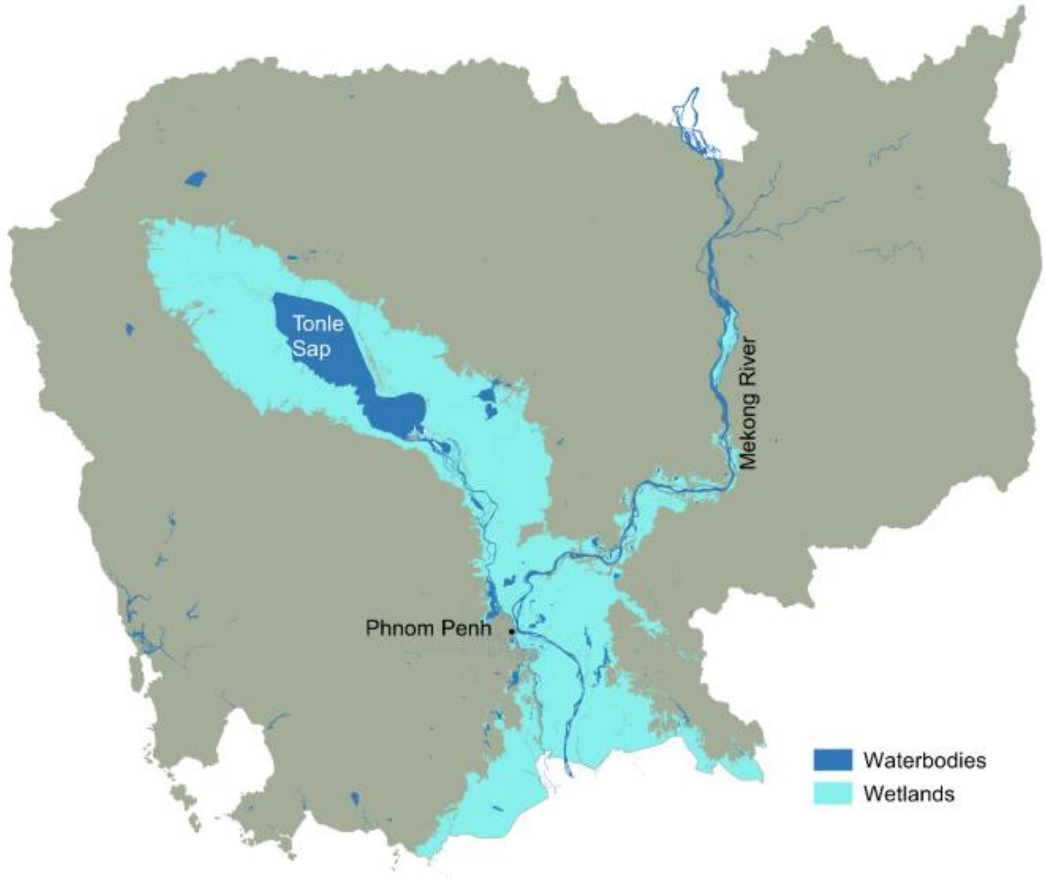


Figure 6: Map of Freshwater wetland in Cambodia.
Source: ASEAN Regional Centre for Biodiversity Conservation, 2017.

a. Mekong River and Its Tributaries

The Mekong River is the longest river in Southeast Asia. The river enters Cambodia from Lao PDR in the northeast and flows southwards towards Phnom Penh. The Mekong delta begins downstream of Kampong Cham and extends into Vietnam (Vathana and Penh, 2003). The Mekong delta is formed by both the Mekong and Bassac Rivers. Overall, a 468 Km stretch of the river flows through Cambodia and around 86 percent of the country lies within the Mekong Basin. The river has seasonal variation in flow. Water levels are at their lowest in April and May. Indeed, by the end of April, many water bodies are isolated and the smaller tributaries have dried out. The river starts to rise again with the monsoon rain in late May and reaches its highest water levels in September or October (Vathana and Penh, 2003).

The Mekong River plays a crucial role in Cambodia's economy and the livelihoods of its people. Here are the primary benefits derived from this vital waterway:

- **Water Supply and Agriculture:** Approximately 86 percent of Cambodia's territory is part of the Mekong Basin, making it essential for water-related economic activities. The river supports agriculture, particularly rice farming, which is a significant part of the country's economy. The fertile lands nourished by the Mekong's sediment facilitate high agricultural productivity, positioning Cambodia as one of the largest rice exporters globally (WWF, 2016).
- **Fisheries:** The Mekong watershed is a vital source of fish protein for many Cambodians. It sustains extensive fisheries that are crucial for food security and

local economies. Many communities rely on fishing as their primary source of income, highlighting the river's role in supporting livelihoods (WWF, 2016).

- **Hydropower Generation:** The river's flow is harnessed for hydropower, contributing to energy security in Cambodia. This renewable energy source is increasingly important as the country develops its industrial sectors, which rely on stable electricity supplies (MRC).

b. Tonle Sap Lake and Its Tributaries

The Tonle Sap Lake is one of the largest freshwater lakes in Southeast Asia. The Mekong River connects to the Tonle Sap Lake via the Tonle Sap River. During the wet season (May to October), the Mekong River swells and its waters flow into the Tonle Sap River and to the Tonle Sap Lake. This causes the lake to expand from 2,500 Km² in the dry season to 13,000 Km² in the wet season.

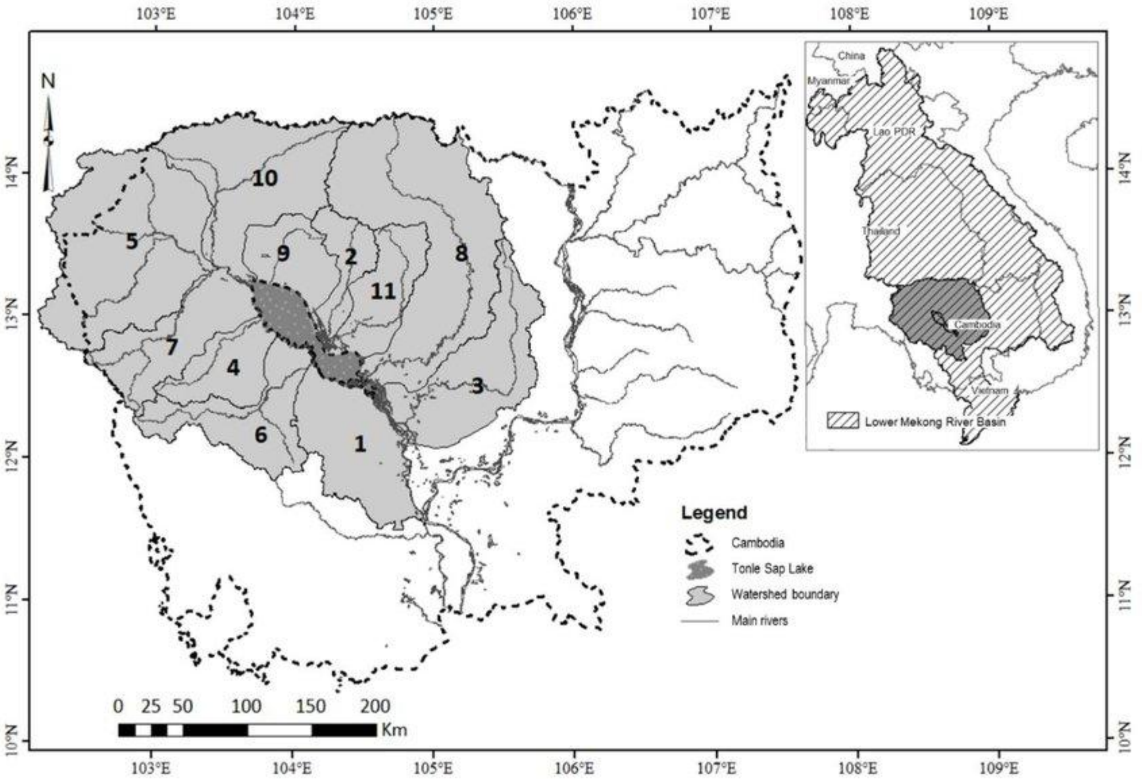


Figure 7: Tonle Sap Lake and its Watershed
Source: (Mab and Kositsakulchai, 2020)

In November, when the level of the Mekong River decreases, the Tonle Sap reverses its flow, and water flows back from the Tonle Sap Lake into the Mekong River. The Tonle Sap Lake has eleven main tributaries namely (1) Stung Boribo, (2) Stung Chikreng, (3) Stung Chinit, (4) Stung Dauntri, (5) Stung Mongkolborey, (6) Stung Pursat, (7) Stung Sangke, (8) Stung Sen, (9) Stung Siem Reap, (10) Stung Sreng, and 11) Stung Staung (Figure 7). The Stung Sen River, originating in the Dangrek Mountains on the border between Cambodia and Thailand, is the largest tributary. In Cambodia the river flows through Preah Vihear Province and Kampong Thom Province (Nagumo, 2013).

Tonle Sap Lake is recognized as one of the most diverse and productive ecosystems globally. It has been designated as a UNESCO Biosphere Reserve due to its high biodiversity and ecological importance (UNESCO, 2023). The lake’s resources are hugely important to the population of Cambodia: around one million people are dependent on the lake’s fisheries for their livelihoods while another 2.6 million are dependent on other lake-related resources (Chadwick and Juntopas, 2008). The key features include:

- **Biodiversity:** The lake supports over 149 species of fish and is home to several globally threatened bird species, including the Spot-billed Pelican and Milky Stork. It also provides habitat for critically endangered species like the Bengal Florican (WCS, 2024).
- **Fisheries:** The annual fish catch is estimated to be between 180,000 and 250,000 tons, making it one of the most productive fisheries systems worldwide. Approximately 60 percent of Cambodia's protein intake comes from fish harvested from this lake (MRC, 2010).
- **Unique Habitats:** The surrounding floodplain includes seasonally flooded forests and wetlands that are critical for breeding and feeding fish and other wildlife (WCS, 2024).

c. Internationally Recognized Wetland Sites

- **Ramsar Sites**

As a Contracting Party to the Ramsar Convention (since 1999), Cambodia has designated five sites as Wetlands of International Importance, also known as Ramsar sites. Ramsar sites are sites that contain representative, rare, or unique wetland types and/or are important for conserving biological diversity. As a contracting Party, Cambodia is expected to manage its Ramsar sites, especially maintaining their ecological character and retaining their essential functions and values for future generations. The Ramsar sites in Cambodia are shown in Table 2.1.

- **Tonle Sap UNESCO Biosphere Reserve**

Due to its cultural, social, environmental, and economic significance to Cambodia, the Tonle Sap Lake and its surrounding area were designated as a UNESCO Biosphere Reserve in 1997. The Tonle Sap Biosphere Reserve, encompassing Tonle Sap Lake and its surrounding floodplains, is Southeast Asia's largest freshwater lake ecosystem. It plays a critical role in Cambodia's inland fisheries, contributing to 60 percent of the nation's inland capture fisheries production (UNESCO, 2024).

Table 5: List of Ramsar sites in Cambodia.

Ramsar Site	Description
Boeng Chhmar and Associated River System and Floodplain **28,000 ha** **Designated in 1999**	The site is part of the Tonle Sap Biosphere Reserve and consists of a permanent lake surrounded by flooded forest in the northeast fringe of Tonle Sap lake. The site merges with Tonle Sap Lake in the wet season.
Koh Kapik and Associated Islets **12,000 ha** **Designated in 1999**	The site consists of alluvial islands immediately off the mainland of Koh Kong Province. The main wetland types at the site are estuarine waters, intertidal mud, sand or salt flats and mangroves.
Middle Stretches of Mekong River North of Stoeng Treng **14,600 ha** **Designated in 1999**	The site consists of a 40 km stretch of the Mekong River in the north of Cambodia. This river habitat is characterized by strong turbulent flow with numerous channels between rocky and sandy islands that are completely inundated during high water as well as higher alluvial islands that remain dry.
Prek Toal **21,342 ha** **Designated in 2015**	The site is located in the north-west upstream end of Tonle Sap Lake and is part of the Tonle Sap Biosphere Reserve. It is mostly covered by freshwater swamp forest which floods annually to depths of up to 8 m.
Stung Sen **9,293 ha** **Designated in 2018**	The site is located along the south-eastern edge of the Tonle Sap Great Lake, and mainly comprises seasonally flooded freshwater swamp forests. The vegetation of Stung Sen is strongly influenced by the exchange of water between the Mekong River, the Stung Sen River and the Great Lake.

Source: Millennium Ecosystem Assessment,2005.

2.3 Update on Existing Human System

According to IPCC 2007, human systems include social, economic, and institutional structures and processes. Related to industry, settlement, and society, these systems are diverse and dynamic, expressed at the individual level through livelihoods. For example, in agriculture and fisheries, human systems involve practices, technologies and policies that determine food production and distribution. Climate change can affect these systems by altering growing seasons, water availability, and the distribution of fish stocks, requiring adaptation strategies to manage these changes effectively (IPCC, 2007).

Human systems are characterized by social structures, which involve community relationships, cultural practices, and social norms that shape societal responses to climate challenges; economic systems, which include industries, labor markets, and policies impacting resource allocation and sustainability; and institutional frameworks, comprising laws and governance systems that guide decision-making in light of climate impacts. Human systems are dynamic and interconnected, evolving to address critical societal needs such as health, food security, water access, energy provision, transportation, and national security (Chu and Karr, 2016). The interplay between these components highlights the importance of understanding how human activities contribute to climate change and the necessity for adaptive strategies to mitigate its effects on society.

2.3.1 Water Access and Food Production

a. Water Access

Cambodia faces significant disparities in water access between urban and rural areas, with a notable gap in basic water access and sanitation coverage (UNICEF and WHO, 2021). The government has set ambitious targets to improve this situation, aiming for 100 percent access to clean water nationwide by 2025 (ODC, 2022). In urban areas like Phnom Penh, Siem Reap city, and Sihanoukville, piped systems are common, while rural communities rely on wells, rainwater harvesting systems, manual fetching from lakes or rivers/ponds, and some private piped systems (WaterAid, 2025). Despite achieving over 80 percent coverage of clean water and sanitation services in rural areas as of recent years, challenges persist due to rapid population growth and financial constraints for connecting households to improved services (ADB, 2014). The government's strategic plans focus on expanding infrastructure development with increased private sector involvement to address these gaps (WaterAid, 2025; ODC, 2022).

b. Food Production

Agricultural sector is a significant contributor to Cambodia’s economy, accounting for approximately 22 percent of GDP in 2022. The primary agricultural commodity is rice, which is the main source of income for rural farmers and the country's largest agriculture export commodity (FAO, 2025). However, cassava has become the most produced and exported crop due to increased production (GIZ, 2020).

According to the Ministry of Agriculture, Forestry, and Fisheries, the following are Cambodia’s key crops and exports (MAFF, 2024):

- **Rice:** Cambodia aims to increase milled rice exports significantly. In 2022, it exported about 630,000 tons of milled rice, amounting to approximately USD 416 million in export value. Rice varieties like Phka Romdoul are well-known globally.
- **Cassava:** This crop has surpassed rice as the most produced and exported due to its high yield. Cambodia exported close to 1.03 million tons of cassava in various forms (fresh, dried, powder, pulp) in early 2023. The value for "manioc (cassava) and manioc starch" exports surged to about USD 285 million in Q1 2023, with cassava playing a major role in Cambodia's GDP, estimated to generate between USD 850 million and USD 1.13 billion annually.
- **Cashew nuts:** Cambodia is now the third-largest cashew producer globally and exported 815,000 tons in 2024, generating over USD 1.5 billion in revenue. Most cashews are exported unprocessed due to limited local processing capacity.
- **Mangoes:** Cambodia exported about 170,000 tons of fresh and dried mangoes in 2022, with dried mango exports valued at roughly USD 127 million in 2023.
- **Vegetables:** In 2022, Cambodia exported vegetables worth approximately USD 28 million, with major destinations including Thailand and Czechia.
- **Coconuts:** Cambodia produced about 248,000 tons of coconuts in 2022. Exports data by value specifically for coconuts in Cambodia is not detailed, but the country is advancing in this sector with market access to China.

- **Jackfruits:** Export data shows exports are relatively small in volume; no significant monetary value was found in recent records.
- **Bananas:** Cambodia exported about 326,000 tons of bananas in the first 10 months of 2022, though export value data is not specified, exports dipped by about 12 percent compared to previous years.

Specific export quantities or values were not found in the recent data for durians (with GI status), Kampot pepper, Koh Trong pomelo, and Kampong Speu sugar, but these are known quality products recognized for their distinctiveness

Regarding agriculture practices, agriculture in Cambodia is predominantly reliant on seasonal rains, with dry season farming necessitating advanced irrigation systems and substantial technological investments (GIZ, 2020). The government promotes agricultural diversification and improved irrigation through policies like the National Policy for Agriculture Development 2022-2030.

Despite socio-economic progress, food insecurity persists, affecting about 15 percent of Cambodians due to global supply fluctuations (Asia Society, 2025). Challenges include infrastructure limitations leading to high post-harvest losses, limited market access for farmers, and widespread malnutrition. Opportunities for improvement lie in adopting modern farming techniques to boost productivity, diversifying crops beyond traditional ones like rice (which includes practices such as the System of Rice Intensification or SRI) (CDRI, 2015), investing in processing facilities to enhance export value (ADB, 2021), and improving irrigation systems like those supported by initiatives such as the Water Resource Management and Agro-Ecological Transition in Cambodia (WAT4CAM) (Asia Society, 2025).

2.3.2 Cities and Key Infrastructure

Cambodia is experiencing rapid urbanization, with significant growth in cities like Phnom Penh and Sihanoukville. The country's urban development is driven by economic growth, infrastructure investments, and strategic planning to decentralize economic activities (Chan, 2020).

Urbanization trends highlight significant changes in population distribution. From 2000 to 2020, urban areas experienced a substantial growth rate of 4.5 percent annually (UN Habitat, 2025). Currently, about 21 percent of the population resides in urban settings (World Bank, 2017). However, this is expected to increase dramatically by 2050, with projections indicating that approximately 36 percent of the population will live in urban areas by then (WB, 2017). This shift underscores the rapid pace at which cities are becoming hubs for human habitation and economic activity globally (WB, 2017).

Cambodia is facing significant challenges and undergoing transformative changes related to key cities and development. Phnom Penh, the capital, grapples with inadequate drainage, wastewater treatment, public transport, and solid waste management (WB, 2019). The city has a Master Plan 2035 aimed at sustainable growth but lacks detailed implementation frameworks (GGGI, 2019). In contrast, areas like Arey Ksat (Mekong Quay) are being transformed into integrated urban hubs through projects that combine residential, commercial, tourism functions with green architecture and modern infrastructure (CIR, 2025). These developments aim to enhance connectivity via new infrastructure funded by international partners (CIR, 2025). Preah Sihanouk province is focusing on sustainable city planning as part of its Vision 2030 strategy (WB, 2017). Overall, these initiatives highlight efforts towards more sustainable urban development across Cambodia.

Cambodia's infrastructure development is pivotal for its economic and social growth, with significant investments in transportation networks, energy systems, and public services. The country has improved its road network with major projects like the Phnom Penh-Sihanoukville Expressway (IPS, 2023). Railway development has also seen a revival with upgrades to existing lines and plans for new connections (IPS, 2023). Additionally, airport infrastructure is being expanded with new international airports, such as Siem Reap–Angkor International Airport (opened in 2023) and Techo International Airport, Official opening in October 2025 (Government of Canada, 2023) (Zhou & Rahul, 2025). Cambodia has recognized the importance of energy access and, over the last twenty years, has made remarkable strides, earning recognition from the World Bank as one of the world's fastest-electrifying nations. The country increased its electricity access rate from just 6.6 percent in 2000 to an impressive 97.5 percent by the end of 2021 (UNDP, 2022). Despite this achievement, as of early 2022, 350 villages still lacked electricity. To address this, the government plans to connect around 170 of these villages to the national grid within the next five-to-seven years. However, this will still leave 180 villages unconnected, many of which are inhabited by some of Cambodia's most vulnerable groups, including indigenous peoples, ethnic minorities, women, children, youth, people with disabilities, the elderly, and displaced individuals. These communities are often isolated, lack road access, and are sometimes located in floating settlements, making electrification particularly challenging. Furthermore, simply connecting villages to the grid does not guarantee reliable or affordable electricity, as almost two-thirds of households experience frequent outages (UNDP, 2022). Despite challenges in rural areas, international partnerships, especially with China through the Belt and Road Initiative, offer opportunities for further development. These efforts aim to enhance connectivity, promote economic growth, and improve living standards across Cambodia.

2.3.3 Health, Livelihood, and Communities

a. Health

The current state of Cambodia's health system reflects significant improvements over recent decades, yet it still faces numerous challenges and disparities. Key improvements include substantial progress in health indicators such as life expectancy, infant mortality rates, and maternal mortality rates (WHO, 2023). The country has increased access to healthcare services through national health reforms and social protection schemes (NSPC, 2024). Achieving lower-middle-income status in 2015 has contributed to advancements in healthcare infrastructure and services (Khim and Anderman, 2021) (WB, 2021). However, challenges persist: urban-rural disparities exist with rural areas lacking adequate resources (GIZ, 2021). There is a rising prevalence of non-communicable diseases due to lifestyle changes and social development, with cardiovascular diseases, cancer, chronic respiratory diseases, and diabetes being the main NCDs causing a significant proportion of deaths (MoH, 2018). High out-of-pocket expenses remain a major issue with limited public funding at about 1.4 percent of GDP (WB, 2021). Socioeconomic inequality affects health outcomes due to unequal access to quality care. Private hospitals offer better quality but are less accessible than public facilities (GIZ, 2021). To address these disparities effectively, strategies include strengthening public sector funding by increasing government spending beyond the current level and improving hospital management processes; regulating private providers through stricter regulations; enhancing social protection by expanding coverage under social health protection schemes; and reducing out-of-pocket expenditures through comprehensive insurance plans (GIZ, 2021; WB, 2021). By focusing on these strategies, Cambodia can move closer towards achieving universal health coverage while reducing existing disparities in its healthcare system.

b. Livelihood

Cambodia's economy remains predominantly rural, with agriculture central to livelihoods and food security, supporting over 70 percent of households primarily through rice farming and other crop production. According to the Cambodia Agriculture Survey 2023, about 93 percent of agricultural households grow crops, with 57 percent mainly producing for home consumption and 43 percent mainly for sale (MoP, 2023). Agriculture accounted for approximately 22 percent of Cambodia's GDP in 2023, employing around 2.6 million people (FAO, 2025; Van, 2025; ITA, 2024). Key crops include rice, cassava, maize, mung bean, and soybean, with rice being the primary agricultural commodity (ITA, 2024).

Fisheries and forestry continue to play crucial roles in supplementing rural incomes and providing food security for millions. Fisheries contributed about 24.8 percent and forestry about 7 percent of the agro-sector's output in 2023 (Van, 2025). These natural resources act as a safety net for rural populations, especially subsistence farmers, amid challenges like resource depletion and climate change.

Rural employment largely remains based on subsistence farming with unpaid family labor, though there has been growth in paid agricultural jobs and agro-industries, which contribute to economic activity and food security (Van, 2025). The government has prioritized modernizing agriculture through policies encouraging diversification, investment in irrigation, technology adoption, and export expansion, aiming to increase agricultural production and sustainability under the National Policy for Agriculture Development 2022-2030 and the Pentagonal Strategy Phase 1 (2023) (Van, 2025; ITA, 2024).

Moreover, urban livelihoods in Cambodia face significant challenges stemming from rapid urbanization, pervasive urban poverty, and unequal access to development and public services, with around 21 percent of the population living in urban poverty concentrated mainly in slum settlements lacking adequate basic services and secure tenure, especially in Phnom Penh (Chap, 2021). The urban poor primarily engage in informal, low-income occupations such as begging, street vending, cyclo-driving, garbage picking, and sex work, confronting heightened risks related to crime, drug abuse, and HIV/AIDS. Urbanization is expanding at approximately 3.7 percent annually, driven by rural-to-urban migration fueled by prospects in garment manufacturing, tourism, and construction sectors, although subsistence agriculture remains a major employment source (UNFPA Cambodia, 2014). Despite rapid growth, urban infrastructure and public services remain insufficient for the poor, with government development efforts largely prioritizing physical modernization, benefiting wealthier populations while often marginalizing squatters perceived as barriers to progress, and lacking comprehensive safety nets or targeted urban poverty reduction programs. Policy efforts aim to reduce poverty through promoting equitable economic growth, improved housing, vocational training, and social inclusion, yet stark disparities between urban and rural populations persist, leaving rural areas even more vulnerable due to limited services and infrastructure (Chap, 2021). In sum, Cambodia’s urban livelihoods constitute a complex interplay of informal labor, socio-economic vulnerability, and insufficient social protections amid ongoing rapid urban growth, particularly in Phnom Penh and other expanding urban centers (Lay and Neang, 2021). Despite robust economic growth averaging about 7.6 percent annually from 1995 to 2019—driven by tourism and manufacturing—challenges persist in sustainable resource management and poverty reduction efforts (ADB, 2021).

In summary, rural areas are dominated by agriculture but face challenges related to sustainability, while urban areas see more formalized employment but still struggle with job creation beyond traditional sectors. The overall economy benefits significantly from tourism and manufacturing while facing ongoing issues related to resource management and poverty reduction efforts.

c. Communities

Cambodia is characterized by diverse social and economic conditions across different communities, particularly rural and urban communities. Rural communities experience higher child mortality rates compared to urban areas due to limited healthcare access. Children in rural areas are three times more likely to die than those in urban areas (under 5 mortalities: rural area 52 versus urban area 18 per 1000 live births); this could be explained in part by economic status and mothers' education, as well as access to health services (Khim and Anderman). 2021 Urban communities in Cambodia have significantly promoted social inclusion through child-friendly development, inspired by UNICEF's global Urban Child-Friendly Communities Initiative. This international framework was localized in Cambodia through the Child-Friendly Community Initiative led by the Cambodian government's National Council for Children, in partnership with Plan International.

Economically, poverty remains a concern despite growth; many live close to the poverty line (WB, 2024). The textile industry is a major employer but offers low wages, while tourism supports local economies but has been impacted by global events. The COVID-19 pandemic exacerbated these challenges by reducing incomes and disrupting essential services (IMF, 2025). Key statistics include a decrease in poverty from 50 percent in 2005 to about 13 percent by 2014, high labor force participation at 87 percent with women at about 84 percent (NIS, 2020), and an unemployment rate of around 2.4 percent as per CSES2019/20 (NIS, 2020). Recommendations for improvement include promoting financial inclusion for small businesses, supporting marginalized groups through targeted programs, and enhancing healthcare access equitably across regions to foster sustainable development goals aligned with national priorities.

2.3.4 Key Economic Sectors

a. Overview of the Country's Economy and Key Economic Sectors

Cambodia's economy has experienced rapid growth over the past few decades, driven by its open market system and strategic integration into regional and global trade networks (WB, 2024). The country aims to become an upper-middle-income economy by 2030 and a higher-income economy by 2050 (WB, 2024). Despite facing challenges from the COVID-19 pandemic, Cambodia is gradually recovering. Key sectors driving this growth include manufacturing, particularly textiles like garment exports (IMF, 2025), as well as emerging industries such as electronics and vehicle parts. Tourism is another significant contributor, with attractions like Angkor Wat, boosting GDP and foreign exchange earnings (Hin, 2024). Agriculture remains vital for many Cambodians, focusing on products like rice, rubber, maize, and cassava (ODC, 2021). The service sector, concentrated on trading and catering services, contributes about 36 percent to GDP.

For 2025, Cambodia's GDP growth projections vary among different organizations. The Cambodian government forecasts a robust growth rate of approximately 6.3 percent (Madina, 2025; ODC, 2025). In contrast, the Asian Development Bank (ADB) projects a slightly more conservative rate of around 6 percent (ADB, 2024) Meanwhile, the World Bank estimates a lower growth rate of about 5.5 percent. These projections underscore Cambodia's potential for continued economic expansion despite facing global uncertainties such as US protectionist policies and China's economic slowdown. Despite these challenges, sectors like garment exports and infrastructure development are expected to bolster economic activity (Madina, 2025). After Cambodia officially updated its national account base year from the 2000 base to the 2014 base, the International Monetary Fund (IMF) estimated that Cambodia's new GDP per capita is expected to be 2,948 USD in 2025 and is expected to increase to 3,974 USD in 2029 (IMF, 2025).

Cambodia presents several promising investment opportunities, particularly in infrastructure development, which includes transportation and logistics. The government has unveiled a comprehensive plan to modernize these sectors with an estimated USD 36.68 billion investments across 174 projects (Hin, 2024). Additionally, tourism infrastructure improvements are attracting foreign investments by enhancing travel experience and boosting local economies (Madina, 2025). Manufacturing sectors, such as textiles, remain appealing due to favorable trade agreements. Overall, Cambodia's economic outlook is positive with a projected GDP growth of 6.3 percent in 2025, though its future growth may be influenced by global economic trends and domestic reforms.

b. Main Challenges and Opportunities for Key Economic Sectors

As mentioned in the above session, Cambodia's economy is heavily reliant on climate-sensitive sectors such as agriculture, fisheries, water resources, construction, manufacturing, and tourism. These sectors are vulnerable to climate change impacts including increased temperatures, more frequent floods and droughts, rising sea levels, and changing rainfall patterns (WB and ADB, 2021). Agriculture faces significant risks from intensified floods and droughts affecting crop yields and food security (MoE and NCSD, 2019; Monin et al., 2024). Fisheries experience reduced productivity due to changes in water temperature and chemistry (MoE and NCSD, 2019). Construction and manufacturing suffer from heat stress, reducing labor productivity. Infrastructure stability is threatened by extreme weather events (WB and ADB, 2021).

Despite these challenges, opportunities for economic growth exist through transitioning to a low-carbon economy by investing in renewable energy like solar power, encouraging private sector investment in green technologies to boost resilience and diversify exports beyond traditional products to reduce vulnerability to external shocks related to climate change impacts on specific industries (UNC, 2021). Implementing policies enhancing resilience against extreme weather events (e.g., flood-resistant infrastructure) can protect key economic sectors while strengthening institutions focused on climate adaptation helps mitigate losses from natural disasters. International collaboration provides access to funding for adaptation projects supporting sustainable development goals (UNC, 2021). By addressing these challenges strategically and leveraging available opportunities, Cambodia can build a more resilient economy capable of navigating the impacts of climate change while achieving its development goals.

2.4 Direction for Future Study

Cambodia's ecosystems and key economic sectors are significantly impacted by climate change. Knowledge gaps on impacts and adaptation in relevant sectors require further research. This section presents an overview of the current understanding and future directions for studies.

2.4.1 Knowledge Gaps

a. Ecosystem Impacts

Biodiversity Loss: There is limited comprehensive data on how climate change specifically affects the biodiversity of Cambodia's coastal ecosystems, including mangroves and coral reefs. While studies indicate a decline in species populations and habitat degradation, detailed assessments of specific species and ecosystem interactions are lacking (Suon and Keo, 2024 (NCSD/MoE, 2020))

Water Resources: The impact of climate change on water systems, particularly the Tonlé Sap and Mekong River, needs more exploration. Changes in precipitation patterns and increased drought frequency threaten these vital resources, yet their long-term ecological consequences remain under-researched (Oeurng et al. 2019; ADB, 2021).

b. Economic Sector Vulnerabilities

Agriculture and Fisheries: Although agriculture is a primary economic sector in Cambodia, studies often overlook the nuanced socio-economic impacts of climate variability on smallholder farmers and fishing communities (Sum and Thav, 2023). Understanding how these communities adapt to changing conditions is crucial.

Heat Stress Effects: There is a significant gap in research regarding the impact of rising temperatures on labor productivity across various sectors, particularly construction and agriculture (NCSD, 2021). Current models underestimate the economic implications of heat stress on workers, which could lead to substantial GDP losses (UNDP, 2018).

2.4.2 Future Research Directions

Integrated Ecosystem Assessments: Conducting holistic studies that integrate ecological, social, and economic data will provide a clearer picture of how climate change affects ecosystems and communities. This includes monitoring biodiversity changes alongside socio-economic impacts.

Integrated ecosystem assessment (IEA) in Cambodia is a comprehensive approach aimed at evaluating the status, trends, and future dynamics of biodiversity and ecosystem services in the country, with the goal of informing sustainable development and policymaking.

Box 2.1: Case studies on integrated ecosystem assessment in Cambodia and other countries

- Cambodia has undertaken integrated ecosystem assessments analyzing the contributions of biodiversity and ecosystem services to sustainable development goals. The National Ecosystem Assessment Initiative provides a holistic framework by combining ecological, social, and economic data to inform policy and conservation efforts (NCSD and RUPP, 2020).
- A study using an extended Social Accounting Matrix (SAMEA) in Cambodia integrates economic and environmental accounts, tracking emissions, resource use, and socio-economic impacts at a national scale. This approach helps disentangle the complex relationships between economic growth, environmental degradation, and income distribution (Mazzoli, et al., 2022).

- Research in Cambodia's wetlands, such as the Boeung Prek Lapouv Protected Landscape, demonstrates the impact of agricultural expansion and hydrological modifications on biodiversity and community livelihoods. Monitoring has shown habitat loss, declining water quality, and threats to species, all linked to socio-economic drivers and climate change (UNEP, 2022).
- Across the Mekong Region (Cambodia, Laos, Myanmar, Thailand, Vietnam), case studies highlight how rapid economic growth and climate change are degrading ecosystems and increasing food and water insecurity. Integrated assessments in these countries help policymakers understand the links between environmental health and community well-being, supporting more resilient development strategies (UNDRR, 2019).

Adaptation Strategies: Research should prioritize identifying effective adaptation strategies for vulnerable communities reliant on agriculture and fisheries. This includes exploring alternative livelihoods and sustainable practices that can mitigate climate impacts. Adaptation strategies are actions taken to adjust to existing or expected climate impacts. These strategies aim to mitigate the negative impacts of climate change and build resilience by modifying processes, practices, and structures. They involve developing and implementing solutions to address current and future climate-related challenges.

Box 2.2: Examples of adaptation strategies in Cambodia and other countries

- The Vulnerability Assessment and Adaptation Project for Climate Change in the Coastal Zone of Cambodia (VAAP) was implemented from 2011 to 2016 with the goal of increasing resilience of coastal communities vulnerable to climate change impacts such as rising temperatures, floods, and droughts. The project rehabilitated 75 hectares of degraded mangrove forests, reconstructed 7 kilometers of dykes, installed 60 rainwater harvesting tanks, and introduced alternative livelihoods including integrated farming systems. These ecosystem-based adaptation measures benefited approximately 2,000 coastal households reliant on agriculture and fisheries across Koh Kong, Kampot, Kep, and Sihanouk provinces. The project also enhanced technical capacity, raised climate change awareness, and provided policy advice and vulnerability mapping to support adaptation planning at national and local levels (UNEP, 2017).
- The Cambodia Community Based Adaptation Programme (CCBAP) supported rural communities by promoting climate-resilient agricultural practices such as composting, integrated pest management, diversified cropping, home gardening, animal and fish raising, and small business development. These strategies improved food security, diversified incomes, and built local capacity to adapt to climate risks. The programme worked to strengthen community awareness and adaptive capacity, addressing the vulnerabilities of climate-sensitive sectors like fisheries and agriculture, which are critical for coastal livelihoods (Landesa, 2025).
- In the broader Mekong region, adaptation research has focused on community-based water management, sustainable agriculture, and alternative livelihoods to reduce vulnerability to climate shocks. These efforts are especially crucial for marginalized populations facing increased droughts and floods (UNDRR, 2019).

Heat Stress Mitigation: More studies are needed to develop interventions that protect workers from heat stress, particularly in sectors with high outdoor labor demands. This could involve exploring technological solutions or policy changes that improve working conditions. To mitigate heat stress, employers and those developing industry should focus on environmental controls, proper hydration, and work practices. This includes using air conditioning, fans, shade, and cool water, as well as adjusting work schedules and encouraging frequent breaks. Additionally, it is important to monitor weather conditions and adjust work practices accordingly, and to be aware of potential risks and provide appropriate training.

Box 2.3: Examples of heat stress mitigation

- Cambodia is piloting projects to build climate-resilient health systems, addressing risks like heatwaves and their impact on public health. Since 2019, interventions have included strengthening health

- infrastructure and capacity to respond to climate-sensitive health risks, though specific technological or policy solutions for outdoor workers are still emerging (WHO, 2021).
- While detailed case studies on heat stress mitigation in outdoor labor sectors are limited, initiatives in the Mekong region and other developing countries focus on early warning systems, improved shelter, hydration, and policy reforms to protect vulnerable workers from rising temperatures (UNDRR, 2019).

2.4.3 Policy Implications

Strengthening Climate Resilience: Future studies should inform policy frameworks aimed at enhancing resilience against climate impacts. This involves collaboration between government bodies, NGOs, and local communities to implement adaptive measures effectively.

Public Awareness and Engagement: Research should also focus on understanding public perceptions of climate change to enhance community engagement in adaptation efforts. This can help tailor interventions that resonate with local needs and realities.

Addressing these knowledge gaps through targeted research will be essential for developing effective strategies to mitigate the impacts of climate change on Cambodia's ecosystems and economy.

Several case studies highlight how effective climate resilience is built through coordinated action between governments, NGOs, the private sector, and local communities, and how important it is to understand public perceptions and foster community engagement to ensure effective adaptation efforts.

Box 2.4: Examples of climate resilience and public awareness and engagement from other countries

- National Climate Resilience Framework: The US has developed a comprehensive framework that embeds climate resilience into planning and management at all levels of government. This includes elevating infrastructure above flood zones, restoring natural infrastructure (wetlands), integrating indigenous knowledge, and ensuring federal agencies partner with local and tribal communities. The approach is explicitly collaborative, requiring input and participation from state, local, tribal, and territorial governments, as well as non-profits and the private sector (The White House, 2023).
- Stakeholder Engagement in Climate Mitigation Initiatives: Successful climate mitigation projects often hinge on multi-stakeholder engagement, including governments, businesses, non-profits, and grassroots organizations. For instance, community-driven reforestation projects have shown greater sustainability and commitment due to local investment in outcomes. Policy support and public participation are critical for tailoring interventions to local needs (Combs, 2024).
- In Del Carmen, in the Philippines, the restoration of mangroves has been a key strategy to enhance the climate resilience of coastal communities. This initiative involves collaboration between local government, NGOs, and community members, focusing on both ecological restoration and sustainable livelihoods. The project not only rehabilitated mangrove forests but also provided training and alternative income opportunities, demonstrating how multi-stakeholder partnerships can drive adaptive measures effectively (ICLEI, 2024).
- The Southeast Asia Climate Adaptation and Resilience Alliance, a partnership involving government, industry, and non-profits, has prioritized public engagement and awareness as a cornerstone of climate resilience. By combining nature-based solutions with AI-driven analytics, the alliance supports municipal planning and resource allocation, while also running campaigns to increase public understanding of climate risks and adaptation strategies. This approach ensures that interventions are informed by public perceptions and tailored to community priorities (Sivaprasad et al., 2023).

CHAPTER 3
VULNERABILITY ASSESSMENT AND EXPOSURE OF ECOSYSTEMS AND PEOPLE

3.1 Introduction

3.1.1 Overview

This chapter assesses vulnerability and exposure of ecosystems and people. The chapter begins with an assessment of current sensitivity and vulnerability. The chapter defines risks and uses various approaches and frameworks for assessing those risks. In the context of climate change, the Intergovernmental Panel on Climate Change (IPCC) has clearly defined the concept and framework of risks, as outlined in the Fifth Assessment Report (AR5) and Sixth Assessment Report (AR6). These reports identified more than 120 key risks, including 8 representative key risks, based on expert judgement, providing a degree of certainty in the risk identification process.

Spatial and temporal analysis is a crucial tool for ensuring that risk identification and assessment are well understood and reflect local and ground-level climate impacts, as well as highlighting vulnerability and exposure through geographical analysis. Several types of future climate projections are essential for accurately estimating changes in temperature, precipitation, drought, and water availability, which are necessary for a fair evaluation of susceptibility and exposure to climate hazards.

Climate change poses several dangers to Cambodia that could lead to significant losses and damages. Climate impacts on Cambodia were identified by using various future climate, social, and physical infrastructure vulnerabilities projections and modellings. Food security and livelihoods in Cambodia may be impacted by significant crop losses brought on by floods and droughts. According to the World Bank (2024a), the 2019 El Niño resulted in rice production losses estimated at USD 100 million. In the event that appropriate adaptation measures are not taken, climate change might cost Cambodia up to 9 percent of its GDP by 2050 (WB, 2024a). This chapter considers physical, economic, social, and cultural vulnerabilities, as well as prospective vulnerabilities and sensitivities.

Weak institutions, limited infrastructure, and inadequate adaptive skills increase the country's vulnerability to climate unpredictability and change. Floods disrupt supply lines, block access to essential services, and damage homes, hospitals, schools, bridges, and roads.

Climate change presents significant economic challenges to Cambodia, affecting vital industries such as tourism, agriculture, and fisheries. Climate change has a disproportionate impact on many social groups in Cambodia, particularly the underprivileged and vulnerable communities, as well as on culture heritage, erosion, and watershed areas. Due to the nation's highly susceptible conditions such as poverty, hunger, flood-prone areas, and limitations in public health services, governance, technology, and health concerns in connection to the consequences of climate change are receiving special attention. Many risks are exacerbated for Cambodia’s largely rural population.

3.2 Objective and Scope

3.2.1 Objective

The main objective of this report is to provide an assessment of the vulnerabilities and the exposure of human systems and ecosystems due to the impacts of climate change, with three primary objectives:

- Review and examine various sources, approaches, and models used to estimate the climate threats to Cambodia;
- Explore the assessment of ecosystem vulnerability and human exposure to climate change; and
- Serve as the focus of future research on several important topics to expand our knowledge and strengthen resilience, including policy and governance studies, climate change scenarios, equity and justice, ecosystem-based adaptation, health impacts, integrated assessment models, community-based participatory research, longitudinal studies, technological innovations, and interdisciplinary approaches.

3.2.2 Scope

This report covers and explores the available sources, methodologies, and vulnerability assessment framework used in IPCC, mainly the AR5 and AR6 for Cambodia's context. With the existing data and analysis, the gap and uncertainty of this chapter depends on each modelling and the data sources. The result of this chapter analysis can be different from the newly developed data and analysis to some extent.

3.2.3 Methodology and Approach

This study was conducted based on the author's relevant work, desk reviews of secondary data. The sources included studies, policies, modeling reports, academic journal articles, and related documents—particularly those available through the IPCC portal. The content was synthesized and analyzed following a specific structure and guidance framework to develop this report. The main documents consulted for this chapter include:

- IPPC's Climate Change 2022 Impacts, Adaptation, and Vulnerability
- Cambodia's Initial, Second, and Third National Communications
- The Ministry of Environment's Fourth State of Environment Report
- Relevant World Bank documents

3.3 Current Sensitivity and Vulnerability Assessment

3.3.1 Risk Assessment

Risk assessment is a process to understand the nature of risk and to determine the level of risk (ISO, 2009). This process deals with identifying potential threats, factors, and levels of vulnerability of the ecosystem and societies to the threats. Risk assessment also involves understanding the exposure to risk and coping capacity, given available resources and policy responses. Vulnerability and risk assessment encompass various approaches and techniques ranging from indicator-based global or national assessments to qualitative participatory approaches of vulnerability and risk assessment at the local level (IPCC, 2012). The risk analysis and assessments in this chapter were conducted based on scientific methodologies to identify causal links between adverse health effects and different types of hazardous events, along with mathematical theories of probability (Covello, 1985).

The IPCC developed guidelines to assess risk from climate change called the Risk Assessment Framework to examine the risks and communicate to decision-makers the potential adverse impacts of, and response options to climate change. The IPCC's Fifth Assessment Report (AR5) used different forms of evidence and expert judgment to integrate evidence into evaluations of risks combined with empirical observations, experimental results, process-based understanding, statistical approaches, and simulation and descriptive models to assess risk from climate change. These methodologies were improved to develop a consistent risk framing in the IPCC's Sixth Assessment Report (AR6). The update added aggregate levels and direction of the effect of each factor influencing to other factors. It provides a more comprehensive risk framework for understanding the increasingly severe, interconnected, and often irreversible impacts of climate change on ecosystems and human systems across regions, sectors, and communities, and coping capacity to reduce adverse consequences of these current and future impacts (IPCC, 2022). Figure 8 below describes the process of risk assessment used in AR5 and AR6, including identifying existing evidence, evidence evaluation, the levels of evidence, confidence evaluation, probabilistic evidence and likelihood of the risk (Evrin, 2021).

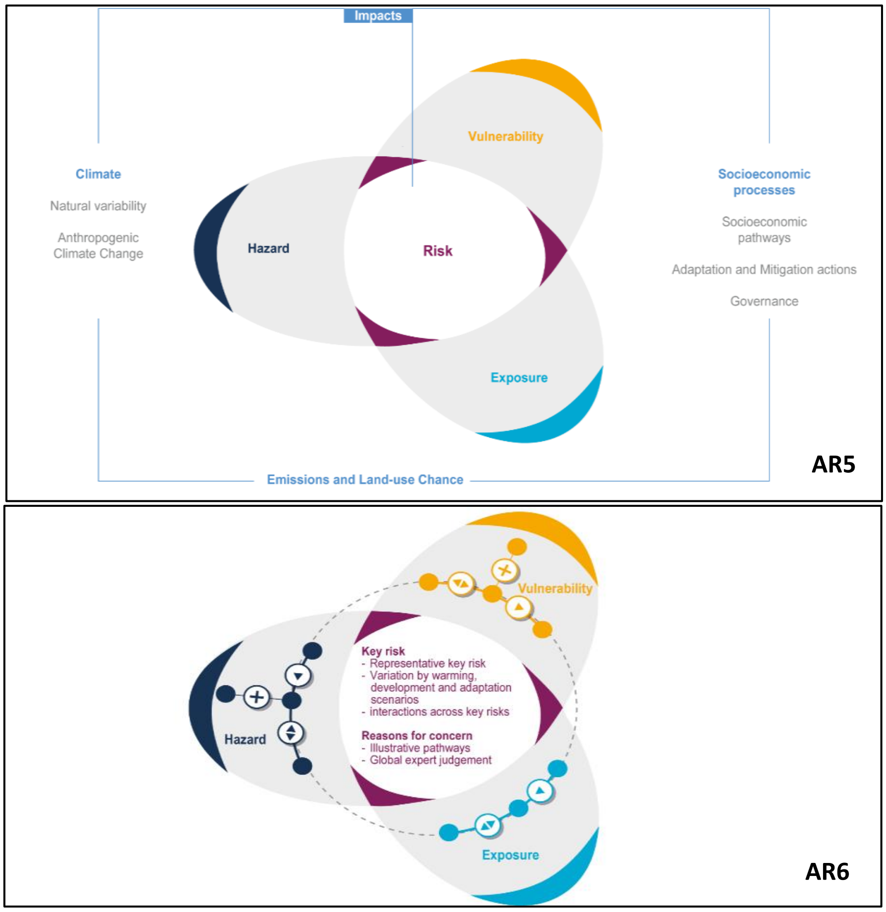


Figure 8: Risk assessment framework.
Source: (IPCC, 2022).

In Cambodia, various methodologies are employed to assess the risks posed by climate change to ecosystems and people by following the IPCC framework AR5 with different modelling. At the national level, the Royal Government of Cambodia evaluates the effect of climate change in the Initial National Communication (INC) assessment by predicting the changes in rainfall, temperature, and sea level rise (MoE, 2002). Next, the effects on the following sectors: government actions, agriculture, forests, human health, and the coastal zone include the recording of hydrological and meteorological data.

Cambodia's Third National Communication (NC3), the vulnerability to climate change at the commune level was assessed using the nationwide commune statistics from 2017 together with a review of relevant documents and expert judgment, and based on the United Framework Convention on Climate Change (UNFCCC) recommended methodological approaches and guidelines (MoE, 2022). There were eight indicators aggregated in the assessment, including (i) education level by age groups, (ii) primary occupation types, (iii) household assets and facilities, (iv) remoteness, (v) source of drinking water, (vi) sanitation facility, (vii) dependency ratio, and (viii) frequency of occurrence of climate extreme events. The assessment followed the vulnerability framework, which examines sensitivity, exposure, and adaptive capacity. Another method to analysis of the observed climate trends used the University of East Anglia's Climatic Research Unit Time Series version 4.02 (CRU TS4.02) and Asian Precipitation–Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) dataset sources. These two datasets provide the primary climate variables of temperature and precipitation, respectively, from long-term data (MoE, 2022).

The Coupled Model Inter-comparison Project (CMIP5) climate forecasts have been widely used by many scholars and World Bank and are incorporated into the database that powers the Climate Change Knowledge Portal (CCKP) (WB, 2021). With the newly updated CMIP6 is used to project effects of these changes on people, livelihoods, and economies, many of which are already underway (WB, 2024). The dataset also involves changes in important climatic parameters that are both long-term and rapidly emerging. The World Bank also used General Circulation Models (GCMs) for projecting various climatic scenarios, including creating socioeconomic scenarios. This aids in comprehending possible effects on various groups, and involving local communities and stakeholders in the evaluation process is known as stakeholder analysis.

The ND-GAIN Country Index compiles a nation's preparedness to increase resilience with its susceptibility to climate change and other global issues. The ND-GAIN calculates a nation's vulnerability considering six life-supporting sectors: food, water, health, ecological services, human habitat, and infrastructure (WB, 2021). Each sector is represented by six indicators, which are reflective of three cross-cutting components: exposure of the sector to climate-related or climate-exacerbated hazards; sensitivity of the sector to the impacts of these hazards; and the sector's adaptive capacity to cope with or adapt to these impacts. It integrates political, geographic, and social perspectives to help governments, corporations, and communities identify better investment priorities for making more effective responses to looming global challenges. This approach uses both historical and projected global climate data to assess the risks in Cambodia.

Another index used to evaluate Cambodia risk profile is INFORM Country Risk 2025. It profiles contain more in-depth information on each country on hazard and exposure, vulnerability, and lack of coping capacity (European Commission, 2025). In addition to the results in the global list, country risk profiles show trends, comparisons with countries with similar risk, regional and income-group averages and more detailed information at the indicator level. These profiles can be used to provide a deeper understanding of risk in a particular country.

One notable approach is the Rapid Assessment of Climate Change Vulnerability and Adaptation Planning, developed by the International Union for Conservation of Nature (IUCN). This methodology focuses on assessing the vulnerability of wetlands, wetland species, and communities to climate change. It involves a series of steps, including defining vulnerability, conceptualizing socio-ecological systems, and using rapid vulnerability assessment tools to identify adaptation strategies.

The nexus approach examines several systems, such as food, energy, and water, to evaluate risk. Emerging ideas for integrated adaptive governance include the Circulating and Ecological Sphere (CES), which refers to a decentralized and self-sufficient community. The connections between disaster risk reduction (DRR) and climate change adaptation (CCA) are highlighted as part of a sustainable development pathway. Surface air temperature is used to illustrate the threat posed by heatwaves, droughts, and floods, as well as the spatiotemporal diversity of future impacts on food production. This analysis shows that different scales of climate change will result in winners and losers (MoE, 2022).

Climate risk modeling and forecasts in Cambodia are constrained by the suitability of models to the Cambodian context as well as inadequate data. Since the new AR6 risk assessment framework has only recently been established, the application of this framework in risk and vulnerability assessment in Cambodia is still limited. More financial resources, as well as enhanced technological and scientific capabilities, are required for effective vulnerability assessments.

3.3.2 Risk Identification

Key risk groups have been identified and deserve special attention, including the risks to food security and safe drinking water, risks to critical infrastructures, economies, health, and peace, as well as risks to ecosystems and coastal areas. The IPCC defines more than 120 key risks across sectors and regions, which were classified into a set of 8 overarching risks, called representative key risks, which can occur from global to local scales but are of potential significance for a wide diversity of regions and systems globally (IPCC, 2014).

In AR6, the key risks assessment was improved and specify by identifying the representative key risks (see Table 6), including risks to (a) low-lying coastal areas, (b) terrestrial and marine ecosystems, (c) critical infrastructures and networks, (d) living standards, (e) human health, (f) food security, (g) water security and (h) peace and human mobility (IPCC, 2022).

Table 6: Climate-related representative key risks.

Code	Rep. Key Risk	Scope
RKR-A	Risk to low-lying coastal socio-ecological systems	Risks to ecosystem services, people, livelihoods and key infrastructure in low-lying coastal areas, and associated with a wide range of hazards, including sea level changes, ocean warming and acidification, weather extremes (storms, cyclones), ice loss, etc.
RKR-B	Risk to terrestrial and ocean ecosystems	Transformation of terrestrial and ocean/coastal ecosystems, including change in structure and/or functioning, and/or loss of biodiversity.

RKR-C	Risks associated with critical physical infrastructure, networks and services	Systemic risks due to extreme events leading to the breakdown of physical infrastructure
RKR-D	Risk to living standards	Economic impacts across scales, including impacts on gross domestic product (GDP), poverty and livelihoods, as well as the exacerbating effects of impacts on socioeconomic inequality between and within countries.
RKR-E	Risk to human health	Human mortality and morbidity, including heat-related impacts and vector-borne and waterborne diseases.
RKR-F	Risk to food security	Food insecurity and the breakdown of food systems due to climate change effects on land or ocean resources.
RKR-G	Risk to water security	Risk from water-related hazards (floods and droughts) and water quality deterioration. Focus on water scarcity, water-related disasters and risk to indigenous and traditional cultures and ways of life.
RKR-H	Risks to peace and to human mobility	Risks to peace within and among societies from armed conflict as well as risks to low-agency human mobility within and across state borders, including the potential for involuntarily immobile populations.

Source: (IPCC, 2022).

These key risks are expected to increase in the coming decades, depending not only on the extend of climate change, but also on changes in societal exposure and vulnerability, as well as the effectiveness of adaptation efforts in reducing the magnitude of severe risks (IPCC, 2022). According to the research, the dangers are greatest when growth paths that maintain high levels of poverty and inequality, subpar health systems, a lack of funding for infrastructure, and other traits that make countries extremely vulnerable are combined with high levels of global warming. Over the course of this century, some hazards in industrialized nations could also get worse. For instance, if climate change has an impact on vital infrastructure like transportation hubs, power plants, or financial centers, those risks could become quite serious. Climate hazards are already deemed high in some situations, such as coral reef habitats and locations already severely impacted by significant extreme events (e.g., recent typhoons or wildfires).

These alterations demonstrate the prevalence of hazards in ecosystems and alter the rights to contact, ecosystem structure, timing, and species range shifts in various Asian ecosystems. The main effects of climate change on the nation's ecosystems are listed as hazards in Asian ecosystem (IPCC, 2022). Fish and invertebrate species distribution is shifting and there is a decline in the possibility for fishing in low latitudes, such as in sub-tropical gyres, equatorial upwelling, and coastal boundary systems (high confidence). Reduced fisheries abundance, biodiversity, and coral reef species along the coast as a result of heat-induced mass coral bleaching and mortality increases that are made worse by ocean acidification, such as in sub-tropical gyres and coastal boundary systems (high confidence). Due to changes in precipitation patterns, intense weather, rising sea levels, and decreased ecological resilience, there will be a loss of habitat along the coast e.g., in coastal boundary systems and sub-tropical gyres (medium to high confidence) (IPCC, 2022).

According the ND-GAIN Country Index, Cambodia was rated the 55th most vulnerable country out of 191 countries in 2019 with a high disaster risk to flood, especially flash and riverine floods (WB, 2021). Cambodia also faced tropical cyclones and severe drought in 2015-2017. Recently, Cambodia was rating 58th most vulnerable country to climate change in 2022 with the overall ranking 149th out of 192 counties. Cambodia has low scores on projected change of cereal yields in food, medical staff in health, and paved roads in human habitat. In the future, Cambodia will likely face exposure to drought, extreme heat, wildfire, and sea level rise. With the exposure of ENSO, provinces in Cambodia may be affected more by flood and landslides.

The INFORM Country Risk Index ranks Cambodia 56th out of 191 countries in 2025 (European Commission, 2025). In addition to the global ranking, country risk profiles show trends, comparisons with countries with similar risks, regional and income-group averages and detailed information at the indicator level. These profiles can be used to gain a deeper understating of the risks in a particular country.

Risk assessment in Cambodia needs to be updated due to the new risk framework in AR6, the instant changes in climate, newly developed and scientific research with more accurate methods and datasets. Proper future risk management needs to be carried out to reduce those risks.

3.3.3 Spatial and Temporal Analysis

Spatial and temporal analysis is crucial for understanding climate risks, as examines how climate impacts vary across different locations and over time. Spatial Analysis helps to understand the geographical distribution risks, allocate resources effectively, and design contextualized interventions, more vulnerable to climate risks, such as coastal areas prone to sea-level rise or regions with high flood risks (MoE, 2022). In addition, spatial analysis ensures that interventions are tailored to the specific needs and conditions of each area. Temporal analysis tracks changes in climate patterns over time, helping to identify trends such as increasing temperatures, changing precipitation patterns, or more frequent extreme weather events, assessing the long-term impacts on ecosystems and human populations (MoE, 2022).

O'Brien (2004) highlighted that societies face dynamic vulnerability in many areas of climate change and natural hazards, where multiple scales of processes and factors simultaneously contribute to vulnerability, rendering traditional indicators inadequate. Vulnerability analysis, especially related to institutional vulnerability, must account for the different functional scales at which climate change, natural hazards, and administrative systems operate.

Current disaster management tools and urban or spatial planning measures, such as specific plans, zoning, and norms, often operate on different functional scales than to climate change. Even the various hazards that climate change may alter encompass different functional scales. Together, spatial and temporal analysis provides a comprehensive view of climate risks, enabling more informed decision-making and effective risk management strategies. These forms of analysis help in understanding the dynamic nature of climate impacts and in developing adaptive measures that are both location-specific and time-sensitive (Evrin, 2021).

Climate risks in Cambodia differ greatly across regions due to various geographical and socio-economic factors. In the central plains, including the areas around Tonle Sap Lake and the Mekong River, seasonal flooding is common. While floods can replenish soil nutrients, extreme flooding events can devastate agriculture and displace communities. This region also faces drought risks, which can severely affect rice production and water availability (WB, 2023). The highland areas in the northeast and southwest experience greater temperature fluctuations, impacting biodiversity and agricultural practices. Coastal areas, especially in the southwest, are highly susceptible to sea-level rise, leading to coastal erosion, saltwater intrusion, and increased flooding. These regions also face threats from storm surges linked to tropical cyclones, which can significantly damage infrastructure and ecosystems. Urban centers like Phnom Penh increasingly experience heatwaves, which exacerbate health issues and put a strain on energy resources. Urban flooding is also a concern, due to inadequate drainage systems and increased rainfall intensity, as shown in Figure 9.

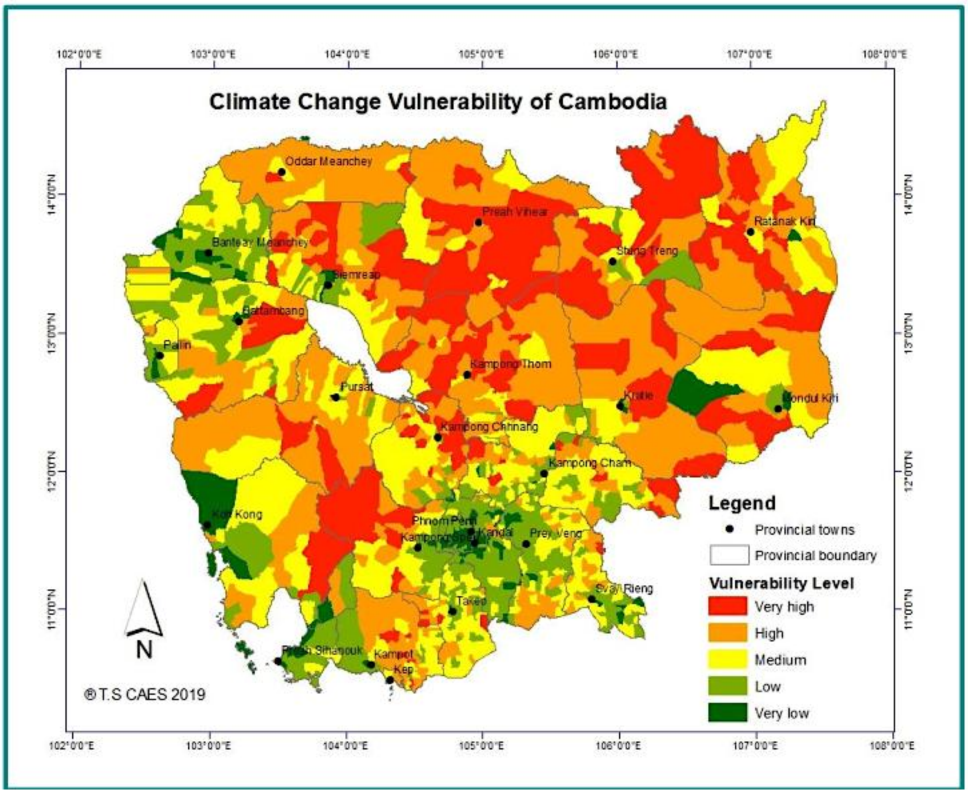


Figure 9: Map of climate change vulnerability in Cambodia.
Source: (MoE, 2022).

Figure 3.9 illustrates that the region's most vulnerable to climate change are the northern and eastern areas, which extend from the country's center and are categorized as Highly and Very highly vulnerable. Eight provinces are included in this analysis: Oddar Meanchey, Kampong Thom, Kratie, Mondulkiri, Ratanakiri, Stung Treng, Preah Vihear, and Siem Reap. Preah Vihear and Kampong Thom provinces include the most important hotspots. Furthermore, a large number of communes in the provinces of Pursat, Kampong Chhnang, and Kampong Speu have been classified as having high to extremely high vulnerability (MoE, 2022). The northwest, which includes Phnom Penh and the provinces around it, Banteay Meanchey, and Battambang, is the least vulnerable. The provinces of Koh Kong and Preah Sihanouk are depicted in dark green and green, respectively, however it's crucial to remember that sea-level rise threats were left out of this evaluation because of data constraints (MoE, 2002).

3.4 Projections for Future Climate Risks in Cambodia

3.4.1 Amount, Frequency, and Intensity of Rainfall

Evidence from several parts of Asia suggests that the severity of sub-daily intense rainfall episodes is rising with warmth. The scant information on Cambodia that is now available generally confirms this pattern; however, more study is necessary (MoE, 2022). A range of model predictions shows that the amount, frequency, and intensity of rainfall have changed drastically due to the impact of climate change. Cambodia's Third National Communication predicted the precipitation changes in Cambodia based on the University of East Anglia's Climatic Research Unit Time Series version 4.02 (CRU TS4.02) and Asian Precipitation–Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) (MoE, 2022). The study indicates that rainfall changes under RCP4.5 will be minor, +/- 10 percent. Under RCP 8.8, changes will be slightly higher, +/- 20 percent in 2080 (see Figure 10).

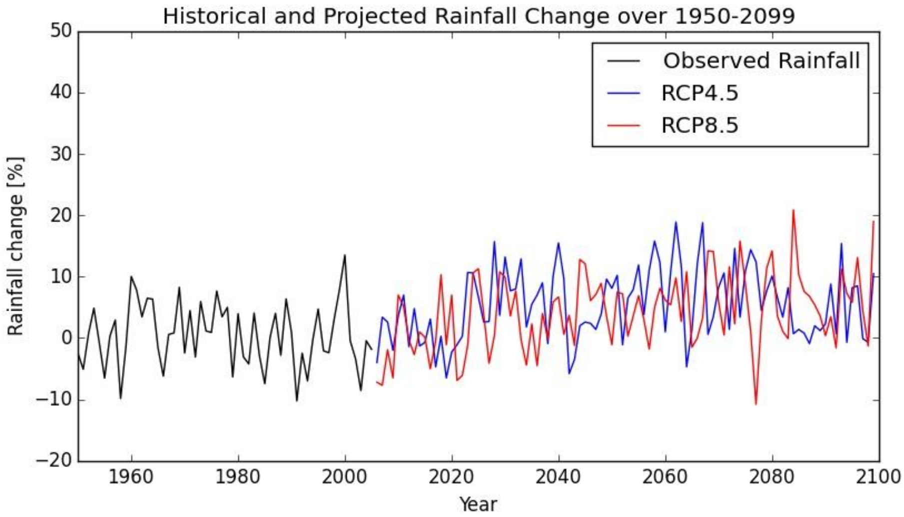


Figure 10: Rainfall trends for Cambodia.
Source: (MoE, 2022).

The General Circulation Models (GCM), with quality assurance from CMIP 5 (AR5), show similar predicted changes to rainfall patterns under RCP4.5 and RCP8.5 scenarios. Average annual precipitation under the RCP4.5 is more than 1800 mm, with a range between 1400 mm to 2600 mm (see Figure 11) (WB, 2021). However, RCP8.5 indicates that annual precipitation will increase to over 1900 mm, with a range between 1200 mm to over 2800 mm (WB, 2021). Based on these results, climate change will cause changes in precipitation patterns and increase the uncertainty and magnitude of the rainfall compared to the historical average annual precipitation of approximately 1800 mm, with a range of 1400 mm to 2400 mm (see Figure 11).

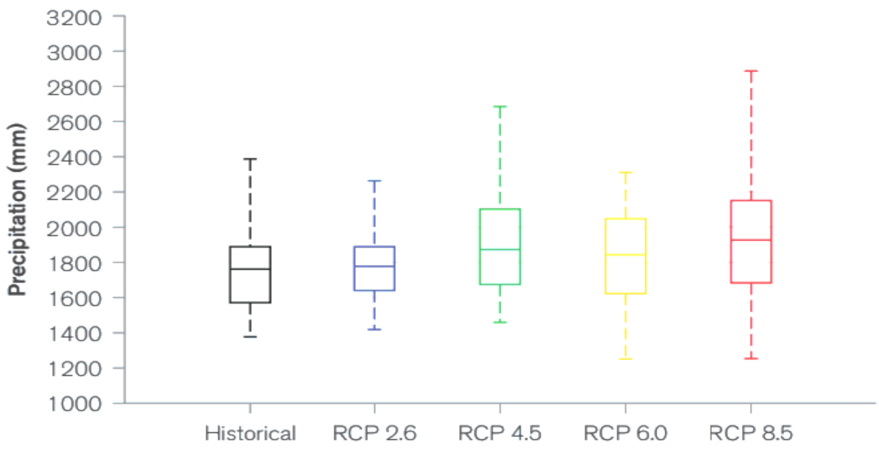


Figure 11 Average annual precipitation projection for Cambodia 2080-2099.
Source: (WB, 2021).

Based on CIMP 6 in AR6 with more accurate and improved methodology, in SSP2-4.5, the annual rainfall will average around 1800 mm from 2080 to 2099, while in SSP2-8.5, the rainfall will rise to almost 2000 mm (see Figure 12). This is similar to previous models, however, in this modelling, climate change will make the intensity of rainfall change smaller than in CIMP5, 1250 mm to 2500 mm, with a range between 1200 mm to over 2800 mm. This change results from improvement and more data for new modelling in CIMP6 to improve the accuracy of the projection.

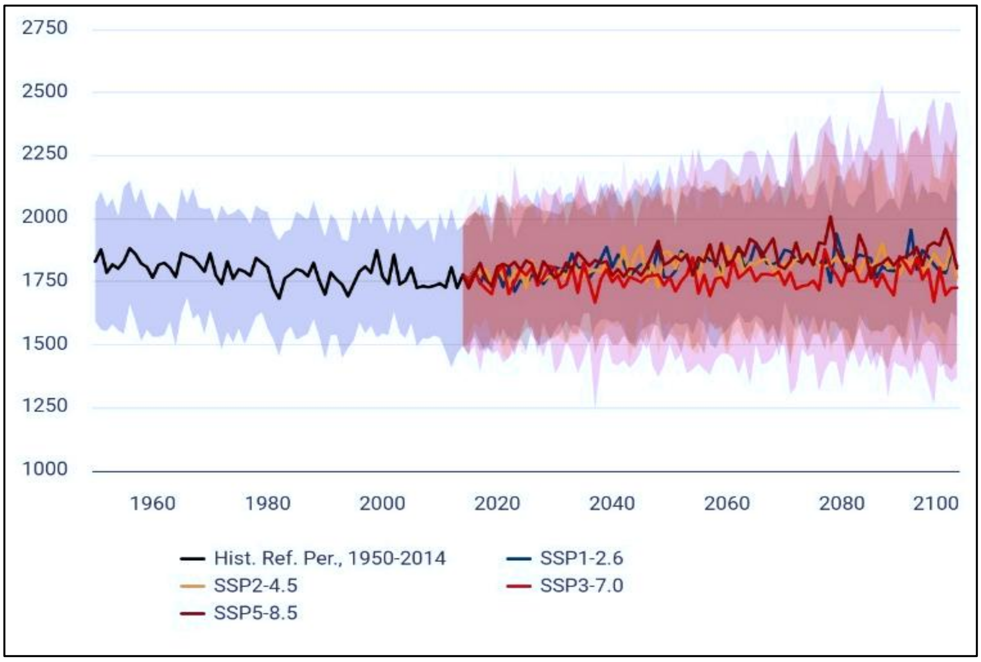


Figure 12: Precipitation projection.
Source: (WB, 2024b).

The quantity, frequency, and intensity of rainfall vary due to climate change, which has an impact on ecosystems, public health, and the country's economy in Cambodia. Variations in rainfall can cause habitat loss and fragmentation, which can have an impact on the stability of ecosystems and species diversity. Freshwater ecosystems can be harmed by both increased and decreased rainfall, which can result in flooding and droughts, respectively (NOAA, 2021). Increase in rainfall and flooding can cause an increase in waterborne illnesses, including diarrhea and cholera, which will affect the human health system (WHO, 2024). Variations in the patterns of rainfall can make heat stress worse, especially in the dry seasons. Unpredictable rainfall patterns will have an impact on crop yields, which will impact the county's economy and may result in food shortages. Heavy rains and flooding can harm infrastructure, increasing the cost of repairs and creating a negative economic impact. These effects emphasize how crucial it is to help agriculture and other sectors adjust to shifting rainfall patterns.

3.4.2 Hazards and Risks from Rainfall

Cambodia is the fourth most flood-prone country in the world according to the Inform Risk Index (WB, 2021). Eighty percent of the country's population lives in the Mekong and Tonle Sap floodplains, which are particularly vulnerable to riverine floods. During periods of intense rainfall, particularly during tropical cyclones, the monsoon, and typhoon seasons, Cambodia is also highly vulnerable to flash flooding. In Cambodia, significant flooding incidents occur roughly every five years. The 3rd NDC showed that in the south-east part of the country, annual rainfall will increase much more likely to the coastal areas. In the north-west of the country, the annual rainfall will decrease by 25 mm annually (see Figure 13) (MoE, 2022).

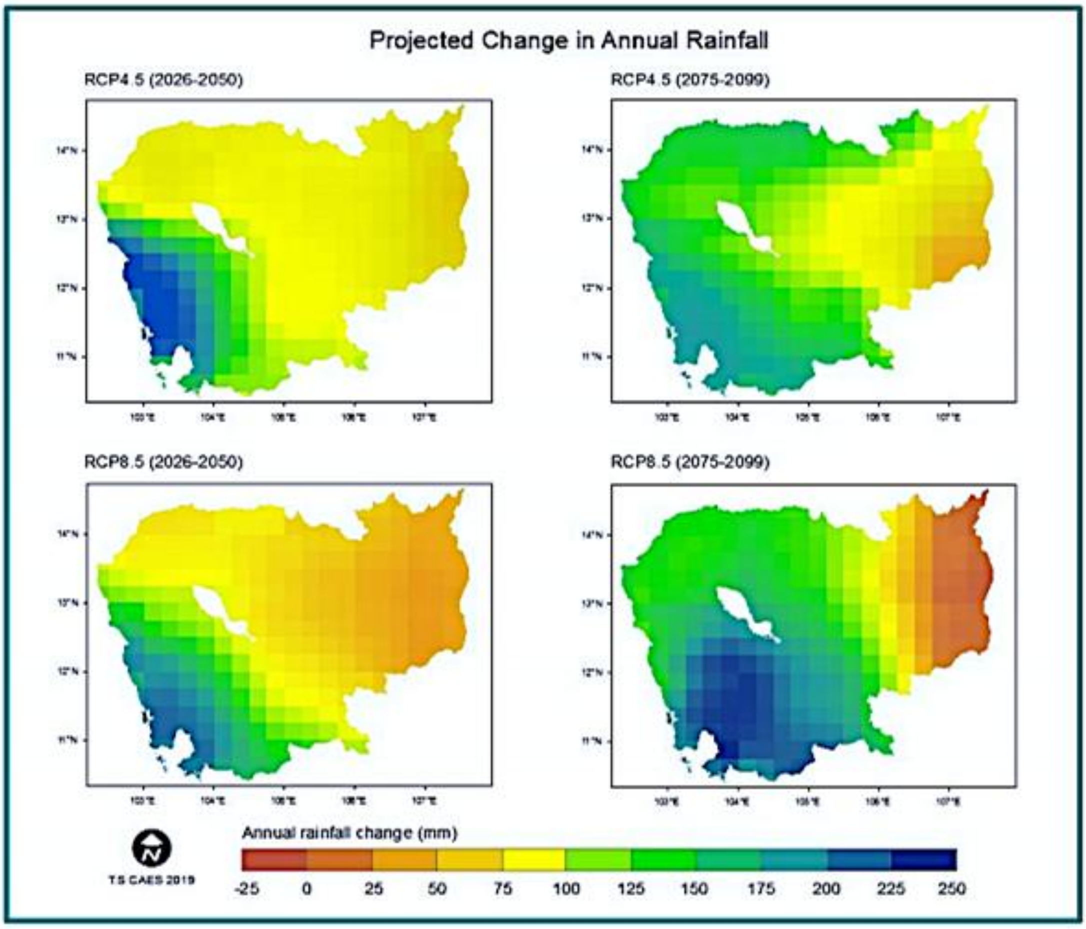


Figure 13: Annual rainfall change (mm).
Source: (MoE, 2022).

Built-up areas of Phnom Penh and major urban towns along the Mekong River (Stung Treng, Kratie, Kampong Cham) are particularly vulnerable, according to analysis conducted for the climate change development report (CCDR) (WB, 2023). The Mekong River, particularly the heavily populated capital city of Phnom Penh and the upstream Mekong Basin, has the highest risk of flooding-related fatalities. In the Tonle Sap region, especially in Battambang, Banteay Meanchey, Kampong Thom, and Siem Reap, where over 7,500 hectares of agricultural land are vulnerable to flooding, agricultural land is most at risk, as shown in Figure 13 (Hrast Essenfelder et al., 2022**).**

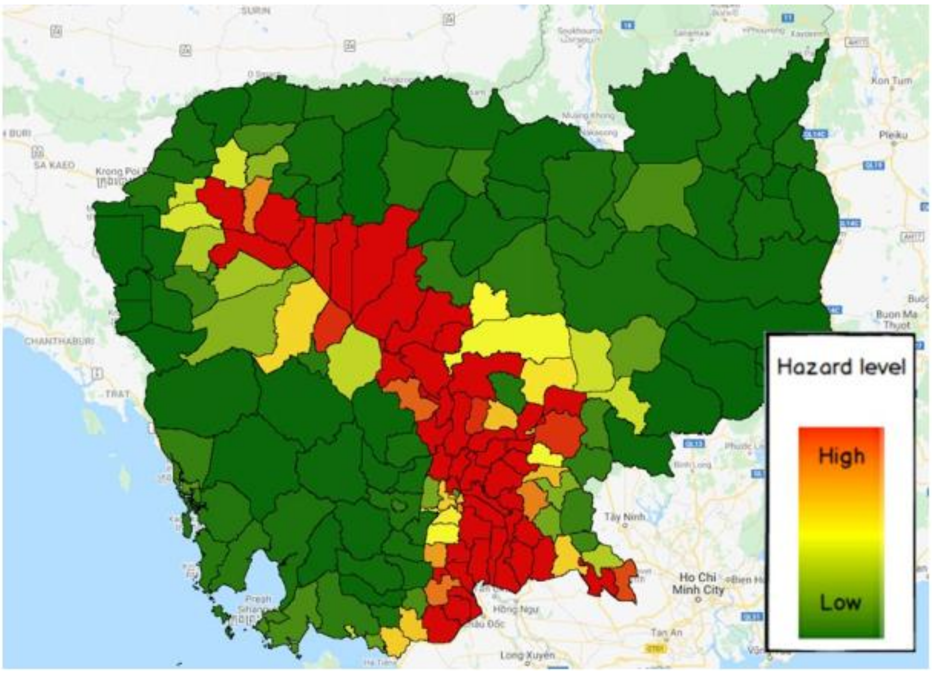


Figure 14: Flood hazard map.
Source: (WFP, 2020).

WFP identified flood hazard levels by using Near Real-Time (NRT) water maps using the NCDM disaster loss-database and other sources, validated by imagery extracted in September 2018. Similar to the World Bank study, results showed that areas around the Tonle Sap Lake and Mekong Basin face high risk of flooding, shown in red in Figure 14.

The economic loss due to floods has been substantial. For instance, the 2020 floods alone resulted in an estimated economic loss of USD 448-490 million (WB, 2023). These floods affected key sectors such as transport, irrigation, and agriculture, causing widespread damage and disruption. A baseline level of flood exposure can be determined using the AQUEDUCT Global Flood Analyzer from the World Resources Institute. As of 2010, the estimated annual population affected by floods in Cambodia is 90,000, and the anticipated annual urban damage is USD105 million, assuming a projection for up to a 1 in 25-year event. These numbers are predicted to rise in response to both economic expansion and climate change. It is possible to separate out the impact of climate change, which is predicted to impact 70,000 people and cause USD 226 million in urban damage under the RCP8.5 emissions pathway (AQUEDUCT Scenario B).

While less common than other hazards, landslides and cyclones can occur in Cambodia. Between April and November, there are an average of six tropical cyclones (typhoons) that affect Cambodia each year. Tropical Cyclone Noru (Category 5) struck northern Cambodia in September 2022, resulting in floods along the Mekong River. The provinces of Svay Rieng and Kampot, where about 230 hectares of agricultural land are predicted to experience some degree of loss owing to yearly tropical cyclones, are particularly vulnerable, according to the analysis for this CCDR. Koh Kong, Battambang, and Kampong Chhnang are particularly vulnerable to landslide threats (WB, 2021).

3.4.3 Hazards and Risks from Drought

Cambodia is highly vulnerable to climate change, with certain provinces being more susceptible to the impacts of decreasing rainfall and drought. At lower levels of global warming, this trend is less significant; nevertheless, once temperature approaches 2-3°C, phenomena that currently occur only once every hundred years may begin to occur more frequently, more than once every fifty years. Using multiple General Circulation Models (GCM) and quality-assured data from CMIP 5 in AR5, the probability of drought occurrence is estimated to be around 0.30 under RCP 4.5 and 0.5 under RCP 8.5 (see Figure 15a). Based on CIMP 6 in AR6, the probability of drought by 2100 is projected to be approximately 0.29 under SSP2-4.5 and 0.67 under SSP2-8.5 (see Figure 15b). These findings consistently indicate that the amplification of drought is more likely to occur in the future due to climate change.

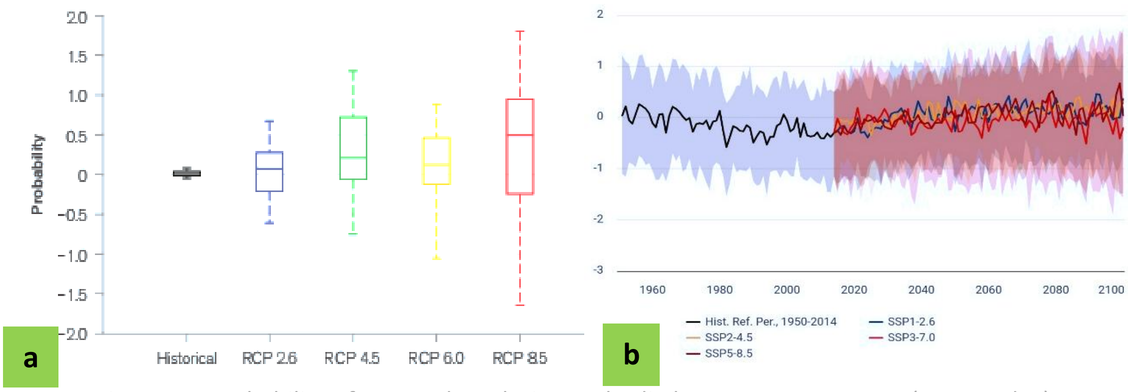


Figure 15: Probability of severe drought in Cambodia between 20280-2099 (2SPEI Index). Source: (WB, 2021; WB, 2024b).

The provinces most affected include Battambang, Banteay Meanchey, Pursat, Kampong Speu and Kampong Thom (WB, 2023). These provinces face significant challenges due to their reliance on agriculture, which is heavily impacted by changes in rainfall patterns and prolonged droughts. The model ensemble's projected likelihood of drought in Cambodia under various emission pathways between 2080 and 2099 (see Figure 15b).

There are two main types of droughts that impact Cambodia: hydrological, which are typically connected with a deficit in surface and subsurface water flow, potentially originating in the region's larger river basins, and meteorological, which are generally related to a shortfall in precipitation. Droughts occur frequently due to variations in rainfall, with the southeast and Pailin province being the most vulnerable. Every five-to-six years, the most vulnerable provinces—Phnom Penh, Svay Rieng, Prey Veng, and Pailin—are severely impacted, with over 30percent of agriculture suffering from drought stress. Rice and maize are both vulnerable to drought, which increases the likelihood of crop failures and food shortages. Sadly, this risk came to pass in 2015–2016 when a severe drought struck 18 out of 25 provinces, affecting almost 2.5 million people. ESCAP (2015) also identified the risk of drought to agriculture, which is highlighted in red in the figure on the right-hand side of Figure 16.

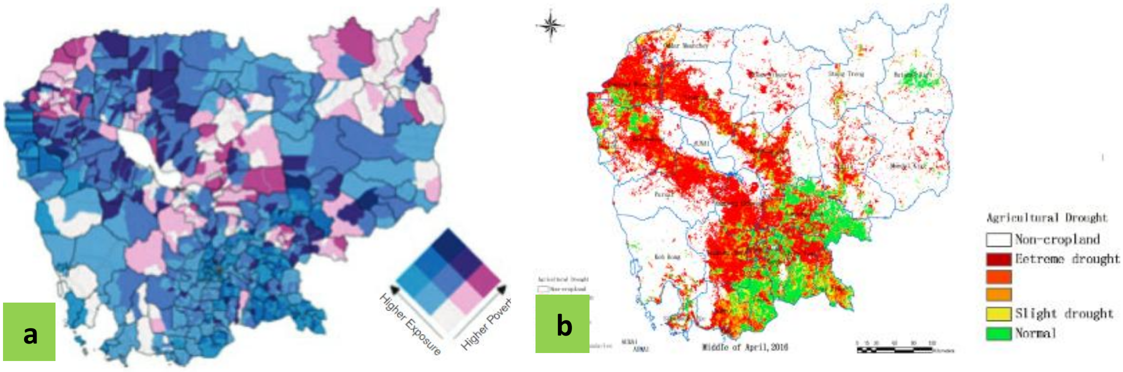


Figure 16: Map of drought risk in Cambodia
Source: (WB, 2023; ESCAP, 2015)

The economic impact of decreasing rainfall and drought in Cambodia has been substantial. Over the past five years, chronic droughts have cost the country more than USD 100 million. The fourth Cambodia State of Environment Report estimated that droughts cost USD 21 million in 2015, USD 8.5 million in 2016, USD 6.7 million in 2017, USD 30 million in 2018 and USD 37 million in 2019 (MoE, 2021). These figures highlight the severe economic strain that droughts place on Cambodia's agricultural sector, which is a critical part of the country's economy. Additionally, projections suggest that without proper adaptation and mitigation measures, climate change could cost Cambodia up to 9 percent of its GDP by 2050 (WB, 2023).

3.4.4 Rainfall and Water Availability

Decreasing rainfall during the dry season as a result of climate change impacts water management, which is compounded by the increase in extreme weather events and the potential for worsening of seasonal water shortages and floods. These difficulties pose a greater threat to developing nations like Cambodia, where meteorological systems are still unable to predict catastrophic weather events such as flash floods and unexpected droughts, which are common in the region. Cambodia is heavily reliant on the water resources provided by both flood and the natural river flow regimes. Maintaining the flow levels required to support ecosystem services is a major focal area addressed in Cambodia's NC2 and NC3, particularly in light of the huge changes to future water flows that will probably be made worse by climate change (MoE, 2015; MoE, 2022). An EU study on water-level changes due to the climate impact shows that there has already been a high level of water change in basins like Tonle Sap Lake and the Lower Mekong River, as shown in Figure 17 (EU, 2018).

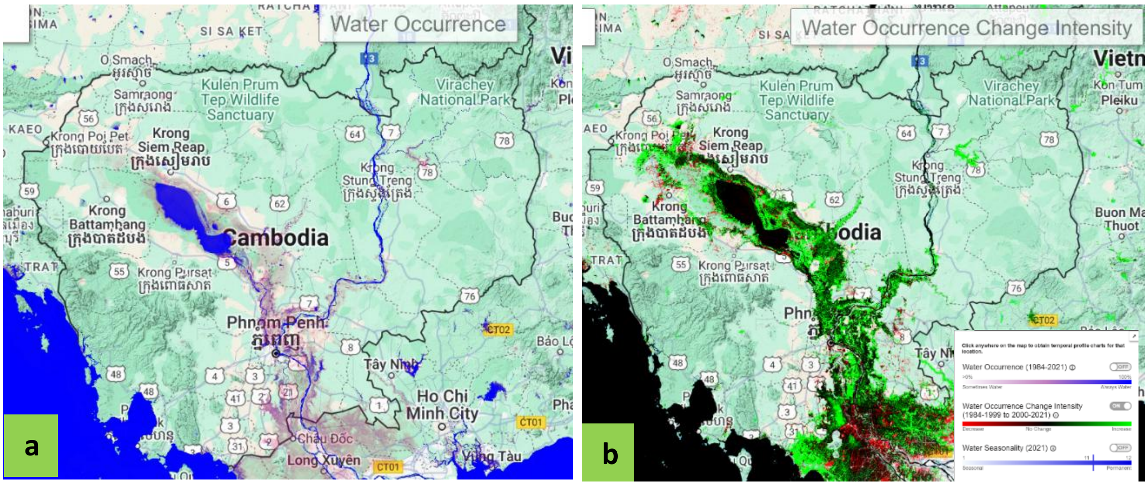


Figure 17: Water occurrence change.
Source: (EU, 2018).

The range of anticipated impacts on water occurrence change due to climate change by 2060 is expected to be the following: the range of annual river flow change is estimated as -38 percent to +28 percent; water level -1.95m to +1.29m; peak flow during the flood season -30 percent to +43 percent; peak level during the flood season -2.83m to +2.96m; minimum 1-day flow -21 percent to +79 percent; and minimum 1-day level -0.18m to +0.90m (MoE, 2022). The alteration in hydrological level and flow will have a more significant impact on several industries, such as agriculture, natural resources, socio-economic systems, he fishing industry, and the individuals whose lives are wholly dependent on these activities. It was determined that if mitigation and adaptation measures are not put into practice, there would be a considerable shift and loss in the ecosystem services that drive ecological production, including habitat cover, net primary productivity, and sedimentation (Shrestha et al., 2016). Without mitigation and adaptation, the consequences of climate change will be linked to a reduction in ecosystem services that diminish ecological production, including NPP, sedimentation, and habitat cover.

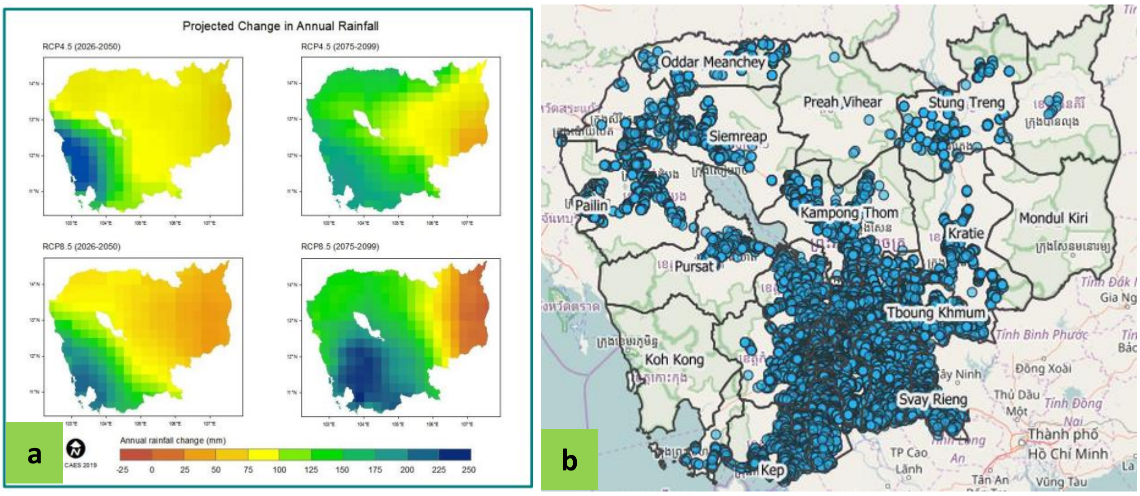


Figure 18: Projected annual rainfall changes and wells.
Source: (MRD, 2023; MoE, 2022).

Periods of low rainfall can significantly impact water availability in Cambodia, affecting both groundwater and surface water resources (see Figure 18). Reduced flow in rivers and streams due to low rainfall can limit the amount of surface water available for use in hydropower, agriculture, and drinking water. Reservoirs and lakes rely on consistent rainfall to maintain their levels. During periods of low rainfall, the surface water bodies can shrink, reducing the water available for public supply and irrigation (NOAA, 2024).

Groundwater relies on rainfall to replenish aquifers. When rainfall is insufficient, the recharge rates drop, leading to lower groundwater levels. During droughts, there is often an increased reliance on groundwater to meet water demands. This can lead to over-extraction, causing the water table to drop further and potentially leading to long-term depletion of groundwater resources (NOAA, 2024). As shown in figure 3.18, rainfall will decrease in the northwest, including Modulkiri and Ratanakiri and some underground water and wells will face scarcity.

The combined effect of reduced surface water and groundwater can lead to significant water scarcity, impacting agriculture, industry, and daily life. Lower water levels can also lead to deterioration in water quality, as contaminants become more concentrated in smaller volumes of water (NOAA, 2024). Cambodia's agriculture, which heavily relies on both surface and groundwater, can suffer during periods of low rainfall, leading to reduced crop yields and economic stress for farmers. Both urban and rural areas may face challenges in accessing clean water, with rural areas particularly dependent on groundwater during dry seasons. Addressing these challenges requires integrated water resource management, including improving water storage infrastructure, promoting efficient water use, and enhancing monitoring and management of both surface and groundwater resources.

3.4.5 Temperature Impact on Evapotranspiration

Generally, higher temperatures increase the rate of evaporation from soil and water bodies, as warmer air can hold more moisture, leading to more water being drawn from the surface. Plants open their stomata (tiny openings on leaves) more frequently in higher temperatures to cool themselves, which increases the rate of transpiration. This means more water is released into the atmosphere from plant surfaces. With rising temperatures, the atmosphere's demand for moisture increases, leading to higher evapotranspiration (ET) rates. This can exacerbate water deficits, especially during dry seasons.

According to the result of modeling by CMIP5 and CMIP6, the number of days with temperature exceeding 35°C is projected to increase to 200 days – 250 days per year by 2100 under worst-case scenarios RCP 8.5 and SSP5-8.5. The frequency of days with a heat index of more than 35°C, which indicates the combination of temperature and humidity to create conditions hazardous to human health, may be used to quantify the degree of this risk at the national level. By the 2090s, it is anticipated that the average yearly frequency of hazardous days would rise under all emissions scenarios, with the highest emissions track, RCP 8.5, potentially seeing a particularly significant increase as shown in Figure 19 (WB, 2023; WB, 2024b).

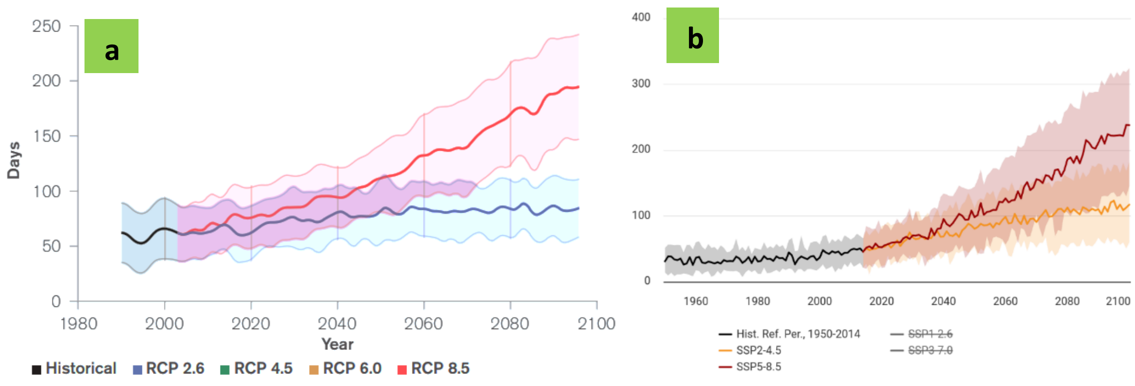


Figure 19: Historical and projected heat index 2060-2099 > 35°C.
Source: (WB, 2023; WB, 2024b).

Cambodia is already a hot country, with an estimated 64 days on average each year when the maximum temperature is more than 40 °C. Currently, there is a 3 percent chance that there will be a heat wave, which is defined as three or more days where the daily mean temperature rises beyond the long-term 95th percentile. In recent decades, there has been a rise in both the frequency and intensity of heatwaves. Based on the available data, it can be concluded that Cambodia is likewise experiencing a shift towards permanent heat stress due to consistent temperatures above what is considered tolerable for both human habitation and biodiversity.

In Cambodia, ET, or the movement of water from the land to the atmosphere through plant transpiration and evaporation from soil and water surfaces, is greatly impacted by temperature increases. Cambodia's agriculture, which heavily relies on consistent water availability, could face challenges. Increased ET can lead to soil moisture depletion, affecting crop yields and requiring more irrigation. Higher ET rates can reduce the availability of surface water and groundwater, impacting water supply for domestic, agricultural, and industrial uses. Natural ecosystems, such as wetlands and forests, may experience stress due to increased water loss, affecting biodiversity and ecosystem services (WB, 2021).

Cambodia has experienced a temperature increase of approximately 0.18°C per decade, with projections indicating further increases (WB, 2023). As temperatures continue to rise, ET rates are expected to increase, intensifying the need for adaptive measures in water management and agriculture. Implementing green infrastructure like urban parks, green roofs, and rain gardens can help manage water resources more sustainably (see Figure 20). Techniques such as drip irrigation can reduce water use while maintaining crop yields. Raising awareness and educating communities about water conservation and climate adaptation strategies is essential. Understanding and managing ET is crucial for climate resilience. Cambodia can better prepare for and mitigate the impacts of climate change on its water resources and agricultural productivity, through strategies like efficient irrigation, drought-resistant crops, and water conservation practices.

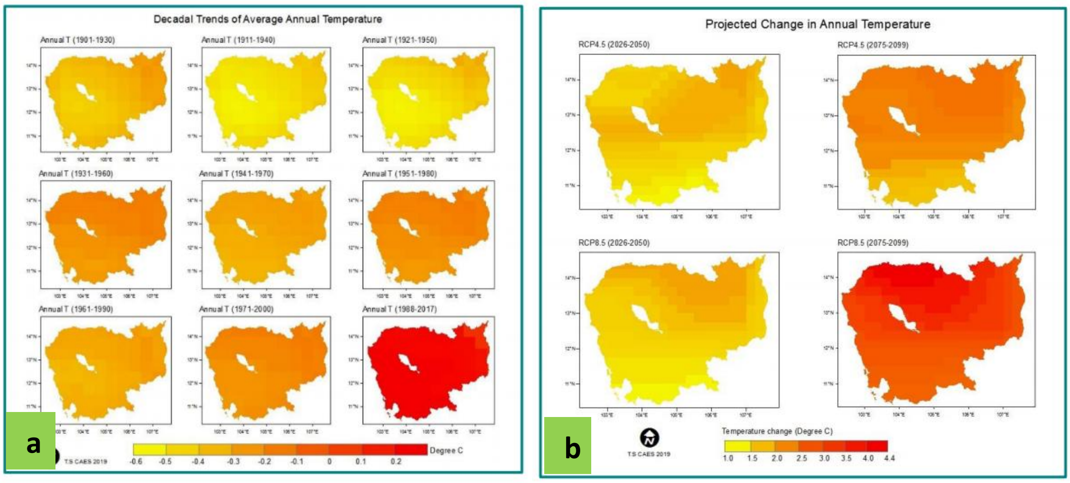


Figure 20: Annual temperature.
Source: (MoE, 2022).

In addition, cities in Cambodia are particularly vulnerable to urban heat island effects, which intensify high temperatures in metropolitan regions as a result of built-up areas. Cambodia is among the top 23 nations with acute exposure to extreme heat, with an average of 64 days per year with a maximum temperature over 40°C. The country also experiences some of the highest temperatures in the globe. The mean urban temperatures in 2020 in Poipet, Siem Reap, Phnom Penh, and Battambang were 36.7, 35.5, 35.2, and 35.2°C, respectively. This is in contrast to 31.9°C in a sample of 100 East Asian and Pacific cities. Urban heat island effects are considerable in Phnom Penh and Siem Reap; in 2020, the urban areas of both cities reported temperatures that were 1.16 and 1.19°C higher than the non-urban areas (WB, 2021)

Since roads and buildings reflect and absorb solar radiation more than natural landscapes do, their construction exacerbates the heat island effect. The urban poor are particularly susceptible to the negative effects of heat on their health and productivity because they frequently labor outside and typically live-in cramped dwellings without proper air conditioning or ventilation.

3.4.6 Risks, Damage, and Loss

Climate change poses various risks to Cambodia, leading to significant damages and losses. These can be categorized into economic, environmental, and social impacts. Climate change offers considerable economic concerns to Cambodia, notably in the agriculture sector. Changes in weather patterns, such as increasing temperatures and changing rainfall, can affect agricultural yields, leading to food shortages and higher costs. Cambodia's agriculture sector, particularly rice production, is highly vulnerable to climate variability. Droughts and floods can lead to substantial crop losses, affecting food security and livelihoods. For instance, the 2019 El Niño caused rice production losses estimated at USD 100 million (WB, 2024a). This in turn impacts both farmers and consumers, generating economic instability. Increased frequency and intensity of floods can damage infrastructure such as roads, bridges, and buildings, disrupting economic activities and increasing repair costs. Health expenditures also grow as climate change enhances the spread of illnesses and produces more frequent heat waves, leading to increased healthcare expenses.

Without intervention, WB, MEF, and GSSD indicate that the effects of climate change might decrease Cambodia's GDP by 3-9 percent by 2050 (Figure 3.21) (WB, 2024a; MoE, 2021; MEF&GSSD, 2019). Estimates of the yearly effects of climate change on GDP are calculated using data from the CGE and MINDSET macroeconomic models compared to a business as usual (BAU) scenario and low and high emissions scenarios. Both estimates of the damage caused by floods to property and the effects of climate change on agricultural yields, labor productivity, and tourism are included.

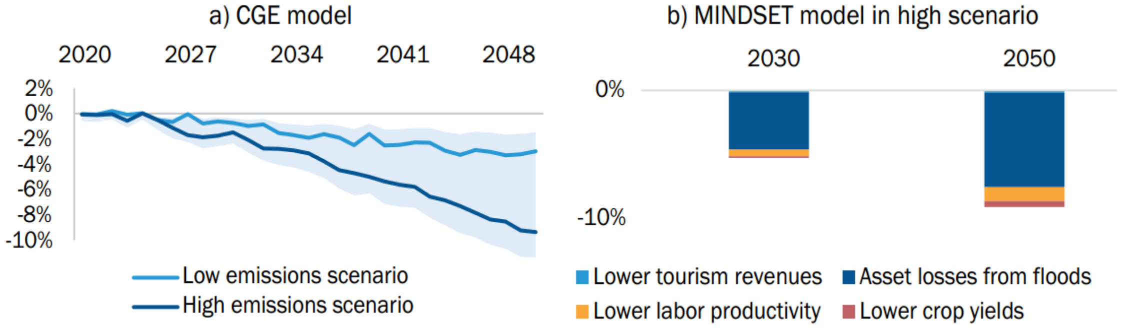


Figure 21: Climate change reduces Cambodia's GDP.
Source: (WB, 2023).

The environmental impacts of climate change in Cambodia are substantial. Biodiversity loss is a big problem, as many plants and animals may not adapt rapidly enough to the changing environment. Changes in temperature and precipitation patterns can threaten Cambodia's rich biodiversity, affecting ecosystems and species that are sensitive to climate variations. This disturbance can harm ecosystems and the services they offer, such as pollination and water purification. Altered rainfall patterns can lead to water scarcity or excessive flooding, impacting both surface and groundwater resources. Additionally, changes in precipitation patterns can result in water shortages in certain locations and flooding in others, hurting both drinking water supplies and agricultural irrigation. Climate change can exacerbate deforestation and forest degradation, reducing carbon sequestration and increasing greenhouse gas emissions.

The societal implications of climate change in Cambodia are equally serious. Increased temperatures and changing weather patterns can lead to health issues such as heat stress, vector-borne diseases (e.g., malaria and dengue), and waterborne diseases. Climate change can exacerbate poverty and inequality, particularly affecting vulnerable communities that rely on natural resources for their livelihoods. The poverty rate could increase by up to 6 percentage points by 2040. Severe weather events such as floods and storms can lead to displacement of communities, causing social and economic disruptions. In September 2022, heavy rainfall caused severe flooding in 14 provinces, affecting 85,000 households and leading to landslides and evacuations. The severe drought in 2015-2016 impacted 18 of 25 provinces and affected over 2.5 million people (WB, 2024a).

Addressing these risks requires comprehensive adaptation and mitigation strategies, including enhancing climate resilience, improving infrastructure, and promoting sustainable development practices. By understanding these risks and their impacts, Cambodia can take proactive steps to mitigate the effects of climate change and better prepare for the future. These impacts highlight the urgent need for climate adaptation and mitigation strategies to protect communities, economies, and ecosystems from the adverse effects of climate change.

3.5 Current and Future Vulnerabilities and Sensitivities

3.5.1 Physical Vulnerabilities

Cambodia’s susceptibility to climatic unpredictability and change is increased by weak institutions, inadequate infrastructure, inadequate adaptive capability, and large rural population. A series of droughts and floods between 1987 and 2007 claimed a large number of lives and caused a large amount of economic damage (WB, 2024b). Cambodia's physical systems, including infrastructure, buildings, and transportation networks, are highly vulnerable to the impacts of climate change. Floods can damage roads, bridges, and buildings, while droughts can affect water supply systems. Physical assets in manufacturing, services, and housing incur significant losses from floods in the absence of adaptation strategies.

Floods cut off access to vital services, impede supply chains, and undermine competitiveness. Flooding of roads in Cambodia has been demonstrated to considerably increase travel times, shutting off access to hospitals and schools and creating crucial delays to supply chains and freight movement. A 1-in-50-year flood decreases the percentage of persons having access to a referral hospital within 60 minutes’ travel time by 47 percent in Battambang, 34 percent in Prey Veng, and 25 percent in Banteay Meanchey. It also decreases the percentage of individuals having access to a high school within 30 minutes’ travel time by 21 percent in Battambang, 20 percent in Kampong Cham, and 20 percent in Prey Veng (see Figure 22a). These interruptions to schooling might have cumulative and compound repercussions on human capital accumulation in these areas. Flooding can also create crucial delays to supply lines and freight operations. Cambodia relies significantly on vital transportation corridors for its cross-border trade and logistics. A seven-day closure of important road networks by a 50- year flood would result in a 5 percent indirect cost increase for foreign trade partners for each day of interruption from freight rerouting or blockage (Figure 22b).

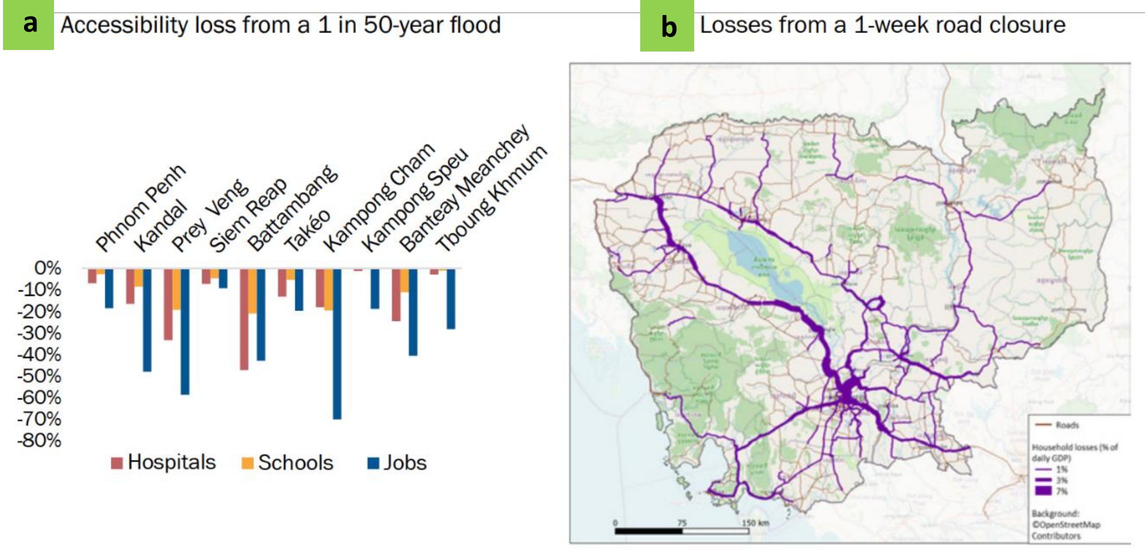


Figure 22: Accessibility loss.
Source: (WB, 2023).

Cambodia is also experiencing more extreme weather events such as widespread flash flooding in 2011 and 2013 and tropical storms like Typhoon Ketsana in 2009. The 2013 flash foods affected 20 out of 24 provinces, a total of 377,354 households, resulting in 168 deaths, while in 2011, flash flooding affected 350,000 households (USAID, 2014).

NCDM reported that the number of houses destroyed by multi-hazards have an increased trend from year to year. Between 2019 to 2020, more than 14,000 houses were damaged. The northeast and south parts of the country, highlighted in green and dark green on Figure 23, were the most affected by hazards.

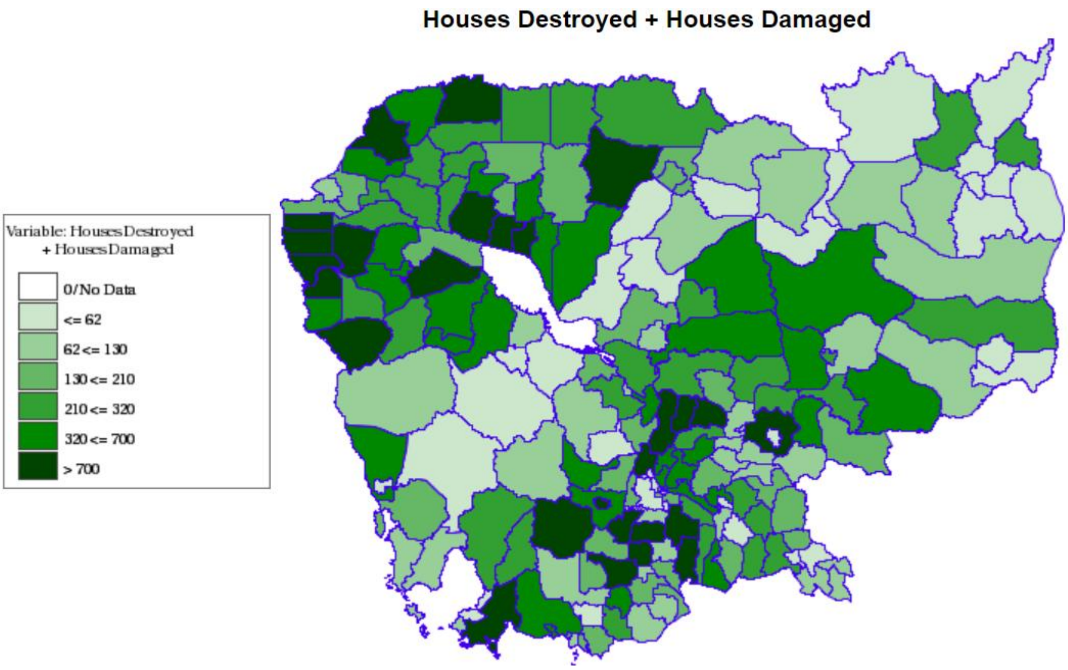


Figure 23: Map of house destroyed and damaged by multi-hazards.
Source: (NCDM, 2023)

In addition to direct injury or death and houses damaged, such events further damage essential health services infrastructure and result in the displacement of people, increased standing water, additional strains on food and water supply, and increased risk of the spread of vector-and water-borne diseases. The effects of flooding may include post-traumatic stress and population displacement in the longer term. According to this analysis, heat-related mortality among Cambodia's elderly (65+ years) is anticipated to grow to about 56 deaths per 100,000 by 2080 under a high emissions scenario, up from an estimated baseline of roughly 4 deaths per 100,000 annually between 1961 and 1990. By 2080, Cambodia is anticipated to have about 56 deaths per 100,000, up from an estimated baseline of around 4 deaths per 100,000 between 1961 and 1990 (USAID, 2019). Box 3.1 shows the example of limited infrastructure to cope with extreme climate events in Cambodia.

Box 3.1: Example of limited climate resilience system

- **Buildings and Infrastructure**

In cities like Phnom Penh, rapid urbanization combined with inadequate drainage systems exacerbates flood risks. Poorly constructed buildings and infrastructure are particularly susceptible to damage during extreme weather events. Many buildings in Cambodia are not built to withstand extreme weather conditions. This makes them vulnerable to damage from floods, storms, and heatwaves. In rural areas, traditional wooden houses are especially at risk. These structures are often not designed to cope with the increasing frequency and intensity of climate.

- **Transportation Network in Cambodia**

The transportation network, including roads and bridges, is frequently disrupted by flooding. This not only affects daily commutes but also hampers emergency responses and economic activities. Cambodia's railways and ports are also at risk. Flooding can disrupt rail services, while rising sea levels and storm surges can impact port operations. Cambodia's physical systems are highly vulnerable to climate change, but with targeted adaptation measures, the country can enhance its resilience and reduce the risks associated with extreme weather events.

3.5.2 Economic Vulnerabilities

a. Agriculture

Climate change poses significant economic challenges to Cambodia, impacting key sectors such as agriculture, fisheries, and tourism. Agriculture is a cornerstone of Cambodia's economy, employing a large portion of the population. Increased frequency and severity of droughts and floods disrupt crop production cycles, leading to reduced yields and income for farmers. For example, in 2012, flash flooding destroyed 267,000 hectares of rice fields (USAID, 2014). Changes in temperature and precipitation patterns contribute to soil erosion and degradation, further reducing agricultural productivity. Warmer temperatures and altered rainfall patterns can lead to more frequent pest and disease outbreaks, which can devastate crops.

Climate change will influence food production through direct and indirect effects on crop growth processes. Direct effects include alterations to carbon dioxide availability, precipitation, and temperatures. Indirect effects involve impacts on water resource availability and seasonality, soil organic matter transformation, soil erosion, changes in pest and disease profiles, arrival of invasive species, and decline in arable areas due to the submergence of coastal lands and desertification. Rice is a staple crop in Cambodia, crucial to national food security and subsistence livelihoods. Without adaptation, but accounting for the benefits of increased atmospheric concentrations of CO_2, the authors report expected yield losses of 10–15percent by the 2040s under both RCPs 4.5 and RCP 8.5 (see Figure 24) (WB, 2023).

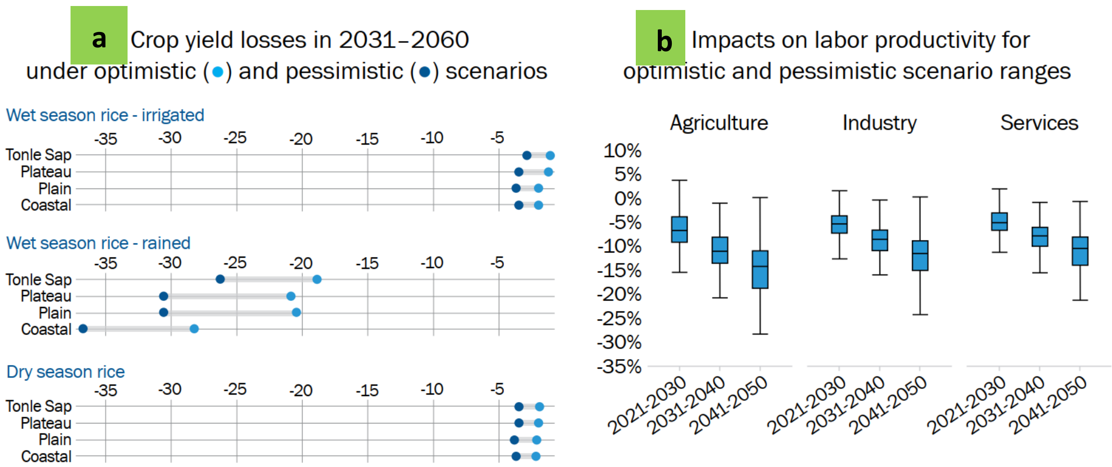


Figure 24: Crop yield losses in 2031-2060.
Source: (WB, 2023).

b. Fisheries

Fisheries are another vital sector, providing food security and livelihoods for many Cambodians. Climate change impacts fisheries through rising water temperatures. It can affect fish breeding cycles and migration patterns, leading to decreased fish populations. Increased sea levels and saline intrusion into freshwater systems can harm freshwater fish species and aquaculture. Storms and floods can damage fishing infrastructure and disrupt fishing activities.

Cambodia's inland fisheries are among of the most productive in the world and they supply the majority of the animal protein consumed by households—roughly 61 percent in rural diets. It is estimated that each individual consumes 63 kilograms of fish annually on average. The MAFF stated that the combined yearly production of aquaculture and fisheries in 2018 was 910,153t, with freshwater accounting for 535,005t, marine accounting for 121,100t, and aquaculture accounting for 254,048t (MAFF, 2018). In 2024, Cambodia's total fisheries and aquaculture production were at 926,934t, compared to 2023 yields an increase of 7 percent (60,684t), with 467,344t of freshwater fisheries, 139,310t of marine fisheries, and 320,280t from aquaculture (FiA, 2024).

There would be major consequences for food security from any decrease in natural productivity of fisheries that other means of food production could not make up for. Short-term effects of climate change on aquaculture may include infrastructure and production losses due to extreme weather events like floods, droughts, and heatwaves, as well as an increase in the danger of parasites, illnesses, and toxic algal blooms. Long-term effects may include decreased wild seed availability and increased competition for freshwater due to decreased precipitation (FAO, 2018).

Certain species and aquaculture producers will be able to withstand droughts and lower water availability due to decreased precipitation in certain locations, while others will be severely impacted. For example, climate change may cause the Tonle Sap Lake's wet season flood level to rise by 2.3 meters by 2030 (Judy Eastham, 2008), increasing fish productivity and expanding feeding areas. The sustainability of aquaculture systems will likely be affected more by storms and flash floods than by slow-paced floods, which may allow for greater flexibility. However, warming is not the only factor influencing fisheries; the construction of irrigation systems and dams on the upstream Mekong also play a role. Climate warming may cause the Tonle Sap Lake's wet season flood level to rise by 2.3 meters by 2030 (Judy Eastham, 2008), increasing fish productivity and expanding feeding areas.

c. Tourism

Tourism is a growing sector in Cambodia, contributing significantly to the national economy. With 70 percent of the service industry related to tourism, there are opportunities to improve value addition, particularly in ecotourism. Tourism earned gross revenue of USD 3.04 billion in 2023 with 5.45 million international tourists last year (MoT, 2024). However, the increased frequency of extreme weather events, such as floods and storms, can deter tourists and damage tourism infrastructure. Changes in climate can lead to loss of biodiversity, affecting eco-tourism and natural attractions. Rising temperatures and extreme weather can harm cultural heritage sites, which are major tourist attractions. Cambodia lost around 25 percent of its tourism earnings because the impact of climate change on tourism sites. Those areas needed to import many things such as labor, furniture, fruits, vegetables, and fish to supplement local supply because they are not available anymore (RGC, 2014)According to the analysis for this CCDR, it indicated that, relative to the baseline scenario, tourism earnings might decrease by up to 17 percent in a high climate change scenario and by about 8 percent on average by 2050 in a low climate change scenario.

d. Economic Impacts

Overall, climate change is projected to cause significant economic losses, with estimates suggesting that it could cost Cambodia up to 10 percent of its GDP by 2050 due to loss and damages. Macroeconomic modeling from CGE and MINDSET predicts that, without intervention, the consequences of climate change might cut Cambodia's GDP by roughly 3 to 9 percent by 2050. Using the CGE model, with the impacts in the low and high climate change scenarios of the CGE model vary from 3.0 to 9.4 percent, respectively (WB, 2023).

However, according to the analysis from the CCDR, climate change may have an impact on the economy by lowering worker productivity, decreasing competitiveness, reducing tourist inflows, and perhaps slowing GDP. It predicted that by the middle of the century, worker productivity might be reduced by up to 20 percent in a pessimistic climate change scenario or by 8 percent in an optimistic one. From 2041 to 2050, the macroeconomic sectors with the greatest worker productivity drop are predicted to be agriculture and industry. A study carried out for the CCDR also reveals that drought or high temperatures during the growing season reduce yields, which in turn affects agricultural production and leads to job loss not only in agriculture, but also in industrial and tourism sectors (WB, 2023).

Floods and other extreme weather events are expected to increase annual losses to infrastructure, including roads, housing, and health centers, from USD 0.5 billion in 2020 to between USD 3.3 billion and USD 10.6 billion by 2050. The predicted asset losses from a 1-in-25-year flood in 2020, according to probabilistic modeling for this CCDR, currently amount to USD 412 million in manufacturing, USD 44 million in services, and USD 108 million in housing (WB, 2023). It is projected that losses in 2020 will average around USD 530 million annually. It is predicted that climate change would lead to an increase in the frequency of high-impact floods, resulting in higher average losses. An optimistic climate change scenario is expected to raise yearly average losses to USD 3.3 billion by 2050. A worse-case climate change scenario predicts average yearly losses at around USD 10.6 billion. This assumes the worst-case situation, when there is no risk-informed land-use planning and a high degree of building in flood-prone locations.

Addressing these challenges requires comprehensive climate adaptation and mitigation strategies, including nature-based solutions, improved climate monitoring systems, and robust data management practices. Integrating these strategies into national and sub-national planning can help build resilience and reduce the economic impacts of climate change on Cambodia.

3.5.3 Social Vulnerabilities

In Cambodia, climate change disproportionately affects certain social groups, especially marginalized and vulnerable populations. With nearly 80 percent of Cambodia's population living in rural areas and relying on agriculture, these communities are highly vulnerable to climate variability and extreme weather events, such as floods and droughts, due to limited and weak adaptive of infrastructure (WB, 2024b). Many of the climate changes projected are likely to disproportionately affect the poorest groups in society because they live in areas prone to flooding and lack access to basic services, making them particularly vulnerable to climate impacts. Climate change can exacerbate economic instability, disrupt livelihoods, and increase poverty levels. For instance, heavy manual labor jobs are commonly among the lowest paid, whilst also being most at risk of productivity losses due to heat stress. Poorer businesses are often unable to afford air conditioning, an increasing need given the projected increase in hot days. Similarly, poorer farmers and communities face significant challenges in affording local water storage, irrigation infrastructure, and other technologies for adaptation.

Women and children are also highly likely vulnerable to climate change due to the roles of women in water collection, food production, and caregiving. Climate-induced stress can increase their workload and reduce access to education and economic opportunities, while children are particularly susceptible to health issues such as malnutrition and waterborne diseases. People with disabilities and the elderly face significant challenges in evacuating during extreme weather events and accessing relief services. They are also more prone to health complications from heatwaves, floods, and other climate-related events (MoE, 2022). In addition, increased temperatures are projected to worsen heat-related conditions for at-risk groups, including the elderly, pregnant women, young children, and infants. Deforestation is likely to exacerbate these effects by increasing temperatures in cleared areas (MoE, 2022). Health infrastructure, such as hospitals, clinics, and cold chain storage facilities, may also be impacted by rising temperatures, heavy rains, and flooding, affecting overall patient care.

Migrants often living in informal settlements with inadequate infrastructure, are highly vulnerable to flooding and other climate impacts. Their limited access to resources and information further increases their vulnerability. Migration from rural to urban areas is already happening at a rapid pace, as is international migration. Without adequate planning such migration can often lead to transfer or creation of new types of risk. The estimated number of Cambodian people affected by climate change caused only the extreme flood are almost 4.5 million on average (see Table 7).

Poverty reduction in Cambodia has been rapid, however, climate change threatens to slow progress. Two key features of progress in Cambodia are highlighted by ADB (2016): first, the rate of poverty decline is broadly outpaced by the rate of GDP growth, indicating that growth is not inclusive and inequality may be growing, though data is scarce; second, poverty reduction is strongly concentrated in urban areas, with changes considerably slower in rural areas. Rural areas face some of the most serious climate change threats, such as the potential rise in ambient temperatures towards levels unsafe for outdoor laborers. As subsistence agriculture remains widespread in Cambodia and undernourishment rates are high, the threat of yield reductions in staple crops and the potentially high costs of adaptation pose significant risks. While climate change is only one of the many pressures on livelihoods in the vicinity of the Tonle Sap Lake, the low adaptive capacity of rural communities in this area, particularly their limited ability to diversify income sources, demands attention.

Table 7: Estimated number of people affected by flood.

Estimated	Population Exposed to Extreme Flood		Increase in Affected Population
	1971-2004	2035-2044	
16.7 Percentile	4,035,515	4,219,445	183.930
Median	4.239.603	4413.765	174.162
83.3 Percentile	4,369.511	4.567.258	197,747

Source: (WB, 2021).

Health issues in relation to climate change impacts are of particular concern because of Cambodia's vulnerabilities in terms of poverty, malnutrition, flood-prone areas, and limitations of public health services, governance, and technology. Major health issues found in Cambodia are connected to climate-related threats such as flooding, temperature rise, flash flooding, and landslides, including heat stress, vector-borne disease, water-borne disease, injury, and death (USAID, 2014). An assessment conducted by time-series analysis between 2001 and 2012 in 16 provinces to evaluate the relation between floods and diarrheal disease incidence in children found a significant correlation between floods and the increased diarrheal disease incidence in two provinces and suggests a possible protective effect from toilets and piped water (Davies et al., G. I, 2015). These impacts could also increase the incidence of water- and vector-borne diseases, such as malaria and dengue. Longer and drier dry seasons also significantly reduce safe drinking water availability, which is already a severe issue in Cambodia. The country faces elevated arsenic levels in groundwater and high rates of diarrheal disease, the latter causes nearly 10,000 deaths annually and could become even more severe due to deforestation and degradation of watersheds (see Table 8).

Table 8: Health-related risks.

Climate Change-related Stressors	Health-related Risks
Increased temperatures	Increased heat stress resulting in illness or injury such as heat stroke, exhaustion, cramps, or rashes
More intense and/or frequent weather events	Shifts in water- and vector-borne disease burdens
Increased and prolonged droughts	Decreased nutrition and food security; Limited drinking water supply
Increased rainfall and flooding	Decreased water quality impacting health, sanitation and hygiene

Source: (USAID, 2019).

3.5.4 Other Types of Vulnerabilities

a. Cultural Vulnerabilities

Climate change poses significant threats to Cambodia’s cultural heritage, impacting both its physical sites and traditional practices.

Impact on Heritage Sites: Cambodia’s iconic heritage sites, such as Angkor Wat, are particularly vulnerable to climate change. Rising temperatures and increased rainfall can accelerate the deterioration of these ancient stone structures. Additionally, more frequent and severe storms pose a risk of physical damage to these sites. Groundwater shortages could affect stability of Angkor’s foundation. Coastal heritage sites also face the threat of sea-level rise and coastal erosion, which can lead to the loss of irreplaceable cultural artifacts (UNESCO, 2020).

Impact on Traditional Practices: Climate change also disrupts traditional practices that are integral to Cambodian culture, for example the traditional fishing method by using net and swidden, or rotation cropping, used by indigenous communities. Altered rainfall patterns and increased droughts can make traditional rice farming techniques less viable. This not only affects the livelihoods of many Cambodians but also threatens the continuation of fishing and agricultural practices that have been passed down through generations. Furthermore, many Cambodian festivals and rituals such as the Water Festival (Bon Om Touk) and Chrat Preah Neng Koul festival, are closely tied to the agricultural calendar. Changes in climate can affect the timing and nature of these events, potentially leading to the loss of cultural traditions.

Adaptation and Mitigation Efforts: To address these challenges, it is crucial to involve local communities in climate adaptation strategies. Traditional knowledge and practices can offer valuable insights into sustainable living and resilience. Additionally, integrating cultural heritage into national climate adaptation plans is essential. This includes measures to protect heritage sites from climate impacts and to support communities in maintaining their cultural practices (UNESCO, 2020).

By taking these steps, Cambodia can work towards preserving its rich cultural heritage for future generations, despite the challenges posed by climate change.

b. Erosion and Sediment Transport

Climate change significantly impacts erosion and sediment transport, with profound implications for both coastal and riverine ecosystems.

Impact on Erosion and Sediment Transport: Climate change leads to more frequent and intense rainfall events, which increase the rate of erosion. This results in greater amounts of sediment being washed into rivers, lakes, and streams. Additionally, rising sea levels and stronger storm surges contribute to coastal erosion, displacing sediments from shorelines and altering coastal landscapes. These changes disrupt the natural sediment balance, leading to increased sediment transport in both coastal and riverine environments (Hew et al., 2023).

Implications for Coastal Ecosystems: Coastal ecosystems, such as wetlands and estuaries, are particularly vulnerable to changes in sediment dynamics. Increased sedimentation can smother aquatic habitats, reducing biodiversity and altering the composition of these ecosystems. Sea-level rise and coastal erosion can lead to the loss of critical habitats, such as mangroves and coral reefs, which serve as natural barriers against storms and support diverse marine life. Changes in sediment transport patterns can also disrupt the nutrient balance in coastal waters, affecting the productivity of these ecosystems (He & Silliman, 2019).

Implications for Riverine Ecosystems: In riverine ecosystems, increased sediment transport can lead to the siltation of riverbeds and reservoirs, reducing water quality and affecting aquatic habitats. This can disrupt the life cycles of fish and other aquatic organisms that rely on clear water for spawning and feeding. Additionally, changes in sediment dynamics can alter the physical structure of rivers, affecting flow patterns and potentially increasing flooding risks. The increased sediment load can also affect human activities, such as agriculture and water supply, by clogging irrigation channels and reducing the capacity of reservoirs (Hew et al., 2023).

Adaptation and Mitigation Strategies: To mitigate these impacts, it is essential to implement sustainable land-use practices that reduce erosion and effectively manage sediment transport. This includes reforestation, the use of cover crops, and the construction of sediment retention structures. Additionally, protecting and restoring natural habitats, such as wetlands and mangroves, can help buffer against the impacts of climate change and maintain the natural sediment balance (Hajigholizadeh et al., 2018).

c. Vulnerability of Watershed Areas

Watershed areas in Cambodia are particularly vulnerable to changes in precipitation, temperature, and land use (MoE, 2022). Variability in rainfall patterns can lead to both droughts and floods. Increased rainfall intensity can cause soil erosion and sedimentation in rivers, while prolonged dry periods can reduce water availability for agriculture and drinking. Rising temperatures can exacerbate water scarcity by increasing evaporation rates and altering the hydrological cycle. This can affect crop yields and water supply for communities (MoE, 2022).

The Mekong subregion in Cambodia has experienced significant changes in water resources, threatening regional ecosystem quality and sustainable development. The Tonle Sap Lake and Mekong River system are particularly vulnerable. Changes in water flow and quality can disrupt ecosystems, affecting fish populations and biodiversity. Climate change impacts on the water sector threaten the productivity of ecosystems supporting Cambodia's inland fisheries, which are a major source of protein for the nation. According to Ministry of Environment (MoE) and UNDP, the changing climate will shift the timing and intensity of rainfall patterns and seasons, change the hydrology of the major rivers and their tributaries, affect ground water aquifers, and increase the frequency and intensity of extreme events, such as floods and droughts (MoE and UNDP, 2011). These changes affect the quantity, quality, availability, and distribution of water.

Climate change also alters the habitats of the Tonle Sap basin: increasing the open water by 2 percent– 21 percent and reducing rain-fed habitats by 2 percent–5 percent, and seasonally flooded habitats by 5 percent–11 percent (MoE, 2015). Such distortions are likely to affect key fishery habitats, thereby leading to substantial impacts on human development, as fish is the main source of protein in the local diet. More importantly, the shift in hydrological level and flow will affect other sectors, including agriculture, natural resources, socio-economic systems, particularly fisheries, and ultimately the people whose livelihoods depend entirely upon such activities.

Deforestation, urbanization, and agricultural expansion can degrade watersheds by reducing vegetation cover, which is crucial for maintaining soil stability and water quality. Land use changes can also increase runoff and reduce groundwater recharge. To assess and manage these vulnerabilities, a combination of methodologies is often used, including climate models to predict future changes in temperature and precipitation patterns, hydrological models to simulate the movement and distribution of water within watersheds, geospatial analysis to map and analyze land use changes and their impacts on watersheds, and community-based assessments to engage local communities to understand their experiences and adaptive capacities. Implementing nature-based solutions such as reforestation, riverbank restoration, and the creation of rain gardens can help mitigate some of these impacts. Additionally, integrating climate education and communication strategies can enhance community resilience and adaptive capacity. Box 3.2 below shows a restoring landscape by applying nature-based solutions.

Box 3.2: An example of applying nature-based solutions in Cambodia
Restoration of the forest and landscape is crucial to building resilience to climate change for ecosystems and livelihoods in Cambodia. Forest degradation and erosion lead to significant sedimentation in the Sangker River Basin of Battambang province, affecting hydropower and irrigation reservoirs. The Asian Development Bank, with assistance from Japan's Government Fund for Prosperous and Resilient Asia and the Pacific, is working with the International Centre for Environmental Management, World Agroforestry, Maddox Jolie-Pitt Foundation, and the Royal Government of Cambodia, Ministry of Environment and Forestry Administration, to enhance local capacity development in implementing innovative climate change adaptation measures through agroecological landscape restoration and climate-resilient landscapes for food security. Five demonstration areas were selected in the headwaters of the Sangker River Basin, one of which was located in the Samlaut Multiple Use Area. The team provided training on restoration techniques, soil erosion prevention, weed control, water supply infrastructure, nursery management, and ecological agriculture livelihood techniques. Through habitat restoration, the community regrew trees to encourage more rain and bring back wild animals (ADB, 2024).

3.6 Direction for Future Studies

Future studies on vulnerability assessment and exposure of ecosystems and people should focus on several key areas to enhance our understanding and improve resilience. Below are some directions for future research:

- **Integrated Assessment Models:** Developing and refining integrated assessment models that combine ecological, social, and economic factors can provide a more comprehensive understanding of vulnerabilities and exposures. These models can help predict the impacts of climate change and other stressors on both ecosystems and human populations.
- **Community-Based Participatory Research:** Engaging local communities in the research process ensures that their knowledge and experiences are incorporated into vulnerability assessments. This approach leads to more accurate and context-specific findings, while empowering communities to take an active role in resilience-building efforts.
- **Longitudinal Studies:** Conducting long-term studies to monitor changes in vulnerability and exposure over time provides valuable insights into the effectiveness of adaptation and mitigation strategies. These studies help identify trends and emerging risks that may not be apparent in short-term assessments.
- **Technological Innovations:** Leveraging advancements in technology, such as remote sensing, geographic information systems (GIS), and big data analytics, enhances the accuracy and efficiency of vulnerability assessments. These tools provide real-time data and facilitate more detailed spatial and temporal analyses.
- **Interdisciplinary Approaches:** Encouraging interdisciplinary research that brings together experts from various fields, including ecology, sociology, economics, and public health, leads to more holistic assessments. This approach helps identify complex interactions and feedback loops between different systems.
- **Policy and Governance Studies:** Investigating the role of policies and governance structures in shaping vulnerabilities and exposures provides insights into how institutional frameworks can be improved. This includes assessing the effectiveness of existing policies and identifying gaps that need to be addressed.
- **Climate Change Scenarios:** Exploring various climate change scenarios and their potential impacts on ecosystems and human populations can help in developing robust adaptation strategies. Scenario analysis provides a range of possible futures, enabling better preparedness and flexibility in planning.
- **Equity and Justice:** Focusing on equity and justice in vulnerability assessments ensures that the needs of the most vulnerable and marginalized populations are addressed. This includes examining how social inequalities influence exposure and vulnerability, as well as developing strategies to promote social justice.
- **Ecosystem-Based Adaptation:** Further research on ecosystem-based adaptation (EbA) strategies can provide valuable insights into how natural systems can be used to enhance resilience. This includes evaluating the effectiveness of EbA measures in various contexts and identifying best practices.
- **Health Impacts:** Investigating the health impacts of climate change and other stressors on vulnerable populations is crucial for developing targeted interventions. This includes studying the connections between environmental changes and health outcomes, as well as identifying strategies to protect public health.

CHAPTER 4
OBSERVED IMPACTS AND RISKS FOR ECOSYSTEMS

4.1 Introduction

4.1.1 Overview

Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. Widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred. This has led to widespread adverse impacts and related losses and damages to nature and people (IPCC, 2023). The combined effects of humanity's actions are making ecosystems less resistant to change and threatening vital ecosystem services humanity relies upon (Zhou, et al., 2024). It is already well known that humanity is driving a myriad of systemic environmental changes: altering the climate, converting forests into farmland, polluting the oceans with plastics, diminishing wild species, and much more. Yet scientists have little idea how these different environmental stresses are combining to impact ecosystems (Asher, 2024). Human-induced environmental changes, such as habitat loss and degradation, overexploitation of bioresources, and the introduction of alien and invasive species also interact with climate change and affect biodiversity and ecosystems. In recent decades there has been a massive loss of biodiversity leading to the initiation of the sixth mass extinction crisis due to human-induced environmental changes (Shivanna, 2022).

In Cambodia, ecosystems face severe threats from environmental degradation, climate change, and human activities, which generate significant risks to biodiversity, local communities, and ecological health. The country has experienced alarming rates of deforestation and habitat loss, losing approximately 100,000 hectares of natural forest in 2022 alone (Standard Insights, 2023). This loss has resulted in the emission of 58.4 million metric tons of CO_2 and has led to a decline in biodiversity as critical habitats such as wetlands and forests are destroyed (Pauly et al., 2022) The destruction of these habitats not only displaces wildlife but also increases extinction risks for rare species. Furthermore, deforestation contributes to soil erosion and flooding, jeopardizing agricultural lands and threatening the livelihoods of local communities, particularly indigenous groups that depend on these ecosystems for cultural practices and sustenance (Flynn, 2024). Water quality is also compromised due to agricultural runoff from fertilizers and pesticides as well as industrial waste pollution, which endangers aquatic life and the health of rural populations reliant on fisheries. Climate change amplifies these challenges through erratic rainfall patterns that lead to crop failures and increased flooding. Additionally, rising sea levels threaten coastal ecosystems that are vital for maintaining biodiversity.

In response to these critical issues, Cambodia is implementing various conservation efforts, including ecosystem-based adaptation projects aimed at rehabilitating degraded areas and developing sustainable resource management policies (MoE, 2023). Immediate action is essential to tackle these environmental challenges effectively in order to safeguard both ecological integrity and the well-being of millions who depend on these natural resources (CI, 2019; WWF, 2021).

This chapter will concentrate on three major sectors affected by climate change including: terrestrial ecosystems, coastal environments, and water and freshwater ecosystems.

Impacts on each sector will be examined with specific case examples from different regions, especially in Southeast Asia and Cambodia, to illustrate the diverse challenges posed by climate change.

4.1.2 Objectives, Scope and Key Issues

This chapter concentrates on three major sectors affected by climate change, including terrestrial ecosystems, coastal environments, and water and freshwater ecosystems. Each sector's impact is examined with specific case examples from different regions, especially in Southeast Asia and Cambodia, to illustrate the diverse challenges posed by climate change. The objectives of this chapter are:

- To describe the impact of climate change on terrestrial ecosystems, including forests and change in land use;
- To discuss the changes in coastal ecosystem caused by climate change;
- To identify the impact on large inland water bodies, marine biogeochemistry, and other coastal components such as estuaries, mangroves, seagrass, and coral reefs;
- To explain the climate impact on water and freshwater ecosystems;
- To discuss key future impacts and risks to ecosystems based on current trends and projections; and
- To analyze knowledge gaps and provide direction for future studies.

4.1.3 Methods and Approach

The method used in this chapter is not different from those used in the previous chapters, as it focuses on the authors' relevant works, primary and secondary data collection. However, for this chapter, the authors require more references compared to the previous chapters because it focuses on the impact of climate change on terrestrial, coastal, and water and freshwater ecosystems in Cambodia. Therefore, specific information from studies and research conducted in Cambodia is needed. Due to the limited research available on these topics in Cambodia, if data is not available, the authors opted for research from Southeast Asia or Asia instead.

Main documents that have been collected to prepare the contents of this chapter include:

- Sixth Assessment Report of the IPCC,
- Reports/publications from UNFCCC, UNDP, World Bank, Asian Development Bank, NCSD/MoE, MAFF, NGOs (e.g., FFI, MCC, WEA), and,
- Other relevant research articles, case studies, and publications

4.2 Impacts and Risks on Terrestrial Ecosystems

The terrestrial ecosystem is a dynamic and diverse community of organisms that inhabit the land. It encompasses an array of ecosystems, including forests, grasslands, deserts, tundra, and wetlands. Terrestrial ecosystems are incredibly diverse and support numerous plant and animal species adapted to their specific environments. The intricate interactions between these living organisms and their physical environment create a complex web of life that sustains and regulates the earth's natural processes (Tancredi, 2023).

Climate change drives terrestrial biodiversity loss and affects ecosystem carbon storage both directly and indirectly via land use change (Malhi et al., 2020). An increase in temperature impacts two aspects of growth and development in plants and animals. One of them is a shift in the distributional range of species, and the other is the shift in phenological events. Plants and animal species have adapted to their native habitat over thousands of years. As the temperature gets warmer in their native habitat, species tend to move to higher altitudes and towards the poles in search of suitable temperature and other environmental conditions. There are a number of reports on climate change-induced shifts in the distributional range of both plant and animal species (Grabherr, 1994; Cleland et al., 2007; Parmesan and Yoke, 2003; Beckage et al., 2008; Miller et al., 2010; Lovejoy and Hannah, 2005; Lobell et al., 2011). Many species may not be able to keep pace with the changing weather conditions and thus lag behind, leading to their eventual extinction. For example, long-term observations extending for over 100 years have shown that many species of bumblebees in North America and Europe are not keeping up with the changing climate and are disappearing from the southern portions of their range (Kerr et al., 2015). Most flowering plants depend on animals for seed dispersal (Beckman et al., 2020). Defaunation caused by climate change and other environmental disturbances has reduced long-distance seed dispersal. Predictions regarding the dispersal function for fleshy-fruited species indicate that the capacity of plants to adapt to climate change has already decreased by 60 percent, severely affecting their range shifts (Fricke et al., 2022).

In summary, climate change significantly impacts terrestrial ecosystems, including changing species distribution, altering biological events, overwhelming ecosystems (e.g., making it harder for ecosystems to cope with extreme events like floods, droughts, and wildfires), disrupting plant and animal patterns, and changing photosynthetic productivity (Warren, et al., 2013).

4.2.1 Forestry

Climate change is significantly impacting forest ecosystems in Cambodia, leading to notable changes in forest health, structure, and overall biodiversity. The effects are multifaceted and driven by a combination of climatic shifts and human activities. Key changes observed include forest health issues such as increased temperature and drought, with longer and hotter dry seasons resulting in more frequent droughts that negatively affect forest productivity, decreasing growth rates and increasing susceptibility to pests and diseases (Mongabay, 2019). Deforestation rates are alarmingly high, with forest cover declining from 73 percent in the early 1960s to approximately 46 percent by 2018 (MoE, 2023). This loss exacerbates warming effects, as a 50 percent reduction in forest cover can lead to temperature increases of up to 1.33 degrees Celsius. In terms of forest structure, fragmentation due to land use changes, particularly for rubber and cashew plantations, disrupts ecological processes essential for forest health (Standard Insights, 2023; ODC, 2016).

The decline in forests also leads to a loss of ecosystem services, diminishing their ability to regulate local weather patterns and water flows. Regarding biodiversity, Cambodia's forests host over 8,000 vascular plant species and numerous animal species, but climate change and habitat loss have increased pressures on these species, with 376 currently threatened due to forest degradation. Indigenous communities relying on forests for livelihoods face severe challenges from both climate change and deforestation, leading to food insecurity and loss of cultural practices tied to the forest environment (MoE, 2018). The interplay between climate change and human activities poses a critical threat to Cambodia's forest ecosystems, necessitating integrated conservation strategies that address environmental sustainability alongside community needs.

a. Observed Changes in Ecosystem Structure

Climate change significantly impacts forest ecosystem structure by altering the distribution of tree species, affecting their growth rates, increasing the risk of pest outbreaks and wildfires, and changing the overall composition of the forest due to shifts in temperature and precipitation patterns, potentially leading to a loss of biodiversity and altered ecosystem services (Marshet and Fekadu, 2019). Cambodia has faced significant forest loss, with forest cover decreasing from approximately 10.83 million hectares (59.64 percent) in 2006 to 8.18 million hectares (45.05 percent) by 2016, predominantly due to agricultural expansion, which saw cropland increase by 34 percent during the same period (MoE, 2018). The Tonle Sap region has experienced a consistent annual forest loss rate of about 1.2 percent. This deforestation has altered tree species composition, particularly in areas like Phnom Kulen National Park, where cashew plantations have replaced native forests, leaving only about 13 percent of the area covered by natural forests (Somaly et al., 2020). Additionally, the conversion of forests to agricultural land has resulted in increased soil erosion and degradation, threatening both environmental integrity and the livelihoods of local communities reliant on healthy soils.

b. Species/Wildlife Range Shifts

Among the most widely predicted climate change-related impacts to biodiversity are geographic range shifts, whereby species shift their spatial distribution to track their climate niches. A series of commonly articulated hypotheses have emerged in the scientific literature suggesting species are expected to shift their distributions to higher latitudes, greater elevations, and deeper depths in response to rising temperatures associated with climate change (Rubenstein et al., 2023) Alternatively, species traits and their ability to adapt to change may affect how well that species can respond i.e. the dispersal ability of the species can affect if a species can adapt to changes in climate (Howard, 2023).

Increased temperatures are expected to alter the distributions of amphibians and reptiles. These species may search for cooler microhabitats within their existing ranges or migrate to higher elevations, potentially leading to declines in lowland biodiversity (Bickford et al., 2010). Over the past three decades, certain amphibian species have already been observed moving to higher elevations (Raxworthy et al, 2008). In Southeast Asia, at least nine lowland amphibian species have shifted upwards by over 500 meters in elevation during the last 70 years, while many high-elevation species have moved downslope (Bickford et al., 2010). This counterintuitive trend may be attributed to increased ultraviolet B (UV-B) radiation and reduced cloud cover at higher altitudes, compelling amphibians from these areas to descend in search of shelter and moisture. Such mid-elevation crowding could intensify competition, reduce population sizes, and alter community structures, ultimately threatening biodiversity (Bickford et al., 2010). Although initial range shifts may lead to increased species richness at these elevations, resource limitations are likely to result in shifts in community composition and the extirpation of less competitive species (Bickford et al., 2010).

Tree species in Southeast Asia have already been affected by climate-related redistribution. Research on the Philippine archipelago indicates that climate change could diminish the distribution of 19 dipterocarp species by a median of 16 percent under a moderate climate scenario (RCP 4.5) and by 27 percent under a severe scenario (RCP 8.5) by 2070. This study highlighted that land cover corrections alone could reduce current species distributions by 67 percent, underscoring the urgent need for enhanced protected area planning for conservation (Pang et al., 2021). Further studies on tropical pines such as *Pinus kesiya* and *Pinus merkusii* suggest that few new areas in mainland Southeast Asia will become suitable for these species due to climate change. Existing lowland populations are particularly vulnerable, while those at higher altitudes may experience less impact (Van et al., 2009).

Research in Peru investigates the functional dispersion (FDis) of frugivorous bird assemblages along an elevational gradient in the Peruvian Andes, focusing on current patterns and future projections under climate change (Bender et al., 2019). To illustrate these shifts, the left side of Figure 25 depicts current bird assemblages, while projected changes due to climate change are illustrated on the right. Presently, the lowest elevations exhibit the highest FDis, which decreases with altitude. Future projections suggest that there may be a loss of FDis at lower elevations as functional specialists emigrate, a stable FDis at mid-elevations if immigrating and emigrating species are functionally similar, and potential species extinctions at higher elevations due to dispersal barriers beyond the tree line. Species ranges may remain constant, contract, expand, or shift in response to climate change, demonstrated by black silhouettes representing species presence at specific elevations, outlines indicating species movement away from those levels, and dotted silhouettes denoting extinction across the gradient. This gradient spans from lowland areas at 250 meters to mountain peaks at 3,750 meters, with forests extending up to 3,500 meters.

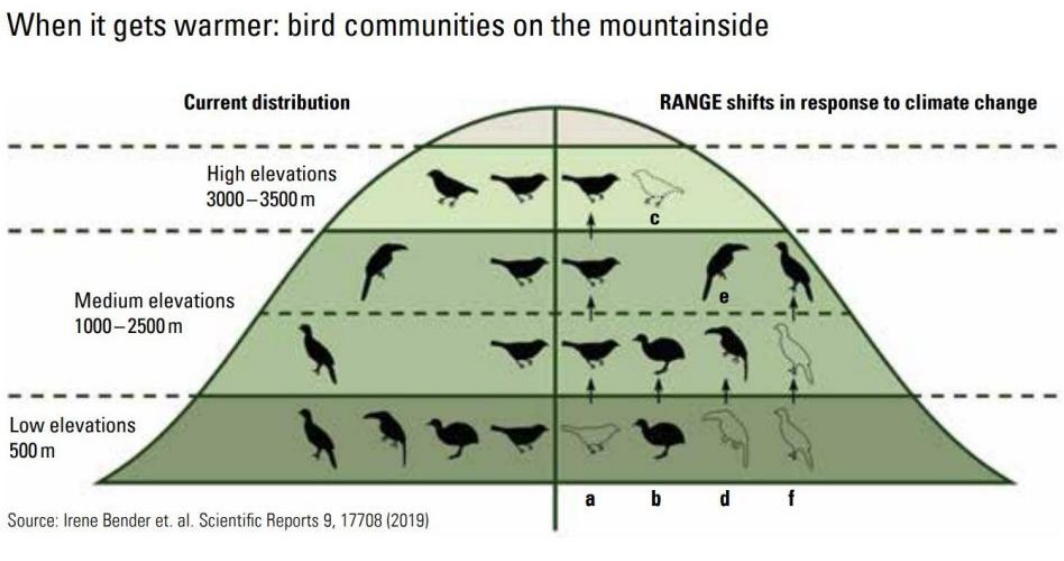


Figure 25: Bird distribution change on the mountainside.
Source: Bender et al., 2019

The following describes effects on species from "a" to "f":

- **a.** Species die out at lower altitudes and their geographical range shrinks.
- **b.** Species expand their geographical range upwards.
- **c.** Species that already live at high levels die out because they cannot move further upwards.
- **d.** Species shift their geographical range upwards.
- **e.** Species adapt to changed climate conditions.
- **f.** Species shift their geographical range upwards.

c. Changes in Phenology

Phenology refers to the seasonal timing of life cycle events and changes in phenology are a sensitive biological response to climate change (Park and Post, 2022). Changing phenology is one of the first observed responses to climate change (Hassan et al., 2023). Eventually, species may also change their abundance, range (i.e where they are found geographically), and even become locally extinct in areas that are less favorable (Wiens, 2016). Therefore, the science of phenology provides a powerful 'early warning' of species that could be 'winners' and 'losers' as the climate changes (Gearries et al., 2024). These changes may affect food chains for plants, insects, and birds, with some species potentially falling out of sync with each other because each respond individually and at different rates to rising temperatures (Prather, et al., 2022). Phenology is a major driver in determining population dynamics, species interactions, animal movement, and the evolution of life histories (Schwartz, 2003; Moller et al., 2008). Population-limiting factors are closely linked to seasonal or interannual phenological events and shifts in phenology can affect ecosystems through changes in ecological interactions such as predator-prey and plant-pollinator dynamics (Cushing, 1990; Encinas-Viso et al., 2012) and the epidemiology of infectious diseases (Harvell et al., 2002; de La Rocque et al., 2008).

There are several examples relevant to phenology change in plants and animals across Southeast Asia region. A comprehensive analysis conducted in Peninsular Malaysia observed a decline in the proportion of flowering and fruiting species from 1976 to 2010. The study found that 57 percent of species in the Dipterocarpaceae family, which are crucial for forest regeneration, respond to both drought and low-temperature cues for flowering (Numata et al., 2022). As climate change progresses, particularly under scenarios RCP 2.6 and RCP 8.5, the availability of low-temperature cues is expected to diminish, leading to reduced flowering opportunities across a wide region from Thailand to Borneo (Numata et al., 2022). Research extending to other areas, such as Trang Province in Thailand and Lambir Hills National Park in Borneo, indicated that while some species are predicted to have decreased flowering probabilities, others remain robust against climate variations. This variability suggests that different species may adapt differently to changing environmental conditions, potentially altering forest composition and regeneration dynamics (Numata et al., 2022; Satake et al. 2022).

A notable case study focuses on migratory birds in Singapore, where researchers analyzed birdwatchers' records from 1987 to 2009. The study found that two species, the Japanese sparrowhawk and curlew sandpiper, experienced a delay in their autumn arrival by approximately 2 days per year. This shift is hypothesized to be linked to warmer temperatures allowing these species to remain longer on their northern breeding grounds before migrating south (Harris et al., 2013). However, other species did not show significant changes in arrival dates, indicating variability in response among different bird species.

A recent study examined how rainfall patterns affect the breeding activities of seven species of tropical songbirds in northeastern Thailand over a decade (2014-2023). The research found that during extreme droughts, such as those associated with El Niño events, birds tend to delay nest initiation and reduce reproductive output. Specifically, the timing of first egg dates and last expected fledging dates was significantly influenced by both the amount and frequency of rainfall leading up to the breeding season. This suggests that insufficient rainfall may lead many birds to forgo breeding altogether in certain seasons, while others might only pause for shorter periods (George et al., 2024).

An example from a study in the Netherlands represents the phenology of great tits and caterpillars in the Hoge Veluwe (Tomotani, 2017. As shown in Figure 26, key reproductive events of the great tit are highlighted by a red line, while the peak food needs of nestlings are indicated by a green line in the upper section. The lower section illustrates caterpillar phenology, also represented by a green line. Historically, the peaks of food demand and caterpillar availability aligned (left side); however, climate change has led to warmer springs, causing the peak caterpillar biomass to shift approximately two weeks earlier. In contrast, the timing of the nestlings' peak food requirements has advanced more slowly, resulting in a "phenological mismatch" between these two critical life stages (right side).

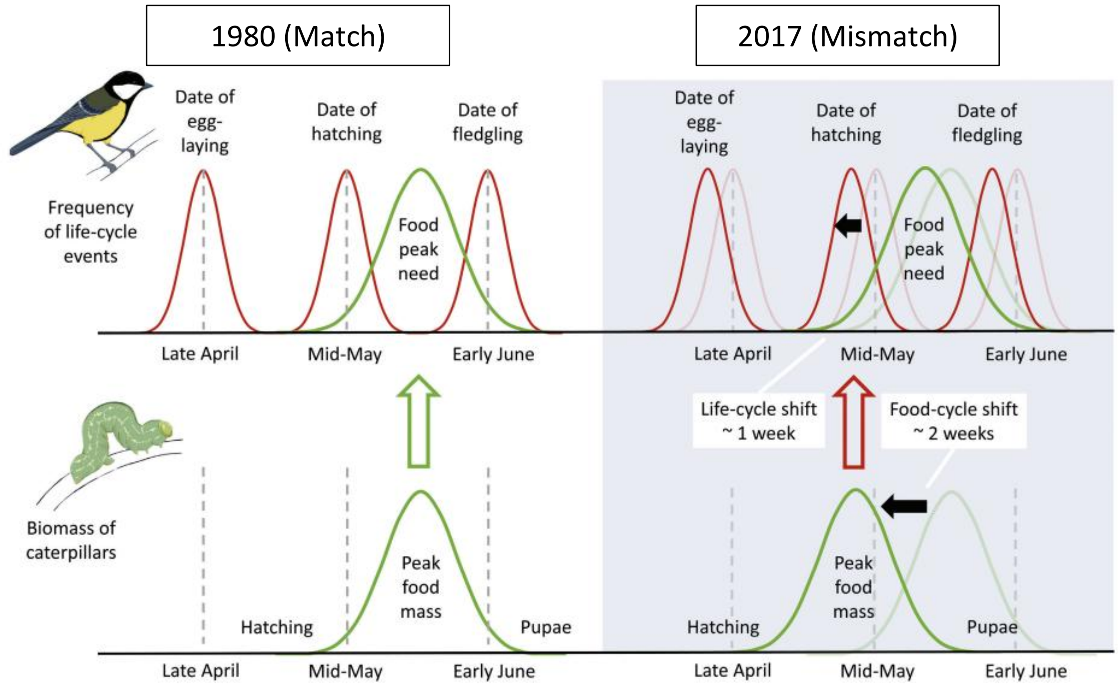


Figure 26: Managing time in a changing world: Timing of avian cycle stages under climate change. Source: Mizumo and Barbara, 2017.

4.2.2 Land Use Changes

Over the past few decades, rapid human population growth and environmental change have been central to discussions on sustainable development. The concept of sustainable development aims to meet the needs of the current population without jeopardizing the well-being of future generations (WCED, 1987; Emas, 2015)The debate surrounding population growth includes the perspective of "population neutralists," who argue that population growth impacts economic performance and resource depletion only when combined with other factors.

The relationship between population and the environment is complex and influenced by multiple dimensions, including population size, distribution, density, and composition, as well as income levels (Hunter, 2001). Additionally, technological, political, and cultural factors mediate this relationship. For instance, technological advancements in energy production and consumption, political policies, and cultural attitudes toward nature all play significant roles (Cohen, 2023; Alsaleh, 2024). The interaction between population and environment varies across different spatial scales: climate change is a global issue primarily influenced by population size and growth, while land-use changes are more localized and often result from shifts in population distribution (Hunter, 2001).

In regions like Southeast Asia, significant land-use changes have been observed, with substantial conversions of forested land to agricultural and residential areas (Fox and Vogler, 2005; Giri et al., 2005; Dhas, 2008). These changes underscore the need for comprehensive policies that address both population dynamics and environmental sustainability to achieve sustainable development goals.

Changes in land use and land cover (LULC) are driven by both natural and human-induced factors. Currently, about one-third of the Earth's surface is dedicated to agriculture and livestock. The increasing human population, infrastructure expansion, urbanization, and shifts in legal frameworks—such as land tenure security and agricultural land expansion—have led to the conversion of natural habitats like forests, shrublands, and grasslands, which are crucial for biodiversity and ecosystem services (Toure et al., 2018; Velastegui-Montoya et al., 2020). While LULC changes can foster economic and social progress, they also contribute to significant issues, including climate change, land degradation, increased natural disasters, habitat loss, biodiversity decline, altered water flows, food insecurity, and health problems (Shaghla et al., 2018) (Anita et al., 2024). As global demand for food, fiber, and biofuels surges, the availability of land decreases, with much remaining available land located in tropical regions. This situation fuels discussions on balancing agricultural needs with forest conservation and maintaining ecosystem services like carbon storage, climate regulation, and biodiversity conservation (Sourn et al., 2021).

In Cambodia, LULC has dramatically changed over the last three decades following major political change, population and economic growth, increased market demand for food crops, climate change, and human migration (Sourn et al., 2021; Niu et al., 2022). For instance, agricultural land expanded from 26 percent to 31 percent between 1997 and 2007 (FAO, 2010). With increased demand for farmland, forest cover decreased through conversion to agricultural land for cropping (Kong et al., 2019).

The most significant observed change in land use and land cover in Cambodia is a substantial decrease in forest cover, primarily due to expansion of agricultural land, leading to a major shift from forested areas to farmland, often driven by population growth, economic development, and land concessions. The most notable impact is the conversion of natural forests to rubber plantations and rice paddies; additionally, built-up areas have also increased, particularly in urban centers like Phnom Penh, further contributing to land use changes (Nut et al., 2021).

Land use and land cover change can significantly impact terrestrial ecosystems and biodiversity by altering habitat availability, disrupting ecological processes, fragmenting landscapes, and affecting species interactions, leading to potential declines in species richness and overall biodiversity loss; particularly when natural areas like forests are converted to agricultural land or urban development, causing habitat destruction for native species (Marino et al., 2023).

4.3 Impacts and Risks on Coastal Ecosystems

Cambodia's 435-440 kilometers coastline harbors ecologically critical marine habitats, including coral reefs, seagrass meadows, and mangrove forests, which sustain biodiverse ecosystems and underpin the livelihoods of coastal communities (WEA and MCC, 2020; ODC, 2016). However, these ecosystems face escalating threats from climate change, industrial expansion, illegal fishing, and coastal development. Recent assessments indicate that Cambodia’s coral reefs have experienced widespread bleaching, seagrass beds have declined by 30–50 percent in key areas like Kampot, and mangrove deforestation has reduced coverage to 9 percent of historical levels (WEA and MCC, 2020; IUCN, 2019). Climate projections predict sea-level rise of 40–60 cm by 2100, intensifying storms, and altered rainfall patterns, which will exacerbate coastal erosion, saltwater intrusion, and habitat fragmentation (IUCN, 2019). Simultaneously, overfishing, bottom trawling, and land reclamation for agriculture and urban infrastructure are degrading marine habitats, threatening species such as the endangered green sea turtle (Chelonia mydas), Irrawaddy dolphin (Orcaella brevirostris), and dugong (Dugong dugon) (WEA and MCC, 2020).

Climate changes impact coastal systems in a number of ways as a result of higher temperatures, accelerated sea-level rise, changed freshwater discharge, more intense precipitation events and droughts, and changes in the frequency and intensity of tropical storms as well as winter storms (Day & Rybczyk, 2019). Increasing temperature will shift the tropical-temperate interface toward higher latitudes. Sea level will likely rise from 1.0 to 1.5 m by 2100 (GEOMAR, 2024).

The IPCC has noted that coastal areas are particularly vulnerable, already experiencing the consequences of climate change, such as shifts in the tropical-temperate interface towards higher latitudes and changes in precipitation patterns, where regions near the equator and higher latitudes may see increased rainfall, while outer tropics and lower temperate zones may experience decreases (IPCC, 2022). These changes will exacerbate coastal erosion and flooding risks, compromise critical infrastructure, and disrupt marine ecosystems that rely on stable conditions (US EPA, 2024). The cumulative effects of these factors underscore the urgent need for adaptive measures to mitigate the profound impacts of climate change on coastal environments and communities. These impacts are expected to lead to the loss of habitat, increased erosion, more frequent inundation, and damage to coastal infrastructure.

In Cambodia, rising sea levels are a critical concern for Cambodia's coastal areas, leading to increased flooding, coastal erosion, and saltwater intrusion. These phenomena threaten agricultural productivity and the livelihoods of communities that rely on farming and fishing. Coastal regions are particularly vulnerable due to their flat topography and proximity to the sea, exacerbating issues such as beach erosion and habitat loss for crucial ecosystems like mangroves and coral reefs (Sum and Thav, 2023).

4.3.1 Coastal Integrity

The impact of climate change on the integrity of coastal ecosystems in Cambodia is profound, affecting biodiversity, habitat stability, and local communities' livelihoods. Key factors include rising sea levels, increased storm intensity, and habitat degradation. In Cambodia, the coastline is subjected to strong tides, waves, and storm surges that contribute to shoreline retreat. Studies have documented significant land loss along specific coasts, such as Pak Khlong and Prey Dach, with erosion rates averaging several meters per year. Pak Khlong and Prey Dach coasts had a total land loss of 11.6 and 4.1 ha and growth of 10.2 and 54.8 ha over the past 38 years (1985-2023), respectively (Sokhorng et al., 2024). Moreover, Cambodia’s coastal zones are increasingly vulnerable to sea-level rise, which is projected to inundate approximately 25,000 hectares by 2090 (Sum, 2021). This would force thousands of people to relocate, especially in the southwestern coastal regions such as Kep Province and Preah Sihanouk Province. The rising sea levels exacerbate seawater intrusion, beach erosion, high tides, and frequent storm surges, which collectively contribute to significant land loss and threaten local livelihoods (Ly, 2023). Mangrove forests, which serve as natural buffers against erosion, also have been extensively lost due to conversion for shrimp farming, salt production and rice farming, industrial and tourism development. In the 1990s alone, over 5,000 hectares of mangroves were lost. This loss continues, particularly in Preah Sihanouk, Kampot, and Kep provinces, worsening coastal erosion and habitat degradation (FAO, 2025).

Cambodia's coastal regions are rich in biodiversity, hosting over 700 unique species in its mangrove forests alone (Delgado, 2024). However, these ecosystems have experienced a dramatic decline. From 1989 to 2017, mangrove forests shrank by more than 40 percent due to large-scale coastal developments, poaching, and climate change impacts such as rising sea levels and increased salinization (Delgado, 2024; Soun S. & Keo S., 2024). Coral reefs and seagrass beds are also under threat from illegal fishing practices, pollution, and habitat destruction caused by tourism and development activities (USAID, 2011).

Koh Kong Province serves as a critical case study for understanding the impacts of climate change on coastal ecosystems. Research in this area highlights the significant loss of mangrove forests due to natural and anthropogenic factors. Local communities have initiated reforestation projects, which help restore habitats and enhance community resilience against climate impacts. These projects have been supported by NGOs and government initiatives, demonstrating the importance of collaborative efforts in addressing environmental challenges (Soun and Keo, 2024).

Rising sea temperatures and pollution from tourism and urban development have severely impacted Sihanoukville's coral reefs. There is a collaborative project between local NGOs and the government that aims to monitor coral health and implement protective measures. This initiative has increased awareness among local stakeholders about the importance of sustainable practices in preserving marine ecosystems. Preliminary results indicate that areas under protection have shown signs of recovery, with increased coral cover and fish populations (Soun and Keo, 2024).

In Kampot, a community-based fisheries management program has been established to address declining fish stocks. This program empowers local fishermen to manage resources sustainably, incorporating traditional knowledge and practices. Results indicate improved fish populations and enhanced community cohesion, demonstrating the effectiveness of local governance in adaptation efforts. The success of this program highlights the potential for community-led initiatives to foster resilience in the face of climate change (Soun and Keo, 2024).

The findings from this research underscore the urgent need for integrated approaches to address the impacts of climate change on Cambodia's coastal ecosystems. This study highlights the interconnectedness of environmental health and community resilience by combining ecological assessments with socio-economic analyses. The case studies illustrate successful adaptation strategies that can serve as models for other coastal communities facing similar challenges.

4.3.2 Marine Biodiversity and Productivity

Climate changes have significant impacts on marine biodiversity and productivity. Those include habitat loss, biodiversity decline, and socio-economic consequences, such as facing increased vulnerability due to declining fish stocks and habitat loss.

Habitat loss: Rising sea levels pose a critical threat to coastal ecosystems. Projections suggest that sea levels could rise by over half a meter by 2090, potentially inundating significant coastal areas and leading to habitat loss for various marine species. Increased storm intensity also contributes to coastal erosion and habitat degradation, further threatening marine biodiversity (Soun and Keo, 2024).

Biodiversity Decline: The combination of habitat degradation from rising sea levels and increased storm activity has led to a decline in biodiversity. Key species of fish and crustaceans, which are vital for local fisheries, are particularly affected. The loss of mangroves and coral reefs further exacerbates this decline by diminishing the natural habitats that support diverse marine life (WEA and MCC, 2020; Soun and Keo, 2024).

Socio-Economic Consequences: Local communities that depend on marine resources for their livelihoods are facing increased vulnerability due to declining fish stocks and habitat loss. Reports indicate that fish catches have decreased significantly, impacting food security and economic stability for these communities (Soun and Keo, 2024). The socio-economic ramifications highlight the urgent need for integrated coastal management strategies that consider both ecological health and community resilience.

ENSO Effects: Cambodia's climate is significantly influenced by the El Niño-Southern Oscillation (ENSO) and monsoon patterns, which have observable impacts on large inland water bodies and upwelling areas. ENSO consists of two primary phases: El Niño, characterized by warmer sea surface temperatures leading to reduced rainfall and drought conditions, and La Niña, marked by cooler temperatures that typically result in increased precipitation and flooding (William et al., 2019). The fisheries sector, crucial for the livelihoods of millions in Cambodia, is particularly sensitive to these climatic variations; for instance, the 2016 El Niño event caused a notable 17 percent decrease in fish production due to drought conditions affecting water levels (William et al., 2019). Additionally, changes in temperature and salinity driven by ENSO can impact nutrient availability in upwelling areas, which are vital for marine biodiversity and fisheries productivity (William et al., 2019). The southwest monsoon season, from May to October, brings heavy rainfall essential for agriculture but can also lead to flooding when combined with La Niña effects. Climate change is making the timing and intensity of monsoons more erratic, with projections suggesting increased rainfall intensity but less predictability (Buckley et al., 2010). The interplay between monsoons and ENSO events affects not only agricultural productivity but also the hydrology of rivers and internal seas, influencing sediment transport and freshwater availability (WB, 2024).

In summary, weather phenomena such as ENSO and monsoons have profound impacts on Cambodia's internal seas and upwelling areas. These effects manifest through changes in precipitation patterns that influence fisheries productivity, agricultural practices, and overall ecosystem health. As climate variability continues to intensify due to global warming, understanding these interactions will be crucial for effective resource management and disaster preparedness in Cambodia.

4.3.3 Mangrove Forests

Mangrove forests in Cambodia are found along its 435 km-long coastlines in four provinces (Koh Kong, Sihanoukville, Kampot and Kep) (Nop et al., 2017). 37 true mangrove species have been identified in Cambodia (Veettil and Quang, 2019). Most commonly found mangrove species are *Rhizophora apiculata* and *Nypa fruticans*. Other species found in Cambodia are *Bruguiera gymnorrhiza*, *B. sexangula, Ceriops tagal, Lumnitzera littorea, Heritiera littoralis, Xylocarpus granatum, Hibiscus tiliaceus, Phoenix palludosa, Acrostichum speciosum, Aegialitis sp. and Acanyus sp*. Mangrove forests in Cambodia are play a key role in protecting coral reefs and seagrass communities and provide habitat for fish breeding and nursing (Veettil and Quang, 2019). Fishery Administration has estimated that 78,405 ha (Kampot – 1900 ha, Kep – 1005 ha, Sihanoukville – 13,500 ha, Koh Kong – 62,000 ha) of land cover in Cambodia are covered by mangrove forests in 2010 (Fisheries Administration, 2023). Cambodia hosts the 10th largest mangrove ecosystem in Asia. However, there are discrepancies in the estimated area of mangrove forests in Cambodia and the rate of mangrove loss. Nop et al., (2017) reported that the total area covered by mangrove forests in Cambodia in 1975 was 94,600 ha. FAO (2007) estimated 69,200 ha, while FiA and other recent studies, such as Rizvi & Singer (2011), estimated coverage as 43,000 ha in 2011.

Currently, mangrove forests are increasingly threatened by both climate change and human activities, leading to significant impacts on biodiversity and local communities. Climate change poses serious risks, with rising sea levels resulting in habitat loss and increased salinity that adversely affect dependent species (Howard et al., 2022). Additionally, the frequency and intensity of severe weather events, such as storms and heavy rainfall, exacerbates erosion and destruction of these vital ecosystems (Segaran, 2023). On the other hand, human activities play a critical role in the decline of mangroves. Coastal development projects, including the construction of ferry terminals and luxury resorts, disrupt local ecosystems and threaten the livelihoods of fishing communities reliant on healthy mangrove habitats. Furthermore, mangroves are often cleared for aquaculture and salt production; in Kampot province alone, substantial areas have been cleared for these purposes. The loss of these forests threatens marine biodiversity as they serve as crucial breeding grounds for various species, leading to declines in fish populations essential for local fisheries (Munoz et al., 2024).

4.3.4 Seagrasses

Seagrass beds are highly vulnerable to climate change. Seagrass beds are particularly at risk of storms, freshwater inflow, sedimentation, and increased water temperatures. Seagrass is sensitive to these impacts and climate change is likely to have a big impact on the biodiversity seagrass beds support (Sorn and Veth, 2019). The impact of climate change on seagrass beds in Cambodia is significant, primarily driven by temperature changes and water quality degradation.

Rising seawater temperatures threaten seagrass ecosystems, with projections indicating an increase in extreme heat days, leading to thermal stress that can reduce resilience and productivity of seagrass species (Tang and Hadibarata, 2022; Sorn and Veth, 2019). Elevated temperatures also exacerbate extreme weather events, such as storms, which physically damage seagrass habitats and increase sedimentation rates (Tang and Hadibarata, 2022; Sorn and Veth, 2019). Concurrently, water quality is deteriorating due to anthropogenic factors like agricultural runoff and urban wastewater discharge, resulting in increased nutrient loading and sedimentation that heightens turbidity levels (Actionaid, 2021; MCC, 2025). This turbidity limits sunlight penetration essential for photosynthesis in seagrasses, while silt accumulation from land-based activities further stresses meadows by smothering them. Destructive fishing practices, such as bottom trawling, contribute to habitat destruction and increased sedimentation, leading to fragmented meadows that are less resilient to environmental changes (MCC, 2025). Seagrass beds are disappearing in shallow waters, especially near Chrouy Bros, In Koh Kong province.

Overall, the combination of rising temperatures and declining water quality due to human activities poses a dual threat to seagrass beds in Cambodia. Without effective management and conservation efforts, these vital ecosystems may struggle to adapt to ongoing climate change impacts, jeopardizing the livelihoods of coastal communities that depend on them for food security and income (MCC, 2025).

4.3.5 Coral Reefs

Cambodia's coral reefs, primarily located along the Gulf of Thailand, cover approximately 2,882 hectares across four coastal provinces: Kep, Kampot, Preah Sihanouk, and Koh Kong. The reefs are characterized by a rich diversity of species but are generally in poor condition. Coral reefs are vital ecosystems that provide habitat and support for a diverse range of marine life. However, they are increasingly threatened by climate change, particularly through the phenomenon of coral bleaching. In Cambodia, the impact of climate change on coral reefs is evident, although recent observations suggest some resilience in local reefs (Byrne, 2024; Munoz et al., 2024).

Coral bleaching occurs when corals become stressed due to rising sea temperatures, leading them to expel the symbiotic algae (zooxanthellae) that provide them with nutrients and color. This process not only results in a loss of vibrant colors but also compromises the health of the coral, making them more susceptible to disease and mortality (Byrne J., 2024). The National Oceanic and Atmospheric Administration has reported that over 54 percent of the world's oceans have experienced heat stress significant enough to trigger bleaching events, which have become more frequent since the first documented event in 1998 (Byrne J., 2024).

In Cambodia, rising sea temperatures have led to widespread coral bleaching, although a recent assessment indicated that only about 7 percent of local coral populations surveyed were affected by bleaching (UN-Habitat, 2012). This lower rate may suggest that Cambodian reefs possess some degree of resilience compared to other regions experiencing severe bleaching.

The health of coral reefs is crucial not only for marine biodiversity but also for local communities that rely on these ecosystems for their livelihoods. Coral reefs support fisheries and tourism industries, which are vital for many coastal communities in Cambodia. The degradation of these reefs due to climate change can adversely affect fish populations and diminish the quality and diversity of marine resources available to local fishermen (UN-Habitat, 2012).

4.4 Impacts and Risks on Freshwater Ecosystems

Freshwater environments cover less than one percent of the Earth’s surface but nevertheless contain around 10 percent of all described species (Dudgeon et al., 2006) (Strayer and Dudgeon, 2010), making them local and global biodiversity hotspots. They provide numerous ecosystem services (Green et al., 2015), such as water supply for drinking and agricultural use, manufacturing, transport, recreational activities, and flood control.

Some of the largest climate change impacts are on the availability of freshwater. There are several effects of climate change impact freshwater resources, including the increase in temperature (increased rate of evaporation, forest fire), melting of ice (increased flooding, adverse effect on the migration of fish), and sea-level rise (salinity intrusion and the decline in freshwater availability). Many studies have shown climatic change and its impact on the availability of freshwater. The freshwater ecosystem is warming, acidifying, and deoxygenating as a consequence of climate change (Gurudatta et al., 2021).

Figure 27 shows an overview of ecosystem services that are directly and indirectly impacted by climate change and local anthropogenic impact. The major impacts of climate change on water and freshwater ecosystems are similar to those of coastal ecosystems: changes in water quality and viability, biodiversity, and habitat change. All of these impacts could affect freshwater ecosystem services.

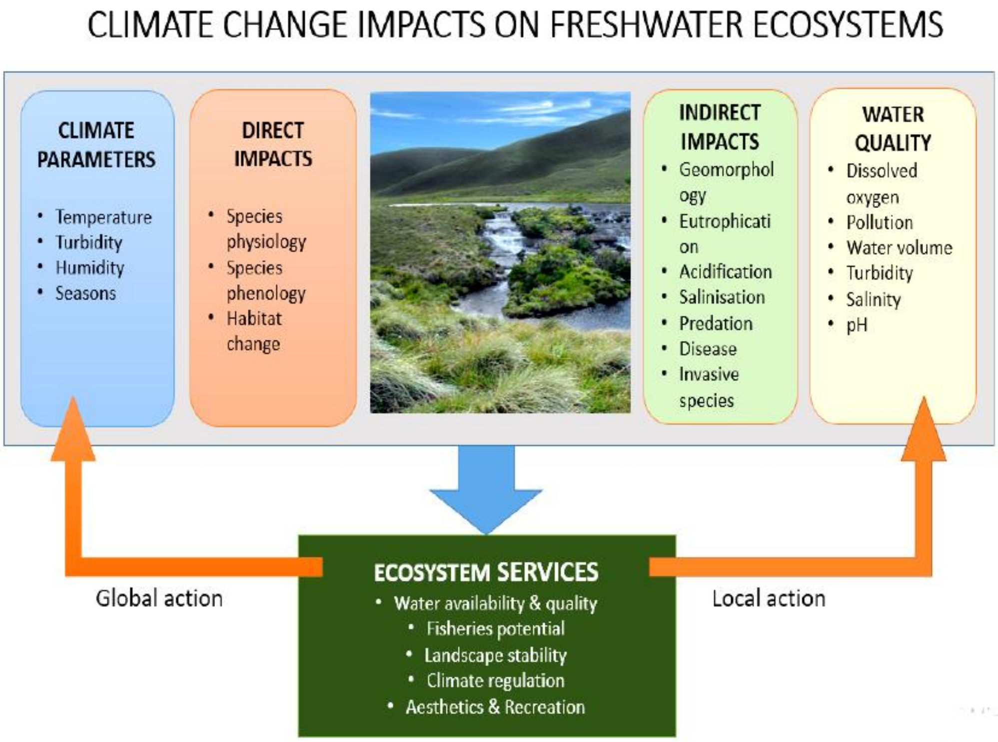


Figure 27: Overview of ecosystem services.
Source: Liu et al., 2015.

4.4.1 Watersheds and Reservoirs

Climate change is significantly impacting watershed ecosystems in Cambodia, leading to alterations in hydrology and sediment transport. Seasonal rainfall patterns are changing, resulting in longer dry seasons and shorter, more intense wet seasons, which exacerbate droughts and increase flood risks during wet periods (UNDP, 2011). The Mekong River's hydrological regime is also being affected, with reduced flow in the dry season and increased flow in the wet season, impacting agriculture and fisheries reliant on stable water levels (UNDP, 2011). Additionally, the natural flood pulse of Tonle Sap Lake is being disrupted due to climate change which can decrease aquatic productivity (Monin, 2021). Sediment transport is similarly affected; dams along the Mekong trap sediments that nourish downstream ecosystems, degrading soil fertility over time (Kondolf et al., 2014). This reduction in sediment transport compromises aquatic habitats by diminishing nutrient inputs essential for fish populations, significantly impacting communities dependent on fisheries (Monin, 2021). Furthermore, biodiversity loss occurs as changes in hydrology disrupt natural cycles necessary for maintaining diverse habitats, particularly flooded forests crucial for fisheries (UNDP, 2011). The economic implications are severe, as increased frequency of floods and droughts leads to crop failures and food shortages, adversely affecting local economies (Oeurng et al., 2019; WB, 2023)

The Tonle Sap Lake has experienced a decrease in wet-season water levels by 1.05 meters from 2010 to 2019, resulting in a 20.6 percent reduction in area and a shorter flooding season by 26 to 40 days (Strangio, 2022). The Mekong River's average annual reverse flow to the Tonle Sap has diminished by 56.5 percent due to dam operations and local irrigation activities Strangio, 2022). Additionally, there has been an increase in dry-season minima and a decrease in wet-season maxima at various monitoring stations, indicating altered flood dynamics (Oeurng et al., 2019). Dry-season minima and wet-season maxima refer to the lowest and highest water levels or flows observed during the dry and wet seasons, respectively. An increase in dry-season minima means that the lowest water levels during the dry season are higher than before, while a decrease in wet-season maxima means that the highest water levels during the wet season are lower than before. This indicates altered flood dynamics, where dry seasons are less dry and wet seasons experience reduced peak flooding. Water quality and availability have also deteriorated and pose serious risks to local communities reliant on fishing and agriculture (Lovgren, 2023; Oeurng et al., 2019).

4.4.2 Groundwater

Groundwater resources in Cambodia are facing significant challenges due to depletion and contamination, exacerbated by climate change and increasing agricultural demands.

a. Groundwater Depletion

Rising Dependence on Groundwater: Since 1960s, groundwater utilization in Cambodia has escalated, particularly for domestic and agricultural purposes. Current estimates indicate that groundwater use is increasing by approximately 10 percent annually (ODC, 2016). This surge in demand is particularly critical in the Lower Mekong Basin, where agriculture heavily relies on groundwater for irrigation. Reports suggest that if current extraction rates persist, many regions may experience groundwater levels dropping below the operational limits of conventional suction pumps within the next 15 years.

Impact of Climate Change: Climate change poses a dual threat to groundwater resources. Although there is an overall increase in annual rainfall, a reduction during the dry season is anticipated, potentially leading to water shortages. Additionally, rising temperatures contribute to increased evaporation rates, further stressing water availability. The combination of these factors could significantly affect groundwater recharge rates, threatening long-term sustainability (NCSD/MoE, 2019).

b. Groundwater Contamination

Reduced groundwater levels can exacerbate contamination by concentrating levels of toxins and salt in groundwater. This includes:

Chemical Contaminants: Groundwater quality in Cambodia is compromised by various contaminants, notably arsenic, manganese, and high iron levels. Arsenic contamination is particularly severe, with concentrations reaching up to 3000 ppb in some areas, far exceeding WHO guidelines (RDI Cambodia, 2012). Manganese also poses health risks as it can affect neurological development in children. Furthermore, fecal coliform contamination from inadequate waste management practices has been reported across shallow aquifers, leading to public health concerns (RDI Cambodia, 2012).

Saline Intrusion: Salinity levels in groundwater are increasing, especially in southern provinces due to seawater intrusion from rising sea levels and excessive groundwater extraction (FAO and GEF, 2022; EPA, 2024). This intrusion threatens both water supply and agricultural productivity by rendering both groundwater and soil unsuitable for irrigation.

The observed changes in groundwater resources in Cambodia highlight a critical need for sustainable management practices (Lwin and Mendal, 2023). As both depletion and contamination threaten the availability and safety of groundwater supplies, strategic interventions are essential to ensure long-term viability (Sok and Choup, 2017). Addressing these challenges will require coordinated efforts among government bodies, local communities, and international organizations to enhance monitoring, implement effective regulations on groundwater extraction, and improve waste management practices (Lenazwski, 2023; ODC, 2016).

4.4.3 Streamflow

Observed changes in streamflow patterns in Cambodia, particularly within the Mekong River Basin and Tonle Sap Lake, have significant implications for freshwater ecosystems. Recent studies indicate a decline in dry-season flows and an increase in mid-dry season water discharge, with projections suggesting that baseflows in rivers like the Chinit and Siem Reap could decrease by up to 90 percent by the 2030s under certain climate scenarios. Conversely, water discharge during the mid-dry season is expected to rise by up to 140 percent, temporarily enhancing water availability. The annual flood pulse, essential for sustaining fisheries and agriculture, has seen a drastic reduction, with a noted decrease of around 12.9 percent in flood duration attributed to increased upstream damming and climate change (Sok et al., 2022). Hydropower projects have further exacerbated these changes, reducing total flood extents by over 20 percent and significantly altering flow regimes (Oeurng, 2019). Additionally, shifts in the timing of high and low flows disrupt the natural life cycles of aquatic species and affect nutrient distribution (Oeurng, 2019). These alterations threaten biodiversity as fish populations and other aquatic organisms rely on specific seasonal conditions for spawning and feeding. As habitats become less suitable, species diversity may decline, impacting local fisheries vital for community livelihoods (MRC, 2021). The health of freshwater ecosystems is closely tied to hydrological patterns. Reduced sediment transport diminishes habitat quality, leading to decreased ecosystem resilience against environmental stressors like climate change (WB, 2024). Furthermore, altered streamflow patterns jeopardize agricultural productivity, especially rice farming, which depends on predictable flooding for irrigation. Given these observed changes, there is an urgent need for adaptive management strategies that consider both ecological integrity and human livelihoods to mitigate the impacts of climate change and infrastructural developments on Cambodia's vital freshwater ecosystems (MRC, 2022).

4.4.4 Surface Water

Cambodia's surface water bodies, including lakes, rivers, and creeks, have been undergoing significant changes due to various environmental factors, particularly climate change and human activities.

a. Changes in Surface Water Availability

Overall Reduction: Recent studies indicate an overall reduction in surface water availability in Cambodia by approximately 4.16 percent from 2000 to 2020. This decline is largely attributed to the expansion of Economic Land Concessions and infrastructure development, which has increased the likelihood of extreme drying and flooding events (Mamalis et al., 2024).

Seasonal Variability: The dynamics of surface water bodies are characterized by strong seasonal variability. For instance, during the wet season (May to October), surface water areas increase significantly, particularly in the Tonle Sap Lake, which can expand from about 2,600 km^2 to approximately 10,500 km^2 (Teng, 2022; Jiang et al, 2024). Conversely, during the dry season (November to April), the water levels drop dramatically as the flow in the Tonle Sap River reverses and drains into the Mekong River (Soum et al., 2021).

b. Water Quality Concerns, Floods and Droughts

Water Quality Concerns: The quality of surface water is also deteriorating due to increasing pollution levels in urban areas. This pollution affects not only human health but also aquatic ecosystems and biodiversity (NCSD/MoE, 2019). Additionally, rising temperature and changes in precipitation patterns are altering the chemical composition of freshwater bodies, potentially impacting fish stocks and overall ecological health.

Floods and Droughts: Cambodia is increasingly vulnerable to climate change impacts, experiencing more frequent floods and droughts. Flooding events have intensified over recent decades, with significant infrastructure damage and agricultural losses reported during severe flood seasons (NCSD/MoE, 2019). The Mekong River's hydrology plays a crucial role in this dynamic, as it swells during monsoon rains and can lead to extensive flooding of adjacent floodplains.

c. Observations from Specific Water Bodies

Tonle Sap Lake: The Tonle Sap Lake is a critical component of Cambodia's water system. Its unique hydrological behavior—where it drains into the Mekong during the dry season—makes it particularly sensitive to changes in river flow caused by upstream dam constructions on the Mekong River (ODC, 2016). The lake's ecosystem supports numerous floating villages and is vital for local fisheries.

Mekong River Dynamics: The Mekong River is the largest river in Cambodia, with an average annual discharge of about 374.2 billion m^3. The river's flow varies significantly throughout the year, peaking during the monsoon season when it can cause widespread flooding (NCSD/MoE, 2019). Changes in sediment transport and water levels due to upstream damming have raised concerns about long-term ecological impacts.

In summary, Cambodia's surface water bodies are facing significant challenges due to climate change and anthropogenic influences. These changes not only affect water availability but also threaten biodiversity and the livelihoods of communities' dependent on these vital resources.

4.4.5 Water Quality

In Cambodia, water quality in lakes, rivers, and other freshwater bodies has been observed to change significantly due to a combination of urbanization, pollution, climate change, and seasonal variations. This section demonstrates impacts and effects on several key bodies of freshwater.

a. Cheung Ek Lake

Water Quality Dynamics: Cheung Ek Lake, located in Phnom Penh, has experienced notable degradation in water quality attributed to urban runoff and wastewater inflow. The lake receives about 70 percent of its water from rain runoff and untreated wastewater from the city. Seasonal studies indicate that electrical conductivity (EC) decreases from the rainy to the dry season, influenced by dilution from rainwater.

Nutrient levels such as nitrate (NO_3^-) and phosphate (PO_4^{3-}) show a decrease from the inlet to the outlet of the lake, suggesting some capacity for nutrient reduction despite ongoing pollution pressures (Somara and Mihara, 2023).

Impact of Urbanization: Rapid urbanization has led to a reduction in the lake's surface area, diminishing its ability to function as a natural wastewater treatment system. The ongoing encroachment on the lake's banks has further exacerbated these issues, leading to increased nutrient loads during certain times of day due to human activities (Somara and Mihara, 2023).

b. Tonle Sap Lake

The Tonle Sap Lake's water quality has been deteriorating due to multiple factors, including pollution from untreated domestic and industrial wastewater, chemical-intensive agricultural runoff, and waste discharge from floating houses. This degradation poses significant risks to the lake's ecosystem and the livelihoods of over one million people who depend on it.

Eutrophication and Pollution: The Tonle Sap Lake has faced significant environmental changes due to pollution from both point and non-point sources. Eutrophication has become a pressing issue as untreated wastewater and poor sanitation practices contribute to nutrient overloads in the lake. This has led to deteriorating water quality, affecting biodiversity and local fisheries (Chihiro et al., 2020).

Seasonal Variability: The lake's water quality is also influenced by seasonal fluctuations in water levels, which can vary dramatically (up to 8 meters). These changes affect surface area and can either dilute pollutants during high rainfall or concentrate them during dry seasons. Continuous monitoring is essential for understanding these dynamics and managing water quality effectively (Oyagi et al., 2017).

c. Mekong River

Cambodia's Mekong River water quality has shown signs of deterioration, primarily due to increasing pollution from urbanization, agriculture, and population growth. Box. 4.2 shows results of a recent comprehensive case study on the water quality of the Mekong River in Cambodia is provided by the MRC's 2022 Water Quality Monitoring Report (MRC, 2022).

Sedimentation Changes: The Mekong River system is experiencing alterations in sediment balance due to upstream dam constructions. Increased erosion in some areas leads to sediment loss, which impacts fish ecology and soil fertility essential for agriculture. The river's hydrodynamics are closely linked with Tonle Sap Lake, making it critical for maintaining ecological balance and supporting local livelihoods (ODC, 2016).

Climate Change Effects: Climate change poses additional challenges by altering rainfall patterns and increasing temperatures, which can exacerbate water quality issues. These changes threaten freshwater availability and increase the risk of pollution during heavy rainfall events when runoff can carry contaminants into water bodies (NCSD/MoE, 2019).

In summary, Cambodia's freshwater bodies are facing significant challenges related to urbanization, pollution, climate change, and seasonal variations. Effective management strategies are essential to mitigate these impacts and preserve water quality for both ecological health and human use.

4.4.6 River and Tributary Ecosystems

The impacts of climate change on river and tributary ecosystems in Cambodia, particularly in the Tonle Sap Lake basin and the Mekong River, are significant and multifaceted. These changes affect hydrology, biodiversity, and local livelihoods.

a. Changes in River Flow

Decreased Water Availability: Climate change is projected to cause a reduction in river flows across various sub-basins of the Tonle Sap Lake. Studies indicate that the mean annual river flows could decrease by 9 percent to 41 percent by the end of the 21st century, with significant reductions in both wet and dry season flows. For instance, baseflows in rivers such as Chinit and Siem Reap are predicted to decline by up to 90 percent during the dry season under certain climate scenarios (Oeurng et al., 2019).

Altered Flood Dynamics: The frequency and intensity of floods are also expected to change. There is a potential decline in flood magnitudes coupled with an increase in drought occurrences, which can severely impact the natural ecosystems that rely on these seasonal floods for regeneration and nutrient cycling (Oeurng et al., 2019). The alteration of the flood pulse, which is crucial for maintaining ecological balance, is likely due to both climate change and human activities like dam construction (UNDP, 2011; Monin, 2021).

b. Biodiversity Impacts

Threats to Aquatic Life: Changes in hydrology directly threaten aquatic biodiversity. The Tonle Sap Lake is one of Southeast Asia's most productive freshwater ecosystems, heavily reliant on seasonal flooding for fish breeding and habitat maintenance. Reduced water levels hinder fish migration and breeding cycles, leading to decreased fish populations and biodiversity loss (WB and ADB, 2021). Local fishermen have reported significant declines in their daily catches, indicating a direct impact on livelihoods as well as food security (WB and ADB, 2021)

Habitat Degradation: In addition to changes in fish populations, alterations in water quality due to reduced flows can lead to habitat degradation. The sediment transport that nourishes aquatic habitats may be disrupted, further exacerbating the decline of fish stocks and other aquatic organisms (Monin, 2021). This degradation threatens not only biodiversity but also the livelihoods of communities that depend on fishing as their primary source of income.

4.4.7 Wetland Ecosystems

The wetland ecosystems in Cambodia, particularly in the Lower Mekong Delta, have undergone significant changes over recent decades. These alterations are primarily driven by human activities, including agricultural expansion, infrastructure development, and climate change, leading to shifts in species composition and hydrological patterns.

a. Changes in Species Composition

The biodiversity of Cambodia's wetlands has been notably affected by habitat loss and environmental changes. Over the past 30 years, approximately 1,600 km^2 of wetland vegetation has been lost, representing a 65 percent decline in natural wetland areas within the Cambodian Lower Mekong Delta (CLMD) (WWT, 2023). This loss has resulted in changes to species distributions and community structures. Key observations include:

Invasive Species: The introduction of invasive plants such as *Mimosa pigra* has been noted, which can further threaten native biodiversity by outcompeting indigenous flora (WWT, 2023).

Fish Populations: Composition of fish species is also shifting. Species like *Henicorhynchus spp.* (trey riel) are becoming more prevalent, as their populations are closely tied to the flood pulse dynamics (NCSD/MoE, 2019).

Vulnerability of Specific Species: Some species are at risk due to changing hydrological conditions. For example, certain fish and aquatic species depend on specific flood durations for breeding and migration; any alteration in these patterns can lead to population declines (MRC, 2023).

b. Hydrological Changes

The hydrology of Cambodia's wetlands is critically influenced by both natural cycles and anthropogenic modifications. The Mekong River's annual flood cycle is essential for maintaining the ecological balance of these wetlands; however, this cycle has been disrupted by various factors:

Infrastructure Development: Construction of hydropower dams has altered water flow patterns. This development has led to a weakened flood pulse and reduced seasonal flooding, which is vital for many wetland species (WWT, 2023).

Agricultural Practices: Intensified agricultural practices have resulted in the construction of dykes and irrigation systems that further modify water retention and drainage patterns. Consequently, areas that were once flooded for extended periods are now drying up quicker after the rainy season (NCSD/MoE, 2019).

Climate Change Impacts: Climate change is expected to exacerbate existing hydrological challenges. Increased rainfall variability and extreme weather events may intensify flooding and drought conditions, altering the timing and duration of water inundation in wetlands (NCSD/MoE, 2019).

The observed changes in wetland ecosystems in Cambodia reflect a complex interplay between human activities and natural processes. The ongoing loss of wetland area and the resulting shifts in species composition pose significant challenges for biodiversity conservation and ecosystem services. Effective management strategies that incorporate sustainable practices and climate resilience will be crucial for mitigating these impacts and preserving Cambodia's vital wetland habitats.

4.4.8 Species Range Shift

Observed shifts in the ranges of key freshwater species in Cambodia are primarily driven by climate change, habitat destruction, and alterations in hydrology, particularly in the Mekong River Basin and Tonle Sap Lake. The vulnerability of species varies, with some likely to thrive under changed climatic conditions while others may face extinction, highlighting the need for targeted conservation strategies (NCSD/MoE, 2019).

Climate change impacts include significant northward distribution shifts for approximately 84 percent of fish species, while about 49 species may experience reductions in suitable habitats, indicating a potential decline in species richness, especially in biodiverse areas like Tonle Sap Lake and River; conversely, regions such as the Sesan, Sekong, and Srepok (3S) River Basins may see increases in fish species richness (IUCN, 2019; Noun et al., 2024). Also, the unique hydrology of Tonle Sap Lake allows it to expand significantly during the wet season, providing essential spawning habitats; however, changes in flood levels due to dam constructions can adversely affect these dynamics, potentially leading to decreased fish production (NCSD/MoE, 2019; The World Fish Center, 2010).

4.5 Key Future Impacts and Risks

Climate change affects ecosystems in many ways and will continue to affect them even more in the future. Climate controls how plants grow, how animals behave, which organisms thrive, and how they all interact with the physical environment (IPCC, 2023). Climate change is having variable and increasing impacts on ecosystem services and benefits, from food production to clean water to carbon sequestration, with consequences for human well-being. It is also the cause of the degradation of ecosystems such as forests, wetlands, drylands, and coastal and marine systems, which is a major driver of disaster risk and a key component of communities' vulnerability to disasters (UNEP, 2024).

Climate change is projected to exacerbate the loss of biodiversity and increase the risk of extinction for many species, especially those already at risk due to low population numbers, restricted or patchy habitats, and limited climatic ranges (Shivanna, 2022).

According to Millennium Ecosystem Assessment (MA) Synthesis Report (2005), there are 3 keys impacts and risks from climate change on ecosystems, including:

a. Ecosystem Conversion and Habitat Loss

Rapid conversion of ecosystems is projected to continue under all MA scenarios in the first half of the twenty-first century. Roughly 10–20 percent (low to medium certainty) of current grassland and forestland is projected to be converted to other uses between now and 2050, mainly due to the expansion of agriculture and, secondarily, because of the expansion of cities and infrastructure. The biomes projected to lose habitat and local species at the fastest rate in the next 50 years are warm mixed forests, savannas, scrub, tropical forests, and tropical woodlands.

Habitat loss in terrestrial environments is projected to accelerate the decline in local diversity of native species in all four scenarios by 2050. Loss of habitat results in the immediate extirpation of local populations and the loss of the services that these populations provided.

b. Extinction of Species

The habitat losses projected in the MA scenarios will lead to global extinctions as numbers of species approach equilibrium with the remnant habitat. As habitat is lost and reduced to smaller fragments, the number of species surviving in those remaining habitats will eventually stabilize or reach a balance that the reduced environment can support. In this new equilibrium state, fewer species are sustained because many have already been lost due to habitat reductions, some immediately and others over time due to time lags in extinction processes. The equilibrium number of plant species is projected to be reduced by roughly 10-15 percent as a result of habitat loss from 1970 to 2050 in the MA scenarios (low certainty). Other terrestrial taxonomic groups are likely to be affected to a similar extent. The pattern of extinction through time cannot be estimated with any precision because some species will be lost immediately when their habitat is modified but others may persist for decades or centuries. Time lags between habitat reduction and extinction provide an opportunity for humans to deploy restoration practices that may rescue those species that otherwise may be on a trajectory towards extinction. Significant declines in freshwater fish species diversity are also projected due to the combined effects of climate change, water withdrawals, eutrophication, acidification, and increased invasions by non-indigenous species (low certainty). Rivers that are expected to lose fish species are concentrated in poor tropical and subtropical countries.

c. Most Vulnerable Ecosystems

Dryland ecosystems are particularly vulnerable to changes over the next 50 years. The combination of low current levels of human well-being (high rates of poverty, low per capita GDP, high infant mortality rates), a large and growing population, high variability of environmental conditions in dryland regions, and high sensitivity of people to changes in ecosystem services means that continuing land degradation could have profoundly negative impacts on the well-being of a large number of people in these regions. Subsidies of food and water to people in vulnerable drylands can have the unintended effect of increasing the risk of even larger breakdowns of ecosystem services in future years. Local adaptation and conservation practices can mitigate some losses of dryland ecosystem services, although it will be difficult to reverse trends toward loss of food production capacity, water supplies, and biodiversity in drylands.

4.6 Directions for Future Studies

All types of ecosystems, including terrestrial, coastal, and freshwater ecosystems, have faced and will continue to experience effects of climate change. These changes are causing ecosystem degradation, biodiversity loss, and habitat change and destruction. Therefore, to effectively study the impact and risk of climate change on ecosystems in Cambodia, future research should focus on several critical areas that address both immediate and long-term challenges posed by climate change. Below are key directions for future studies on the ecosystem and its impact by climate change:

4.6.1 Understanding Ecosystem Vulnerabilities

Biodiversity and Habitat Loss: Research should investigate how climate change affects biodiversity, particularly in sensitive areas like the Tonle Sap Lake and coastal ecosystems. Studies should assess species vulnerability, habitat degradation, and the potential for ecosystem shifts due to temperature increases and altered precipitation patterns.

Soil Erosion and Agricultural Impact: Investigating soil health, erosion rates, and the consequent impact on agricultural productivity is crucial. For instance, studies have shown that droughts have significantly reduced yields in paddy fields, indicating a need for adaptive agricultural practices.

4.6.2 Climate Projections and Economic Implications

Economic Modeling: Future studies should incorporate economic models that predict the impacts of climate change on GDP, especially in agriculture-dependent sectors. Projections indicate that climate change could reduce Cambodia's GDP by nearly 10 percent by 2050 if current trends continue. Understanding these economic impacts will help in formulating effective policies.

Adaptation Strategies: Research should evaluate the effectiveness of current adaptation strategies in mitigating economic losses. This includes assessing government-led initiatives aimed at improving infrastructure resilience to extreme weather events.

4.6.3 Health and Social Dimensions

Enhance Surveillance and Early Warning Systems: Cambodia should strengthen its health system's capacity to monitor climate-sensitive diseases such as vector-borne diseases (dengue, malaria), waterborne diseases (diarrheal diseases), and heat-related illnesses through improved early warning systems and rapid diagnosis mechanisms. This will allow timely public health responses to outbreaks linked to extreme weather events like floods and heatwaves.

Conduct Targeted Epidemiological Research: There is a critical need for detailed studies on the correlation between rising temperatures and the incidence of diseases such as diarrhea, respiratory infections, and heat stress, especially in children. Research should use climate data (temperature, precipitation) alongside health outcomes to forecast and prepare for future disease burdens under different climate scenarios.

Address Heat Stress Among Vulnerable Groups: Given the projected temperature rise of up to 3.1°C by the 2090s, heat stress poses a major health threat, particularly for outdoor laborers and urban populations. Public health initiatives should include heat health action plans, community awareness campaigns, and infrastructure adaptations to reduce heat exposure.

Improve Water, Sanitation, and Hygiene (WASH) Infrastructure: Floods and droughts increase waterborne disease outbreaks by compromising water quality. Investments in resilient WASH infrastructure and emergency water supply during climate extremes are essential to reduce diarrheal disease risk.

Focus on Women, Children, and Rural Communities: These groups are disproportionately vulnerable due to factors such as lower education levels, poverty, and residence in hazard-prone rural areas. Tailored health education and social support programs should be developed to address their specific risks and improve adaptive capacity.

Address Socioeconomic and Health Inequalities: Climate change amplifies existing disparities in health outcomes. Policies should incorporate social determinants of health, ensuring equitable access to climate-resilient health services, nutrition support, and mental health care, especially in vulnerable populations.

Strengthen Multi-sectoral Collaboration: Effective vulnerability assessment and response require coordination across health, environment, agriculture, water management, and social sectors. Cambodia's National Strategic Plan for Climate Change Adaptation and Disaster Risk Reduction in the Health Sector (2019-2023) provides a framework for such integrated action.

4.6.4 Policy Development and Implementation

Framework for Climate Action: Future studies should contribute to developing comprehensive frameworks for climate action that integrate scientific findings with policy-making processes. This includes evaluating Cambodia's Nationally Determined

Contributions (NDCs) and their effectiveness in reducing greenhouse gas emissions while promoting sustainable development.

Community Engagement: Research should emphasize participatory approaches that involve local communities in climate resilience planning. Engaging stakeholders can enhance the relevance and effectiveness of adaptation strategies. For instance, a project titled "Collaborative Forest Landscape Governance Towards a Resilient and Sustainable Future," implemented by the Department of Forestry and Environmental Science from 2023 to 2027, aims to develop a model of forest landscape governance. This model emphasizes collaboration from community to national levels to promote effective forest management conclusion, addressing the multifaceted impacts of climate change on Cambodia's ecosystems requires a holistic approach that combines ecological research with socio-economic analysis. By focusing on vulnerabilities, economic implications, health risks, and policy frameworks, future studies can provide valuable insights that inform effective responses to climate challenges in Cambodia.

CHAPTER 5
OBSERVED IMPACT AND RISK ON HUMAN SYSTEM

5.1 Introduction

5.1.1 Overview

The increasing emission of greenhouse gases (GHG) and anthropogenic activities drive the phenomenon of climate change, posing an unprecedented global challenge with profound implications for human systems (IPCC, 2021). Human systems, which encompass societies, economies, infrastructure, and institutions, are inextricably linked to environmental conditions, rendering them particularly susceptible to climatic change (Hoegh-Guldberg et al., 2019). The effects of climate change on these systems are already discernible across a range of geographical regions, manifesting in altered weather patterns, increased frequency and intensity of extreme events, and transformation of ecosystems (CCCSP, 2014). Due to these accelerated changes, risks to human systems become more evident, affecting health, livelihoods, and well-being of billions of people.

Cambodia, a Southeast Asian nation with a rich cultural history and a predominantly agro-based economy, is confronted with significant and complex challenges resulting from climate change (ADB, 2021b). The country is particularly susceptible to the consequences of climate change, largely due to its topography, limited capacity to adapt, and dependency on climate-sensitive sectors such as agriculture, fisheries, and forestry (NCSD, 2015). The effects of climate change in Cambodia are becoming increasingly evident. Rising temperatures, shifting rainfall patterns, and the increasing frequency and severity of extreme weather events are having significant effects on the country's human systems, affecting food security, public health, infrastructures, migration patterns and economic stability (NCSD, 2017).

In 2019, the estimated total population of Cambodia was 15.7 million. Of this number, 48 percent were male and 52 percent were female. Approximately 66.1 percent of the country's population resided in rural areas, while 33.9 percent inhabited urban areas (MoP, 2019). In 2022, the gross domestic product (GDP) was calculated at a value of USD 30.0 billion, with an annual GDP growth rate of 5.2 percent and a GDP per capita of approximately USD 1,800. The agricultural sector, particularly rice cultivation, forestry, and fishery production, continues to be a significant contributor to the economy, accounting for 21.9 percent of GDP (WB, 2014).

In recent years, the impact of climate change on the population of Cambodia has become increasingly visible, particularly in rural areas. As reported by the World Bank, floods and droughts are the most frequent hazards. Extreme flooding with widespread impacts occurred during the monsoon season in 2000, which affected approximately 3.5 million people and resulted in nearly 350 deaths (WB, 2014). In 2001 and 2002, more than 3 million people were affected, with more than 100 deaths. The most recent of these disasters occurred in 2011 and 2013, affecting more than 2 million people, resulting in over 400 deaths, and causing estimated damages of USD 451 million and USD 356 million, respectively (MoE, 2022). Extreme droughts have also had severe impacts. Droughts during the years 1995, 1996, and 2002 affected approximately 2.5 million people, while droughts during 2004 and 2005 impacted 30 percent of the country's agricultural land and resulted in a 14 percent decline in agricultural output; and a drought in 2015–2016 affected a further 2.5 million people across 18 provinces (MoE, 2022; UNDP, 2023). Poorer farmers who rely on rainfed farming systems are especially vulnerable to more frequent and extreme declines in precipitation or longer dry seasons because just 20 percent of Cambodia's rice fields have irrigation (USAID, 2019).

As the risks associated with climate change intensify, vulnerable populations, particularly women, children, marginalized groups, and many relevant important sectors, are disproportionately affected due to limited resources and lack of adaptive capacities. It is crucial to understand the observed impacts and risks of climate change on Cambodia's human systems in order to develop effective policies and strategies that mitigate these challenges, enhance resilience, and safeguard development progress in the context of mounting environmental pressures.

5.1.2 Objectives, Scope and Key Issues

The objectives of this chapter are focused on understanding the specific vulnerabilities, risks and consequences faced by different sectors. The following are the specific objectives of this chapter:

- **Identifying the observed impacts of climate change on key human systems**: To identify and demonstrate the observed impacts of climate change on various human systems in Cambodia, including agriculture, water resources, health, livelihoods and infrastructure.
- **Assessing vulnerability and risk factors**: To assess the vulnerability of different socio-economic groups, with particular emphasis on rural and urban populations, as well as gender and socio-economic disparities.
- **Providing policy recommendations for climate change adaptation**: To provide actionable recommendations for policymakers based on the findings by focusing on enhancing the resilience of human systems in Cambodia, which means first identifying gaps in current policies and then proposing solutions for integrating climate resilience into development planning.

5.1.3 Methods and Approach

This research was conducted primarily through desk research, including both primary and secondary data sources, as well as the authors' own relevant works. The objective of this chapter was to identify the documented impacts of climate change on key human systems, such as agriculture, water resources, health and livelihoods, in Cambodia. The desk review commenced with a comprehensive review of existing literature, including academic journals, government reports, policy documents, and publications from national and international institutions. The risk assessment considered factors such as exposure to climate hazards, sensitivity of human systems to these hazards, and the adaptive capacity of communities and institutions. This helped in quantifying relative risks faced by different sectors and regions in Cambodia. All findings from the literature review, data, and best practices were synthesized into a comprehensive report. The main documentation reviewed for this chapter included materials and reports from the following sources:

- Public Sector: MoE, NCSD, MAFF, NIS, etc.
- Development Partners/NGOs: ADB, FAO, UNDP, World Bank.

- Other relevant documents, research articles, and publications.

5.1.4 Existing Relevant Models

This section explains existing relevant models that have been used in this and related research to understand effects of climate change.

A. Crop Impact Modelling

A considerable array of crop simulation models (CSM) is available. These models permit the execution of simulations for a specific weather time series and production environment (Kelly et al., 2023). The majority of these models are equipped with a graphical user interface, enabling users to modify parameters related to crops, soil, and management practices. So, each research can use different types of sources for crop simulation models to specify crops into their field.

B. Socio-economic Modelling and Analysis

The Ministry of Economy and Finance (MEF) has developed a model to assess the impact of climate change on Cambodia's economic development. This model, known as the Climate Economic Growth Impact Model (CEGIM), is a scientific tool that quantifies the anticipated effects of climate change on Cambodia's economy in the medium and long term. It enables the Royal Government of Cambodia, development partners, and other key stakeholders to rigorously quantify the impact of climate change and provides evidence and support in developing more realistic and effective policy options, strategies, and programs to sustain long-term progress and ensure optimal outcomes. CEGIM is a simple economic model, built on a spreadsheet, that distills the key features of the most widely used models of the economic impact of climate change. The model is driven by a production function that determines GDP in any given year based on the capital and labor stocks present in that same year (MEF, 2019). Figure 28 shows CEGIM results for costs of damages resulting from natural events from 1991-2020.

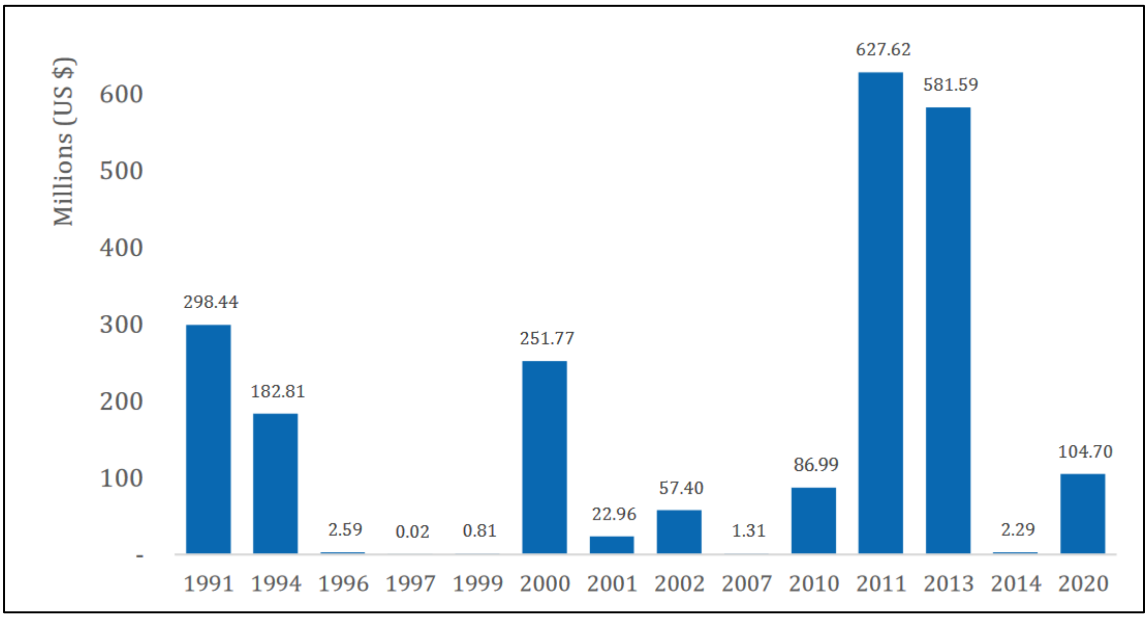


Figure 28: Damage adjusted for natural phenomena events in Cambodia.
Source: (UNDP, 2023)

According to the GEGIM analysis by MEF, in the year 2050, reduced labor productivity will be responsible for 57 percent of all Loss and Damage, affecting all sectors but particularly impacting those related to manufacturing and construction. The loss of income will account for 17 percent of all Loss and Damage, with the majority concentrated in the four agricultural sectors. Damage to assets constitutes 26 percent of all Loss and Damage, with a distribution across all sectors, though it is especially significant for service sectors, which are affected by damage to roads.

5.2 Impacts and Risks on Agriculture and Water Resources

5.2.1 Overview

Agriculture plays a pivotal role in the Cambodia’s economy and rural communities, with rice being the most important crop. Cambodia's climatic conditions, comprising a tropical monsoon climate, characterized by distinct wet and dry seasons, is well-suited for the cultivation of a diverse range of crops.

Rice is the principal crop in Cambodia, occupying a dominant position within the country's agricultural landscape. Rice is both a staple food and a major export product. The Mekong River and Tonle Sap Lake provide crucial water resources for rice cultivation, particularly for rain-fed wet-season rice and other crops (Frappart et al., 2018). Cambodian rice production has seen improvements in yield due to advancements in farming techniques and improved seed varieties. However, challenges such as flooding, droughts, and soil degradation persist (MAFF, 2014). In addition to rice, Cambodia's agricultural output encompasses a range of other crops, including chili peppers, cucumbers, tomatoes, mangoes, and bananas. These produce items are of significant domestic consumption value and serve to diversify Cambodia's agricultural output (MAFF, 2022).

The agricultural sector in Cambodia, which contributes significantly to the national economy and employs approximately 50 percent of the population, is particularly susceptible to the impacts of climate change. The country is already witnessing alterations in weather patterns, including increased temperatures, erratic rainfall, and a greater frequency of extreme weather events like floods and droughts. These changes present significant risks to crop production, food security and rural livelihoods (FAO, 2020).

The monsoon season in Cambodia is exhibiting a decline in predictability, as evidenced by the occurrence of heavy precipitation outside of the region's historically established cyclical patterns, which has led to the emergence of both droughts and flooding in the area. Inconsistent rainfall has affected planting and harvesting schedules, thereby increasing the risk of crop failure. Cambodia is prone to flooding during the rainy season, particularly in the Mekong River basin. Conversely, droughts, particularly in provinces such as Prey Veng and Svay Rieng, have resulted in crop failures and reduced yields in both wet and dry seasons. These dual risks of floods and droughts are further exacerbated by climate change, posing a significant threat to both rain-fed and irrigated agriculture (GSSD, 2018).

Additionally, the phenomenon of climatic change exerts an influence on the elevation of sea levels. This is due to the heating of the climate system, which has caused a global mean sea level increase as a consequence of ice depletion on land and thermal expansion resulting from oceanic warming. Moreover, the result of climate change-induced salinization of coastal areas is affecting soil health and reducing crop yields, particularly in provinces like Kampot and Kep, where saltwater intrusion from rising sea levels has been reported (USAID, 2019). The increased frequency and intensity of extreme weather events, such as heavy rains, contribute to soil erosion, which reduces the fertility and productivity of agricultural lands. The combination of poor soil conditions and changing weather patterns makes it increasingly difficult for farmers to sustain productivity.

The crop production in Cambodia is facing significant challenges, particularly in rice production, due to the impact of climate change. The incidence of rising temperatures, unpredictable rainfall patterns, and extreme weather events such as floods and droughts are on the rise occurrence. Higher temperatures, particularly during critical crop growth stages, result in a reduction in yields, while irregular monsoon patterns lead to disruption of planting schedules (Grigorieva et al., 2023). While floods can, on occasion, prove beneficial, they can also result in significant crop losses. Furthermore, prolonged droughts are leading to water shortages, which in turn are threatening crop productivity. The deterioration of soil quality due to heavy precipitation, elevated salinity in coastal zones, and the proliferation of pests and diseases as a consequence of warmer, wetter conditions serve to exacerbate these challenges. The cumulative impact of these climate-related risks represents a significant threat to Cambodia's food security and the livelihoods of rural communities that rely on agriculture (FAO, 2022a). In light of these concerns, it is imperative that the country prioritize adaptation strategies, including enhanced irrigation, sustainable farming practices, and the development of climate-resilient crops, to ensure the long-term sustainability of its agricultural sector.

Cambodia is inextricably linked to its natural resources, most notably those associated with agriculture and hydrology. Approximately 70 percent of the population relies on agriculture as a source of income, while water resources are essential for irrigation, drinking, and sanitation. However, the threat of climate change represents a significant challenge to the stability and development of these sectors. The effects of climate change on agricultural productivity in Cambodia are significant, primarily manifesting as altered rainfall patterns, increased temperatures, and the occurrence of extreme weather events (CDRI, 2021). The Food and Agriculture Organization (FAO) has observed that irregular precipitation patterns can result in both droughts and floods, which in turn can compromise crop yields and food security (FAO, 2020). For example, the erratic nature of the monsoon season presents a challenge for farmers, frequently resulting in diminished harvests and heightened susceptibility to pests and diseases.

The consequences of climate change on agriculture have significant socio-economic ramifications. A reduction in agricultural productivity results in food insecurity, which affects the most vulnerable populations who rely on subsistence farming. As posited by the World Bank, climate change has the potential to elevate poverty rates in rural regions by up to 12 percent by 2030. This is due to the challenge of adapting to a changing climate while maintaining livelihoods (WB, 2021). This heightened vulnerability may precipitate migration to urban areas, thereby exacerbating existing challenges such as urban overcrowding and intensifying the burden on urban services.

The availability of water resources is of paramount importance to the productivity of agricultural activities and the maintenance of human health. The effects of climate change have resulted in altered rainfall patterns and rising temperatures, both of which present a significant threat to the availability and quality of water resources. The Mekong River Commission (MRC) has issued a warning that climate change could result in significant fluctuations in river flow, which would in turn impact both the availability of surface water for irrigation and drinking water supplies (Mekong River Commission, 2021). Droughts can significantly restrict access to water resources, while heavy precipitation can result in flooding, further complicating the management of these resources. The scarcity of water has a direct impact on agricultural outputs, as a significant proportion of farmers rely on irrigation to cultivate their crops. ADB underscores the potential for reduced agricultural yields resulting from water scarcity, which could in turn affect food security and household incomes (ADB, 2021b). In regions where water resources are already scarce, competition for these resources can give rise to conflicts between users in the agricultural, industrial, and domestic sectors. This further exacerbates social inequalities and tensions. Furthermore, the quality of water is also at risk as a consequence of climate change. An increase in precipitation can result in runoff that carries pollutants into water bodies, thereby compromising water safety and increasing the risk of waterborne diseases.

5.2.2 Agriculture

Approximately 30 percent of the country's GDP and 70 percent of the population are dependent on the agricultural sector, which is crucial for ensuring food security and economic stability. However, Cambodia faces challenges to agricultural productivity and livelihoods due to shifting weather patterns, rising temperatures, and extreme weather events. Changes in precipitation patterns are among the most significant consequences of climate change in Cambodia. The monsoon season, which is essential for rice cultivation, has become increasingly unpredictable. Farmers often experience prolonged droughts followed by intense flooding, which disrupts planting and harvesting schedules. Furthermore, increasing average temperatures represent another pressing concern. Studies indicate that mean temperatures in Cambodia have risen by approximately 1.2°C from 1995 (27.4°C) to 2014 (28.6°C), with projections suggesting further increases (World Bank, 2024). Higher temperatures can negatively impact crop growth, leading to heat stress, particularly in heat-sensitive crops such as rice and maize. The Cambodia Inter-Censal Agriculture Survey (CICAS) conducted in 2019 estimated that a total of 1,735,000 households, representing 23.5 percent of all households in the country, managed agriculture holdings, which are distributed unevenly across the country's socio-geographic zones (CICAS, 2019).

The plain zone had the largest number of agricultural holdings (42 percent), followed by the Tonle Sap Lake zone (35 percent), the Plateau zone (15 percent), and finally the Coastal zone (8 percent) as shown in Figure 29 (CICAS, 2019). However, soil degradation, which is critical to the productivity of agricultural activities, is exacerbated by climate change. Increased rainfall intensity can lead to soil erosion, while changes in water tables may lead to salinization, particularly in coastal regions. Soil fertility loss represents a significant challenge to the sustainability of agricultural practices, impeding farmers' capacity to maintain productive fields (FAO, 2022b).

The impact of rising temperatures on crop growth, especially in rice, which is Cambodia's most important crop, is profound. Research indicates that elevated temperatures during crucial growth phases, such as flowering, can markedly diminish rice yields by intensifying plant stress and abbreviating the growing season (Redfern et al., 2017). It has been demonstrated that temperatures in excess of 35°C during the flowering period can result in spikelet sterility, which has the effect of reducing rice productivity to a significant degree (IPCC, 2021; Redfern et al., 2017). This trend is a cause for concern, as rice is not only a staple food in Cambodia but also a significant export commodity.

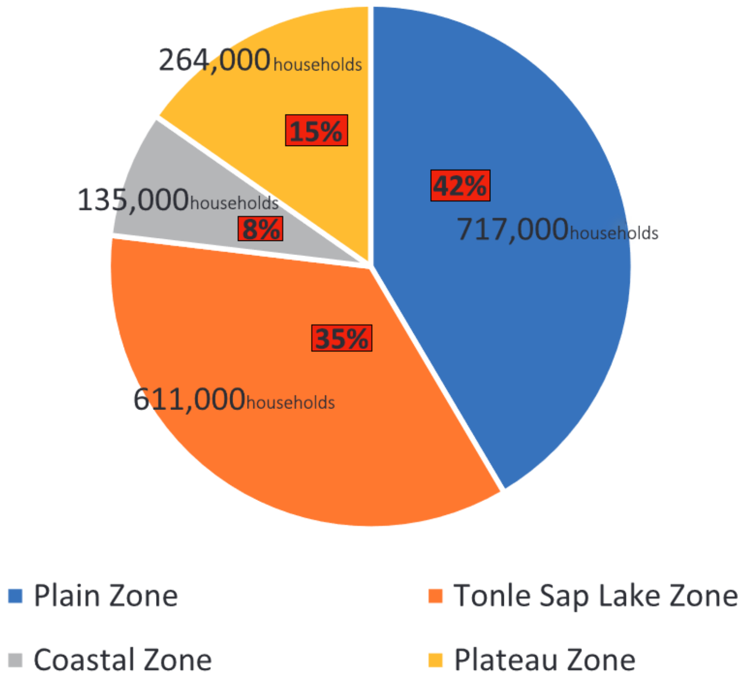


Figure 29: The number and percentage of household agricultural holdings by socio-geographic zone. Source: (CICAS, 2019)

The consequences of climate change on agriculture extend beyond changes in crop yields. Millions of Cambodians livelihoods are depended on their agriculture, with smallholder farmers being particularly vulnerable. The disruption of food production can lead to increased food insecurity, malnutrition, and poverty. Those displaced from their agricultural livelihoods may seek alternative employment in urban areas, potentially exacerbating social and economic challenges in cities that are already experiencing rapid population growth (FAO, 2022a).

The impacts of climate change on agriculture in Cambodia are profound and multifaceted, affecting food security, economic stability, and rural livelihoods. Addressing these challenges requires a collective effort from the government, communities, and development partners. By investing in adaptive strategies and sustainable practices, Cambodia can strengthen its resilience to climate change, ensuring that its agricultural sector can thrive in an uncertain future.

5.2.3 Livestock

As evidenced by data from the Cambodia Inter-Censal Agriculture Survey 2019 (CICAS), the rearing of livestock, particularly poultry, represents a significant aspect of the country's agricultural sector. This activity plays a pivotal role in supporting livelihoods and generating income for a considerable proportion of Cambodia's agricultural households. In fact, data from CICAS indicates that approximately 75 percent of the 1,726,000 agricultural households in Cambodia engage in the raising of livestock, with this figure representing approximately 1,301,000 holdings. It is estimated that 1,278,000 holdings reported raising poultry, while 658,000 reported raising cattle. The greatest number of agricultural holdings engaged in cattle rearing was observed in Plain Zone (269,000 holdings), followed by Tonle Sap lake zone (210,000), Plateau zone (116,000), and coastal zone (62,000). The Plain Zone once again recorded the highest number of household agricultural holdings raising poultry (495,000), followed by Tonle Sap lake zone (438,000), Plateau Zone (199,000), and Coastal Zone (146,000), as shown in Figure 30.

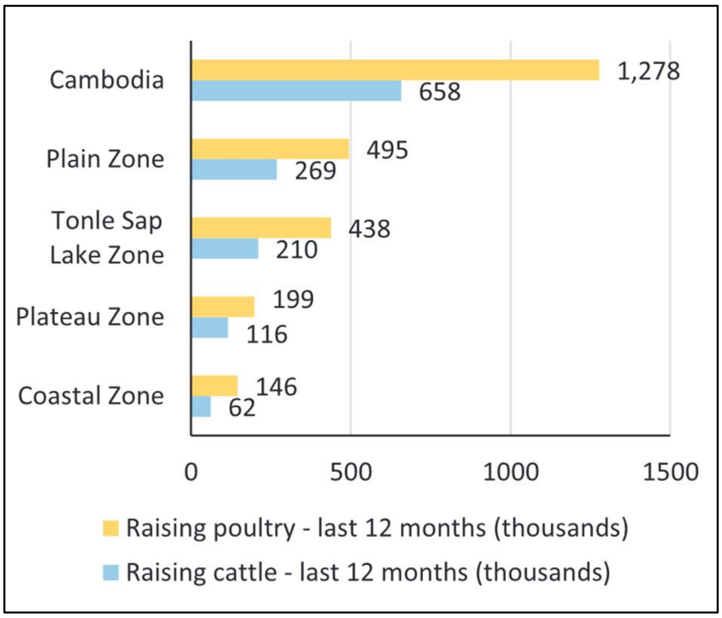


Figure 30: Number of household agricultural holdings reported a livestock raising activity by socio-geographic zone.
Source: (CICAS, 2019).

The livestock farming industry is particularly susceptible to the effects of climate variability, which include rising temperatures, altered rainfall patterns, and an increased frequency of extreme weather events. It is therefore imperative to gain an understanding of these impacts in order to guarantee food security, economic stability, and the well-being of rural communities (MAFF, 2014). The prevalence of commercial livestock production units has increased markedly in recent decades, with projections indicating a high probability of continued growth. The expansion of commercial units is accompanied by an increase in the utilization of advanced genetic technologies and more productive management practices, including elevated stocking rates. The anticipated climatic shifts will have a detrimental impact on high-performance breeds when managed in high-density systems (Grigorieva et al., 2023).

Nationwide data indicates that 76 percent of households engaged in cattle rearing kept between one and four animals, with an average of 3.8 cattle per holding. In the case of households engaged in poultry rearing, 91 percent reported keeping between one and 49 birds, with an average of 28.5 birds per holding (CICAS, 2019). More information about animal production in households is shown in Figure 31.

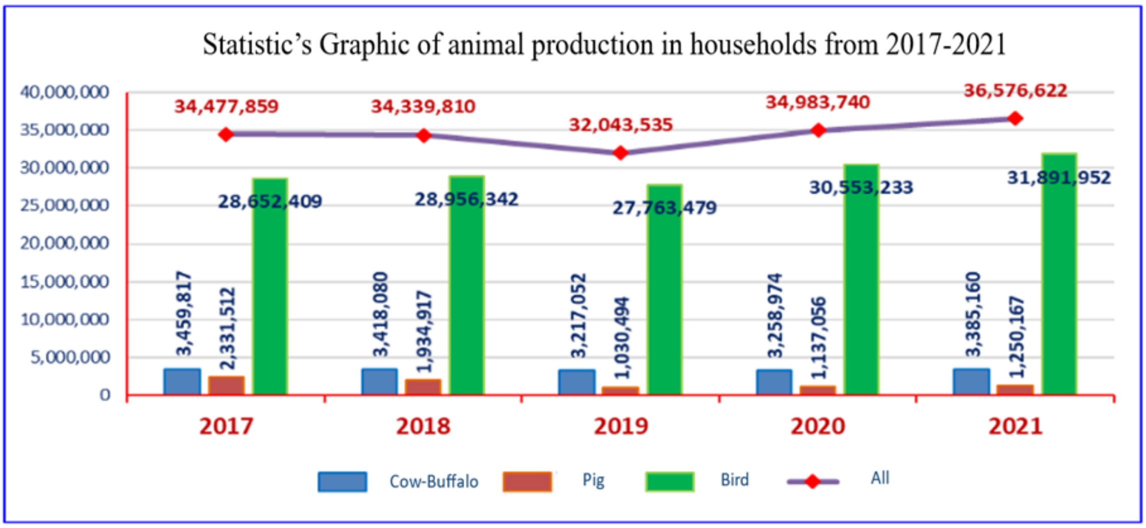


Figure 31: Statistic's Graphic showed about the animal production in households from 2017-2021. Source: (MAFF, 2022)

The principal impact of climate change on livestock in Cambodia can be attributed to a number of factors, as outlined below:

a. Effects of Rising Temperatures

The most imminent threat to livestock in Cambodia is the rise in average temperatures. As global temperatures rise, livestock experience heat stress, which can result in decreased productivity, reduced fertility rates, and increased mortality. A report by the Food and Agriculture Organization (FAO) indicates that higher temperatures can adversely affect feed intake and digestion, leading to lower growth rates in animals (FAO, 2022b). In Cambodia, where the livestock sector includes cattle, pigs, and poultry, this stress can significantly impact meat and milk production.

b. Changing Rainfall Patterns

Another critical factor affecting livestock is the alteration of rainfall patterns, which can have a significant impact on the health and productivity of animals. Unpredictable precipitation patterns can result in insufficient water supplies and inadequate pasture availability, which can directly impact the health and productivity of livestock. Those regions that depend on rain-fed systems may experience severe droughts, which could result in feed shortages and increased competition for resources. Some scientific research indicates that such conditions can result in malnutrition and an increased susceptibility to diseases among livestock (Rojas-Downing et al., 2017).

c. Increased Disease Incidence

Furthermore, climate change can intensify the prevalence of diseases in livestock. An increase in temperature and humidity levels creates an environment conducive to the proliferation of pathogens and parasites. The prevalence of disease in livestock is likely to increase, which may further compromise productivity and result in economic losses for farmers. The World Health Organization (WHO) has observed that climate change has the potential to alter the geographic distribution of diseases, thereby introducing new risks to livestock health in regions that have not previously been affected (WHO, 2003).

d. Water Scarcity

Access to water is a critical factor in maintaining the health of livestock, however, the effects of climate change are exacerbating the scarcity of water resources in Cambodia. As drought conditions become more prevalent, the availability of potable water for livestock is increasingly limited. This scarcity has implications beyond animal health, as it also complicates management practices, leading to increased stress on both animals and farmers. The World Bank (2021) underscores the necessity for enhanced water management strategies to bolster livestock farming in the context of these challenges.

The effects of climate change on livestock in Cambodia are complex and pose considerable risks to food security and rural livelihoods. The productivity and health of livestock are threatened by rising temperatures, changing rainfall patterns, and increased disease prevalence. To effectively address these challenges, a comprehensive approach is necessary, encompassing adaptive strategies, improved management practices, and supportive policies. By allocating resources toward the development of resilience-building measures, Cambodia can protect its livestock sector and ensure the well-being of its rural communities in the context of climate uncertainty.

5.2.4 Forestry

Cambodia is endowed with a plethora of rich and diverse forest ecosystems that play a pivotal role in the country's environmental health, economic development, and social well-being. These forests provide essential resources, including timber and non-timber forest products, as well as habitats for biodiversity. However, climate change represents a significant threat to forestry in Cambodia, intensifying existing challenges such as deforestation, land degradation, and biodiversity loss (MoE, 2022).

The alterations in temperature and precipitation patterns are a contributing factor to the reduction in forest growth. Climate change is precipitating substantial modifications in temperature and precipitation patterns in Cambodia. The mean temperature has increased, with projections indicating a rise of 1.5°C to 2.0°C by the end of the century (IPCC, 2021). Such an increase may disrupt the growth patterns of forest species, particularly those that are sensitive to temperature changes. Furthermore, altered precipitation patterns can result in prolonged periods of drought and intense precipitation events, which can impact forest health and regeneration. The MoE has issued a warning that such changes can result in shifts in species composition and increased vulnerability to pests and diseases (MoE, 2011). Furthermore, the combination of elevated temperatures and altered precipitation patterns increases the likelihood of forest fires in Cambodia. The occurrence of forest fires has the potential to result in the destruction of extensive areas of forest, which can subsequently lead to the loss of habitat and biodiversity. As reported by the MoE, an increase in the frequency and intensity of fires is already being observed, representing a direct threat to both natural forests and forest-dependent communities (Kim, 2021). Such fires not only contribute to greenhouse gas emissions but also impede the ability to achieve climate resilience.

Cambodia is home to a diverse range of flora and fauna, many of which are endemic and rely on the maintenance of healthy forest ecosystems (MoE, 2022). The disruption of these ecosystems by climate change may ultimately lead to habitat loss and an elevated risk of extinction for vulnerable species. Decline in biodiversity can impede the provision of essential ecosystem services, such as carbon sequestration and soil stabilization, which are vital for mitigating climate change. The ramifications of climate change on forestry in Cambodia are considerable and complex, endangering not only the well-being of forest ecosystems but also the livelihoods of millions of individuals. To address these challenges, a comprehensive approach that integrates sustainable management practices, community engagement, and supportive policies is required (CDRI, 2021). By allocating resources toward resilience-building measures, Cambodia can pursue the dual objective of ensuring the sustainability of its forests and the well-being of its communities in the context of climate change.

5.2.5 Fisheries and Aquatic Life

A recent global study on the vulnerability of economies to the impacts of climate change on fisheries ranked Cambodia as the 30th most vulnerable country in the world (MAFF, 2014). Fisheries production is closely linked to natural hydrological patterns and the integrity of fish habitats. It is not simply a matter of volume of water equaling volume of production. The onset of the flood season acts as a trigger for migration, with fish moving along the main stem of rivers or between rivers and floodplains, where they migrate to breed, spawn, and feed, and then retreat as the waters recede. Significant factors, including the amount of water in a given year, the timing of the flood, the number of peaks during the flood season, and the area of land inundated, affect biodiversity, especially fish migration. The area of flooded land provides important habitat for feeding, breeding and spawning, while the quality of vegetation, such as flooded forests, and wetlands, and the connectivity of floodplain ecosystems are also important factors in fishery production (Mekong River Commission, 2023).

Rising temperatures, changes in rainfall and river flows, sea level rise, and increased storm intensity will all affect fish biodiversity and productivity (MAFF, 2014). The exceptionally high biodiversity of aquatic ecosystems in the Lower Mekong Basin buffers capture fisheries from climate change. As a result, some species are likely to benefit from changing conditions, possibly maintaining overall fishery productivity, while other less adaptive species will decline. This is likely to result in an overall loss of biodiversity. However, very little is known about the water quality tolerances of most Mekong fish species, though species within the same groups have similar water quality requirements. Seen in this light, the threats posed by climate change are daunting.

Data from CICAS indicates that aquaculture and capture fisheries are additional economic activities for 16 percent of the household agricultural holdings in Cambodia (about 268,000 holdings). The zone with the highest number of household agricultural holdings engaged in aquaculture and/or capture fisheries was the Tonle Sap lake zone (118,000). The Coastal zone had a smaller number of holdings engaged in aquaculture and/or capture fisheries (32,000), but it had the highest proportion (24 percent) of household agricultural holdings engaged in one of these activities. Not surprisingly, the Plateau zone had the lowest number of holdings with aquaculture and/or capture fisheries (17,000).

As shown in Figure 32, most agricultural holdings with aquaculture and/or capture fishery activities were only engaged in capture fishery (81 percent) in coastal or fresh waters. A much smaller proportion of the holdings (6 percent) were only engaged in aquaculture, understood as the controlled cultivation of fish, usually in ponds or rice fields. 13 percent of the household holdings surveyed indicated that they were engaged in both aquaculture and capture fisheries (CICAS, 2019).

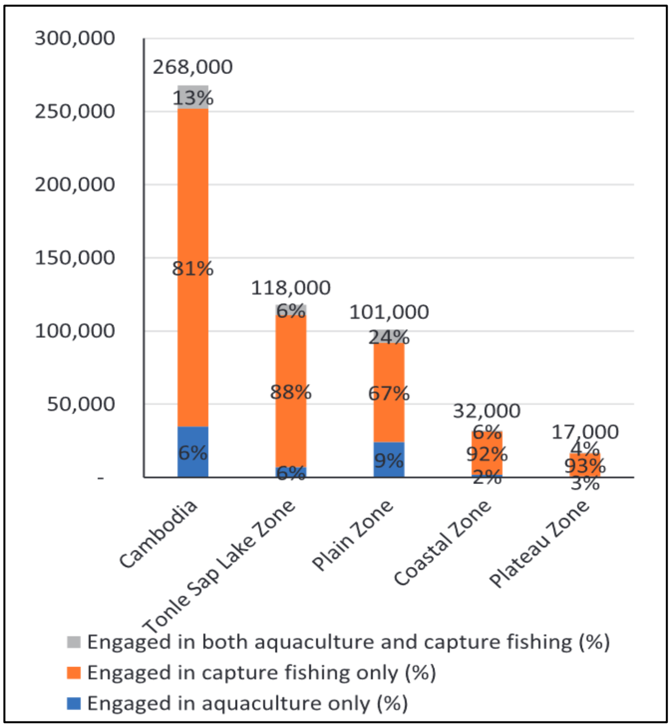


Figure 32: Number of household agricultural holdings reporting an aquaculture and/or capture fishing activity by socio-geographic zone.
Source: (CICAS, 2019).

The Tonle Sap fishery will be particularly vulnerable climate change, but so will people dependent on the fisheries of the upper Mekong and 3S tributaries (Sesan, Srepok, and Sekong rivers) in Stung Treng, Kratie, Ratanakiri, and Mondulkiri. Vulnerability assessments were conducted to confirm the hypotheses by MAFF as follows: (a) upland fish will be most vulnerable to climate change; (b) migratory white fish will be vulnerable to climate change; (c) black fish, which have limited migration, will be more "climate resilient" than other fish species; and (d) invasive species will become more prevalent due to climate change (MAFF, 2014). Climate change can affect fisheries and aquatic life in a number of ways, the most significant of which are as follows:

a. Changes in Water Temperature

One of the most immediate consequences of climate change on fisheries is the increase in water temperature. The distribution and behavior of fish species may be altered by warmer waters, which can affect spawning and feeding patterns. For example, species that are sensitive to temperature changes may migrate to cooler areas, which could result in shifts in local fisheries. A review of the literature suggests that certain fish populations in the Mekong River, which represents a vital source of fisheries for Cambodia, are already displaying indications of stress due to rising temperatures (FAO, 2020).

b. Altered Rainfall Patterns and River Flow

The hydrological cycle exerts a significant influence on Cambodia's fisheries, particularly the replenishment of river systems and floodplains, which is brought about by the annual monsoon rains. It is anticipated that climate change will result in more erratic rainfall patterns, which will in turn lead to both flooding and drought conditions. Such fluctuations have the potential to disrupt breeding cycles and the availability of suitable habitats for a range of fish species. As reported by the Mekong River Commission (2023), a reduction in river flow during the dry season can have a significant impact on fish stocks, particularly those that depend on seasonal migrations.

The consequences of climate change on Cambodia's fisheries and aquatic life are significant and varied, endangering not only the livelihoods of millions but also the long-term stability of the aquatic ecosystem. In order to effectively address these challenges, it is essential to adopt a collaborative approach that involves the participation of government entities, local communities, and international organizations (MAFF, 2014). By adopting sustainable management practices and investing in adaptation strategies, Cambodia can work towards ensuring the resilience and sustainability of its vital fisheries sector in the face of climate change.

5.2.6 Water Resources

Cambodia is endowed with a rich network of water resources that are essential for agricultural, industrial, and domestic usage. However, climate change is exerting a profound influence on water access, water supply, and potable water availability in the country. These changes are posing significant risks to public health, food security, and overall socioeconomic stability. The NCSD demonstrated the interconnection between climate change and freshwater resources in Cambodia. The consequences of climate change have resulted in notable shifts in the quality and quantity of groundwater and surface water. An increase in the average air temperature will result in a corresponding rise in the temperature of freshwater bodies, including lakes, seas, and oceans (Sok & Choup, 2017). This, in turn, will lead to an increase in evapotranspiration. Such changes may result in alterations to the chemical composition and ecological water quality, which could potentially impact fish stocks. An increase in evapotranspiration can result in a scarcity of water and alterations to vegetation, which may be accompanied by an escalation in erosion, land degradation, and the concentration of sediments in rivers, lakes, and coastal regions. Sea level rise is accompanied by an increased risk of flooding and saltwater intrusion. Sea level rise also impedes the drainage of river deltas and coastal provinces, including Koh Kong, Preah Sihanouk, Kampot, and Kep (GSSD, 2018).

On a global scale, it is anticipated that the hydrological cycle will intensify, and that average rainfall will increase. However, this projection differs across different regions of the planet, with some areas experiencing an increase in precipitation and others a decrease. The discrepancy among climate models regarding the regions that will become wetter or drier introduces an element of uncertainty. A further consequence of climate change is the alteration in the frequency and intensity of weather events, including the timing of rainfall, the occurrence of storms, and the incidence of droughts. This is the least understood and predictable aspect of climate change, as it occurs at the regional and local levels and is not well represented in global models. It is anticipated that weather events will become more severe, with an increase in the frequency and intensity of rainstorms and an extension of the duration and intensity of droughts. Changing weather patterns are expected to influence the frequency, timing, and intensity of peak flows, as well as the duration and intensity of the dry season minimal flow and the overall water availability. Additionally, changes in recharge of shallow groundwater and groundwater level may occur, which could have implications for vegetation, agriculture, and water availability in wells (NCSD, 2019).

The majority of Cambodians face water scarcity during the dry season and the "little dry season" within the wet season but experience excessive water and floods during the wet season. The irrigation infrastructure is largely inadequate, old, and dilapidated, which has serious implications for water storage, distribution and supply, sanitation, and food production.

Marine waters, especially along coasts and river mouths, must be carefully managed to support healthy ecological systems and fisheries, as well as sustainable economies, particularly fishing and tourism. Shipping and offshore oil and gas exploration pose further risks to water resources. River transport, particularly of petroleum products to the port of Phnom Penh, threatens water quality in the Mekong River and its tributaries through the delta. Beyond the unpredictable risk of a major accidental oil spill, there is likely to be continuous leakage and spillage of fuel and cargo, along with contamination from ballast tanks. The increasing use of outboard motors by other river users also poses a pervasive threat to surface water quality through spills and leaks. Currently, no data are available on hydrocarbon contamination (MOWRAM, 2012).

According to MOWRAM in 2019, there are a total of 131 hydrological stations across the country, but only 59 are operational. Of these, 47 stations are installed along the Mekong River and 12 stations are installed on major tributaries, as shown in Figure 33. The stations were installed to collect real-time data on water levels of major rivers and streams, particularly along the Mekong River, Tonle Sap River, and Tonle Sap Great Lake. In addition, real-time data from the hydrological stations on water levels will assist in effective weather forecasting and the preparation of appropriate emergency responses to disasters such as flooding (NCSD, 2019).

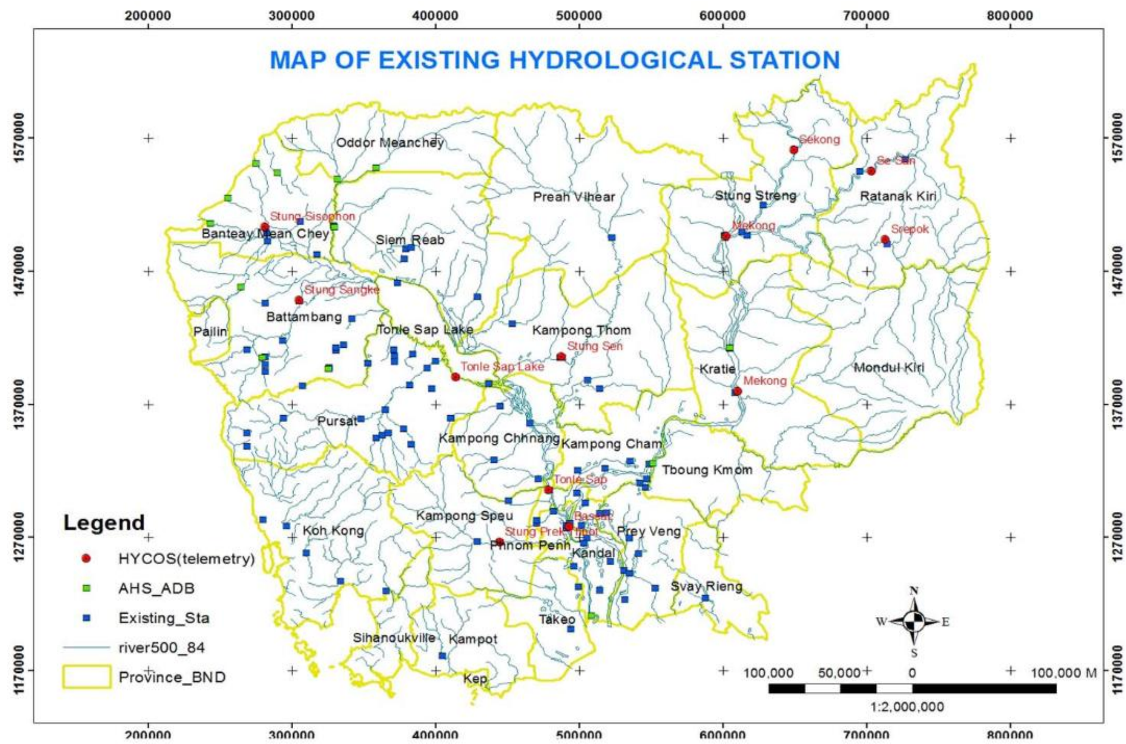


Figure 33: The map located hydrological stations in Cambodia.
Source: (NCSD, 2019).

In addition, the consequences of climate change also affect water access and supply, as described below:

a. Changes in Water Supply

The reliability of the water supply in the Mekong region depends on two principal sources: seasonal rainfall and the Mekong River system. The effects of climate change have led to increasingly erratic rainfall patterns, characterized by both prolonged droughts and intense flooding. The MRC reported that altered precipitation significantly impacts river flow and reservoir levels, which are critical for agriculture and domestic water use (MRC, 2023). During the dry season, reduced rainfall can cause water scarcity, presenting challenges for farmers in irrigating crops and for communities in accessing water for drinking and sanitation.

b. Impact on Water Availability

The availability of water in Cambodia is increasingly vulnerable to the impacts of climate variability. Rural areas, which often depend on surface water sources such as rivers and lakes, are especially susceptible to change in seasonal patterns. Climate-induced droughts can deplete these water sources, limiting access for local populations (ADB, 2021b). Urbanization exacerbates water access issues, as the rapid growth of cities places significant strain on existing infrastructure, making it challenging for urban populations to secure reliable water supplies.

c. Impact on Potable Water Access

The accessibility of potable water is a pivotal issue in Cambodia, where a significant proportion of communities lack secure access to safe drinking water. The impact of climate change is further compounded by its effect on water quality. An increase in precipitation levels can result in runoff that carries pollutants into rivers and groundwater sources, thereby compromising the safety of the water. The World Health Organization (WHO) has indicated that poor water quality can result in significant health concerns, including waterborne diseases that have a disproportionate impact on vulnerable populations (WHO, 2015). In rural areas, accessing clean water is particularly challenging, as many households rely on untreated water sources, leaving them vulnerable to contamination.

The impacts of climate change on the country's water resources are both considerable and complex, influencing water accessibility, supply, and quality. Addressing these issues requires a holistic approach that includes sustainable management practices, infrastructure development, and community participation. By implementing effective adaptation strategies, Cambodia can work towards ensuring the sustainability of its water resources and the well-being of its population in the context of climate change.

5.3 Impacts and Risks on Human Health, Livelihoods, and Vulnerable Groups

Climate change is one of the most urgent and far-reaching challenges of the 21st century, with implications extending beyond environmental concerns. In Cambodia, a country with an agricultural economy, densely populated urban areas, and significant poverty levels, the effects of climate change are particularly severe. Rising temperatures, irregular rainfall patterns, and increasing frequency of extreme weather events threaten human health, livelihoods, community stability, and the overall well-being of the population. The most vulnerable groups, including women, children, people with disability, the elderly, and the poor, bear the brunt of these impacts, which exacerbates existing inequalities and hinders development efforts. In addition, the repercussions of climate change on public health in Cambodia is considerable. An increase in temperature contributes to the proliferation of vector-borne diseases, such as dengue fever and malaria, which place an additional strain on an already overburdened healthcare system (WHO, 2015). Furthermore, the exacerbation of air pollution and deterioration of water quality resulting from flooding and droughts give rise to an increase in respiratory and waterborne diseases, which in turn have an adverse impact on the overall health of the population (ADB, 2021a). Those most vulnerable to the effects of climate change, particularly children and the elderly, are at greater risk due to their heightened susceptibility to climate-related health issues. In addition, the Cambodian economy is significantly dependent on the agricultural sector, which is particularly susceptible to climatic fluctuations. The occurrence of extreme weather events, such as floods and droughts, has the potential to disrupt agricultural activities, threaten food security, and diminish incomes for rural households (FAO, 2022a). Given that approximately 60 percent of the population relies on agriculture for their livelihood, the economic consequences of climate change, including increased poverty rates and decreased resilience, are significant (WB, 2021).

5.3.1 Overview of Loss and Damage

Cambodia is highly susceptible to the impacts of climate change, which has led to land use change across various sectors, including agriculture, infrastructure, and human settlements. The frequency of extreme weather events, such as floods, droughts, and storms, has increased in recent decades, causing widespread socio-economic disruption. Cambodia's agricultural sector, which serves as the foundation of the country's economy and provides sustenance for the majority of rural communities, is especially vulnerable to the effects of climate change. Provinces such as Battambang, Banteay Meanchey, Kampong Thom, Pursat, and Prey Veng are experiencing some of the highest levels of loss. Crop failures due to droughts and floods directly translate into financial losses for farmers, most of whom are smallholders with limited capacity to recover. These losses also affect agricultural micro, small, and medium enterprises (MSMEs) that rely on stable weather patterns for productivity. The FAO has emphasized the urgent need for more resilient agricultural systems and increased climate finance to mitigate these impacts (FAO, 2024). The sections below summarize losses and damages caused by various effects of climate change.

a. Loss and Damage from Floods

While floods can have beneficial effects on agriculture, ecology, and fisheries, in excess, they cause loss of life, destruction of crops and livestock, and damage to homes and community infrastructure (schools, health centers, irrigation canals, roads, and bridges). In 2011, water levels in the Mekong River increased due to the precipitation caused by Typhoons Nesat and Nalgae in late September and early October. This resulted in 354,217 households, comprising over 1.7 million individuals, in 18 provinces being adversely affected. A total of 51,950 families were evacuated, with 250 fatalities and 23 injuries reported. The damage to infrastructure included 115 health clinics, 1,396 schools, 363 km of national and provincial roads, 1,842 km of rural roads, 177 bridges and culverts (a total of 925 km), 329 irrigation systems, 77,544 wells, and 579 contaminated community ponds. Furthermore, 10 percent of rice crops were adversely affected, with 6.6 percent being completely destroyed and more information as shown in Table 9 (CFE-DM, 2020).

Table 9: Damages and losses from the 2011 floods (millions of USD).

Sector	Damages	Losses	Total Impact
Infrastructure	**375.70**	**34.70**	**410.40**
Transport	328.60	23.30	351.90
National/provincial roads	217.90	-	217.90
Rural roads	110.70	23.70	134.40
Rural water and sanitation	**20.00**	**11.40**	**31.40**
Irrigation / water management	27.10	-	27.10
Channels	5.90	-	5.90
Embankments	21.20	-	21.20
Social sectors	**34.70**	**-**	**34.70**
Education	20.00	-	20.00
Health	3.00	-	3.00
Accommodation	11.70	-	11.70
Productive sectors	**40.80**	**138.50**	**179.30**
Agriculture, Livestock and Fisheries	40.80	138.50	179.30
Total	**451.20**	**173.20**	**624.40**

Source: (UNDP, 2023).

In the final quarter of 2013, a confluence of successive typhoons, rising Mekong River levels, transboundary flash floods in western provinces, and above-average monsoon rains precipitated extensive flooding in Cambodia. The NCDM reported that the floods resulted in the deaths of 168 individuals (predominantly children) and damages amounting to approximately USD 356.23 million to infrastructure, including 26 roads, agricultural and irrigation systems, and 377,354 households (1.8 million people) across 20 provinces, four of which are situated along the Mekong River and Tonle Sap and were the most severely impacted, as shown in Table 10 (Leng Heng, 2014).

Table 10: Flood Damage and losses 2013 (millions of USD).

Sector	Damages	Losses	Total Impact
Infrastructure	**134.27**	**-**	**134.27**
Transport	79.61	-	79.61
Rural water and sanitation	2.66	-	2.66
Irrigation / water management	52.00	-	52.00
Social sectors	**16.47**	**38.36**	**54.83**
Education	15.65	0.12	15.77
Health	0.17	0.09	0.26
Accommodation	0.65	0.55	1.20
Livelihoods	-	37.60	37.60
Productive sectors	**2.54**	**164.59**	**167.13**
Agriculture, Livestock and Fisheries	0.36	151.50	151.86
Industry and commerce	2.15	11.30	13.45
Tourism	0.03	1.73	1.76
Marketplace	-	0.06	0.06
Total	**153.28**	**202.95**	**356.23**

Source: (UNDP, 2023)

In October 2020, rain fell across much of the country; approximately 176,000 households as well as several roads, schools, health centers, and agricultural lands were affected in

14 provinces, mainly in Pursat, Battambang, Banteay Meanchey, and Pailin, shown in Table 11.

Table 11: Impact of floods on Cambodia's provinces, October 2020.

Household saffected	Displaced households	Deaths	Houses affected	Affected health centers	Schools affected	Length of path concerned (m)	Agricultural land affected (ha)
175,872	14,299	38	161,552	22	686	2,148,433	329,754

Source: (UNDP, 2023)

b. Loss and Damage from Drought

Other challenges include variations in the frequency of droughts across Cambodia, which are primarily caused by delayed onset of precipitation and its erratic occurrence. This phenomenon is further exacerbated by limited irrigation coverage (approximately 20 percent) and construction of dams along the Mekong River, which contribute to reduced water availability. Large-scale artificial irrigation remains infeasible in Cambodia due to these constraints. From late 2018 to July 2019, precipitation was notably absent across the country, resulting in the onset of droughts in some regions due to the delayed start of the rainy season and a reduction in river water availability. In 2019, the volume of water in the Tonle Sap was insufficient, which had an adverse impact on the fishing activities of local communities. Some districts, towns, and provinces experienced domestic water shortages, including Khemarak Phumin of Koh Kong, Stung Staung of Kampong Thom province, Stung Maung Russey and Stung Sangker of Battambang, Ta Pon reservoir of Koh Kong, Stung Mongkulborey, and the Trapaing Thmar reservoir of Bateay Meanchey. The drought persisted throughout the rainy season due to the delayed onset of precipitation, resulting in significant losses for the agricultural sector in 16 provinces. A total of 324,641 hectares of rice and 44,734 hectares of other crops were affected (MRC, 2021).

c. Loss and Damage from Storms

From September 29th to October 5th, 2009, Cambodia was struck by Typhoon Ketsana, which had a significant impact on fourteen provinces, resulting in the deaths of forty-three individuals and injuries to an additional sixty-seven. The disaster resulted in the destruction of approximately 49,000 households and the disruption of the livelihoods of 180,000 individuals, representing 1.4 percent of Cambodia's total population; see Table 5.8 (Royal Government of Cambodia, 2010). The total damages and losses caused by Typhoon Ketsana were estimated at USD 132 million, comprising USD 58 million in damages and USD 74 million in losses. The sector most significantly affected was the productive sector, comprising agriculture, livestock, and fisheries. The agricultural sector was particularly affected by the typhoon, with 10 provinces experiencing destruction and damage to rice crops, amounting to 40,136 hectares destroyed and 67,355 hectares damaged. The total damages and losses in agriculture, livestock, and fisheries subsectors were estimated at USD 56 million. The industry and commerce subsectors sustained damages and losses amounting to USD 3.5 million, with micro and agribusinesses bearing the brunt of the impact. These enterprises play a pivotal role in the country's economic development, and thus, their resilience is crucial for the nation's long-term growth and stability. In the infrastructure sector, the total damages and losses amounted to USD 28.7 million, with the majority concentrated in the transportation subsector (USD 25.5

million). The damage affected urban, national, provincial, and rural road networks in 18 provinces. The most significant losses were incurred from vehicle operating costs and extended travel times for cargo and passengers due to the deterioration of road conditions. In the social sector, damages and losses amounted to USD 42.8 million, with the education subsector being the most affected (USD 24 million), followed by housing (USD 18.5 million). Over 1,200 schools in the floodplain were affected, with 155 schools being so severely damaged that they had to close for up to nine weeks; more than 450,000 students were unable to access schools during the floods. In the housing sector, the provinces of Kampong Thom, Preah Vihear, Ratanakiri, and Kratie were the most affected (CFE-DM, 2020).

Table 12: Damages and losses caused by Typhoon Ketsana, 2009 (millions of USD).

Sector	Damages	Losses	Total Impact
Infrastructure	**17.23**	**11.48**	**28.71**
Transport	14.39	11.08	25.47
Rural water and sanitation	0.06	0.39	0.46
Irrigation / water management	2.78	0.01	2.79
Energy	0.03	0.01	0.03
Social sectors	**39.55**	**3.33**	**42.88**
Education	24.21	3.29	27.50
Health	0.06	0.04	0.10
Housing	15.28	-	15.28
Productive sectors	**1.05**	**59.01**	**60.06**
Agriculture, Livestock and Fisheries	0.09	56.42	56.51
Industry and commerce	0.96	2.59	3.55
Transversal Sector	**0.21**	**0.10**	**0.31**
Environment	0.03	0.10	0.13
Public Administration	0.17	0.00	0.18
Total	**58.04**	**73.93**	**131.96**

Source: (UNDP, 2023).

In 2015, a storm resulted in a daily rainfall of 103mm in Phnom Penh, which led to widespread flooding that inundated stores and homes, rendering the roads nearly impassable. In October 2020, localized flooding occurred when the Prek Thnot river, which empties into the Bassac river south of Phnom Penh, overflowed following a tropical storm, compelling thousands of residents to evacuate from gated communities in southwestern and southern Phnom Penh (JICA, 2023). According to Open Development Cambodia (ODC), in 2016, storms resulted in the destruction of 1,997 residences and the opening of the roofs of 8,147 others. There were 21 fatalities (due to home collapses, falling trees, and sinking boats) and 193 injuries. Lightning strikes resulted in 108 fatalities and 105 injuries in 2016 (ODC, 2016).

5.3.2 Gender and Vulnerable Groups

Impacts of climate change tend to be exacerbated for vulnerable groups. Women, children, the elderly and disabled, poor rural populations, and indigenous minorities are often most severely affected by climate-related disruptions, which further deepens existing social and economic inequalities. The effects of climate change serve to exacerbate the challenges associated with poverty, health, and access to resources, particularly for rural populations, women, and children. Women in Cambodia are disproportionately impacted by climate change, largely due to pervasive gender inequalities. As primary caretakers and food producers, women depend heavily on natural resources such as water and arable land, which are increasingly affected by droughts, floods, and irregular rainfall. In rural areas, women's livelihoods — closely tied to agriculture and informal work—are directly threatened by these climate disruptions as shown in Table 13. Furthermore, a review of the literature shows that women are often excluded from decision-making processes related to climate adaptation, limiting their ability to respond effectively to environmental changes (UN Woman, 2021).

Table 13: Share of wage employment for women aged 18 years and about in 2019.

Economic sectors	Cambodia	Phnom Penh	Other urban	Other rural
	Number in thousands			
Agriculture (Primary)	1,419	7	190	1,222
Industry (Secondary)	979	160	328	491
Service (Tertiary)	1,562	453	500	608
Total	3,960	620	1,019	2,321
	In per cent			
Agriculture (Primary)	35.8	1.5	15.9	50.2
Industry (Secondary)	24.8	28.3	17.7	24.9
Service (Tertiary)	39.4	70.2	66.4	24.9
Total	100	100	100	100

Source: (UN Woman, 2021).

Moreover, the gender roles prevalent in Cambodia often require women to assume responsibility for both domestic duties and agricultural activities, which leaves them with limited opportunities for education or participation in economic diversification. As a result, they are more vulnerable to poverty when climate-related shocks, such as crop failures or resource shortages, occur. As indicated in a UN Women report, the implementation of gender-responsive climate action is of paramount importance to ensure that women in Cambodia are able to adapt to these changes and contribute to mitigation strategies (UN Women, 2023).

Furthermore, other vulnerable demographic groups, including children, the elderly, individuals with disabilities, and indigenous populations, also face an elevated risk of adverse effects from climate change. Children are particularly susceptible to climate-related health hazards, including malnutrition, waterborne illnesses, and heat stress (CCCSP, 2014). The long-term social impact of climate change on education and well-being is profound, as families facing economic difficulties may choose to withdraw their children from school in order to contribute to household income (UNICEF, 2021). Indigenous communities, which depend on land and natural resources for their survival, are experiencing an increase in displacement and a loss of traditional livelihoods due to deforestation, changing rainfall patterns, and flooding (FAO, 2022b). Similarly, coastal communities are threatened by rising sea levels, which are encroaching on land, threatening homes and reducing access to clean water sources.

Climate change in Cambodia disproportionately affects women, children, and other vulnerable populations, further exacerbating social inequalities. To effectively address these challenges, it is crucial to implement a comprehensive strategy that integrates gender-responsive and inclusive approaches in climate adaptation and resilience-building initiatives. In the absence of targeted measures, climate change is likely to exacerbate poverty, inequality, and social instability in Cambodia.

5.3.3 Displacement

Impacts of climate change are fueling migration in Cambodia and globally. The concept of migration is multidimensional, encompassing the movement of individuals from one place to another, whether within or across national borders. Migration can be voluntary or involuntary, temporary or permanent, circular or linear, regular or irregular, and is influenced by a multitude of factors, including economic, social, political, cultural, environmental, and demographic. The impact of migration on the origin and destination areas can be either positive or negative, depending on the context and the characteristics of the migrants involved. A displacement constitutes a particular form of migration that occurs when individuals are compelled to abandon their usual place of residence as a result of a perceived threat or actual hazard. Displacement can be internal or cross-border, sudden-onset or slow-onset, protracted or short-term, and individual or collective (IDMC, 2020). Furthermore, displacement can have considerable humanitarian, human rights, development, and security implications for both displaced individuals and host communities.

The issue of population displacement due to environmental events has gained significant attention in recent years. However, there remains considerable uncertainty regarding the actual reactions of populations to long-term environmental change. The relationship between climate change and migration flows is often conceptualized as deterministic, whereby all populations residing in regions affected by climate change are compelled to relocate (Asif et al., 2023). However, numerous empirical studies have demonstrated that this relationship is considerably more intricate and is influenced by a multitude of social, economic, and political factors.

A study by ADB (2012) demonstrated a significant correlation between climate change and migration. Individuals living in areas vulnerable to effects of climate change, such as increased flooding or changes to agriculture, are compelled to relocate. Individuals are driven to migrate as a consequence of abrupt catastrophes and extreme climatic risks as well as gradual or slow-onset environmental changes, including sea-level rises, soil erosion, deforestation, and desertification. Migration prompted by climate change can be either temporary or permanent. Temporary migration occurs when individuals or communities flee severe storms or droughts but subsequently return when the threat has subsided. In contrast, permanent migration involves relocating to a new area or country when the current territory becomes uninhabitable.

In the Asia-Pacific region, significant numbers of individuals are forced to leave their homes on an annual basis due to a range of natural disasters, including floods, droughts, soil degradation, typhoons, and cyclones. Those living in poverty bear a disproportionate burden of mortality, displacement, and damage resulting from such events. Due to the necessity of economic subsistence, these individuals are compelled to reside in areas of low elevation, namely coastal deltas, riverbanks, flood plains, and steep slopes, or occupy degraded urban settings where the consequences of extreme weather events are most acutely felt (WB, 2024). Consequently, they are particularly vulnerable to the devastation wrought by these climate change effects, rendering them less capable of recovery. Although the region is anticipated to experience considerable impact from climate change in the coming decades, it is also expected to undergo other significant social, political, and economic transformations. It is therefore probable that migration behaviors will be influenced by this extensive range of transformations, which encompasses climate change and the advent of cheaper travel. It is evident that public policies, including adaptation strategies and migration management, will exert a significant influence on nature and extent of population movement. Moreover, migration in Asia and the Pacific is motivated by a multitude of factors, including labor mobility and the diversification of incomes, family reunification, expectations and perceptions about the destination region, and environmental changes. It is anticipated that climate change will markedly increase the significance of environmental change. The growth of mobile telephony and the internet, the expansion of diaspora networks, the development of improved transport links, and the advent of cheaper travel options have all facilitated increased mobility (ADB, 2012).

In Cambodia, climate change has resulted in a series of extreme weather events, including floods and droughts, which have significantly impacted socio-economic development, particularly in the agricultural sector. As confirmed by Chihh et al. (2023), impacts of climate-induced droughts on rural populations have become more extreme, frequent, and severe., which may have an impact on Cambodia's high internal and external migration rates. The Cambodian General Population Report (2019) indicated that rural-urban migration (34 percent) is more prevalent than urban-urban (30 percent), urban-rural (30 percent), or rural-rural (29 percent) migration. The report identifies the following reasons for migration: mobility with families, when other family members follow a head of household who has migrated, often for economic or employment reasons (44.9 percent); employment (19.4 percent); marriage (14.9 percent); job opportunities (9.1 percent); and education (2.3 percent), as shown in Figure 34.

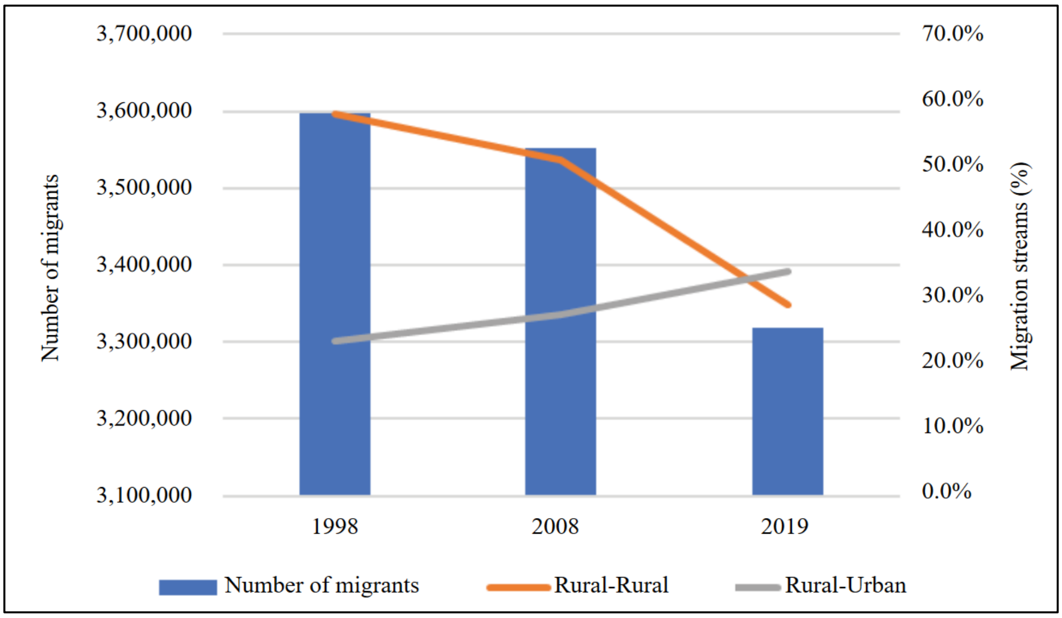


Figure 34: Internal migration trend in Cambodia 1998-2019.
Source: (Nong et al., 2024).

As climate-fueled migration is a relatively new phenomenon, more research is needed on drivers and impacts of climate-related migration. A study conducted by the International Organization for Migration (IOM) in 2009 revealed that environmental stressors and migration pressures force rural populations to seek alternative means of diversifying their income streams to ensure the sustainability of family livelihoods and food security in changing circumstances. The effects of climate change are experienced differently by men and women in terms of their access to and control over assets, as well as their overall level of well-being. Migration represents one of the most significant impact areas, along with agricultural production, food security, health, and water and energy resources. The effects of climate change are placing increasing pressure on the inefficiency of urban infrastructure, which will in turn lead to an increase in greenhouse gas (GHG) emissions from manufacturing, transportation, and energy use in urban areas. Concurrently, the abandonment of agricultural land and farming activities in rural areas due to outmigration to cities is a further consequence of climate change.

5.3.4 Heritage Sites

The phenomenon of climate change represents a considerable threat to Cambodia's cultural heritage, particularly in regard to its historical and archaeological sites. Cambodia, renowned for its rich history and celebrated landmarks such as the Angkor Wat temple complex, confronts a multitude of risks associated with rising temperatures, intensified flooding, and evolving weather patterns. These changes accelerate the deterioration of both above-ground and underwater cultural heritage sites, thereby endangering the preservation of centuries-old structures, artifacts, and landscapes that are central to Cambodia's identity (Chim et al., 2021).

One of the most evident consequences of climate change on Cambodia's cultural heritage is the increased risk of flooding, which threatens the integrity of ancient temples and monuments. The Angkor Wat complex, a UNESCO World Heritage Site, is particularly vulnerable to extreme weather events, including intensified monsoon rains that cause waterlogging and erosion of its sandstone structures. The intricate water management system of the Angkor archaeological park, designed centuries ago, is now being compromised by erratic rainfall, undermining the site’s sustainability. Furthermore, the stone carvings and intricate bas-reliefs are also threatened by increasing humidity and fungal growth due to higher temperatures (WB, 2023b).

Furthermore, the increase in sea levels is endangering Cambodia's coastal and underwater heritage sites. In recent years, UNESCO and the Cambodian Ministry of Culture and Fine Arts have placed a significant emphasis on the necessity of developing emergency preparedness strategies and implementing effective measures for the protection of Cambodia's underwater cultural heritage sites. The combination of coastal erosion and human activities, such as overfishing and mangrove deforestation, is accelerating the deterioration of significant archaeological sites situated in proximity to or submerged beneath the water's surface. The underwater cultural heritage of Cambodia, comprising sunken vessels and submerged artefacts, is facing an escalating array of threats, both environmental and anthropogenic in origin (UNESCO, 2023).

The safeguarding of these sites has become a priority for Cambodia, especially given the country's growing recognition of the pivotal role cultural heritage plays in its national identity and economic growth through tourism. Several international organizations, including UNESCO, are collaborating with Cambodian authorities to enhance disaster preparedness and resilience at these cultural landmarks. These endeavors include the formulation of frameworks for integrating cultural heritage protection into comprehensive climate adaptation and disaster risk reduction strategies (Smithsonian Magazine, 2020).

In summary, climate change is significantly impacting Cambodia's cultural heritage, affecting both renowned sites like Angkor Wat and lesser-known underwater and coastal locations. Given the increasing risks posed by rising seas, heavier precipitation, and more intense weather patterns, there is an urgent need for coordinated national and international action to preserve these cultural assets for future generations.

5.4 Impacts and Risks on Infrastructure

5.4.1 Urban and Key Infrastructure

The urban infrastructure of Cambodia, particularly in cities such as Phnom Penh, is becoming increasingly vulnerable to the impacts of climate change. This is particularly the case given the rising frequency of extreme weather events, including floods, storms, and rising temperatures (Asif et al., 2023). Such occurrences are already placing considerable strain on the country's infrastructure systems, which are frequently ill-equipped to cope with the challenges posed by climate change.

Flooding represents a significant challenge in Cambodia's urban areas, particularly in Phnom Penh and other cities situated along the Mekong River. The process of rapid urbanization has resulted in the loss of natural flood defenses, including lakes and wetlands. For example, the large-scale land reclamation in Phnom Penh, where lakes and wetlands that previously served as natural flood defenses have been filled in for development purposes, has diminished the city's resilience to climate-related hazards such as flooding. This has contributed to the occurrence of urban flooding, with inadequate drainage systems serving to further exacerbate the problem (WB Blogs, 2023). Moreover, in secondary cities such as Battambang, Kratie, and Kampot, the increasing prevalence of flooding poses a significant threat to the infrastructure of these urban areas. The damage caused by floods to roads, bridges, and public facilities frequently results in economic losses and disruptions to daily life. In numerous instances, public spaces, sewage systems, and transportation networks are unable to accommodate the influx of water that occurs during heavy rainfall, which can result in prolonged floodwater retention in urban areas (Asif et al., 2023).

Furthermore, climate change exerts an influence on critical infrastructure, including educational establishments and healthcare facilities. In provinces such as Stung Treng and Kratie, studies have demonstrated that a considerable proportion of health and education facilities are at risk of flooding. Approximately 31 percent of health centers in Stung Treng and 20 percent in Kratie are situated in areas that experience annual flooding, which limits access to essential services. Furthermore, the disruption of transportation routes following flooding further restricts access to healthcare and education, with a particularly adverse impact on the rural poor who depend on these urban services (Mekong River Commission, 2021).

According to the MPWT, in 2011, 16 out of 25 provinces and municipalities experienced flooding, affecting over 1.5 million people. The damage from the 2011 flooding exceeded that of the floods in 1996 and 2000. A total of 186 national and provincial roads were affected by flooding, with a damaged length of 718.08 km. Furthermore, 20 provincial and national bridges were damaged, underscoring the widespread impact of the flooding (MPWT, 2013).

Despite the commencement of initiatives to construct climate-resilient infrastructure in Cambodian urban areas, significant obstacles remain. Initiatives such as the Climate Vulnerability and Adaptation Assessment of Cambodian Secondary Cities (CVAA) are designed to prioritize investments in climate adaptation strategies. Such measures include the construction of flood protection structures, such as levees, the implementation of improved drainage systems, and the creation of eco-friendly recreational spaces that serve dual purpose as flood storage areas. Other recommendations include the development of local government capacity for sustainable urban planning, with the objective of enhancing resilience to future climate impacts. While urban resilience plans, such as the Sustainable City Plan in Phnom Penh, exist, there is still a gap between policy and practical implementation. Urban expansion frequently prioritizes economic growth over sustainable infrastructure development, leaving many communities, particularly the urban poor, vulnerable to climate hazards.

The urban infrastructure of Cambodia is confronted with considerable challenges as a consequence of the intensifying effects of climate change. The prevalence of flooding, inadequate drainage systems, and the degradation of natural ecosystems, such as wetlands, presents a significant risk to the provision of public services, transportation, and housing, particularly in Phnom Penh and other rapidly developing urban centers. While efforts are being made to enhance resilience, it is imperative that sustained investment in climate-adaptive infrastructure be made in order to protect Cambodia's cities from future climate impacts.

5.4.2 Transportation Infrastructure

Transportation infrastructure in Cambodia is susceptible to the impacts of climate change, with floods and extreme weather events representing a significant threat. The country's transportation networks are of critical importance for economic development, serving as conduits for the movement of goods and people between rural and urban areas. However, climate-related events disrupt this essential infrastructure, thereby impeding socio-economic progress.

Flooding represents the most significant climate-related threat to Cambodia's transportation infrastructure. The country is experiencing an increase in the intensity of flooding due to an increase in the amount of monsoon rainfall and an increase in the unpredictability of weather patterns driven by climate change. For example, in October 2020, extreme flooding caused damage to over 1,400 kilometers of rural roads, resulting in the disruption of essential services for rural communities and the cessation of the flow of goods, particularly agricultural products, as shown in Figure 35 (Devdiscourse, 2024). Such disruptions can result in the isolation of entire regions, which in turn exacerbates poverty and limits access to healthcare and education. Furthermore, floods not only result in immediate damage to roads and bridges but also accelerate long-term deterioration through erosion and waterlogging. Rural roads are particularly susceptible to damage due to the lack of adequate drainage systems. In regions such as Battambang and Prey Veng, enhancements to road drainage systems have been identified as a vital strategy for mitigating the impacts of flooding and ensuring the sustained accessibility of essential services (ADB, 2019).

Figure 35: Road infrastructure damaged by floods: a) flood damaged National Road no. 5 and b) heavy rain damaged National Road 76 at Mondulkiri province.
Source: (Cambodia News, 2023).

The effects of climate change on Cambodia's transportation infrastructure have significant economic implications. The disruption of transportation systems impedes the flow of agricultural products, constraining the capacity to deliver produce to the market, both domestically and internationally. Cambodia's increasing reliance on transportation infrastructure for trade makes it evident that climate-induced damage not only endangers rural livelihoods but also jeopardizes national economic growth. In the absence of substantial investment in climate-resilient infrastructure, it is probable that these challenges will intensify. As stated by the ADB, Cambodia must develop more resilient transportation networks that can withstand climate variability and continue to support economic growth and poverty reduction efforts. The financial resources allocated for the maintenance of roadways are often inadequate to guarantee the long-term sustainability of their use, as shown in Figure 36. While allocations for routine maintenance of national and provincial roads have been increased to an appropriate level, the funding for routine maintenance of rural roads and periodic maintenance of all roads remains insufficient.

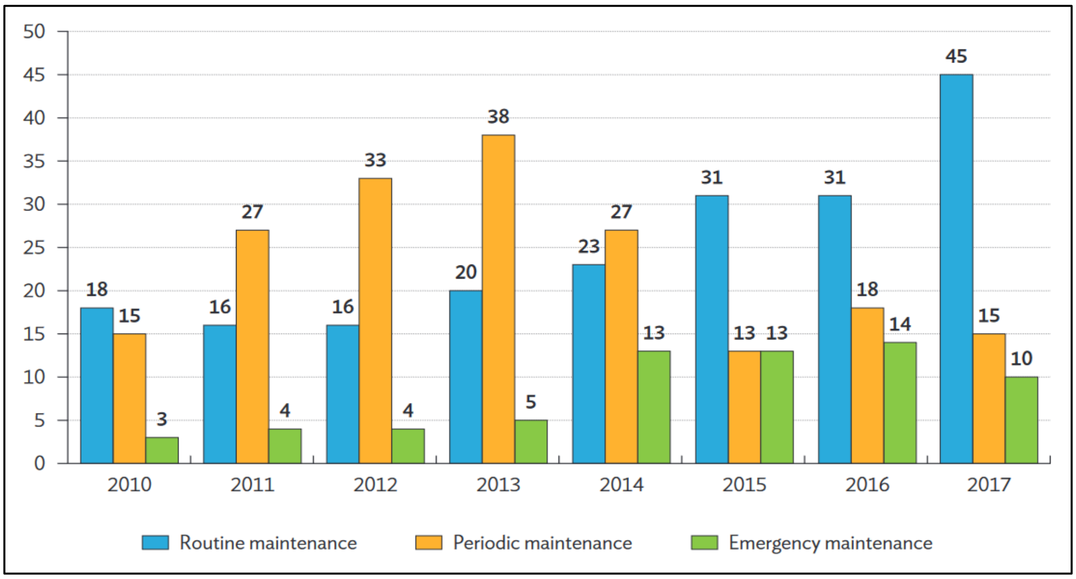


Figure 36: Maintenance budget allocation for national and provincial roads (USD million).
Source: (ADB, 2019).

To summarize, climate change, especially flooding, presents a significant array of challenges for Cambodia's transportation infrastructure. Nevertheless, strategic investments and resilience-building initiatives can help mitigate these risks and support sustained economic growth. It is of the utmost importance that these vulnerabilities are addressed if Cambodia is to achieve its development goals in the face of a changing climate.

5.4.3 Other Physical Infrastructure

The effects of climate change are being felt acutely in Cambodia, with significant implications for the country's infrastructure, particularly buildings and essential systems. This is increasing in vulnerabilities across urban and rural areas. As the frequency of extreme weather events rises, the nation's physical structures, including residential, commercial, and public buildings, face an elevated risk of damage. In urban areas such as Phnom Penh, the combination of rapid development and population growth with climate challenges is a significant concern. The issue of increased flooding, exacerbated by the encroachment of urban sprawl into wetlands, is particularly problematic (Asif et al., 2023). The damage caused by floods goes beyond the immediate destruction of buildings; it also compromises their long-term structural integrity, requiring frequent repairs and retrofits. Furthermore, the rise in temperatures and the increased frequency of storms contribute to the degradation of both modern and traditional Cambodian architectural styles. Infrastructure in rural areas is similarly endangered, with a considerable number of health facilities and educational institutions situated in regions susceptible to flooding. Research findings indicate that those provinces located along the Mekong River and the Tonle Sap basin are particularly at risk. In provinces such as Kratie and Stung Treng, a considerable proportion of health facilities and educational institutions are exposed to annual floods, which disrupts access to essential services (WB Blogs, 2023).

As temperatures increase, particularly in Phnom Penh and other major cities, durability of construction materials is compromised. Elevated temperatures accelerate the deterioration of buildings, particularly those constructed with inexpensive materials. The phenomenon of urban heat islands has a detrimental impact on the quality of life in urban areas, leading to increased energy consumption and costs associated with cooling. Furthermore, traditional construction techniques that are less climate-resilient are more susceptible to damage from extreme temperatures and precipitation (JICA, 2023).

It is also important to note that floods represent a significant threat to Cambodia's urban infrastructure. Coastal cities such as Sihanoukville are becoming increasingly vulnerable to flooding, with the problem being further exacerbated by sea-level rise. Urban infrastructure, including roads, housing, and drainage systems, frequently proves unable to cope with heavy rainfall, resulting in inundation and damage to residential and commercial buildings. This, in turn, causes disruptions in economic activities and increases repair costs. Coastal infrastructure of Cambodia, including the port in Sihanoukville, is vulnerable to the dual threats posed by rising sea levels and storm surges (WB, 2024). Climate-related factors not only present a threat to the country's physical infrastructure but also impede its capacity to engage in regional trade and supply chains.

Cambodia’s infrastructure is confronted with an increasing number of challenges as a consequence of climate change. The vulnerability of buildings and transportation networks to extreme weather events necessitates a substantial investment in resilience and adaptation. As Cambodia strives to become an upper-middle-income nation by 2030, it is imperative that the vulnerabilities identified in this report be addressed in order to ensure sustainable development.

5.5 Impacts and Risks on Key Economic Sectors

5.5.1 Overview

The country is currently on track to transition from its current status as a least developed country (LDC), with a goal of achieving upper middle-income status by 2030. However, this transition period is characterized by significant challenges presented by climate risks, including a reduction in productivity, an increase in operational and recovery costs, and overall economic losses, particularly to sectors that are critical to the nation's economic growth and development. These challenges have the potential to impede the country's progress towards achieving its economic goals. The nation's economy, which is heavily reliant on agriculture, manufacturing, and construction, is particularly vulnerable to the effects of climate change, which highlights the urgency of addressing these challenges (UNDP, 2024).

Effect of climate change, including heightened temperatures, anomalous precipitation patterns, and extreme meteorological events such as floods and droughts, have a strong negative impact on the agricultural sectors. These impacts result in a reduction of crop yields, particularly in the case of rice, a staple foodstuff and export product. This, in turn, gives rise to food insecurity and a loss of income for those residing in rural areas. Furthermore, the issue of water scarcity is becoming increasingly critical, with a detrimental impact on agricultural productivity. The growing unpredictability of monsoon rains and the increase in average temperatures have resulted in a decline in crop yields, which has in turn threatened food security and reduced incomes for rural households, which constitute a significant proportion of the population. In years characterized by extreme weather events, such as the 2016 drought, there was a notable decline in agricultural output, necessitating a reliance on food imports to meet domestic needs. Climate change could result in a reduction of agricultural productivity by 8-20 percent by 2050, which would have significant implications for food security and rural livelihoods (WB, 2021). It is anticipated that extreme weather events, such as an increase in the frequency of droughts and floods, will intensify, affecting not only crop production but also the fisheries industry, which is vital for rural communities, particularly those around the Tonle Sap Lake (NCSD, 2019).

The regular occurrence of flooding can significantly impact transportation infrastructure, reducing industrial productivity and deterring foreign investment. Furthermore, the financial burden of rebuilding infrastructure after climate-related disasters diverts resources from other critical development projects, impeding overall economic progress. The occurrence of increased flooding and other extreme weather events has resulted in damage to roads, bridges, and urban infrastructure, which has in turn led to a hindrance of economic activities and an increase in maintenance costs. The disruption to transport networks has an adverse effect on supply chains and access to markets, which in turn impedes economic growth and development (World Bank, 2023c). The recurrence and intensity of extreme meteorological events such as flooding could result in financial losses amounting to billions of dollars for Cambodia. By 2050, the annual financial losses from climate-related damages to infrastructure such as roads, factories, and housing are projected to increase from USD 0.5 billion to between USD 3.3 and USD 10.6 billion

(UNDP, 2024). This will have a detrimental impact on the country's industrial growth, particularly in sectors such as garment manufacturing, which contributes significantly to exports.

Furthermore, climate change exerts an influence on public health, which is inextricably linked to economic development. The rise in temperatures and alterations in precipitation patterns are facilitating the dissemination of waterborne diseases, such as diarrhea, in addition to vector-borne diseases, including malaria and dengue fever, which are prevalent in Cambodia. Such health impacts may result in diminished labor productivity, augmented healthcare expenditures, and augmented economic burdens on households. As indicated by the World Health Organization (WHO), climate change is anticipated to result in an increased prevalence of these diseases in Cambodia, particularly in rural and coastal areas where healthcare accessibility is constrained. This not only jeopardizes the well-being of the population but also exerts considerable pressure on the country's labor force, which is indispensable for maintaining economic growth (WHO, 2015).

It is evident that an increase in global temperatures and the prevalence of extreme weather conditions have a significant impact on economic activity. A 2018 UNDP report estimated that if global temperatures rise by 2°C by 2050, Cambodia's GDP could be 9.8 percent lower than projected. A significant portion of this economic loss can be attributed to reduced labor productivity resulting from heat stress, particularly in pivotal sectors such as manufacturing and construction. These industries, which are vital to Cambodia's economy, are particularly vulnerable because a significant proportion of the workforce operates in non-air-conditioned environments, thereby rendering them more susceptible to heat exhaustion (UNDP, 2018). Furthermore, it exacerbates existing socio-economic inequalities. Those residing in rural areas, particularly smallholder farmers, are especially susceptible to the adverse effects of climate change. The increasing frequency of floods and droughts not only impacts agricultural production but also exacerbates poverty, as these communities rely heavily on natural resources for their livelihoods. This, in turn, has the effect of undermining the efforts that are being made to reduce poverty and to improve living standards (ADB, 2021a). Those living in rural communities, which are heavily reliant on agriculture and fisheries, are the most vulnerable to the effects of climate-related shocks. A study conducted by the World Bank indicates that climate change could potentially result in an additional 1.5 million Cambodians being pushed into poverty by the year 2050. This is largely attributed to a decline in agricultural productivity and an increase in food prices. This could result in the reversal of the notable progress Cambodia has made in poverty reduction over the past two decades. The government's capacity to address these challenges is constrained by limited financial resources and a lack of adaptive capacity at the community level. If left unaddressed, the growing socio-economic inequalities could further impede Cambodia's long-term development prospects (WB, 2023a).

According to a joint study between the MoE and the MEF (2019), estimated under changing climate will reduce GDP Growth by 2.5 percent by 2030 and 9.8 percent by 2050. Loss and Damage (L&D) from climate change can be grouped into three types of impact: a) loss of income, mostly from declining natural resource productivity (DY); b) reduction in labor productivity arising from heat stress (DL); and c) damage to assets (DK). There are many studies in Cambodia and Southeast Asia that consider these individually. The Climate Economic Growth Impact Model (CEGIM) triangulates all these sources and then integrates them into a single analytical framework. The CEGIM accommodates the three types of direct L&D in the following ways:

- Loss of income reduces GDP in the year of loss but has no direct effect on subsequent GDP.
- Heat stress and health effects reduce GDP through labor productivity.
- Damage to assets from extreme events and sea level rise reduces capital stocks.
- Any reduction in GDP indirectly reduces future GDP by reducing investment.

Economic development in Cambodia is inextricably linked to its natural environment. The effects of climate change present significant challenges to Cambodia's growth trajectory. From agriculture to health, infrastructure, and poverty reduction, climate change has the potential to impede or even reverse development gains unless proactive adaptation and mitigation measures are implemented. It is imperative that the Cambodian government, with assistance of international organizations, prioritizes climate resilience in its development planning in order to ensure the country's future economy.

5.5.2 Industry

Over the past few decades, Cambodia has witnessed a notable expansion of its industrial sector, with manufacturing, construction, and tourism emerging as pivotal contributors to the country's economic growth. However, climate change represents a considerable threat to these industries, with the potential to disrupt production processes, increase operational costs and reduce overall productivity. The impact of climate change on Cambodia's industrial sector is complex and multifaceted. It encompasses physical damage from extreme weather events, disruption to the supply chain, and a reduction in labor productivity due to rising temperatures, floods, and droughts.

The manufacturing sector, which contributes approximately 32 percent to Cambodia's gross domestic product (GDP), is highly vulnerable to the impacts of climate change, particularly heat stress. A significant portion of Cambodia's manufacturing industries, including garment and textile factories, operate in facilities that lack air conditioning. As a result, employees are exposed to elevated temperatures, directly affecting their health and well-being. The garment industry accounts for over 75.9 percent of the country's total exports. The majority of workers in the garment sector are women, who may be more vulnerable to heat stress as a result of pregnancy, breastfeeding, or other gender-related health concerns. Rising temperatures due to global warming can reduce productivity in manufacturing facilities, many of which are poorly ventilated and lack adequate cooling systems. The effects of heat stress extend beyond workers' health, impacting the financial viability of companies that must invest in costly measures to maintain productivity, as shown about the activities of workers in Figure 37.

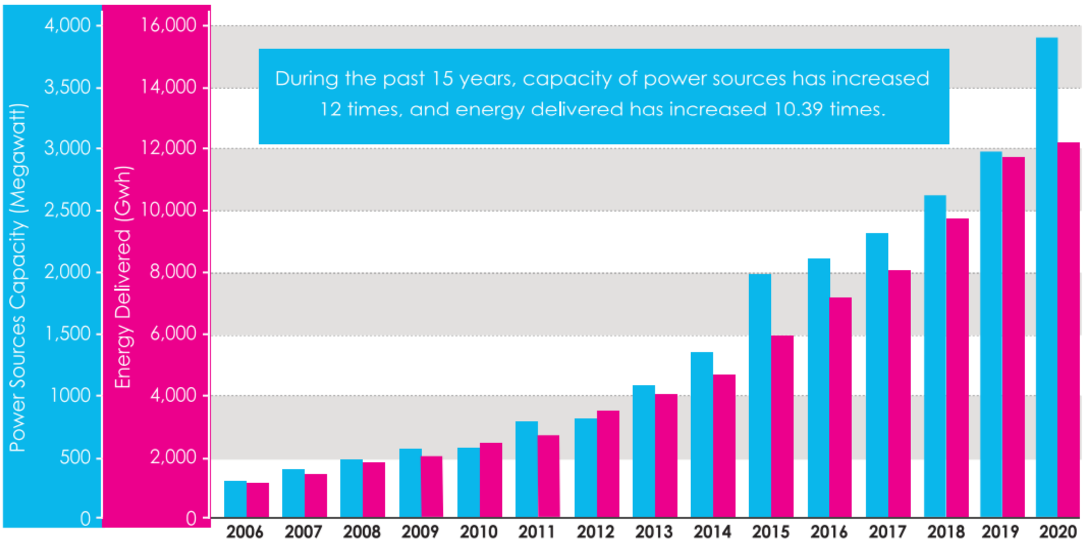
Figure 37: The activities of workers in the garment factory.
Source: (Phnom Penh Post, 2015).

As temperatures increase, the demand for cooling rises, leading to higher energy costs. Extreme heat can also affect machinery performance, further diminishing overall productivity. This results in a reduction in worker productivity and an increase in absenteeism due to heat-related illnesses, which has a detrimental impact on production output (Responsible Business Hub, 2022). Furthermore, the disruption of global supply chains resulting from extreme weather events, such as floods that damage roads, ports, and transport networks, further impedes manufacturing operations. The textile industry, which relies heavily on imported raw materials and exports finished goods, is particularly susceptible to these disruptions (WB, 2023a). The costs associated with maintaining production facilities, including the potential need for cooling systems to combat heat stress, contribute to overall operational expenses, thereby reducing profit margins for businesses (WB, 2023b). The occurrence of extreme weather conditions, such as floods and storms, has the potential to cause significant damage to buildings and infrastructure, leading to delays in construction projects and an increase in construction costs. For instance, heavy precipitation can result in flooding at construction sites, impeding the continuity of work and leading to extended project timelines. Furthermore, elevated temperatures and humidity levels can impair the durability and quality of construction materials. For instance, concrete and asphalt may degrade more rapidly in the presence of extreme heat, resulting in elevated maintenance costs and a reduction in the lifespan of infrastructure. The industry is confronted with rising material costs as climate change affects the availability and transportation of materials. In particular, roads, bridges, and other infrastructure are increasingly susceptible to damage from floods and extreme heat, necessitating more frequent repairs and replacements (WB, 2023c).

The consequences of climate change are being felt profoundly in Cambodia's industrial sector, with effects on productivity, increased costs, and the potential for long-term economic losses. The manufacturing, construction, and related sectors are particularly susceptible to climate-related disruptions. In order to mitigate these impacts, Cambodia must invest in climate-resilient infrastructure, adopt new technologies, and implement policies that encourage sustainable industrial development. Enhanced climate adaptation strategies are essential for ensuring the long-term viability of the country's industrial sector and overall economic growth.

5.5.3 Energy

Cambodia is experiencing a period of significant transformation in its energy system, driven by the dual forces of rapid urbanization and industrialization that have led to an exponential increase in electricity demand. This has been accompanied, however, by a concomitant increase in climate change-related challenges, which have the potential to affect not only the country's energy infrastructure but its long-term sustainability. Among the most significant of these challenges are the heightened vulnerability of Cambodia's hydropower resources, the rise in energy consumption, and the necessity for a more diversified and resilient energy matrix moving forward, the progress of development of power sources during the past 15 years is shown in Figure 38 below.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Power Sources Capacity (MW)	325	419	490	579	584	793	825	1,088	1,359	1,986	2,115	2,322	2,635	2,999	3,897
Energy Delivered (GWh)	1,203	1,517	1,858	2,077	2,515	2,788	3,527	4,051	4,713	5,990	7,175	8,073	9,739	11,738	12,499
Energy Increase (%)	24.46	26.73	22.52	11.76	21.08	13.26	23.84	14.83	16.35	27.09	19.79	14.78	20.64	20.53	6.48

Figure 38: Development progress of power sources during the past 15 years.
Source: (EAC, 2020).

Hydropower represents a pivotal aspect of Cambodia's energy production, accounting for approximately 50 percent of the country's electricity generation. Cambodia's major rivers, particularly the Mekong River, have been a significant source of hydropower for the country. However, climate change is significantly altering hydrological patterns, resulting in a reduced river flow and more erratic rainfall, which directly affects the reliability of hydropower. Modifications in precipitation patterns and increased evaporation resulting from elevated temperatures can influence water levels in reservoirs, thereby reducing hydropower output (Mekong River Commission, 2022). Furthermore, altered rainfall patterns can result in variability in water flow, which may subsequently affect the reliability and stability of hydropower generation.

Indeed, prolonged droughts, such as those experienced in recent years, result in decreased water levels, thereby reducing the capacity of hydropower plants to generate electricity. This dependence on fluctuating water availability renders Cambodia's energy system highly vulnerable to changes in precipitation patterns brought on by climate change (WB, 2021). In 2019 and 2020, the impact of drought conditions in the Mekong region resulted in a reduction in energy output from hydropower, necessitating importation of electricity from neighboring countries to meet domestic demand (WB, 2023a).

The rise in global temperatures and the increased frequency of heatwaves are driving a higher demand for electricity, particularly for the purpose of cooling in urban and industrial areas. Cambodia, situated in a tropical climate zone, is already witnessing considerable increases in its mean temperature, which are projected to persist throughout the 21st century (Cheat, 2023). As an increasing number of homes and businesses employ air conditioning and cooling systems, the country's energy grid is experiencing heightened strain, particularly during peak demand periods in the hottest months (UNEP, 2023). This heightened demand can strain the energy system and increase electricity consumption, particularly during heatwaves. Furthermore, Cambodia's reliance on an already overburdened energy infrastructure increases the risk of power shortages, particularly when combined with reduced hydropower generation during dry seasons. The higher energy demand not only places pressure on the national grid but also increases the country's energy imports, further complicating efforts to achieve energy independence.

The energy system in Cambodia is confronted with considerable challenges resulting from climate change, particularly with regard to overdependence on hydropower and the growing demand for electricity in response to elevated temperatures. The ramifications of climate change on Cambodia's energy system have far-reaching consequences for the country's national energy security and economic development. As a consequence of the declining reliability of hydropower output, Cambodia has been compelled to rely increasingly on electricity imports from neighboring countries, particularly Thailand and Vietnam. This growing dependence on external energy supplies gives rise to concerns about energy security, particularly in view of fluctuating regional electricity prices and the potential for geopolitical tensions (Kang, 2023). Furthermore, increased energy imports result in elevated costs for the Cambodian economy, which may impede the country's industrial development and raise energy prices for consumers. The energy system's vulnerability to climate impacts not only affects current energy production but also complicates the country's efforts to achieve long-term energy independence and sustainability.

The imperative to diversify the energy mix with renewable sources such as solar and wind power is urgent. However, barriers such as infrastructure limitations and financial constraints impede progress. In order to guarantee energy security and sustain economic growth, Cambodia must give priority to climate-resilient policies and extend investments in renewable energy technologies. It is imperative that Cambodia receives international cooperation and financial support in order to facilitate a transition to a more sustainable and resilient energy future.

5.5.4 Tourism

Tourism constitutes a pivotal component of Cambodia's economic landscape; in 2019, the sector directly employed 630,000 people, with tourism receipts peaking at USD 4.9 billion, or 18.2 percent share of Cambodia’s GDP. The sector is confronted with a number of challenges, including changes in climate patterns, extreme weather events, and impacts on natural and cultural attractions. The rise in the frequency of extreme weather events, including heatwaves, storms, and flooding, has the potential to dissuade tourists, diminish their comfort, and precipitate the cancellation of tours, particularly in destinations with a significant outdoor component, such as Angkor Wat (as shown in Figure 39) and the beaches of Koh Rong. Furthermore, the growing unpredictability of weather patterns can disrupt travel plans, rendering the tourism sector more susceptible to volatility. Elevated temperatures and heat stress have the potential to negatively impact the experiences of tourists visiting Cambodia's renowned heritage sites, leading to a reduction in visitor satisfaction (Aguilar-Gomez et al., 2024).

Figure 39: The disturbance of high temperature and rain on the tourists visiting.
Source: (Phnom Penh Post, 2018).

Cambodia's rich biodiversity represents another significant draw for tourists, who visit national parks and ecotourism sites such as Cardamom Mountains and the Mekong River. However, climate change is precipitating shifts in ecosystems, which are in turn leading to biodiversity loss. Rise in temperatures and alterations in precipitation patterns are influencing the condition of forests, wildlife, and the accessibility of fresh water, which are essential for eco-tourism. The reduction in wildlife populations and the deterioration of natural habitats have the potential to diminish Cambodia's appeal as a destination for eco-tourism, which is an increasingly significant component of the country's tourism market. Furthermore, coastal areas, including coral reefs, are susceptible to the detrimental effects of rising sea temperatures and ocean acidification, which can result in coral bleaching and degradation. Such changes can impact marine tourism and local livelihoods that depend on these ecosystems (Nhep et al., 2021).

Historical sites such as Angkor Wat are also highly susceptible to the effects of climate change. An increase in precipitation and the incidence of flooding can result in damage to the ancient structures, while higher temperatures can render these sites less conducive to visitor comfort (Chim et al., 2021). Preservation of cultural heritage is challenged by extreme weather events, which can accelerate the deterioration of ancient structures and artifacts. In the absence of adequate adaptation and preservation measures, Cambodia may witness a notable decline in cultural tourism (Michelle, 2020).

The effects of climate change are being felt in Cambodia's tourism sector, with impacts observed on natural and cultural attractions, particularly in coastal regions, eco-tourism destinations, and cultural heritage sites. In order to mitigate these impacts, it is essential to adopt sustainable tourism practices, invest in climate-resilient infrastructure, and implement effective conservation measures. Furthermore, engaging local communities and promoting economic opportunities through sustainable tourism can also enhance resilience and ensure long-term benefits.

5.6 Key Future Impacts and Risks

Cambodia, a Southeast Asian country with a rich agricultural heritage and a rapidly growing economy, is increasingly vulnerable to the impacts of climate change. With its reliance on agriculture, extensive river systems, and low-lying geography, Cambodia faces numerous challenges that are expected to intensify in the coming decades (MoE, 2022). As global temperatures rise and extreme weather events become more frequent, Cambodia's socio-economic systems, human health, and environmental integrity are at risk. This paper outlines the key future impacts and risks of climate change in Cambodia, focusing on the following areas: agricultural productivity, water resources, coastal systems, human health, and socio-economic stability.

However, the threat of climate change poses a significant challenge to the continued viability of vital sectors. The increasing frequency of droughts, floods, and irregular monsoon seasons has the potential to reduce crop yields, particularly for rice, the country's staple food. An increase in temperature may intensify pest and disease transmission, further compromising agricultural productivity (Grigorieva et al., 2023). Consequently, food security may be jeopardized, particularly for vulnerable populations in rural areas who depend on subsistence farming. A reduction in agricultural output could lead to higher food prices, making it more difficult for the population to afford basic necessities (FAO, 2022a). Cambodia's coastal areas, though less developed than other regions, are vulnerable to rising sea levels. The country's coastline, particularly in the provinces of Preah Sihanouk and Koh Kong, is home to significant ecosystems such as mangroves and coral reefs, which serve as natural barriers against storm surges and erosion. Rising sea levels and increasing salinity could result in the potential loss of these critical ecosystems, coupled with a decline in fisheries crucial for local livelihoods. Furthermore, the loss of coastal land may drive migration from rural to urban areas, exacerbating the strain on cities and infrastructure (NCSD,2019).

It is anticipated that climate change will intensify the prevalence of health risks in Cambodia, particularly in relation to the spread of infectious diseases. The rise in temperature and the variability of precipitation patterns create ideal conditions for the transmission of vector-borne diseases, including malaria, dengue fever, and cholera. Furthermore, flooding can lead to contamination of drinking water, which may contribute to the emergence of waterborne diseases. The potential for heat stress, particularly in rural areas where access to healthcare is limited, could further strain the healthcare system and a reduction in productivity (WHO, 2015). Those most vulnerable to the health impacts of climate change include the elderly, children, and individuals with pre-existing health conditions.

5.7 Directions for Future Studies

Cambodia faces significant challenges due to the adverse effects of climate change. The observed impacts of shifting weather patterns, extreme events, and rising temperatures have increasingly affected Cambodia's human systems, including health, livelihoods, infrastructure, and vulnerable groups. In order to enhance resilience and ensure sustainable development, prioritizing future studies is crucial. These studies should aim to deepen the understanding of climate vulnerabilities, strengthen adaptation strategies, and identify pathways for long-term sustainability, and to explore key areas for future research on impacts and risks of climate change on human systems in Cambodia.

Integrated models to Combine Climate Data with Socio-economic Trends: It is recommended that future studies focus more on the development of integrated models that combine climate data with socio-economic trends. These models can simulate variety of scenarios, helping policymakers in anticipating the long-term impacts on human systems. For example, predictive analyses can investigate how altered rainfall patterns may affect internal migration patterns or how rising temperatures could intensify public health challenges. Such models are of great value in the design of adaptive measures that are aligned with Cambodia's socio-economic goals, including the poverty reduction and urban planning. The effects of climate change in Cambodia are pervasive, requiring a comprehensive approach to adaptation that considers the interconnections between various sectors.

Investigate Synergies and Tradeoffs: Further research should investigate the potential synergies and trade-offs between interventions in agriculture, water resources, and infrastructure. For instance, strategies designed to improve irrigation for agricultural purposes may also serve to alleviate water scarcity in urban areas. By investigating these interconnections, studies can propose integrated solutions that maximize co-benefits while minimizing unintended consequences.

Focus on Vulnerable Populations: Those populations deemed vulnerable, including women, children, indigenous communities, and the elderly, frequently experience the most severe consequences of climate change. Future research must prioritize the investigation of adaptive capacities and the development of interventions that are specifically designed to meet the needs of these populations. For example, research could examine the potential of women-led community initiatives to bolster resilience in rural areas or the role of indigenous knowledge systems in sustainable resource management. It is imperative that these groups be included in adaptation planning in order to ensure equitable and effective climate action.

Monitoring and Evaluation: To assess the effectiveness of adaptation initiatives, it is essential to implement robust monitoring and evaluation frameworks. Future research should focus on developing participatory M&E systems that engage local communities and relevant stakeholders. These frameworks can help track progress, identify shortcomings, and ensure accountability in the implementation of climate adaptation strategies. Additionally, integrating real-time data collection methods, such as remote sensing and geographic information systems (GIS), can further enhance the effectiveness of these systems.

Technology and Advanced Tools: The importance of technology in addressing climate change cannot be overstated. Future studies should explore the potential of advanced tools, such as geographic information systems (GIS), remote sensing, and early warning systems, to enhance climate risk management. Equally important is developing the capacity of local communities to effectively use these technologies. Another area for research is the design of training programs and knowledge-sharing platforms that empower communities and local governments to implement climate-resilient practices. By pursuing these research avenues, Cambodia can strengthen the resilience of its human systems and establish a foundation for sustainable development in an era of environmental uncertainty.

CHAPTER 6
CAMBODIA ADAPTATION GOVERNANCE AND ADAPTIVE CAPACITY ASSESSMENT

6.1 Introduction

6.1.1 Overview

Adaptation to climate change is essential for protecting communities, ecosystems and economies from the growing adverse effects of global warming. As climate change intensifies, the implementation of adaptation measures, including infrastructure upgrades, adoption of resilient agricultural practices, and the establishment of early-warning systems, become crucial strategies for reducing climate vulnerability and enhancing resilience. In the absence of proactive measures, the adverse effects of climate change including rising sea levels, more intense storms, droughts, and heatwaves, will continue to threaten food security, human health, and economic stability. In its February 2022 report, the IPCC described current global adaptation efforts as small-scale, incremental, and fragmented, with limited evidence of transformational adaptation (IPCC, 2022). Furthermore, most adaptation actions fail to address the longer-term impacts of climate change, potentially reinforcing existing vulnerabilities and making corrective measures more challenging and costly in the future. International adaptation finance flows to developing countries reached a total of USD 29 billion in 2020. This represents a mere 10 percent of the estimated requirement for 2030, which is projected to be USD 340 billion per annum, and is significantly below the amount that will be needed in subsequent decades (UNEP, 2023). It is imperative that adaptation finance is increased globally, given that countries in Africa already spend between 2 percent and 9 percent of their GDP on adaptation. In some cases, this represents a greater proportion of government expenditure than is spent on healthcare, education, or other public services (Campbell, 2023). Adaptation is highly dependent on location. In many cases, adaptation involves the construction or enhancement of infrastructure, such as the installation of a more effective storm drain system to facilitate the management of increased flooding. Adaptation can also entail the utilization of natural solutions, such as restoration of wetlands to serve as a buffer against storms, or implementation of behavioral and policy alterations, including the cultivation of novel food crops that are better equipped to withstand warmer seasons and droughts (Toth & Rio, 2023).

Cambodia is frequently identified as one of countries most susceptible to the adverse effects of climate change, with significant projected impacts on agricultural production, infrastructure (including transportation, irrigation, and urban systems), and public health. The initial estimates indicate that there will be a reduction in annual GDP growth of 2.5 percent by 2030, with this annual rate increasing in subsequent years as a consequence of climate change. It is imperative that both public and private investment be made to address these threats and to minimize the impact of climate change on the economy, business environment, and well-being of the population of Cambodia. In order to effectively address these challenges, it is imperative that Cambodia's governance structures and adaptive capacity are both robust and responsive.

This assessment provides an overview of Cambodia's adaptation governance and evaluates the country's capacity at the national, regional, and local levels to implement climate adaptation strategies (NCSD, 2019). The Royal Government of Cambodia (RGC) has committed to the development and promotion of climate-smart and green technologies as part of its green growth strategy and Climate Change Strategic Plan. In Cambodia, recent climate public expenditure reviews provide the most up-to-date information on public financing levels for climate change, along with guidance on improving the mobilization and management of public climate finance. The RGC developed the Cambodia Climate Change Strategic Plan (CCCSP) 2024-2033 to promote sustainable development through the adoption of low-carbon technologies and the enhancement of climate resilience with three strategic priorities: promote the reduction of greenhouse gas emissions in line with the Long-Term Strategy for Carbon Neutrality 2050, strengthen adaptive capacity to climate change, and enhance good governance and promote digital transformation.

The adaptation governance framework in Cambodia reflects an awareness of the need to address the far-reaching consequences of climate change. Through the implementation of national policies, institutional reforms, and international cooperation, the country is establishing the foundation for a more climate-resilient future. Nevertheless, the resolution of financial, institutional, and data-related challenges will be essential to the long-term viability of these endeavors. As climate change continues to intensify, Cambodia's capacity to adapt will depend on its ability to mobilize resources, strengthen institutions, and engage vulnerable communities in the governance process (WB, 2024b).

6.1.2 Adaptation Governance

The concept of adaptation governance encompasses the processes, policies, and institutions through which climate adaptation is managed and implemented at various levels of government and society. In Cambodia, adaptation governance is a rapidly emerging area of concern due to the country's considerable vulnerability to the adverse effects of climate change, including floods, droughts, and rising temperatures. Effective adaptation governance ensures the integration of climate resilience measures into national development plans and their implementation in an inclusive, transparent, and accountable manner.

At the national level, the Cambodian government has taken significant steps to establish a framework for climate change adaptation, such as the Royal Degree on the organization and functioning of the National Council for Sustainable Development. The Ministry of Environment plays a pivotal role in developing climate change policy, while the National Council for Sustainable Development (NCSD) is responsible for integrating climate change considerations across all sectors. Furthermore, the National Committee for Disaster Management (NCDM) is responsible for preparedness and response to climate-related disasters, such as floods and droughts. The Department of Climate Change (DCC), under the Ministry of Environment, is tasked with developing policy through conducting climate research and working with international partners to obtain funding for climate change projects. At the sub-national, regional, commune, and local levels, adaptive governance entails the implementation of national strategies in a manner that is sensitive to local contexts and needs.

a. Governance in the Context of Adaptation

Climate adaptation governance can be defined as the systems, processes, and institutions through which societies manage and respond to the risks posed by climate change. It requires the coordination of multiple levels of government, the private sector, civil society, and communities to develop and implement strategies that reduce vulnerability and enhance resilience to climate impacts (GCF, 2024). Effective climate adaptation is contingent upon robust governance. It entails the establishment of inclusive, transparent, and flexible systems that facilitate the effective empowerment of stakeholders in addressing climate risks.

The role of governance in facilitating and implementing climate adaptation strategies is a critical factor in enabling societies to plan for and adapt to the impacts of climate change. Effective governance is essential for ensuring the coordination, inclusivity and sustainability of adaptation strategies. It encompasses a wide range of activities, from policy formulation and resource allocation to stakeholder engagement and monitoring, across all levels of society (WB, 2023). These frameworks provide the legal authority, institutional structures, and policy directions required to guide adaptation efforts across all levels of society. They ensure that climate adaptation measures are integrated into development strategies, regulations, and sectoral policies, while promoting accountability and transparency (NCSD, 2017a). Effective governance is crucial for ensuring that climate adaptation efforts are inclusive, equitable, transparent, and accountable enabling countries and regions to respond proactively to climate risks. As climate change increasingly impacts ecosystems, economies, and societies, robust governance becomes indispensable for the formulation of policies, the distribution of resources, and the mobilization of action across sectors.

The Paris Agreement and other international frameworks highlight the crucial role of governance in climate adaptation. Article 7 of the agreement places particular emphasis on the global goal of adaptation, which is to enhance adaptive capacity, strengthen resilience and reduce vulnerability. It is recommended that nations develop National Adaptation Plans (NAPs) that reflect their specific contexts and governance capacities (UNFCCC, 2015). Cambodia, which is particularly susceptible to the effects of climate change, has implemented the Cambodian Climate Change Strategic Plan (CCCSP) to direct its adaptation initiatives. Through the NAP, Cambodia has addressed vulnerabilities in key sectors, including agriculture, water resources, forest ecosystems, fisheries, infrastructure, health, and coastal zones. The stocktaking report and recommendations for the NAP roadmap informed the development of three essential documents: the National Adaptation Plan Process in Cambodia 2017, the Cambodia National Adaptation Plan Financing Framework and Implementation Plan 2017, and the Cambodia National Adaptation Plan: Communication Strategy 2018.

b. Importance of Governance in Effective Adaptation

The establishment of governance structures enables the integration of climate adaptation into Cambodia's broader development agenda. Significant policies, including the Cambodian Climate Change Strategic Plan (CCCSP) and the National Strategic Development Plan (NSDP), delineate methodologies for the integration of adaptation strategies across sectors such as agriculture, water resources, and urban development. This integration guarantees that climate resilience is an indispensable element in attaining Cambodia's socio-economic objectives.

Governance structures are key for the effective implementation of climate adaptation strategies. Governance establishes structures through which adaptation strategies are developed, implemented, and monitored, thereby ensuring that efforts are aligned across sectors, scales, and stakeholders. Effective structures guarantee that adaptation is not only efficient but also equitable, inclusive, and responsive to the needs of those most vulnerable to climate change impacts (NCSD, 2017b). Governance structures are critical for effective climate adaptation at several levels and mechanisms:

- **National to Local Integration:** Climate adaptation encompasses a range of actions at various governance levels, including national, regional, and local. Governance structures serve to facilitate coordination between these levels, thereby ensuring that local adaptation needs are reflected in national strategies and that national policies are implemented effectively at the local level (ADB, 2021a).
- **Cross-Sectoral Collaboration:** The effects of climate change are far-reaching, impacting a multitude of sectors, including agriculture, health, infrastructure, water, and more. Effective governance structures facilitate collaboration between these sectors, ensuring a unified response to climate-related risks. By aligning sectoral policies with national climate goals, governance structures guarantee that each sector contributes to the collective adaptation objectives (ADB, 2021a).
- **Strategic Planning:** Governance structures serve as the foundation for establishing national adaptation priorities and objectives. By means of policies such as National Adaptation Plans (NAPs), countries are able to undertake a strategic assessment of their vulnerabilities, identify priority areas for action, and subsequently allocate resources in a manner that is aligned with these findings (GSSD, 2020).
- **Access to Finance:** Effective governance structures are instrumental in securing and managing the financial resources essential for adaptation. This encompasses both domestic resources and international climate finance from mechanisms such as the Green Climate Fund (GCF) and other donors. Effective governance structures guarantee the transparent allocation of funds and their efficient utilization to support adaptation measures across sectors and regions.
- **Technical and Technology Resources:** Governance structures play a pivotal role in the advancement and dissemination of technical expertise and data, which are indispensable for effective adaptation planning. This encompasses climate modeling, risk assessment, and capacity-building endeavors, all of which are indispensable for effective decision-making in adaptation.
- **Transparency:** Effective governance is essential for ensuring transparency in decision-making processes and resource allocation. This foster trust among stakeholders, including local communities and international donors, and guarantees that adaptation efforts are both credible and effective. Accountability mechanisms, such as regular reporting and public consultations, further enhance trust and the legitimacy of adaptation actions. Effective governance is crucial for ensuring that adaptation efforts are equitable and that the benefits of adaptation are distributed fairly across society. This is of particular importance given that climate change disproportionately affects vulnerable groups, such as women, indigenous communities, and the poor.
- **Capacity Building:** The establishment of governance structures serves to facilitate the growth of institutional and human capabilities, thereby enabling more effective responses to climate-related risks. This encompasses the provision of training for government officials, the cultivation of technical

expertise, and the advancement of community-level capacity to effectively manage climate risks (CCCA, 2020).

- **Monitoring and Evaluation:** Governance structures are of paramount importance in the creation of systems designed to assess the efficacy of adaptation strategies. Such systems assist governments in monitoring progress, identifying deficiencies, and implementing requisite adjustments to policies and actions over time.
- **Sustainability of Efforts:** Governance structures serve to guarantee the long-term sustainability of adaptation efforts by integrating them into national policies, legislation, and development plans.

Figure 40 below illustrates the process of climate adaptation in Cambodia, as it relates to governance structures. Governments and relevant stakeholders across various sectors have formulated policy, strategy, and planning documents for adaptation. These documents are disseminated to national or local people for implementation and feedback, which is then used to inform national-level reports.

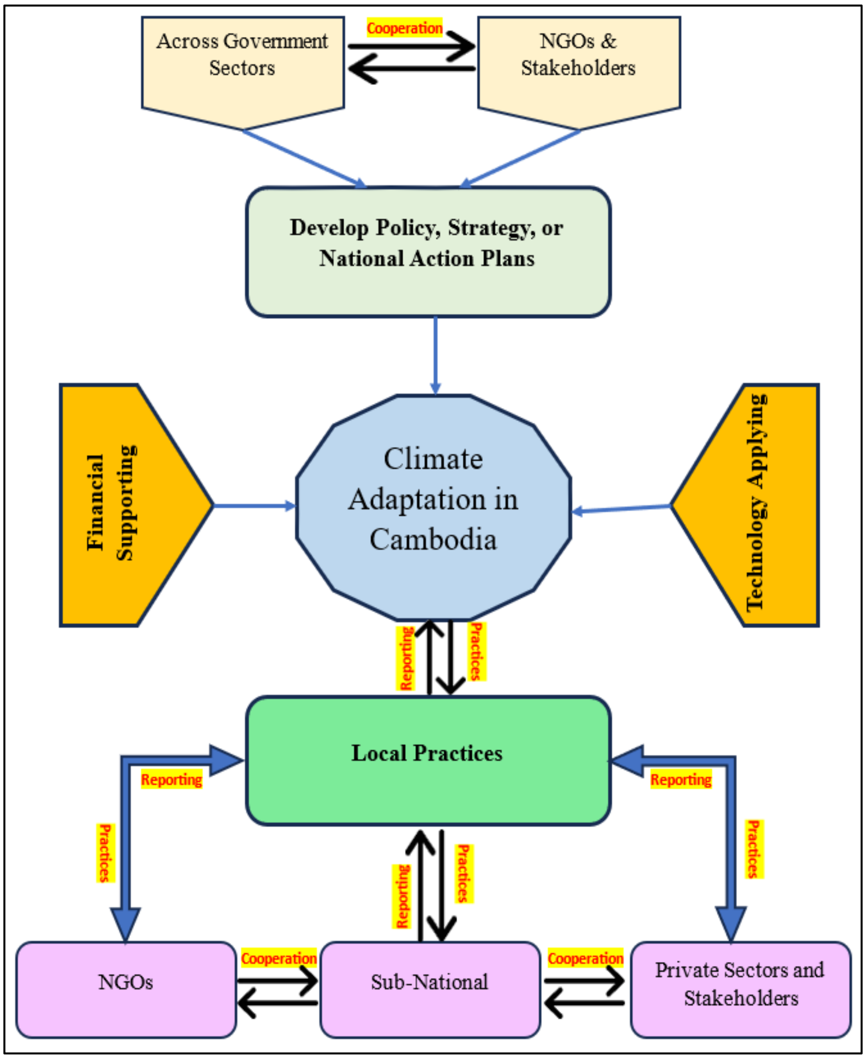


Figure 40: Governance process of climate adaptation in Cambodia.
Source: The authors.

6.1.3 Principles of Effective Governance for Adaptation

Effective governance is a crucial element in ensuring that climate adaptation efforts are coordinated, inclusive, transparent, and resilient. To mitigate the ever-evolving climate risks, it is essential to implement clear strategies, establish effective mechanisms for stakeholder engagement, mobilize resources, and conduct continuous evaluation. The following section outlines the key principles of effective governance for climate adaptation, along with methods and approaches that can be applied in various contexts:

- **Transparency:** Transparency helps stakeholders understand objectives, procedures, and development of adaptation initiatives, thereby mitigating the probability of misadministration or corruption. Transparency fosters public trust and encourages collaborative participation. It is recommended that national governments submit regular reports on adaptation efforts to national stakeholders and international bodies, such as the UNFCCC (CCCA, 2022).
- **Inclusiveness and Participations:** Vulnerable communities, civil society organizations, private sector actors, and local community. It is essential to conduct multi-stakeholder consultations in a manner that ensures the participation of marginalized groups, including women, indigenous communities, and the poor. This approach guarantees that adaptation strategies are aligned with local needs and promote social equity (NCSD, 2019).
- **Accountability:** The establishment of clear roles, responsibilities, and accountability mechanisms is essential for ensuring that those involved in adaptation governance can be held accountable for their actions. It is essential to develop transparent governance structures that delineates roles and responsibilities of national, regional, and local communities, as well as private sector entities, in adaptation efforts.
- **Flexibility and Responsiveness:** Flexible governance allows for adjustment of strategies based on emerging science, technology, or shifting vulnerabilities. Adaptive management strategies that allow for regular monitoring and adjustment of adaptation plans should be implemented.
- **Integration Across Sectors and Scales:** Effective governance for adaptation requires horizontal integration across priority sectors (agriculture, water resources, infrastructure, forest ecosystems, coastal zones, and human health) and vertical integration across scales (from national to local levels) ensures alignment across sectors like energy, transport, agriculture, and urban planning. Creating mechanisms to align national adaptation goals with regional and local implementation, ensuring consistency in policies and funding allocations across all governance levels is key (ADB, 2021a).
- **Knowledge-Based Decision-Making:** Adaptation policies and strategies must be informed by accurate, up-to-date scientific knowledge and local data on climate impacts, vulnerabilities, and risks. Regular climate vulnerability and risk assessments should be conducted at national, regional, and local levels. Governments should collaborate with research institutions and universities to integrate the latest climate science into policy development and decision-making processes.
- **Resource Mobilization and Efficiency:** Successful climate adaptation requires sufficient resources, including financial investments, human capacity, and technical expertise. It is important to develop national strategies to provide access to international climate finance (e.g., the Green Climate Fund), mobilize domestic funding, and incentivize private sector investments in climate adaptation. Establishing transparent and efficient resource allocation mechanisms to ensure funds are directed to priority areas, particularly vulnerable communities or sectors most impacted by climate risks, is crucial.

- **Long-Term Vision and Sustainability:** Climate adaptation requires a long-term perspective, as the impacts of climate change will intensify over time. Ensure that adaptation strategies are embedded in national and local development plans, laws, and regulations (MoE, 2020b).
- **Monitoring and Evaluation:** Monitoring and evaluation is necessary to assess the effectiveness of adaptation actions and ensure that lessons learned inform future policies and strategies. Robust monitoring, evaluation, and learning system should be implemented to track the progress and effectiveness of adaptation projects.

The principles of effective governance for climate adaptation—transparency, inclusiveness, accountability, flexibility, and integration—are essential to ensure that adaptation efforts are coordinated, equitable, and resilient in the face of climate challenges. Key best practices include engaging stakeholders in participatory planning, ensuring transparency and accountability, integrating actions across sectors and scales, and grounding decisions in scientific evidence. Successful adaptation governance also requires mobilizing resources to support long-term climate adaptation and sustainable development.

Cambodia’s Ministry of Environment is in the process of implementing the Circular Strategy on Environment for 2023-2028 to serve as a roadmap for the environmental sector for the next five years. This core strategy serves as the driving force for the other three strategies, which include: Strategy 1: Clean, Strategy 2: Green, and Strategy 3: Sustainable, to ensure environmental sustainability in response to climate change, improve climate adaptation governance, and promote a more efficient green economy with the great benefits for all generations of Cambodians while enhancing the prestige of Cambodia in the international arena (MoE, 2023).

6.2 Role of Stakeholders and Institutional Frameworks

The involvement of multiple stakeholders working within robust institutional frameworks is essential for effective climate adaptation. These stakeholders, which include governments, private sector entities, local communities, and international organizations, play a pivotal role in the planning, implementation, and monitoring of adaptation strategies. Each group contributes a distinct perspective, expertise, and resources, which are crucial for building resilience to climate impacts (NCSD, 2019a). The following section outlines the roles that different stakeholders play and the institutional frameworks that support effective adaptation.

6.2.1 Government Adaptation Capacity

The government musts be able to respond effectively to the challenges posed by climate change, particularly in a country such as Cambodia, which is highly vulnerable to climate-related impacts. The government’s adaptation capacity describes the ability of national, subnational, and local bodies to plan, implement, and manage climate adaptation initiatives. This capacity requires access to technical expertise, financial resources, policy frameworks, and institutional coordination mechanisms that enable government organizations to respond to climate risks and build resilience across sectors. The formulation of climate adaptation strategies in Cambodia is informed by a number of pivotal policy frameworks, including the Cambodia Climate Change Strategic Plan (CCCSP) 2014-2023. This strategic plan delineates the government's long-term vision for climate resilience. The National Council for Sustainable Development (NCSD), operating under the Ministry of Environment, is the principal government entity tasked with the supervision of climate change policies, coordination of adaptation initiatives across sectors, and assurance of consistency with international commitments, including the Paris Agreement. The NAP provides a comprehensive framework for the identification of priority sectors (e.g., agriculture, water resources, infrastructure) and the development of adaptation strategies tailored to the specific needs of those sectors. The government has incorporated climate adaptation into the National Strategic Development Plan (NSDP), thereby ensuring that climate risks are taken into account in the context of broader national development goals. The government is developing its technical expertise in climate risk assessments, data management, and adaptation planning through a variety of training programs and partnerships with international organizations. The Ministry of Environment (MoE); the Ministry of Agriculture, Forestry, and Fisheries (MAFF); and the Ministry of Water Resources and Meteorology (MoWRAM) are enhancing their technical capabilities to monitor climate data, assess vulnerabilities, and develop suitable responses (NCCC, 2013).

At the sub-national level, provincial departments of agriculture, water resources, and the environment, have been granted greater authority to address local climate risks, such as flooding, droughts, and coastal erosion. The incorporation of climate adaptation as a fundamental element within the overarching framework of both the Commune Development Plans (CDPs) and the District Development Plans (DDPs) represents a significant advancement in the capacity for local authorities to facilitate the implementation of adaptation projects at the community level.

The Cambodia Climate Change Alliance (CCCA) played a significant role in enhancing the institutional capacity of Cambodian government agencies to address climate change. The CCCA facilitated the development, implementation, and monitoring of adaptation projects by building capacity at national, subnational, and local levels. The CCCA, a joint initiative of the Royal Government of Cambodia and development partners, has been instrumental in supporting the country's climate change response since 2010. A key focus of CCCA has been to strengthen the institutional capacity of the government agencies to effectively address climate change challenges (CCCA, 2022).

6.2.2 Community Adaptation Capacity

Local communities at the sub-national level in Cambodia, particularly those situated in rural areas, are among the most susceptible to the consequences of climate change. These communities, which rely heavily on natural resources for their livelihoods, are confronted with an increasing number of threats resulting from climate-induced hazards, including floods, droughts, coastal erosion, and alterations in temperature and rainfall patterns (MoE, 2018a). The following section presents an analysis of the adaptation capacity of key community groups, their limitations, and the efforts being made to enhance their resilience.

- **Protected Area Communities:** The Protected Areas Law, under the Code on Environment and Natural Resources (MRP, 2023), provides a framework for involving communities in the management of natural resources, which indirectly supports adaptation by promoting ecosystem-based approaches. However, communities often lack the requisite technical expertise to manage resources sustainably or adopt advanced adaptation measures, such as climate-resilient agriculture or ecosystem-based approaches. Furthermore, protected area communities have limited access to financial resources for adaptation projects, relying heavily on external support from NGOs and development partners (WB, 2022).

- **Forestry Communities:** Community-based REDD+ initiatives, which offer financial incentives for forest conservation and support local adaptation strategies, strengthen capacity to manage resources in a sustainable manner and to engage in adaptation projects. In the absence of formal land rights, these communities are susceptible to exploitation and the subsequent degradation of their natural resources.
- **Fisheries Communities:** The combined effects of overfishing and climate change have resulted in the depletion of fish stocks, thereby reducing the resilience of fisheries ecosystems and limiting the effectiveness of community-based adaptation strategies. Fisheries communities frequently lack access to adequate water management systems, such as flood control mechanisms and irrigation, which are indispensable for the maintenance of fish populations and the sustenance of aquaculture (Sam, 2016).
- **Agricultural Communities:** Agriculture represents the foundation of Cambodia's rural economy, and farming communities are particularly susceptible to the consequences of climate change. The occurrence of extreme weather events, such as droughts and floods, in conjunction with alterations in precipitation patterns, directly impacts crop yields and poses a significant threat to food security. Some communities are implementing climate-smart agriculture (CSA) practices, including the cultivation of drought-resistant crops, the use of water-efficient irrigation systems, and diversification of crops (NCSD, 2018). Such practices assist farmers in adapting to climate variability and in reducing the risks associated with extreme weather. Inadequate irrigation systems, roads, and storage facilities constrain farmers' capacity to implement adaptive agricultural practices and transport their produce in an efficient manner. A significant proportion of communities continue to rely on rain-fed agriculture, rendering them particularly susceptible to alterations in precipitation patterns and extended droughts (MAFF, 2014).
- **Indigenous Communities:** Indigenous communities possess a wealth of knowledge regarding local ecosystems and have developed traditional practices for the sustainable management of resources, including rotational farming and forest conservation. However, the threat of climate change endangers these ecosystems and the traditional livelihoods that depend on them. This severely constrains their ability to implement effective adaptation strategies and to recuperate from the adverse effects of climate-related disruptions (ADB, 2019).
- **Farmer Water User Community (FWUC)**: FWUCs, which manage irrigation systems in a collective manner, face considerable challenges, including unpredictable rainfall, droughts, and floods, all of which pose threats to crop productivity and food security. In order to enhance climate resilience, FWUCs are adopting adaptive strategies such as modernized irrigation systems, drought-resistant crop varieties, and agroecological practices. These strategies are supported by the Ministry of Water Resources and Meteorology (MOWRAM) through infrastructure upgrades and technical training (Chan, 2023). International partnerships, such as ADB initiatives in the Mekong Delta, have bolstered FWUC capacity-building programs, integrating climate risk assessments and participatory planning (ADB, 2021b).

6.2.3 Industrial Adaptation Capacity

As Cambodia grapples with the consequences of climate change, its industrial sector faces increasing risks, including extreme weather events, disruptions in water and energy supplies, and damage to infrastructure. At the same time, the industrial sector holds a dual responsibility: to reduce its own greenhouse gas (GHG) emissions and to support climate change mitigation through sustainable practices and adaptation measures (MIME, 2013). However, this sector is particularly vulnerable to climate-related risks, including supply chain disruptions, water shortages, and energy reliability issues. In response, textile and garment factories are adopting energy-efficient technologies with the objective of reducing energy consumption and emissions. The installation of solar power facilities and the utilization of energy-efficient machinery are assisting in the mitigation of climate-related risks pertaining to energy supply. Those industries that are particularly water-intensive, such as the textile industry, are becoming increasingly aware of the necessity to manage water resources in a sustainable manner. A number of companies are investing in water recycling and wastewater treatment systems with the objective of minimizing their water footprint and reducing the risk of water scarcity. The manufacturing sector continues to rely heavily on non-renewable energy sources, which not only contribute to GHG emissions but also render it susceptible to energy supply disruptions resulting from climate-induced events. A significant proportion of Cambodia's industrial base is constituted by small and medium-sized enterprises (MME, 2015). However, these entities often display a limited awareness of climate change risks and adaptation opportunities, which impedes their capacity to adopt sustainable practices.

The construction and real estate sectors are particularly susceptible to the effects of climate change, including rising temperatures, extreme weather events, and sea-level rise. It is imperative that construction practices and materials evolve in order to mitigate these risks and contribute to climate resilience. Some construction companies are beginning to integrate climate-resilient designs, such as elevated buildings, flood defenses, and the utilization of heat-resistant materials, into their construction practices in order to withstand extreme weather conditions (Ben, 2024). Geen building certifications are becoming increasingly prevalent, particularly in the context of commercial real estate, where energy-efficient designs and materials play a pivotal role in climate adaptation and mitigation. There is a growing trend of collaboration between government and private sector actors on urban planning projects that incorporate climate adaptation measures, including improved drainage systems, green spaces, and disaster-resilient infrastructure. A significant number of developers and construction companies persist in utilizing conventional construction materials and techniques that are not climate-resilient, thereby rendering buildings susceptible to extreme weather and environmental degradation. The initial financial outlay required for climate-resilient construction practices is frequently perceived as a significant barrier by smaller developers, despite the long-term advantages in terms of reduced vulnerability to climate risks (NCSD, 2020).

The energy sector is both a source of greenhouse gas (GHG) emissions, which contribute to climate change, and a key player in climate adaptation efforts. Cambodia's dependence on hydropower and fossil fuels renders its energy infrastructure susceptible to the effects of climate change, including fluctuations in water levels and extreme temperatures. Cambodia is making notable progress in expanding its renewable energy capacity, particularly in solar energy, which reduces reliance on fossil fuels and mitigates climate impacts. The installation of solar energy facilities is becoming more prevalent in industrial zones and rural areas, with the objective of enhancing energy security and resilience. Some industries are participating in government and donor-led initiatives aimed at improving energy efficiency in manufacturing and industrial processes. This not only mitigates emissions but also reduces the sector's vulnerability to energy supply disruptions caused by climate change (MME, 2020). Cambodia's reliance on hydropower represents a significant vulnerability in the context of climate change. Reduced water levels during droughts or altered rainfall patterns have the potential to disrupt electricity generation, thereby exacerbating the country's exposure to climate-related risks.

6.2.4 Business Adaptation Capacity

A business cluster can be defined as a geographic concentration of interconnected businesses, suppliers, and associated institutions within a particular field. They serve as a vital catalyst for economic expansion and innovation. However, the sustainability and resilience of these clusters are threatened by the challenges posed by climate change (IPCC, 2022). The evaluation of the adaptation capacity of business clusters necessitates an examination of the extent to which these clusters are equipped to withstand and respond to climate-related risks, including extreme weather events, supply chain disruptions, and resource scarcity. Business clusters are equipped with climate-resilient infrastructure in order to ensure their continued functionality during and after extreme weather events. Such measures include the implementation of flood protection strategies, the incorporation of sustainable building designs, and the integration of enhanced energy systems. The adoption of energy-efficient technologies and renewable energy sources by business clusters enables them to better withstand the risks posed by climate change, including disruptions to energy supply and price volatility. Clusters that have diversified and climate-resilient supply chains are less vulnerable to the impacts of extreme weather or resource scarcity (WB, 2015).

Figure 41: The installation solar rooftop for energy supply in the factory.
Source: (B2B Cambodia News, 2017).

Access to climate finance is a crucial factor for businesses within a cluster to invest in adaptation measures, such as resilient infrastructure or sustainable technologies. Clusters that have access to private capital, public funding, or international climate funds are better positioned to enhance their overall resilience. Public-private partnerships (PPPs) can facilitate the mobilization of private sector investment in climate adaptation, particularly in infrastructure projects such as renewable energy installations or flood protection systems. An increasing number of companies are integrating sustainability principles into their core operations, including the use of renewable energy, energy-efficient processes, and sustainable sourcing (GSSD, 2019). It is crucial that the private sector engages in collaboration with government agencies and NGOs in the implementation of climate adaptation projects. In certain instances, the private sector's influence may facilitate alterations in public policy or facilitate the allocation of financial resources for the implementation of extensive infrastructure enhancements. In Cambodia, industrial zones are collaborating with government bodies to adopt climate-smart technologies and engage in national adaptation planning processes. The private sector is becoming increasingly involved in the provision of green finance products, including loans for renewable energy projects and investments in climate-resilient infrastructure. By providing financial resources for adaptation initiatives, the private sector can assist in alleviating the financial constraints faced by businesses striving to enhance their climate resilience.

In an effort to reduce their reliance on fossil fuels and enhance resilience to energy price volatility, several industrial zones in Cambodia are undergoing a transition to renewable energy sources, including solar power. The installation of solar panels in Special Economic Zones (SEZs) is assisting businesses in reducing their carbon footprint and enhancing energy security, as shown in Figure 41 (Cleantech Solar, 2016). Cambodia's agribusiness clusters are adopting climate-smart agriculture (CSA) practices in order to mitigate the impacts of changing weather patterns. These practices include the implementation of improved irrigation systems, diversification of crops, and the adoption of sustainable land management practices, which collectively serve to safeguard both the agricultural production and food processing industries from the detrimental effects of climate disruptions (MAFF, 2019). In particular, those engaged in the tourism industry, and in particular eco-tourism, are at the vanguard of efforts to protect natural ecosystems that are critical for climate resilience. Eco-tourism clusters situated along Cambodia's coastline are collaborating with local communities to implement sustainable practices that reduce environmental degradation, enhance biodiversity, and protect against coastal erosion and flooding (MoT, 2015). A significant number of small and medium-sized enterprises (SMEs) within clusters lack the requisite awareness, knowledge, and technical capacity to implement effective climate adaptation strategies. These entities frequently prioritize short-term profitability over long-term resilience. The capacity of business clusters to adapt is of paramount importance for the resilience of entire economies in the context of climate change. Clusters that invest in sustainable infrastructure, diversify their supply chains, and foster innovation are better positioned to withstand climate-related shocks and private sectors and integrating climate adaptation into core business strategies. Business clusters in Cambodia and beyond can make a significant contribution to the development of climate-resilient economies.

6.2.5 NGOs and Other Social Adaptation Capacity

The NGOs and social and cultural institutions are of critical importance in the advancement of climate adaptation, particularly in communities where government capacity may be constrained. In Cambodia, as well as globally, these organizations contribute to the following: raising awareness, mobilizing resources, building local resilience, and facilitating the participation of vulnerable groups in adaptation planning (UN Habitat, 2018). This section assesses the capacity of NGOs and other social and cultural institutions to adapt to climate change, as well as the contribution of civil society to climate adaptation efforts. Non-governmental organizations (NGOs) in Cambodia are highly active in engaging local communities, particularly those that are vulnerable, including rural farmers, indigenous groups, and coastal communities. These organizations endeavor to enhance public consciousness regarding climate-related dangers and provide assistance to community-based adaptation (CBA) initiatives. A significant number of NGOs facilitate participatory planning processes, which engage local stakeholders in the design and implementation of adaptation projects. This approach guarantees that adaptation strategies are context-specific and meet the needs of those most affected by climate change.

NGOs play a pivotal role in the process of capacity building. They provide training to local communities, government authorities at the sub-national level, and other stakeholders on the implementation of climate-resilient practices including sustainable agriculture, water management, and disaster preparedness. By facilitating the transfer of knowledge and providing technical assistance, NGOs enhance the adaptive capacity of communities, equipping them with the tools and techniques necessary to mitigate climate risks. NGOs frequently possess the capability to mobilize financial resources from international donors, foundations, and development agencies for the purpose of funding climate adaptation projects (GCF, 2024). In regions where sub-national levels may have limited financial capacity, these funds are of particular importance. By forming alliances with international organizations, NGOs can gain access to climate finance mechanisms, such as the Green Climate Fund (GCF) or the Adaptation Fund. These resources can then be allocated to community-level initiatives (MoE, 2018b). In Cambodia, numerous NGOs have effectively advocated for the incorporation of climate adaptation into national development plans and environmental policies, thereby facilitating the prioritization of adaptation within governmental agendas. A number of NGOs are engaged in the promotion of ecosystem-based adaptation, which entails the utilization of biodiversity and ecosystem services to assist communities in adapting to the impacts of climate change. The implementation of ecosystem-based adaptation projects offers a multitude of advantages, including the mitigation of climate change, the conservation of biodiversity, and the enhancement of local livelihoods.

In Cambodia, Buddhist temples and other religious institutions play a significant role in fostering community cohesion and social resilience. Such institutions frequently function as focal points for disaster relief operations during periods of extreme weather, offering a reliable source of information and assistance to local communities (The Phnom Penh Post, 2023). Universities and research institutes play a role in the construction of local knowledge about climate change and adaptation strategies. They are engaged in research activities, development of innovative adaptation technologies, and training of the next generation of climate scientists and practitioners. In addition, educational institutions collaborate with non-governmental organizations (NGOs) to develop climate education programs, thereby raising awareness among students and local communities about the significance of adapting to a changing climate. Indigenous communities and rural populations in Cambodia possess a substantial corpus of traditional knowledge that has been transmitted across generations, particularly with regard to sustainable land and water management practices (MoE, 2020b). NGOs and cultural institutions collaborate to integrate traditional knowledge with modern adaptation practices, thereby enabling local communities to draw on both their heritage and new scientific approaches to enhance resilience. Civil society organizations, including grassroots movements and community-based organizations, are becoming increasingly active in mobilizing collective action on climate adaptation. These networks frequently concentrate on empowering marginalized groups, including women, youth, and indigenous populations, with regard to their participation in adaptation planning and implementation. Additionally, civil society organizations (CSOs) play a role in the monitoring and evaluation of adaptation projects, thereby facilitating accountability and transparency in the utilization of adaptation funds.

The NGOs and other social and cultural institutions in Cambodia play a pivotal role in climate adaptation. They engage local communities, build capacity, advocate for policy changes, and mobilize resources, thereby contributing to the resilience of communities and the country as a whole. Their work serves to complement governmental efforts and to fill critical gaps, especially in rural and vulnerable areas. Nevertheless, for these organizations to achieve their full potential in supporting climate adaptation, challenges related to financial sustainability, technical capacity, and policy coordination must be addressed. The establishment of more robust collaborative relationships between civil society, government, and the private sector in Cambodia will facilitate the development of a more climate-resilient society.

6.3 Coordination Mechanisms Across Sectors

The National Adaptation Plan (NAP) process provides a formal framework for coordinating climate adaptation efforts across sectors at the national level. The NAP integrates climate adaptation into national development policies, ensuring that various sectors, including agriculture, water, energy, and health, collaborate to address climate risks. The Ministry of Environment assumes a principal role in the NAP process and engages the participation of numerous government ministries, including the Ministry of Agriculture, Forestry and Fisheries (MAFF); the Ministry of Water Resources and Meteorology (MOWRAM); and the Ministry of Public Works and Transport (NCSD, 2017b). Inter-ministerial committees or climate change task forces are constituted with the objective of coordinating actions across different government ministries. These bodies facilitate collaboration by convening representatives from sectors such as agriculture, water, energy, and health, with the objective of aligning adaptation efforts. The National Council for Sustainable Development (NCSD) is responsible for the oversight of climate-related policies and the facilitation of inter-ministerial and inter-sectoral coordination. The NCSD serves as a forum for stakeholders from government ministries, NGOs, and the private sector to collaborate on the design and implementation of climate adaptation policies. Public-private partnerships (PPPs) are mechanisms that facilitate collaboration between government entities and the private sector with the objective of supporting climate adaptation projects (ADB, 2022). These partnerships are crucial for mobilizing private sector investment in areas such as renewable energy, resilient infrastructure, and climate-smart agriculture.

6.3.1 Adaptation Capacity in Tourism Sector

The tourism sector is particularly susceptible to the effects of climate change, particularly in countries such as Cambodia, where cultural heritage sites, coastal areas, and ecotourism destinations are integral to the industry. An increase in temperature, the occurrence of extreme weather events, a rise in sea level, and alterations to ecosystems have the potential to significantly disrupt tourism activities, which in turn affects livelihoods, local economies, and national revenue. In light of this vulnerability, it is imperative to assess the adaptation capacity of the tourism sector, defined as its ability to cope with, adapt to, and recover from climate impacts. This encompasses the ability of tourism operators, government institutions, and local communities to implement strategies that enhance climate resilience and sustainability in tourism.

As temperatures rise, the appeal of tourism destinations may diminish, particularly in the case of outdoor attractions such as Angkor Wat, which is one of Cambodia's most significant cultural heritage sites. Prolonged periods of high temperatures may act as a deterrent to visitors, resulting in shorter stays and consequently impacting tourism revenues. Coastal tourism destinations, including Sihanoukville and other beach resorts, are susceptible to the adverse effects of sea-level rise and coastal erosion. The tourism industry, particularly in areas with constrained water resources, can intensify the scarcity of this vital resource. As a consequence of the impact of climate change on water availability, there is a potential for tensions to arise between the tourism sector and local communities with regard to the utilization of water resources. It is imperative that tourism operators and government bodies invest in climate-resilient infrastructure in order to safeguard tourism assets from the detrimental effects of climate risks. It is recommended that hotels, resorts, and tourist facilities adopt sustainable water management practices, including rainwater harvesting, efficient irrigation systems, and water recycling (NCSD, 2019).

The implementation of ecosystem-based adaptation measures, such as the restoration of mangrove ecosystems in coastal areas, can serve to prevent erosion and buffer against storm surges. The promotion of reforestation and biodiversity conservation serves to support ecotourism and protect wildlife habitats. It is imperative that those engaged in the tourism industry are equipped with the requisite knowledge and skills to adapt to the challenges posed by climate change. The Cambodian Ministry of Tourism, in collaboration with the Ministry of Environment, plays a pivotal role in the promotion of climate adaptation within the tourism sector. The government can spearhead the development of climate-resilient infrastructure, formulation of sustainable tourism policies, and implementation of environmental regulations.

Local communities, particularly those engaged in community-based tourism (CBT) and ecotourism, are of critical importance in the process of climate adaptation. Their familiarity with the local ecosystem and traditional practices can facilitate the development of a more sustainable tourism industry. In numerous instances, the tourism industry serves as a source of revenue for local communities. Consequently, the participation of these communities in decision-making processes and adaptation planning is of paramount importance to ensure the long-term sustainability of the sector. In Cambodia, the ecotourism sector is becoming increasingly focused on promoting sustainable tourism practices that conserve ecosystems while providing livelihoods to local communities, particularly in protected areas (as shown in Figure 42) such as the Cardamom Mountains and Tonle Sap. Ecotourism initiatives focus on wildlife conservation, community-led forest management, and sustainable agricultural practices. These initiatives protect Cambodia’s rich cultural heritage from the detrimental effects of climate change, particularly at sites such as Angkor Wat, which are vulnerable to both climate-related challenges and the adverse effects of excessive tourism. One such initiative is the implementation of improved water management techniques to prevent flooding at Angkor (WB, 2020).

Figure 42: Increasing ecotourism in Cambodia: a) tourism to visit waterfall in Kulen mountain, and b) Promoting camping tourism at Knorng Phsar mountain.
Source: (Cambodia News, 2021)

As is the case in numerous other countries, the tourism sector in Cambodia is confronted with considerable obstacles posed by climate change. However, by developing its capacity to adapt through the implementation of sustainable practices, the construction of climate-resilient infrastructure, and enhanced coordination among stakeholders, the sector can continue to flourish while simultaneously safeguarding the environment and local communities. Adaptation in the tourism sector serves to ensure the sustainability of the sector itself, while also contributing to the overall economic resilience of Cambodia in the face of climate impacts (MoT, 2015).

6.3.2 Adaptation Capacity in Health Sector

The health sector is confronted with distinctive challenges as a consequence of climate variability, particularly in regard to rising temperatures, evolving disease patterns, water scarcity, and extreme weather events that have the potential to disrupt health services. adaptation capacity in the health sector refers to the ability of this sector to anticipate, respond to, and manage the health risks associated with climate change. This encompasses the capacity of healthcare systems, institutions, and communities to diminish vulnerability and fortify resilience against climate-induced health threats. An increase in temperatures and the frequency of heatwaves can result in a rise in the incidence of heat-related illnesses, including heat exhaustion and heatstroke. Populations that are particularly vulnerable to the effects of climate change include the elderly, children, and those with pre-existing health conditions (WHO, 2021).

The high levels of humidity in Cambodia serve to exacerbate the effects of heatwaves, thereby posing additional risks to individuals engaged in outdoor work, including farmers and construction workers. Modifications in precipitation patterns, temperature, and humidity create optimal conditions for the dissemination of vector-borne illnesses, including dengue fever and malaria. An increase in flooding creates optimal conditions for mosquito breeding, which may result in an elevated incidence of mosquito-borne diseases. Contamination of water sources by extreme weather events, such as floods, can result in the outbreak of waterborne diseases, including diarrhea, cholera, and typhoid. Furthermore, the presence of stagnant water during and after floods serves to elevate the risk of infection. The lack of adequate sanitation infrastructure in rural areas increases the vulnerability of communities to these diseases during extreme weather events. The threat of climate change to food production is manifold. Droughts, floods, and changing rainfall patterns have the potential to cause food insecurity and malnutrition. A scarcity of food increases the risk of contracting diseases related to malnutrition and weakens the body's immune response, thereby rendering populations more susceptible to other health issues (WB, 2024a).

The Ministry of Health (MoH), in conjunction with the National Committee for Disaster Management (NCDM) and other government agencies, bears the responsibility of responding to climate-related health risks. The health sector has developed disaster preparedness plans, with a particular focus on the risks posed by floods and heatwaves. Table 14 shows climate change expenditure by Ministry of Health.

Table 14: Climate change expenditure in Ministry of Health.

	2012	2013	2014	2015	2016	2017
MOH's climate change expenditure in billion Riel	16.9 ($4.16M)	32.7 ($8.05M)	28.5 ($7.02M)	46.2 ($11.38M)	29.7 ($7.32M)	29 ($7.14M)
MOH's climate change expenditure in percentage of total	3.3%	4.7%	3.2%	5.3%	4.3%	3.4%
Total climate change expenditure in million USD	134.6	189.2	248.1	244.4	192.6	228.0

Source: (MoH, 2019).

The incorporation of climate-related risks into national health policies, as exemplified by Climate Change Strategic Plan and National Adaptation Plans, offers a framework for addressing the health impacts of climate change. It is of the utmost importance to raise awareness among healthcare professionals about the connection between climate change and health outcomes. This is a crucial step in building an adaptive health workforce that can anticipate and manage emerging health threats (MoH, 2019).

Local communities frequently serve as the initial responders to health impacts resulting from climate change. Community-based health systems, particularly in rural areas, are of great importance in providing primary care and disease prevention services. It is imperative to reinforce the adaptive capacity of these systems, particularly through enhanced health education, promotion of clean water and sanitation practices, and expansion of healthcare access. Rural and marginalized communities frequently have restricted access to health services, rendering them more susceptible to climate-related health hazards (WHO, 2021).

Local healthcare providers and community health workers can be trained to educate the public on prevention and response strategies, including the use of mosquito nets, safe water practices, and early warning systems for extreme weather events. Water treatment equipment has also been installed in health centers – see Figure 6.43. Reinforcement of early warning systems for climate-sensitive diseases and extreme weather events can serve to augment the sector's capacity to prepare for and respond to health crises. Such systems can facilitate the monitoring of disease outbreaks and the dissemination of pertinent information to healthcare providers and the public in a timely manner.

Figure 43: The installation of water treatment equipment in health centers in Ratanakiri province.
Source: (WHO, 2021)

6.3.3 Adaptation Capacity in Education Sector

The adaptation capacity of the education sector entails an assessment of its capability to integrate climate change into curricula, enhance educational infrastructure to withstand climate-related risks, and cultivate climate awareness and resilience at both the local and national levels. Education systems play a pivotal role in cultivating climate literacy, which encompasses an understanding of the underlying causes, consequences, and potential solutions to climate change. Integrating climate change education into national curricula can facilitate the development of the knowledge and critical thinking skills that are essential for addressing environmental challenges. Campaigns designed to enhance awareness of climate change among both students and teachers can facilitate the adoption of sustainable practices and bolster resilience at the community level. Schools can function as hubs for disseminating climate adaptation knowledge beyond the classroom, engaging families and communities at large (NCSD, 2020).

The education on disaster risk reduction (DRR), early warning systems, and sustainable natural resource management provides students with the practical tools necessary to adapt to climate-related risks, including floods, droughts, and heatwaves. Furthermore, education can facilitate innovation and capacity-building, thereby empowering young people to develop local solutions for climate adaptation, including sustainable agriculture, water management, and renewable energy technologies. Teachers and students can be trained to serve as leaders in disaster preparedness and response within their communities, thereby enhancing local resilience through the dissemination of knowledge and the implementation of practical measures. While Cambodia has made strides in integrating climate change topics into its school curricula, there is a pressing need to extend this integration across all levels of education, from primary schools to universities, in order to achieve comprehensive climate literacy. Climate education must extend beyond theoretical knowledge to encompass practical learning experiences that enable students to apply their understanding in authentic contexts. The creation of bespoke educational materials in conjunction with environmental experts and local knowledge holders guarantees that climate education is both context-specific and pertinent to Cambodia's distinctive challenges (UNESCO, 2024).

It is imperative that educators be provided with the tools and resources necessary to effectively disseminate climate-related information, ensuring the efficacy of climate education. This necessitates the provision of continuous training and resources, which should equip teachers with the requisite skills and knowledge to facilitate meaningful discourse with their students about climate change. Teacher training programs should include instruction on climate adaptation, disaster risk reduction, and sustainability practices. This will empower educators to foster climate resilience and inspire change among their students. It is imperative that the physical infrastructure of educational institutions be adapted to withstand the impacts of climate change, particularly in areas prone to floods, storms, and other extreme weather events. This encompasses the construction of flood-resistant classrooms, the provision of secure water and sanitation facilities, and the enhancement of school buildings to achieve greater energy efficiency and sustainability. In rural and vulnerable communities, the utilization of school facilities as emergency shelters during extreme weather events can serve as an additional function for schools in contributing to local resilience efforts (NCSD, 2019).

6.3.4 Gender and Vulnerable Group Adaptation Capacity

The effects of climate change are experienced differently by individuals, depending on their social, economic, and cultural backgrounds. This makes vulnerable groups such as women, children, the elderly, persons with disabilities, and marginalized communities more susceptible to its impacts. Assessing adaptive capacity related to gender and other vulnerable groups is essential for developing inclusive adaptation strategies that address these disparities. Gender-sensitive adaptation considers the specific needs, capacities, and roles of women and men, while inclusive adaptation ensures that all vulnerable groups are equipped to respond to climate challenges (UN Women, 2021).

It is imperative that women and vulnerable groups be afforded equitable access to climate-resilient infrastructure, including clean water, sanitation facilities, and sustainable energy. Investments in these areas have the potential to alleviate burdens faced by women, particularly in rural communities, and improve health outcomes. The provision of climate-smart agricultural inputs and training can facilitate the adaptation of women farmers to changing weather patterns, enhance food security, and augment household resilience. The implementation of social safety nets, such as cash transfer programs, food aid, and healthcare support, is of paramount importance for the reduction of the vulnerabilities of women, children, and marginalized communities during climate-related crises (FAO, 2022). It is imperative that these mechanisms be gender-sensitive, addressing the specific needs of various groups and preventing further marginalization during periods of crisis. Community-based adaptation (CBA) approaches place an emphasis on the role of local communities, including women and marginalized groups, in leading adaptation efforts. By engaging local knowledge and traditional practices, CBA fosters inclusive decision-making and ensures that adaptation strategies are context-specific and responsive to the needs of vulnerable populations. It is imperative to enhance awareness about climate risks and adaptation strategies among women, children, and marginalized groups to bolster resilience. Educational institutions, community hubs, and NGOs can facilitate climate education programs that target these populations and equip them with the requisite knowledge to respond to climate change (UNICEF, 2021). Furthermore, educational programs must address gender norms and social inequalities, promoting gender equality as an integral component of broader climate adaptation efforts (CCCA, 2022).

The prevailing gender roles and norms may act as a significant barrier to women's participation in adaptation initiatives. Marginalized communities may encounter discrimination that restricts their access to resources. The absence of gender-disaggregated data on climate impacts and adaptation makes it challenging to design targeted interventions. Those who are vulnerable often have less access to financial resources, which in turn limits their ability to invest in adaptation measures. The formation of collaborative relationships between government agencies, NGOs, and international organizations can serve to enhance the capacity of vulnerable groups to adapt. The implementation of gender-focused programs, which are supported by donors and climate finance mechanisms, can serve to address gender disparities in adaptation efforts. The indigenous knowledge and traditional practices of various communities offer valuable insights with regard to climate adaptation, particularly in the context of natural resource management. The application of this knowledge can enhance the resilience of local communities while simultaneously preserving their cultural heritage. It is of the utmost importance to enhance the capacity for adaptation within the gender sector and among vulnerable groups in order to build resilience in the face of climate change. A gender-sensitive and inclusive adaptation strategy is essential for ensuring that all members of society, particularly those most at risk, are empowered to respond to climate challenges. By addressing gender disparities, promoting inclusive decision-making, and strengthening the capacity of vulnerable groups, Cambodia can create a more resilient and equitable future (Chan, 2023). Investment in education, infrastructure, and social protection mechanisms tailored to the needs of vulnerable populations will facilitate more effective adaptation, thereby ensuring that no individual or group is left behind in the fight against climate change.

6.3.5 Ecosystems, Biodiversity, and Resource Management

The provision of essential services by healthy ecosystems enables communities to adapt to and mitigate the effects of climate change. These services include regulation of water cycles, prevention of soil erosion, and maintenance of biodiversity. The effective management of these resources can enhance resilience to climate impacts, whereas poor management can exacerbate vulnerability (Kim, 2021). The objective of natural resource management is the sustainable use of land, water, forests, and other natural assets, with the aim of ensuring that they continue to provide economic, environmental, and social benefits. Coastal zones and biodiversity management are essential components of climate adaptation strategies, particularly for countries like Cambodia that are vulnerable to climate change impacts such as sea level rise, coastal erosion and biodiversity loss. Effective coastal and biodiversity management can strengthen the resilience of ecosystems and human communities to these growing threats (MoE, 2014).

a. Coastal Zones Management

Coastal zones are highly vulnerable to the impacts of climate change, in particular sea level rise, increased storm frequency, and coastal erosion. These factors threaten coastal communities, infrastructure and ecosystems such as mangroves, coral reefs, and wetlands that provide natural defenses against storm surges, flooding, and erosion. Restoring and maintaining these ecosystems increases the adaptive capacity of coastal areas. Mangrove restoration helps to reduce the effects of rising sea levels and storm surges by stabilizing shorelines, filtering water and absorbing carbon dioxide. Mangroves also provide habitats for various marine species, supporting biodiversity and fisheries (MoE, 2020a).

Integrated Coastal Zone Management is an adaptive approach to coastal management that integrates environmental, social and economic concerns across different sectors (fisheries, tourism, urbanization). This multi-sectoral approach improves the resilience of coastal areas by promoting sustainable use of resources, preventing overdevelopment in vulnerable areas, and planning for climate impacts. Coastal zoning regulations ensure that critical ecosystems (e.g. mangroves, wetlands) are protected, while limiting development in high-risk areas such as floodplains or eroding coastlines. Coastal infrastructure, including sea walls, dikes, and stormwater systems, must be designed or retrofitted to withstand rising sea levels and extreme weather events. Climate-resilient infrastructure reduces the vulnerability of coastal communities and ensures continued access to essential services. Nature-based infrastructure (e.g. dunes, vegetated shorelines) complements grey infrastructure (e.g. seawalls) and provides flexible, cost-effective alternatives for managing coastal risks. Involving local communities in coastal management is crucial for adaptation (Nhep et al., 2021).

Communities often have valuable local knowledge of the coastal environment and are key stakeholders in the management of fisheries, tourism, and coastal resources. Community-based coastal monitoring can help track changes in coastal erosion, coral reef health and mangrove cover, and inform adaptive management decisions. Involving local people ensures that adaptation measures are aligned with community needs and priorities. Rapid coastal urbanization, tourism development, and industrial activities can lead to habitat destruction and put further pressure on coastal ecosystems, reducing their capacity to adapt to climate impacts. Many coastal regions in developing countries face financial and technical constraints in implementing effective adaptation measures. Limited resources hamper the construction of resilient infrastructure and the enforcement of coastal protection laws. In some low-lying areas, sea level rise may make retreat necessary, but relocating communities is socially and economically challenging. There is often resistance to abandoning areas of cultural, economic, or historical significance (UNEP, 2019).

The promotion of nature-based solutions in coastal zones can provide cost-effective, flexible, and sustainable alternatives to traditional engineering approaches. For example, the restoration of coastal wetlands or coral reefs can provide long-term protection against the effects of sea-level rise and storms. The implementation of sustainable fisheries management strategies that take into account the impact of changing ocean temperatures and fish migration patterns can play a pivotal role in the protection of marine biodiversity and the assurance of food security for coastal communities. Coastal management frequently necessitates transboundary collaboration, particularly with regard to matters such as marine pollution, migratory species, and fisheries management.

b. Biodiversity Management

Biodiversity management is of pivotal importance for climate adaptation, as the diversity of ecosystems and species directly influences an ecosystem's capacity to cope with climate change. The provision of essential services by healthy ecosystems includes the regulation of water cycles, carbon sequestration, and maintenance of food security. However, the climate change presents a considerable threat to biodiversity, manifesting in the forms of species extinction, habitat degradation, and ecosystem imbalance. Protected areas, such as national parks and wildlife reserves, serve as vital refuges for biodiversity and contribute to the resilience of ecosystems in the face of climate change (ADB, 2021a).

It is imperative that conservation planning incorporates climate projections to guarantee the continued viability of protected areas as temperatures rise and precipitation patterns shift. As a consequence of climate change, species are migrating to cooler areas or higher altitudes. The fragmentation of habitats resulting from urbanization, agricultural activities, and infrastructure projects represents a substantial obstacle to species migration. The maintenance and restoration of ecological corridors (i.e., linkages between habitats) can enhance the species' adaptive capacity through the implementation of biodiversity management strategies. Reforestation and habitat restoration projects can facilitate the rehabilitation of degraded lands, thereby creating new areas where species can flourish as they shift in response to climate change. Monitoring of changes in biodiversity, including species population shifts, habitat loss, and ecosystem degradation, is of paramount importance for the implementation of an adaptive management strategy. Biodiversity monitoring programs can serve as an early warning system for ecosystem decline, enabling the implementation of prompt and effective responses to emerging threats (MAFF, 2019). Community-based natural resource management provides local populations with the capacity to assume an active role in the conservation of biodiversity and the sustainable management of ecosystems, thereby reducing their vulnerability to the impacts of climate change. Loss and degradation of habitats represent a significant challenge to biodiversity conservation. The effects of climate change serve to exacerbate the existing pressures on biodiversity, including the destruction of habitats resulting from agricultural activities, deforestation, and the construction of infrastructure. The risk of extinction for species that are unable to adapt or migrate quickly enough is heightened by the effects of climate change. A reduction in species diversity results in a loss of ecosystem resilience, thereby impeding the ability of ecosystems to recover from disturbances. Invasive species may proliferate as a of altered environmental conditions, displacing native species and compromising ecosystem stability. The management of invasive species represents a crucial element in the maintenance of biodiversity in the context of climate change (MoE, 2020a).

The implementation of financial incentives for biodiversity protection, such as biodiversity offsets, can promote conservation efforts. This mechanism permits the conservation of biodiversity in one area to offset the effects of development in another, thereby facilitating adaptation efforts. Integrating biodiversity into agricultural landscapes through the implementation of sustainable farming practices, such as agroforestry, facilitates the maintenance of essential ecosystem services, including pollination, water regulation, and soil health. Additionally, this approach enhances resilience to climate variability. Ecotourism can serve as a means of providing alternative sources of income for local communities while simultaneously generating funds for the protection of biodiversity. The establishment of conservation finance mechanisms, such as conservation trust funds, can facilitate the long-term sustainability of biodiversity management and adaptation programs.

b. Cropland Management

The management of cropland is of critical importance in the context of climate change, particularly in regions where agriculture represents a fundamental pillar of livelihoods and food security. The capacity of cropland management to adapt to climate change is largely contingent upon the ability of farming systems and agricultural practices to withstand the impacts of climate change, including rising temperatures, altered precipitation patterns, and an increased frequency of extreme weather events (ADB, 2021a).

The field of agroecology is concerned with the harmonization of agricultural practices with natural ecosystems, with the objective of enhancing the resilience of crops and soil. The approach emphasizes biodiversity, ecological balance, and the sustainable use of natural resources, thereby enabling farms to withstand the effects of climate shocks. The integration of trees, cover crops, and livestock within an agroecological system serves to enhance biodiversity, improve soil structure, and reduce reliance on external inputs, thereby enhancing the resilience of the farming system as a whole. Agroforestry is the integration of trees with crops and livestock, whereby the trees provide shade, reduce wind erosion, and enhance water retention. Furthermore, trees serve as carbon sinks, thereby mitigating the effects of climate change by absorbing carbon dioxide. This system diversifies income sources, enhances soil fertility, and contributes to the resilience of agricultural systems. Conservation agriculture is characterized by minimal soil disturbance, such as no-till farming practices and the maintenance of soil cover through the use of mulching. Crop rotation is a key component of conservation agriculture. These practices enhance soil moisture retention, reduce erosion, and improve soil fertility, thereby increasing the resilience of agricultural systems to drought and flooding (Redfern et al., 2017). The implementation of conservation agriculture practices enhances the soil's capacity to store carbon, thereby contributing to the mitigation of climate change. Precision farming technologies, such as drip irrigation and remote sensing, facilitate the optimization of water and nutrient utilization, thereby reducing waste and enhancing efficiency. These technologies guarantee that crops receive the requisite amount of water and nutrients at the optimal time, thereby limiting water waste and enhancing resilience to drought and water scarcity. The utilization of compost and organic fertilizer in organic farming practices serves to enhance soil health and biodiversity. Organic farming is less reliant on synthetic inputs, which reduced the environmental footprint of agriculture while simultaneously enhancing the resilience of ecosystems to climate change. The concept of "water-smart agriculture" encompasses the efficient management of water resources through techniques such as rainwater harvesting, drip irrigation, and mulching, with the objective of reducing water loss. These practices guarantee that crops receive an adequate quantity of water, even in regions prone to drought (MAFF, 2019).

The capacity of cropland management to adapt to changing conditions is enhanced through the adoption of sustainable agricultural practices that prioritize soil health, water efficiency, crop diversity, and ecosystem resilience. The integration of climate-smart agriculture, agroforestry, and conservation agriculture into farming operations provides farmers with the capacity to more effectively address the challenges posed by climate change. The implementation of sustainable agricultural practices serves to protect crops from the immediate impacts of extreme weather events while simultaneously enhancing long-term resilience, thereby ensuring the continued viability of food production in the context of a changing climate.

c. Water Use Efficiency and Integrated Water Resource Management

The efficient use of water and integrated water resource management (IWRM) are essential elements of climate adaptation, particularly in light of the impact of climate change on precipitation patterns, the increased frequency of droughts, and the disruption of water availability. These strategies bolster the resilience of ecosystems, agriculture, industries, and communities by guaranteeing the sustainable and equitable utilization of water resources in the context of mounting climate-related risks.

The management of water resources is approached as an integrated system that transcends the boundaries of disparate sectors, including agriculture, industry, and urban development. Integrated water resources management (IWRM) encompasses the entire hydrological cycle, including surface water, groundwater, and ecosystems. Effective IWRM necessitates the involvement of all stakeholders, including governments, local communities, the private sector, and civil society organizations, in decision-making processes to guarantee equitable access and sustainable water use. The IWRM approach is flexible, allowing for the evolution of water management strategies based on new data, technologies, or emerging challenges, such as climate change. The capacity for adaptation is contingent upon the ability to effectively monitor water resources. The implementation of real-time water monitoring systems, weather forecasting, and early warning systems for droughts or floods serves to enhance decision-making and resource allocation (ADB, 2021b).

For governments and water management institutions to implement WUE and IWRM effectively, they require sufficient technical expertise, infrastructure, and financial resources. The institutional capacity of water management agencies can be strengthened in order to enhance their ability to respond to climate challenges. The efficacy of IWRM is contingent upon robust inter-sectoral coordination, encompassing agriculture, industry, and urban planning. In regions where water is shared across multiple sectors, the establishment of transparent and well-defined policies and governance frameworks is essential to prevent conflicts and ensure the sustainable allocation of water resources. The implementation of WUE and IWRM is contingent upon the availability of adequate infrastructure, including the construction of dams, reservoirs, irrigation systems, and desalination plants. It is imperative that governments allocate sufficient resources towards the development of resilient infrastructure, in order to ensure the efficient management of water resources in the context of a changing climate (Sreymom & Sokhem, 2015).

The importance of efficient water management practices for climate adaptation cannot be overstated. The scarcity and variability of water resources are among the most immediate and significant impacts of climate change, underscoring the critical role of efficient water management in climate adaptation strategies. As global temperatures increase, the hydrological cycle is disrupted, resulting in more intense precipitation in some regions and prolonged droughts in others. Efficient water management enables regions to better withstand periods of drought or flooding. The implementation of enhanced water storage, harvesting, and distribution systems enables communities to mitigate the impact of water scarcity and maintain productivity in agriculture and other sectors dependent on water during periods of drought. Conversely, during periods of excess rainfall or floods, integrated water resources management (IWRM) can facilitate the management of water resources to prevent waterlogging, damage to infrastructure, and contamination of freshwater supplies. The implementation of efficient water usage practices serves to mitigate the strain placed upon aquifers and rivers, thereby ensuring the preservation of these vital resources for future agricultural requirements. Ecosystems such as wetlands, rivers, and lakes play a vital role in maintaining biodiversity, regulating water flows, and providing ecosystem services such as water filtration and flood control. The implementation of effective water management strategies is essential for ensuring the continued functionality of these ecosystems, even in the face of changing climate conditions. Implementation of efficient water usage practices in sectors such as agriculture and industry have the potential to reduce the energy requirements associated with the pumping, transportation, and treatment of water. Such practices not only result in cost savings but also contribute to the reduction of greenhouse gas emissions associated with energy use, thereby facilitating climate mitigation efforts. Efficient and sustainable water management is a vital support for livelihoods, particularly in rural and agricultural communities. The availability of water for irrigation and other productive uses, ensured by WUE and IWRM, contributes to the generation of income, the reduction of poverty, and the long-term resilience of vulnerable populations (ADB, 2021b).

The collection and storage of rainwater for irrigation or domestic use enhances water availability during periods of drought. The cultivation of crops that require less water can result in an increase in water use efficiency (WUE), particularly in arid and semi-arid regions. An increasing number of industries are adopting water recycling and reuse systems with the objective of reducing their intake of freshwater. This entails the enhancement of industrial procedures with the objective of minimizing water consumption and reducing pollution, thereby ensuring that less water is wasted and more is utilized in an efficient manner. The utilization of low-flow faucets, toilets, and efficient appliances, such as washing machines, can markedly diminish household water consumption. The promotion of water-saving habits, such as the reduction of shower duration and the identification and repair of leaks, also contributes to the objective of WUE (NCSD, 2019b). In the agricultural sector, the implementation of water-efficient practices, such as drip irrigation and soil moisture conservation, has the potential to ensure consistent crop yields even in areas experiencing reduced rainfall. This helps to maintain food production and security in vulnerable regions where agriculture is the primary source of livelihood (NCSD, 2019b).

The capacity for adaptation regarding water use efficiency and integrated water resource management is of the utmost importance for the enhancement of resilience to climate change. The implementation of efficient water management practices in agriculture, industry, and urban planning ensures the optimal and sustainable utilization of scarce water resources. Furthermore, IWRM provides a comprehensive framework for the management of water across sectors and ecosystems. Investment in WUE technologies, infrastructure, and institutional capacity will be pivotal to ensuring the sustained availability of water and the protection of vulnerable communities in the context of a changing climate.

d. Land Management and Urban Planning

Proper land management is a critical aspect of ensuring sustainable development, environmental stewardship, and social well-being. These practices ensure that land is utilized in a manner that safeguards long-term environmental integrity and human well-being while mitigating climate-related risks. Practices such as sustainable agriculture, reforestation, and urban green space development assist in the management of climate impacts by reducing greenhouse gas emissions, enhancing carbon sinks, and improving the resilience of ecosystems and communities (MoE, 2018b).

Urban planning is a vital tool for building resilient cities that can withstand the impacts of climate change, including floods, heatwaves, and rising sea levels (MLMUPC, 2015). Effective inter-sectoral coordination (between agriculture, industry, and housing, for example) is essential for the sustainable management of land, with the objective of mitigating climate risks. The implementation of zoning regulations that safeguard vulnerable ecosystems (e.g., wetlands, forests) while facilitating sustainable development can enhance the overall resilience of both urban and rural areas.

The ability to adapt urban environments to the effects of climate change is contingent upon the quality of the infrastructure in place. Cities with resilient infrastructure, including climate-proof buildings, flood management systems, and green spaces, are better equipped to handle extreme weather events (NCSD, 2020). Land-use planning is of critical importance in the context of disaster risk reduction (DRR), as it enables the identification of high-risk areas and ensures that development activities are conducted in a manner that avoids floodplains, landslide-prone areas, or zones vulnerable to sea-level rise. The integration of disaster risk reduction (DRR) into urban planning can assist in the reduction of population exposure to climate-related hazards.

At the subnational and local levels, the manner in which governance is exercised plays a significant role in the implementation of land-use policies and urban planning measures. The efficacy of adaptation efforts is contingent upon the capacity of sub-national levels to plan for climate risks, engage communities, and enforce regulations. The role of sustainable land use practices in climate adaptation is of paramount importance. Reducing Emissions from Deforestation and Forest Degradation (REDD+) is a global initiative aimed at mitigating climate change by reducing deforestation and promoting forest conservation. Forests act as vital carbon sinks, absorbing CO_2 from the atmosphere and providing a natural buffer against climate impacts such as floods and landslides. By offering incentives for forest protection and the implementation of sustainable forestry practices, REDD+ contributes to the mitigation of climate change and the adaptation to its effects. Forests play a pivotal role in regulating local microclimates, providing essential water filtration services, and safeguarding biodiversity, which collectively enhances ecosystem resilience. The co-benefits of REDD+ include the creation of livelihood opportunities for local communities, particularly those that depend on forests for their subsistence (AFoCO, 2023). Climate-smart agriculture (CSA) promotes sustainable farming practices that enhance productivity while fortifying resilience to climate variability. Techniques such as crop diversification, conservation tillage, and agroforestry can enhance the capacity of rural areas to adapt to changing weather patterns. CSA mitigates the impact of land use on the environment, enhances soil quality, and improves water retention, thereby enhancing the resilience of agricultural land to droughts and floods. By reducing the necessity for deforestation and excessive water usage, CSA contributes to the comprehensive sustainability of land management systems.

Green infrastructure, encompassing parks, urban forests, and green roofs, is of paramount importance in facilitating urban adaptation to climate change. Such systems serve to mitigate the effects of urban heat islands, facilitate the management of stormwater, and enhance air quality. The absorption of excess precipitation by green infrastructure serves to prevent flooding and reduce the burden on drainage systems. It is imperative that sustainable urban planning incorporates nature-based solutions to create cities that are resilient to heatwaves, storms, and other climate-related hazards (Noor, 2023). In coastal areas, ICZM integrates land-use planning with marine and coastal resource management, thereby addressing the risks posed by sea-level rise, coastal erosion, and extreme weather events. This approach integrates the sustainable utilization of coastal resources with protective measures, such as the restoration of natural buffers (e.g., coral reefs, sand dunes). By balancing the competing demands of economic development, conservation, and disaster risk reduction, ICZM provides a framework for fostering long-term climate resilience in coastal communities (CCCA, 2020).

The pursuit of economic growth, which necessitates urban expansion or industrial development, frequently presents a challenge to the achievement of sustainable land management objectives. Such practices can result in unsustainable resource extraction, deforestation, and degradation of ecosystems that are critical for adaptation. The capacity to address these issues is limited in developing countries. A significant number of developing countries encounter substantial institutional and financial obstacles when attempting to implement sustainable land-use practices. The absence of technical expertise and inadequate infrastructure frequently impede efforts to plan and manage land in a climate-resilient manner. Inconsistent or inadequate land-use regulations may result in the ineffective implementation of climate adaptation strategies. The absence of coherent policy at the national and local levels presents a significant obstacle to the integration of sustainable land management with broader climate objectives. The expansion of international climate finance, such as the Green Climate Fund and REDD+ initiatives, can facilitate the development and implementation of sustainable land-use strategies. Involving local communities in the planning of land management strategies facilitates the adaptation of such strategies to the specific context and local needs of the communities in question. Community-based adaptation projects facilitate the development of local ownership and enhance the sustainability of land-use practices. The advent of geospatial technologies and remote sensing has facilitated enhanced monitoring and management of land resources. Such technologies can facilitate more efficacious urban planning, flood risk mapping, and land-use planning (MoE, 2018a).

It is imperative that sustainable land management and urban planning be employed as a means of enhancing the capacity for adaptation to the effects of climate change. Practices such as REDD+, ecosystem-based adaptation, and green infrastructure serve to mitigate climate risks while simultaneously conferring long-term environmental and social benefits. By addressing the challenges of urban sprawl, informal settlements, and resource conflicts, and leveraging opportunities such as climate finance and community engagement, Cambodia can enhance the resilience of both urban and rural areas to climate impacts. Investment in sustainable land-use practices will be instrumental in achieving resilient cities, sustainable agriculture, and protected ecosystems, thereby creating a more adaptive future.

6.4 Policy and Legislative Support for Adaptation

In response to the challenges posed by climate change, countries and regions around the world are implementing a range of adaptation plans and programs with the objective of enhancing resilience across multiple sectors. Adaptation plans and programs are indispensable instruments for fostering resilience to climate change at all levels: global, national, and local. The objective of these initiatives is to equip communities, ecosystems, and economies with the capacity to withstand the risks posed by climate variability, including extreme weather events, rising sea levels, and shifts in ecosystems. Cambodia has made noteworthy strides in the implementation of climate adaptation strategies to mitigate its vulnerability to climate change. These endeavors are spearheaded by national and international collaborations, with the objective of mitigating risks across a spectrum of sectors, including agriculture, water management, and disaster preparedness. Below are some examples of key international and national initiatives for climate adaptation:

- Cambodia's National Adaptation Plan (NAPs) is a framework developed under the auspices of the UNFCCC with the objective of assisting countries in the planning of medium- and long-term adaptation strategies. The objective is to integrate adaptation into national development strategies, thereby enabling countries to identify vulnerabilities and prioritize climate resilience. Such plans provide a platform for accessing international funding and technical support, thereby aligning with global climate goals, such as those outlined in the Paris Agreement (NCSD, 2017b).

- The Global Environment Facility (GEF) and the Least Developed Countries Fund (LDCF) provide financial support for adaptation initiatives in Least Developed Countries (LDCs). The GEF offers assistance through the LDCF; Cambodia received funds for financial support on adaptation projects that address critical vulnerabilities in sectors such as agriculture, water management, and health.
- The Green Climate Fund (GCF) The Green Climate Fund (GCF) represents one of the most significant global financing mechanisms for adaptation and mitigation projects. The fund provides financial assistance to developing countries for the implementation of projects that enhance resilience to climate impacts, including infrastructure development, agricultural initiatives, water management strategies, and the conservation of ecosystems. Proposals for GCF funding are submitted by countries, with a particular emphasis on community-based adaptation, nature-based solutions, and technology transfer for climate resilience (GCF, 2024).
- The Adaptation Fund, established under the Kyoto Protocol, provides financial resources to support climate change adaptation projects and programs in developing countries that are particularly vulnerable to the adverse effects of climate change. The Adaptation Fund, established in accordance with the provisions set forth in the Kyoto Protocol, provides financial resources to support the implementation of projects and programs in developing countries including Cambodia that are particularly vulnerable to the adverse effects of climate change.
- Cambodia Climate Change Strategic Plan: In order to integrate climate adaptation into its national development agenda, Cambodia has developed the Cambodia Climate Change Strategic Plan 2014-2023 (CCCSP, 2014).

While numerous initiatives have already been implemented, persistent challenges, such as inadequate funding and coordination, must be addressed to ensure the optimal efficacy of these endeavors. By maintaining a commitment to investment in adaptation, countries can ensure the protection of their populations, ecosystems, and economies from the adverse effects of climate change.

In accordance with the most recent update to the NDC updated in 2020, the Cambodian government has outlined a series of adaptation actions to adapt climate change, with a total of 58 actions being prioritized. These actions encompass a wide range of sectors, including: Agriculture, including agribusiness, animal health and production; agriculture/energy, and agriculture/gender (17 actions); Coastal zones (2 actions); Energy (2 actions); Human health (5 actions); Industry (1 action); Infrastructure, including roads, buildings, and urban land use planning (15 actions); Livelihoods, poverty, and biodiversity (7 actions); Tourism (3 actions); Water resources (6 actions) (GSSD, 2020).

a. Current Trends and Proposals of Adaptation

An increasing number of countries are integrating climate adaptation into their national development plans, recognizing that adaptation is not a standalone activity but rather one that must be embedded across multiple sectors. National Adaptation Plans (NAPs) and sector-specific strategies in agriculture, water management, health, and infrastructure are becoming increasingly prevalent. It is becoming increasingly imperative for governments to guarantee climate resilience in development projects and infrastructure investments. Cambodia's adaptation to climate change is primarily focused on key sector of agriculture, water management, and infrastructure. These initiatives are in alignment with both national policies and global climate commitments, thereby exemplifying a shift towards integrated, community-based, and innovative adaptation solutions.

Climate change has now become a pervasive theme in Cambodia's development strategies, including the National Strategic Development Plan (NSDP) for the period 2019-2023 (MoE, 2020b). The CCCA is a program supported by UNDP, the European Union, Danida and the Swedish Government. It is anchored to the National Council for Sustainable Development (NCSD) and managed by the Department of Climate Change. The CCCA's key areas of intervention include the establishment of a legal framework for climate change, the development of national and sectoral monitoring and evaluation frameworks for climate change, the testing and dissemination of adaptation and mitigation approaches, the strengthening of planning and budgeting systems for the mainstreaming of climate change finance, and the provision of support to research, development, and learning on climate change (CCCA, 2022).

The Cambodia Climate Change Alliance Phase III (CCCA III), a joint initiative between UNDP, Sweden, the European Union, and the Royal Government of Cambodia, has been implemented by the National Council for Sustainable Development with the objective of enhancing the capacity of communities to cope with the effects of climate change. As part of this initiative, 22 innovation grants have been awarded to local adaptation projects, including grants for the promotion of technologies for climate-smart farming and water management (UNDP, 2024). The implementation of contemporary meteorological infrastructure, exemplified by the deployment of automated weather stations, serves to enhance disaster preparedness. Initiatives such as the early warning system (EWS) provide essential notifications to populations that are particularly vulnerable to the effects of adverse weather conditions.

Community-based adaptation initiatives place an emphasis on the utilization of local knowledge and the involvement of grassroots communities in order to facilitate the adaptation of solutions to the specific vulnerabilities of communities (MoE, 2018a). The objective is to empower local communities to assess their own vulnerabilities and design adaptation strategies. This encompasses training in climate-resilient agricultural practices, disaster preparedness, and water conservation techniques. It is essential to engage communities in the decision-making process in order to ensure that adaptation measures reflect their needs and priorities, particularly in rural or marginalized regions. The provision of microfinance and small grants for community-level projects aimed at building climate resilience represents a promising avenue for future research. The popularity of nature-based solutions is on the rise, as they offer cost-effective and sustainable alternatives to traditional engineering approaches. The restoration of wetlands, forests, and mangroves serves to enhance natural defenses against floods, droughts, and coastal erosion. The incorporation of natural elements, such as urban green spaces and permeable pavements, is an effective method for the management of stormwater and the reduction of the heat island effect in urban areas. It is essential to guarantee the protection and management of ecosystems in a manner that serves to mitigate the impact of climate change on communities. This can be achieved through the promotion of agroforestry and sustainable land management practices.

In light of the prevailing climatic conditions in Cambodia, it is imperative to put forth a series of recommendations pertaining to prospective adaptations, including:

- **Long-Term Adaptation Planning:** Cambodia is currently engaged in the process of updating its National Adaptation Plan (NAP), with the objective of providing guidance on actions to be undertaken beyond the year 2023. The proposed plan is designed to align with the Paris Agreement and to enhance resilience across all sectors (MoE, 2020b).
- **Investments in Climate-Resilient Infrastructure:** It is proposed that investments be made in resilient infrastructure, including the construction of flood-resistant roads, improved irrigation systems, and sustainable urban planning in areas prone to flooding (UNEP, 2023).
- **The Scaling up of Ecosystem-based Adaptation:** Proposals include the expansion of mangrove restoration projects, watershed conservation initiatives, and the implementation of biodiversity-friendly practices, with the objective of enhancing natural defenses against the adverse effects of climate change (WB, 2024b).
- **Strengthening Institutional Capacity:** It is of the utmost importance to enhance coordination between national and subnational institutions. Proposed measures include an expansion of technical expertise, the securing of financing, and the integration of climate change considerations into governance structures.
- **Leveraging International Funding and Cooperation:** Cambodia is seeking to enhance its collaborative relationships with global donors and organizations. The objective is to obtain financial resources for adaptation initiatives through mechanisms such as the Green Climate Fund (GCF) (GCF, 2024).

b. Mainstreaming of Adaptation in Infrastructure Development Plan

The integration of climate adaptation into infrastructure development plans is crucial for ensuring community and economic resilience in the context of climate change. Infrastructure systems, including transportation, water supply, energy, and urban development, are frequently among the most vulnerable to the effects of climate change. By incorporating climate-related considerations into these plans, governments can enhance the durability, operational capacity, and safety of infrastructure, which will ultimately reduce economic losses and safeguard public welfare.

The integration of climate adaptation into infrastructure development plans is of paramount importance for the following reasons:

- **Climate Resilience:** Infrastructure designed with high technology and/or adapted for withstand extreme weather events, such as floods, storms, and heatwaves, reduces the risk of damage and service disruption (NCSD, 2020).
- **Economic Stability** is another key benefit. The integration of climate resilience into infrastructure development plans can contribute to economic stability and growth by reducing the impact of climate-related disruptions by minimizing downtime and damage during climate events. his protection reduces losses in productivity, avoids costly emergency repairs, and helps safeguard livelihoods, particularly in climate-vulnerable economies. In the long-term, resilience investments can stimulate economic growth by enhancing confidence in public systems and reducing risk for businesses (UNEP, 2023).
- **Long-term Savings:** The initial investment in climate-resilient infrastructure can result in reduced maintenance and repair costs associated with climate-related damage in the future. These savings come from reduced repair costs, lower insurance claims, and avoidance of economic losses due to service disruption.

- **Attracting Investment:** The provision of resilient infrastructure can facilitate the attraction of private sector investment, given the stability it offers for business operations. Investors are increasingly considering environmental and climate risk factors, and resilient infrastructure aligns with environmental, social, and governance priorities.
- **Synergies With Other Goals:** Climate-adapted infrastructure can support broader goals such as poverty reduction, public health, and environmental sustainability by ensuring essential services remain operational under changing conditions. For example, resilient water systems reduce the risk of disease outbreaks during floods, supporting public health. Reliable transport infrastructure ensures continuity of education and access to markets, contributing to poverty reduction. Moreover, integrating nature-based solutions like green roofs and wetlands can also support biodiversity and environmental sustainability (GSSD, 2019).
- **Local Involvement:** Integrating adaptation into infrastructure planning encourages community participation, ensuring that local needs and knowledge inform development decisions. Community engagement enhances the effectiveness and social acceptance of projects, making them more sustainable over the long term.
- **Building Trust:** Engaging communities can strengthen relationships between governments and citizens, fostering greater support for adaptation initiatives. This trust is crucial for the success of future climate policies, as it encourages cooperation, compliance, and collective action.

Figure 44: Climate adaptation of infrastructure in Cambodia: a) Concrete Road for flood adaptation, b) increasing irrigation for agriculture, c) water pumping for people in local community usage, and d) rainwater harvesting in rural areas.
Source: (MoE, 2015)

Indeed, the Strategic Program for Climate Resilience also encompassed climate adaptation initiatives within Cambodian infrastructure. Cambodia has constructed numerous infrastructure projects designed to adapt to climate change, including roads for transportation, irrigation systems for the agricultural sector, and water pumping infrastructure for local communities as see some activities in Figure 44 (MoE, 2015).

The integration of climate adaptation into infrastructure development plans is a crucial step in fostering resilience against climate impacts. The implementation of proactive adaptation measures has been demonstrated to offer dual benefits: the protection of infrastructure and the promotion of sustainable economic and community development. In light of the ongoing challenges posed by climate change, the integration of adaptation strategies into infrastructure planning will be of paramount importance for the safeguarding of future growth and well-being (ADB, 2022).

c. Transboundary Cooperation Mechanisms

Transboundary cooperation can be defined as collaborative efforts between two or more countries that share natural resources or are connected by ecosystems, such as rivers, mountains, or coastal areas. In the context of climate adaptation, these mechanisms are of paramount importance for the management of shared resources and the mitigation of climate impacts that transcend national boundaries. Regional collaboration ensures that adaptation strategies are aligned, efficient, and mutually beneficial for all parties involved. Examples of transboundary cooperation include coordinated water management, which is necessary to ensure sustainable use and equitable access. The MRC facilitates joint management of water resources, ensuring that countries develop adaptation strategies that address the river's changing flow due to climate change. The Mekong River Basin, which is shared by Cambodia, Laos, Thailand, Vietnam, Myanmar, and China, is particularly susceptible to the adverse effects of climate change, including droughts, floods, and alterations in water flow patterns (Ratana, 2018).

The following section will outline the importance of regional collaboration for effective adaptation. Ecosystem connectivity is a crucial aspect that must be considered when examining the effectiveness of regional collaboration for effective adaptation. It is evident that numerous ecosystems extend beyond the boundaries of nation-states. A comprehensive regional strategy is essential for the effective management of ecosystems, including river basins, forests, and coastal zones, in a manner that enhances their resilience to climate change. Regional collaboration can facilitate the implementation of consistent land-use practices, conservation efforts, and disaster response strategies across national borders.

The Regional cooperation enables countries to pool resources and expertise, thereby facilitating the development of more robust and resilient adaptation strategies. By working together, countries can implement large-scale adaptation projects, such as flood control systems, drought management programs, and reforestation initiatives, which would otherwise be infeasible on a national level. The establishment of shared infrastructure is a further potential benefit of regional collaboration. The implementation of collaborative regional projects can prove beneficial to multiple countries. Examples of such projects include the construction of dams on a regional scale, the establishment of early warning systems for the entire region, and the creation of shared irrigation infrastructure (ADB, 2021a).

Transboundary cooperation mechanisms are of vital importance in the context of climate adaptation, as they facilitate collaboration between countries that share ecosystems and resources. Regional collaboration facilitates more effective, equitable, and sustainable climate adaptation measures, as countries work together to address shared climate challenges. By facilitating cooperative policies, shared infrastructure, and joint funding, transboundary mechanisms assist in the development of resilience, the prevention of conflicts, and the assurance of a coordinated response to the impacts of climate change.

d. Costs, Limits, and Trade Offs in Adaptation

The financial cost of implementing climate adaptation measures is contingent upon a number of factors, including the scale, sector, and region in question. Such costs can be considerable and entail both initial investment and long-term maintenance. The construction of infrastructure designed to withstand the effects of climate change (e.g., flood defenses, resilient roads, stormwater management systems) can be a costly endeavor. Yet, these investments are essential to avert more substantial economic losses attributable to climate impacts. The transition to climate-resilient technologies (such as drought-resistant crops or energy-efficient buildings) may necessitate a substantial initial capital investment. However, these technologies offer long-term savings in reduced vulnerability and enhanced sustainability. The development of human resources and institutional capacity for climate adaptation, including training, research, and policy development, necessitates substantial financial resources. The implementation of adaptation measures may result in disruption to local communities, particularly those that are dependent on climate-sensitive industries such as agriculture or fishing. The social costs of climate change can be defined as the costs incurred by individuals or communities when they are forced to relocate, change their livelihoods, or adapt their social and economic practices to accommodate new circumstances (CCCA, 2020).

The potential for adaptation strategies is not limitless. Some impacts of climate change may be too severe to be effectively managed, while other factors may constrain the capacity for adaptation. These constraints may be physical, economic, technological, or social in nature. The concept of ecosystem thresholds is of particular relevance in this context. It is possible that natural systems may be constrained in their capacity for adaptation. The process of adaptation frequently entails the negotiation of trade-offs between competing objectives, sectors, or stakeholder interests. It is imperative that these trade-offs be managed with great care and precision to prevent unintended consequences, inefficiencies, or increased vulnerability for specific groups. Adaptation measures that prioritize economic growth, such as infrastructure expansion, may prove to be in conflict with environmental conservation goals (UN Habitat, 2018).

In light of the considerable costs, constraints, and trade-offs associated with climate change adaptation, it is imperative to develop strategies that are both cost-effective and equitable, with the aim of maximizing benefits and minimizing negative impacts. It is imperative that governments and organizations prioritize investments in sectors and regions where adaptation is most urgent and cost-effective. This entails concentrating on low-cost, high-impact interventions, such as nature-based solutions (e.g., wetland restoration, reforestation), that offer long-term resilience and ecosystem benefits (Campbell, 2023).

The process of climate adaptation is inherently complex and costly, with significant limitations and trade-offs that must be carefully managed. Effective adaptation necessitates a balance between economic, environmental, and social objectives, while ensuring that strategies are inclusive and equitable. By prioritizing cost-effective, nature-based solutions and ensuring active stakeholder participation, governments and organizations can develop adaptation plans that protect vulnerable communities, preserve ecosystems, and promote sustainable development in a changing climate (UN Habitat, 2018).

6.5 Financial Resources Needed for Climate Response

In order to achieve an effective climate response, it is necessary to consider both the financial requirements for adaptation, which encompasses the adjustment of systems to climate impacts, and those for mitigation, which pertain to the reduction of greenhouse gas emissions. Global financial estimates indicate that trillions of dollars are necessary on an annual basis to enhance climate resilience and facilitate the transition to low-carbon economies.

Modelled cost of adaptation	Adaptation finance needs	Adaptation finance flows	Adaptation finance gap
US$215 billion/year this decade (central estimate), with a range of US$130–415 billion/year	US$387 billion/year (median), with a range of US$101–975 billion/year (up to 2030)	US$21.3 billion (2021)	The adaptation finance gap is estimated at US$194–366 billion per year (currently)
Central range of US$215–387 billion/year for developing countries this decade			Adaptation costs/finance needs are 10–18 times as much as current flows

Figure 45: Summary of the adaptation finance gap in developing countries, based on AGR evidence. Source: (UNEP, 2023)

Adaptation measures are designed to enhance resilience in sectors that are particularly vulnerable to climate change, including water resources, agriculture, infrastructure, and health. Financing is required for activities such as enhancing climate-resilient infrastructure, constructing early warning systems, and implementing nature-based solutions. The estimated costs of adaptation for developing countries could range from USD 101 billion to USD 975 billion per year by 2030, as shown in Figure 45 (UNEP, 2023). Mitigation efforts necessitate investment in renewable energy, energy efficiency, sustainable transportation, and the protection of carbon sinks, such as forests. The transition from fossil fuels to clean energy will necessitate substantial capital investments in renewable energy infrastructure, grid modernization, and technological innovation. As indicated by the IEA, investments amounting to approximately USD 4 trillion annually will be necessary by 2030 in order to achieve net-zero carbon emissions (Energy Transition, 2023).

It is imperative that financial and resource support be provided to several critical sectors in order to implement effective climate responses. The transition to renewable energy sources, including solar, wind, hydro, and bioenergy, is a crucial step in reducing emissions. This requires substantial investments in infrastructure, along with support for research and development activities related to novel technologies, such as energy storage and carbon capture.

Based on the NDC updated in 2020, the aggregate funding requirement for adaptation initiatives amounts to slightly over USD 2 billion, as shown in Table 15. Of the total funding required, the highest allocation is designated for infrastructure, water, and agriculture. It is noteworthy that the majority of this funding is contingent upon international support.

Table 15: Climate financial adaptation in major sectors.

Sector	Estimated finance necessary (US $)

Agriculture	**306,268,600**
Coastal zones	**72,000,000**
Enabling actions	**21,050,000**
Energy	**322,000**
Human health	**467,685**
Industry	**Not reported**
Infrastructure	**957,990,000**
Livelihoods, poverty and biodiversity	**211,125,000**
Tourism	**2,500,000 (as minimum)**
Water resources	**468,798,900**
TOTAL	**2,040,522,185**

Source: (NCSD, 2020).

The mobilization of financial resources from a diverse array of public and private sources will be essential for the effective implementation of climate change mitigation strategies. International funds such as the Green Climate Fund (GCF), the Adaptation Fund, and the Global Environment Facility (GEF) are of critical importance in supporting climate adaptation and mitigation projects, particularly in developing countries. These financial instruments provide grants, concessionary loans, and technical assistance to countries for the implementation of climate action plans (GCF, 2024). Governments at national and local levels play a pivotal role in financing climate responses through public investments in infrastructure, energy, and adaptation programs. It is imperative that countries prioritize climate action within their national budgets and develop policies that foster climate-resilient development. The private sector has the potential to contribute to climate finance through investments in green technologies, renewable energy projects, and the adoption of climate-friendly business practices. Public-Private Partnerships (PPPs) have the potential to facilitate the mobilization of capital for large-scale adaptation and mitigation projects, including initiatives such as the construction of solar farms, the development of electric transportation systems, and the implementation of energy-efficient building designs (MME, 2020). Carbon pricing, which encompasses both carbon taxes and cap-and-trade systems, provides an incentive for businesses to reduce their emissions by attaching a cost to carbon. The revenue generated by these mechanisms can be reinvested in adaptation projects and renewable energy initiatives. Carbon markets provide an additional mechanism through which companies can purchase and sell carbon credits, thereby creating an incentive for emissions reductions and providing finance for climate-friendly projects. Financial institutions such as the World Bank, the Asian Development Bank (ADB), and the African Development Bank (AfDB) play a pivotal role in providing loans and financial assistance for climate resilience projects. These financial institutions frequently prioritize projects pertaining to renewable energy, sustainable infrastructure, and disaster risk reduction (UNEP, 2023).

The financial and resource requirements for climate response are substantial, yet indispensable for mitigating climate vulnerability and facilitating a transition to a low-carbon, resilient future. Mobilizing financial resources from public, private, and international sources, enhancing institutional capacity, and facilitating access to climate-smart technologies are pivotal to addressing the challenges posed by climate change. Nevertheless, the attainment of sufficient funding, particularly for developing countries, necessitates a unified global approach, with an emphasis on equitable and cost-effective solutions that prioritize the most vulnerable communities and ecosystems (WB, 2024b).

6.6 Challenges and Barriers to Effective Adaptation Governance

There are numerous challenges and barriers in Cambodia that impede climate change adaptation effectiveness. These challenges manifest at various levels, from institutional deficiencies to financial limitations. The following section outlines the principal challenges and potential solutions to overcome them.

- **Institutional Deficiencies:** In Cambodia, climate change responsibilities are spread across ministries such as the Ministry of Environment (MoE), Ministry of Water Resources and Meteorology (MOWRAM), and Ministry of Agriculture, Forestry and Fisheries (MAFF). Enhancing coordination between the different departments and stakeholders with a view to empowering local authorities and communities to implement adaptation measures based on local needs is key for effective climate adaptation (CCCA, 2020). Moreover, as financial support for climate prevention is still limited, it is necessary to prioritize areas for the application of funding.
- **Lack of Technical Capacity, Expertise, and Resources:** A significant challenge facing many government institutions, particularly in developing countries including Cambodia, is lack of current climate data and forecasting capacity that is required to effectively plan and implement adaptation measures (IPCC, 2022). Collaboration with universities, research institutions, and international organizations is needed to provide technical assistance and share best practices, as well as implement digital tools and data-sharing platforms to improve access to climate information and facilitate evidence-based decision-making. This report is one example of how universities and research institutions can support governance by providing information for decision-making.
- **Limited Access to International and Domestic Finance:** Cambodia has faced challenges in directly accessing the international fund due to limited accredited national entities. Cambodia has had difficulty accessing large-scale funding from the International Climate Fund (ICF), with only a handful of approved projects. Meanwhile, domestic financing is constrained, as budget allocations often prioritize infrastructure expansion (roads, hydropower) over climate adaptation. To address this challenge, it is essential to enhance access to international climate finance mechanisms, such as the Green Climate Fund and the Adaptation Fund. Additionally, it is crucial to mobilize domestic funding through innovative mechanisms, including green bonds, carbon taxes, and public-private partnerships (PPPs), to bolster adaptation efforts at the national and subnational levels (GSSD, 2019).
- **Limited Public Awareness and Stakeholder Engagement:** The general public's comprehension of climate-related risks and adaptation strategies is frequently constrained in Cambodia, particularly in communities that are particularly susceptible to their effects. The absence of stakeholder involvement may result in

the formulation of policies that fail to adequately address local needs or which lack the requisite public support (MoE, 2020b). Awareness campaigns led by the public sector and NGOs are beginning to bridge this gap.

- **Mainstreaming climate resilience into development planning:** Cambodia's rapid infrastructure growth, such as road expansion and urbanization, often overlooks climate risks. It has led to severe urban flooding during heavy rains. It is necessary to promote climate-resilient development. This can be achieved by demonstrating that sustainable economic growth and adaptation can be mutually reinforced. Furthermore, climate risk assessments should be incorporated into development projects. This will ensure that economic investments are resilient to future climate impacts. Finally, cross-sectoral dialogue between development and environmental agencies is essential to ensure alignment of goals.

To address these challenges to adaptation governance, it is necessary to implement a combination of institutional strengthening, capacity building, legal reform, and stakeholder engagement. By fostering coordinated, inclusive, and well-funded governance systems, countries can overcome these barriers and create a resilient framework for effectively addressing the impacts of climate change (UN Habitat, 2019).

6.7 Case Studies of Effective Adaptation Governance

The following case studies from Cambodia illustrate the various approaches and strategies employed in the context of climate adaptation.

The Cambodia Community-Based Adaptation Programme was developed with the objective of implementing community-based projects that seek to enhance the resiliency of communities to climate change impacts through local-level climate risk management projects. The traditional practice of using short-term rice has been modified, and the cropping calendar has been altered before and after flooding through the introduction of early wet and late wet season rice cultivation, which represents a significant departure from previous practices. The rice yield demonstrated a notable increase (UNDP, 2013).

The lessons learned from these community projects will then be leveraged with the intention of promoting the replication of successful community practices and the integration of lessons into national and sub-national policies and local planning processes that reduce vulnerability to climate change impacts.

Coastal Areas in Cambodia: This study was conducted in provincial and coastal areas of Cambodia with the objective of gaining insights into the implementation of climate change adaptation policies at the national and sub-national levels. The study aimed to determine the current status of climate change adaptation policy plans in Cambodia, with a particular focus on the coastal areas. Based on the research, it found the main barriers of climate change adaptation in the sub-national level include lack of relevant information, lack of experience and understanding, weak governance, and lack of financial resources. So, this research also provides some implementation for climate adaption development policy and action plan that can improve the capacity of climate change response for the sub-national level (Sum & Kim, 2020).

Farmers' perceptions on the impact of climate change: The perception of farmers regarding the impacts of climate change and identifying the coping mechanisms they currently employ for climate change adaptation. This case study examines the challenges faced by Cambodian farmers in adapting to climate change. Financial constraints, limited potential for irrigation, land scarcity, lack of information, and labor shortages are among the obstacles hindering their ability to effectively address and prepare for the impacts of climate change on their agricultural practices (Thav et al., 2023).

The Building Climate Resilience Across Cambodia: The agricultural sector in Cambodia is particularly vulnerable to climate variability, with floods and droughts representing significant challenges. In collaboration with the UNDP and the Global Environment Facility (GEF), Cambodia introduced drought-tolerant rice varieties and provided training to local farmers in water management techniques. Local communities were actively engaged in the process of identifying climate-related risks and developing adaptation strategies, which ensured that the interventions were tailored to the specific context of the local area. The training of farmers in new agricultural techniques enhanced the local capacity to cope with climate variability, thereby enhancing food security and livelihoods. By integrating adaptation measures into local development plans, the project ensured long-term resilience against climate change (UNDP, 2024).

Community-Based Flood Adaptation: Cambodia is highly susceptible to seasonal flooding, particularly in rural provinces. The impacts of flooding are extensive, affecting agriculture, infrastructure, and community livelihoods in significant ways. In response to this situation, the Cambodian government and local NGOs implemented a community-based adaptation project with the objective of reducing the risk of flooding. A community-based early warning system was developed, enabling villagers to receive timely information regarding potential flood risks, thereby allowing them to take appropriate preventive measures. The use of early warning systems significantly reduced the impact of floods on vulnerable populations, which demonstrates the importance of integrating technology in adaptation strategies (MoE, 2018a).

Droughts in Cambodia: The frequency and severity of droughts in Cambodia's rural provinces, particularly in Battambang and Siem Reap, are increasing. The impact of these droughts on agriculture, water availability, and food security is significant. In order to cope with the scarcity of water, local communities, with the assistance of non-governmental organizations (NGOs), constructed rainwater harvesting systems with the objective of storing water during the wet season for use during dry periods. The integration of adaptation strategies within sub-national level structures enhances coordination and sustainability. The transition to drought-resistant crops and climate-resilient farming techniques offers long-term benefits to rural communities, improving both livelihoods and food security (UNCCD, 2019).

The following key lessons can be derived from the Cambodian case studies with regard to adaptation governance:

- It has been demonstrated that involvement of local communities in the design and implementation of adaptation strategies is a crucial element in ensuring the success and sustainability of these initiatives.
- Restoring and protecting natural ecosystems, such as mangroves and forests, provides a dual benefit in terms of both environmental and socio-economic outcomes, thereby making it a pivotal strategy for climate adaptation in Cambodia.
- The incorporation of livelihood diversification into adaptation efforts, such as the promotion of ecotourism, sustainable agriculture, and fisheries, serves to reduce vulnerability and foster long-term resilience.

- Effective adaptation governance necessitates coordination across a multitude of sectors and levels of government, from national-level policies to local-level actions.

6.8 Monitoring, Reporting, and Evaluation in Adaptation Governance

Monitoring, reporting, and evaluation (MRE) are frameworks that facilitate the monitoring of adaptation actions, ensure accountability, and promote learning and continuous improvement. The MRE constitutes a pivotal element of adaptation governance, providing a systematic methodology to track the progress and effectiveness of adaptation actions, ensure transparency, and inform decision-making processes. In the context of climate adaptation, MRE frameworks help evaluate the effectiveness of adaptation strategies and interventions in achieving their intended outcomes, as well as in determining their contribution to the development of climate resilience at various levels, including national, regional, and local.

The MRE process is typically comprised of three fundamental elements:

- **Monitoring Phase** involves the ongoing observation and measurement of relevant variables to assess the progress and effectiveness of the adaptation process. It includes the continuous aggregation of data and information to track the progress of adaptation initiatives according to established indicators.
- **Reporting Phase** involves the dissemination of pertinent information to relevant stakeholders, including policymakers, civil society, and international donors. The regular communication of progress, challenges, and results to relevant stakeholders, including policymakers, civil society, and international donors, is essential for the effective implementation of adaptation initiatives.
- **Evaluation Phase** of projects assess their efficacy, relevance, efficiency, and sustainability, typically at designated milestones or upon the conclusion of an intervention (CCCA, 2020).

The MRE frameworks facilitate transparency by ensuring systematic documentation of adaptation actions and making this information accessible to relevant stakeholders. This enhances accountability, especially when adaptation efforts are financed through public or international funds. The data collected through MRE processes provides evidence to inform policy and decision-making, assisting governments, institutions, and communities in adapting their strategies to improve effectiveness and address emerging climate risks. MRE also plays a pivotal role in fulfilling international commitments, such as those outlined in the Paris Agreement, which requires countries to submit progress reports on their Nationally Determined Contributions (NDCs), in enhancing long-term climate resilience at the governmental and organizational levels.

As climate impacts intensify, robust MRE systems will become increasingly necessary, facilitating the advancement of climate resilience and the fulfillment of adaptation objectives in countries such as Cambodia (MoP, 2018).

6.9 Directions for Future Studies

This chapter has demonstrated the key areas of knowledge that are necessary for successful and sustainable climate change adaptation. The section below highlights key areas where knowledge and capacity gaps exist. These are suggested areas for future research:

- **Assessing Long-Term Adaptation Effectiveness:** While many adaptation projects are implemented, there is limited research on the long-term effectiveness of these measures. A key gap is understanding how well adaptation actions perform over extended periods, especially as climate impacts intensify (IPCC, 2022).
- **National technical and institutional knowledge:** It is crucial to identify the key technical and institutional capacity needed for sustainability of adaptation measures. Additional capacity is needed, in terms of technical and institutional knowledge, to respond to future climate science research, as well as to update policy documents, including the NDC update, NAP update, and other instruments involving priority sectors in Cambodia (MoE, 2020b).
- **Economic Valuation of Adaptation Actions:** The economic costs and benefits of adaptation strategies, particularly in developing countries like Cambodia, are not well understood. More research is needed to quantify the economic value of adaptation investments, including cost-benefit analysis and the evaluation of trade-offs between short-term costs and long-term gains in resilience (GCF, 2024).
- **Local and Indigenous Knowledge in Adaptation:** The role of local and indigenous knowledge in enhancing adaptation remains underexplored. Understanding traditional practices and community-based adaptation approaches may offer valuable insights, yet they are often overlooked in formal adaptation planning. Research should aim to document and integrate indigenous and local knowledge into adaptation strategies (ADB, 2019).
- **Private Sector Engagement in Climate Adaptation:** While the private sector's involvement in climate mitigation is well-documented, its role in adaptation remains under-researched. Understanding how businesses, particularly in sectors such as agriculture, tourism, and infrastructure, can contribute to and benefit from adaptation is an emerging area of study. Business models and incentives must be developed that encourage private sector investment in climate adaptation. Research on public-private partnerships, corporate social responsibility (CSR) initiatives, and financial mechanisms that promote adaptation will be key for effective private sector engagement in climate adaptation (UNEP, 2023).
- **Gender and Social Equity in Adaptation:** Despite the recognition that vulnerable groups, including women, children, and the elderly, are disproportionately affected by climate change, there is a lack of detailed research on how to design gender-sensitive and socially inclusive adaptation policies. This includes evaluating how various policies and actions impact marginalized groups and identifying ways to enhance their resilience to climate impacts (UN Women, 2021).
- **Cross-Sectoral and Multi-Level Coordination:** Adaptation requires coordination across multiple sectors (e.g., agriculture, water, health) and governance levels (national, regional, local). However, there is limited understanding of how to effectively manage these interdependencies and foster integrated adaptation planning. Future research should examine the mechanisms for fostering better cross-sectoral collaboration, particularly in countries like Cambodia, where limited institutional capacity may hinder coordination (ADB, 2022).

- **Transboundary Adaptation and Regional Collaboration:** Climate adaptation often requires regional and transboundary cooperation, especially for shared resources such as river basins and ecosystems. However, there is limited research on how countries can effectively collaborate on transboundary adaptation. Case studies of successful transboundary adaptation projects and the role of international agreements could provide valuable insights into how countries can work together to build climate resilience (ADB, 2021a).

Addressing these knowledge and financial gaps will be critical for advancing climate adaptation governance. By focusing on areas such as long-term effectiveness, economic valuation, equity, and cross-sectoral coordination, future studies can help inform more robust, equitable, and sustainable adaptation strategies. These efforts will be essential for building resilience to climate impacts, both in Cambodia and globally.

CHAPTER 7
CLIMATE RESILIENT DEVELOPMENT

7.1 Introduction

7.1.1 Overview

The IPCC defines climate resilience as the capacity of social, economic, and ecosystems to cope with hazardous events, trends, or disturbance. Additionally, climate-resilient development (CRD) is a process that involves implementing greenhouse gas mitigation and adaptation strategies to support sustainable development for all (IPCC, 2022). The IPCC developed an analytical, systems-based approach to building resilience to climate change, called the Climate Resilience Framework (CRF) (see Figure 46). The goal of this structured framework is to build networked resilience that is capable of addressing emerging, indirect, and slow-onset climate impacts and hazards. This framework consists of five pillars: threshold capacity, coping capacity, recovery capacity, adaptive capacity, and transformative capacity (IPCC, 2022).

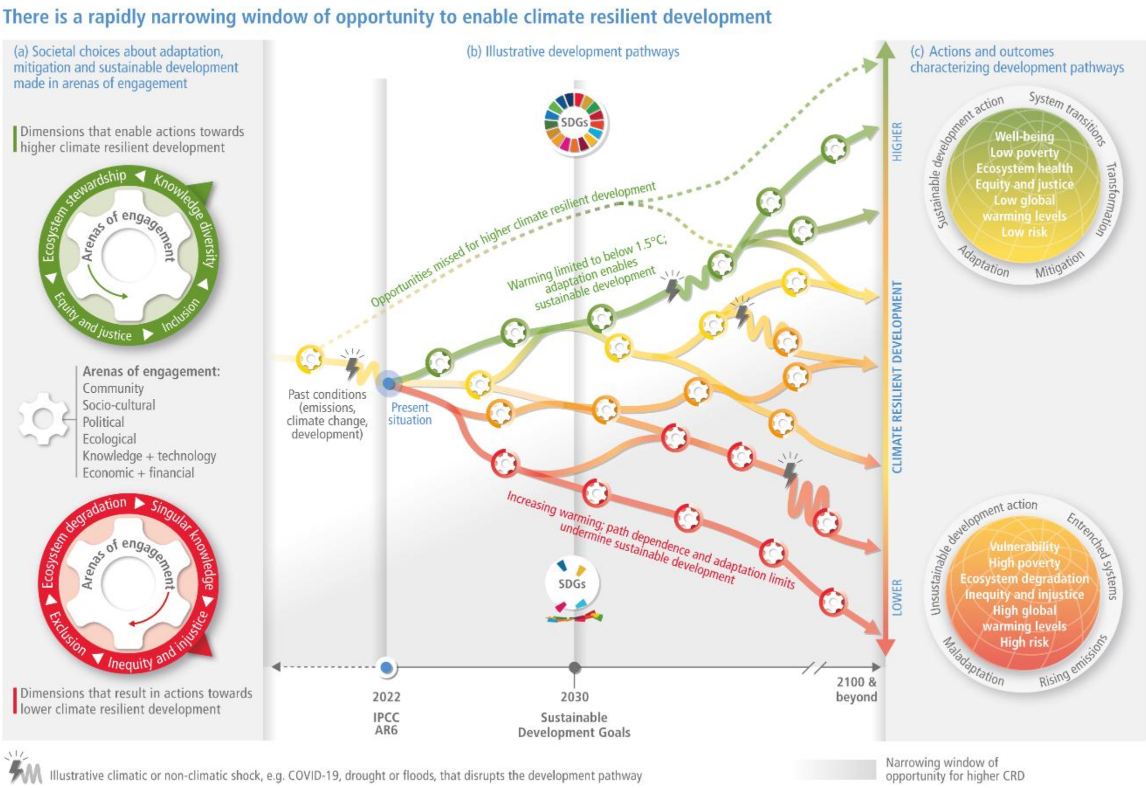


Figure 46: Window opportunity to climate resilient development.
Source: (IPCC, 2022).

When combined with suitable enabling conditions and inclusive engagement areas, systems transition can facilitate CRD (extremely high confidence). Energy, industry, land and ecosystems, urban and infrastructure, and society are the five systems transitions that are taken into consideration (Figure 47) (IPCC, 2022). In certain situations, advancing CRD can require concurrent work on all five transitions. When taken as a whole, these system changes can provide actors and decision makers with more useful alternatives, expand the space of possible solutions, and hasten and intensify the execution of sustainable development, adaptation, and mitigation measures.

Energy, industry, land and ecosystems, urban and infrastructure, and society are the five systems transitions that are taken into consideration (IPCC, 2022). In the energy and industrial system, resilience in power supply and reliable energy are the key to coping with climate change. In the industrial sector, there is a need to become more resilient, by applying ecolabels and focusing on energy efficiency and technology. Nature-based Solutions (NbS) are key for effectively building resilience in land and ecosystems, as well as in urban and infrastructure. They provide actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively while providing simultaneous benefits for people and nature. In the social system, integration of planning and social policy with the impacts of climate change to improve the climate resilience of people, especially vulnerable populations, during climate-related events are the keys.

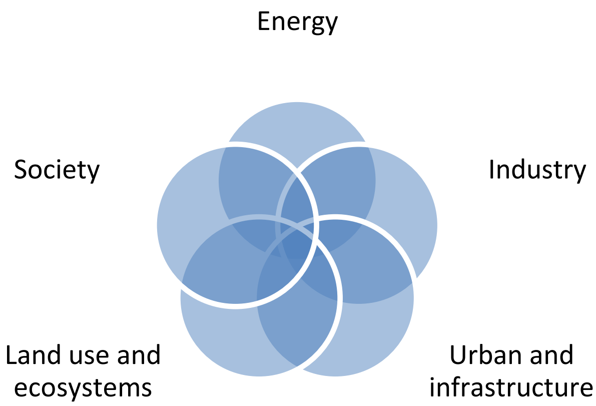


Figure 47: Transition in key systems. Source: (IPCC, 2022).

7.1.2 Objective

The purpose of this chapter is to discuss and provide scientific information related to climate resilient formulation. The main specific objectives are:

- To discuss the importance and benefits of measures and strategies to improve the transitions in key systems;
- To provide information on transitions in key systems, nature-based solutions, planning and social policy, and implication of climate change to sustainable development;
- To provide informative inputs for researchers and policymakers, especially relevant government agencies for improving climate resilient capacity; and
- To identify existing potential risks and recommendations to the climate resilient development.

7.1.3 Scope

This report covers and explores the available sources, methodologies, and vulnerability assessment framework used in IPCC, mainly the AR5 and AR6 for Cambodia’s context. With the existing data and analysis, the gap and uncertainty of this chapter depends on each modelling and the data sources. The result of this chapter analysis can be different from the newly developed data and analysis to some extent.

7.1.4 Methods and Approach

The process of data collection and analysis for climate resilience in this report was done by literature review, including collecting information and data from IPCC, UN agencies, government, research journals, and other trustworthy sources related to the climate resilience development, five key system for transitions, nature-based solutions, and climate strategy planning process (see Figure 47). Some analyses were based on the author's experience and relevant works.

To understand climate-resilient development, the methodology included collecting various types of data related to climate, socioeconomic factors, and environmental data with a participatory approach. Data on temperature, precipitation, sea levels, and extreme weather events from sources such as meteorological stations, satellites, and climate models provide important climate data for making predictions and decisions on climate response actions. Socioeconomic data collected included information on population demographics, economic activities, infrastructure, and social services. This data helps to understand the vulnerability and adaptive capacity of different communities. In addition to climate and socioeconomic data, environmental data such as land use, vegetation cover, water resources, and biodiversity is crucial for assessing the health of ecosystems and their role in climate resilience.

The main data sources were synthesized from the available documents and reviews as the following:

- Academic journal articles
- National Adaptation Plan 2017
- Fifth and Sixth Assessment Report (AR5 and AR6) by the IPCC
- Pentagonal Strategy Phase I
- Other related government documents

7.2 Transitions in Key Systems

7.2.1 Energy

The energy sources may be roughly divided into two categories, which are renewable and non-renewable (IEA, 2024). Figure 48 tracks share of electricity production by both renewable and non-renewable energy sources from 1985 to 2020. The trends show that non-renewable sources, such as coal and oil, have been used less, accounting for around 30 percent and less than 5 percent of the world's share, respectively. Meanwhile, renewable energy sources, such as wind, solar, and others, have tended to be used more, representing around 5 percent of the total electricity production share. Globally, Solar PV is increasingly being used to generate electricity, with a total share of almost 45 percent of power generation (IEA, 2024b). According to IEA (2024b), with support from more than 130 countries in terms of policy development to promote renewable technologies, and additional 507 GW of electricity capacity can be generated in 2023 by renewable sources, almost 50 percent higher than in 2022.

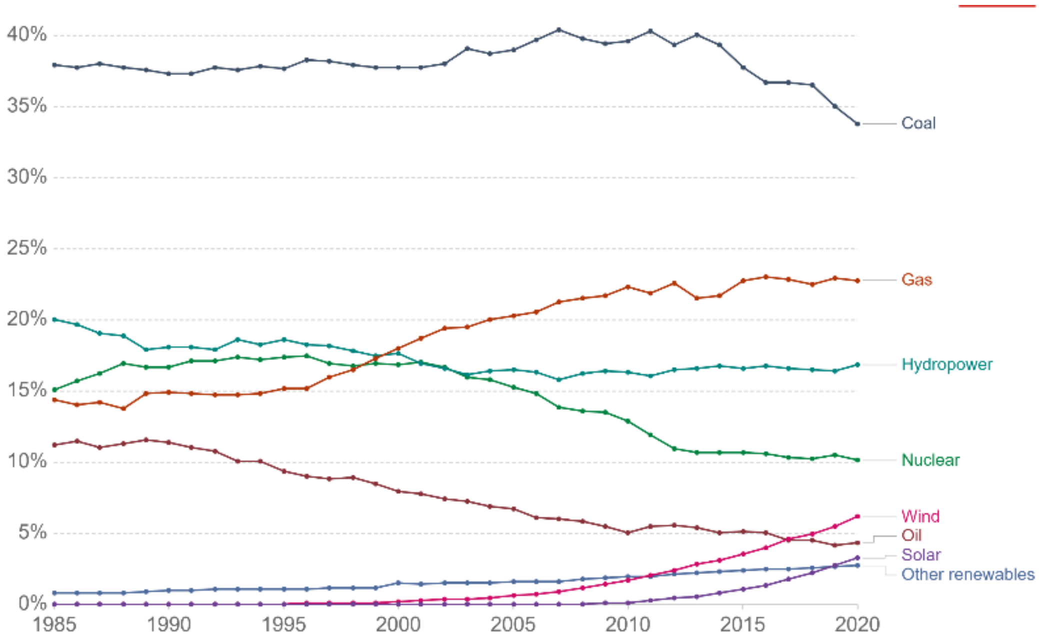


Figure 48: Energy sources in electricity share
Source: (Energy Institute, 2024).

To deal with climate change interventions, the power systems need to be resilient to climate change. It means having responses to disruptive events or the ability of the grid to recover from power system outages and shutdowns due to the climate change (Felder and Petitet, 2022). It becomes evident that resilience is associated with low-probability, high-impact events (Felder and Petitet, 2022). Power system resilience has key aspects, which are planning and risk assessment and measures including resilience planning, preventive response, resilience response, emergency response, restoration which are packed into the preservation and recovery measures for pre, during, and post-event.

Planning for power system resilience is a significant process for the system for both distribution and transmission levels, including applying hardware and software-based strategies for short to long-term versions with hardening measures to operational resilience strategies (see Table 16).

Table 16: Resilience planning.

Time	Hardening Measures	Operational Resilience Strategies
Short-term	• Reserve planning • Black-start capabilities installed • Repair crew member mobilization • Installation of DER or other onsite generation units • Coordination with adjacent networks, and repair crews	• Accurate estimation of the weather location and severity • Demand side management • Fast topology reconfiguration • Microgrid island operation • Automated protection and control actions: load and generation rejection, system separation, etc.
Long-term	• Tree trimming/vegetation management • Undergrounding the distribution/ transmission lines; • Upgrading poles and structures with stronger, more robust materials	• Monitoring: development of situation awareness; advanced visualization and information systems • Ensure communications functionality • Microgrids • Advanced control and protection schemes, such as system integrity protection schemes (SIPS)

	• Elevating substations and relocating facilities to areas less prone to flooding • Redundant transmission routes by building additional transmission facilities	• Disaster assessment and priority selling • Risk assessment and management for evaluating and preparing for the risk introduced by such events

Source: (Yanling Lin, 2018)

Focusing on power system resilience keeps the power system strong. According to Yanling (2018), a resilient power system can better and more quickly resist/absorb, response/adapt, and recover than the traditional one during disruptions. However, the climate keeps changing, so the system needs to be improved substantially, with steps for resilience enhancement including preparation and planning, response to the disruption, recovery, and adaptation and improvement after events (Asit Mohanty, 2024). Resilient power system strengthens physical infrastructure, such as reinforcing transmission lines and substations, which can help withstand extreme weather events, equipment failure, energy deficits. This includes using materials and designs that are more resistant to high winds, flooding, and other climate-related impacts.

Resilient power systems and sustainable systems benefit energy demand of not only the current generation, individuals, environment, and economy, but they also provide and secure energy demand for future generations. By integrating renewable energy sources into the system, systems can transition to carbon-neutral to meet net-zero carbon targets. It provides an environmentally friendly and societal system to meet the first goal to cope with climate change and environmental pollution (Asit Mohanty, 2024).

Cambodia is going through a significant energy transition, shifting from fossil fuels to renewable energy sources and to greener and resilient energy production. In the early 2000s, the nation's electricity was heavily dependent on fuel oil. However, in 2023, 57 percent of energy was produced from renewable sources, including biomass, hydropower, and solar. The government has since set a goal to increase that percentage of renewable energy sources to 70 percent by 2030, demonstrating its strong commitment to climate resilience and sustainability (Oxfam and EnergyLab, 2025). Moreover, another key strategy to improve Cambodia's energy in the future is energy efficiency. Since 2010, the average annual growth in Cambodia's electricity consumption has been over 20 percent, which has resulted in significant investments in electricity generation (Oxfam and EnergyLab, 2025). The country's low-carbon growth path may be ensured by energy efficiency, which has great potential to slow down the constantly increasing demand for power. This results in greater energy security, sustainability, and cost savings.

Cambodia has emerged as one of the world's fastest electrifying nations to reach the domestic electricity demand. Power system infrastructure and energy mix are the keys to increase domestic generation capacity, including scheduled power imports from Laos and energy advancements, planned hydro dams (non-mainstream Mekong River), solar PV plants, and BESS projects as in the Cambodia's Power Development Plan 2022–2040, which required a total investment of USD $9,260 million (ADB, 2024b). This plan will provide the best possible plan for moving the power system toward a cleaner grid, reliable, and resilient energy, while upholding current government agreements (ADB, 2024b). To meet its primary objectives of meeting demand in an affordable, reliable, and secure manner, while adhering to national and global commitments on the climate and the environment, Cambodia must maximize the deployment of domestic renewable energy resources and energy efficiency measures, and excluding the development of additional coal plants and hydro dams on the mainstream Mekong River. Low-carbon energy alternatives to uncommitted projects will be evaluated and considered in the future, including emerging technologies such as Carbon Capture Utilization and Storage (CCUS) and hydrogen.

With diversification of energy sources and good infrastructure, Cambodia can build up a strong power system to secure and stabilize the electricity demand. However, climate change causes the consequences in sea level rise, unpredictable precipitation patterns, rising global temperatures, and an increase in the frequency and severity of extreme weather events which impacts these goals.

7.2.2 Physical Infrastructure

a. Green Infrastructure

Green infrastructure refers to the use of vegetation and trees to control water, temperature, soil and air quality to create healthier, resilient urban environment (MPWT&NCSD, 2019). Green infrastructure includes a range of measures that use plant or soil systems, permeable pavement, or other permeable surfaces or substrates, to store or infiltrate stormwater and reduce flows to sewer systems or to surface water (EPA, 2023). Green infrastructure includes rain gardens, porous pavements, green roofs, infiltration planters, trees, and rainwater harvesting to harvest and reuse rain and stormwater. In the broader context, green infrastructure refers to a network of natural and semi-natural systems that provide environmental, economic, and social benefits. It includes features like parks, green roofs, rain gardens, wetlands, and permeable pavements. These systems work by mimicking natural processes to manage water, improve air quality, and enhance urban environments. At the site level, green infrastructure practices protect and restore natural features, hydrology, soil health, and native vegetation at the site and municipal and neighborhood scales.

Green infrastructure reduces runoff and water waste and can improve air quality by capturing pollutants and providing cleaner air. It also supports biodiversity by creating habitats for various species, enhancing the ecological health of urban areas. Moreover, green infrastructure contributes to climate resilience by protecting coastal areas from erosion and storm surges. It can also help communities prepare for droughts by improving water retention and reducing the stress on local water supplies. Overall, green infrastructure offers a sustainable and cost-effective approach to enhancing climate resilience, improving public health, and creating more livable urban environments (Hamel, et al., 2021).

b. Irrigation Systems

Resilient irrigation systems are crucial for ensuring agricultural productivity and food security, especially in the face of climate change. These systems help farmers manage water resources more efficiently, reducing the impact of erratic rainfall, prolonged droughts, and other climate-related challenges. Resilient irrigation systems provide a reliable water supply, enabling farmers to grow crops even during dry periods (Nandeha and Trivedi, 2024). This consistency helps increase crop yields and allows for multiple growing seasons, which is essential for meeting the food demands of a growing population.

Resilient irrigation systems also improve farmers' climate adaptation ability. As climate change leads to more unpredictable weather patterns, resilient irrigation systems act as a buffer against these changes. They help farmers adapt to varying conditions by ensuring that crops receive adequate water, regardless of rainfall variability. These systems improve water efficiency while also providing climate adaptation measures for water scarcity.

The economic stability is vital for rural communities that rely heavily on agriculture for their livelihoods (Arthur et al., 2022). Resilient irrigation practices support the sustainable use of water resources, helping to conserve water and reduce environmental impacts (R. Q. Grafton, 2018). Some aspects of resilient irrigation systems include:

- **Drip Irrigation:** This method delivers water directly to the plant roots through a network of tubes and emitters, minimizing evaporation and runoff. Drip irrigation is highly efficient and can significantly reduce water usage compared to traditional irrigation methods (Patrícia and Alexandra, 2024).
- **Smart irrigation:** Utilizing technologies such as soil moisture sensors, weather forecasts, and data analytics, ensures that crops receive the right amount of water at the right time. This approach optimizes water use and enhances crop health. Proper scheduling of irrigation based on crop needs and soil moisture levels helps avoid overwatering and waterlogging. Using soil moisture sensors and weather data can improve the accuracy of irrigation schedules.
- **Rainwater Harvesting:** Collecting and storing rainwater for irrigation purposes can reduce dependence on groundwater and surface water sources. Key techniques include rain barrels, rain gardens, storage, integration with existing irrigation systems, supplemental water supply, and dual systems.
- **Conservation Agriculture:** Practices such as crop rotation, cover cropping, and reduced tillage improve soil health and water retention. Healthy soil can store more water, reducing the need for frequent irrigation.
- **Water Reuse:** Recycling treated wastewater for irrigation can provide a reliable water source and reduce the pressure on freshwater resources. This practice is especially useful in water-scarce regions.
- **Integrated Water Management:** Combining various water-saving techniques and technologies, such as drip irrigation, rainwater harvesting, and precision irrigation, can create a holistic approach to water management. This integrated strategy ensures optimal water use and sustainability.
- **Adoption of Modern Technologies:** Implementing advanced technologies like remote sensing, internet of things (IoT) devices, and automated irrigation systems can help monitor and optimize irrigation practices. These technologies provide real-time data and insights, enabling farmers to make informed decisions.

Implementing resilient irrigation systems can enhance agricultural productivity, support climate adaptation, and ensure food security for future generations. Farmers can improve irrigation efficiency, conserve water resources, and enhance the sustainability of agricultural practices. These measures not only benefit the environment but also contribute to long-term agricultural productivity and resilience.

c. Seawalls

Seawalls protect the coast against sea-level rise and storm surges, among others, by preventing high tide and storm surges inland, which eventually causes flooding. They are constructed along and parallel to the shoreline. Materials and construction styles vary, including a slope, step, or sometimes vertical forms devised to resist wave action up to 30 to 50 years (see Figure 52). Seawalls provide flood prevention by serving as a physical barrier against storm surges and high tides, which prevents seawater from flooding the coastal areas. They are key infrastructure in low-lying areas and urban areas prone to flooding. For example, the Netherlands, famous for its well-developed flood defense systems, has constructed long lengths of seawalls and dikes to protect its low-lying areas against the North Sea. These are integral structures to the holistic approach of the country toward water management and flood prevention (Glen Lake, 2020).

Figure 49: Seawall.
Source: (IStock, 2025).

Seawalls play a critical role in protecting our coastal communities from hazards like storm surges and erosion. By absorbing and deflecting wave energy, seawalls help to reduce coastal erosion. This protects the land behind the seawall from being worn away by the constant action of waves. Seawalls safeguard critical infrastructure such as roads, buildings, and utilities located near the coast. This is essential for maintaining the functionality and safety of coastal communities. While the construction and maintenance of seawalls can be expensive, they provide long-term economic benefits by protecting valuable coastal properties and reducing the costs associated with flood damage and erosion (Cornell, 2013). However, their construction can have negative consequences on marine ecosystems and natural coastal processes. To mitigate that, environmental impact assessment and nature-based solutions are the solutions to minimize disruption to natural habitats, reduce sediment pollution, and preserve the integrity of coastal ecosystems.

d. Water Storage

Storing water to balance inter-temporal problems is fundamental to meeting the variable and uncertain demands and needs of a society and periodic shocks such as floods and droughts (Gaupp et al., 2015). These systems help communities manage water resources more effectively, providing a buffer against the impacts of climate variability and change. Some key reasons why resilient water storage systems are important include:

Drought Mitigation: During prolonged dry periods, water storage systems such as reservoirs, dams, and aquifers can store excess water from wetter seasons. This stored water can then be used to meet agricultural, industrial, and domestic needs during droughts, ensuring a continuous water supply (EPA, 2024b).

Flood Control: Water storage systems also play a crucial role in managing floodwater. By capturing and storing excess runoff during heavy rainfall events, these systems can reduce the risk of flooding and protect downstream communities and infrastructure (EPA, 2024b).

Water Security: Resilient water storage systems enhance water security by providing a reliable source of water even when natural water sources are compromised. This is particularly important in regions that experience frequent and severe weather events (EPA, 2024b).

Large-scale Reservoirs: Large-scale storage solutions like reservoirs can capture and store significant amounts of water. These structures not only provide a reliable water source but also offer flood control (EPA, 2024b).

By implementing resilient water storage systems, communities can better manage their water resources, ensuring availability during times of scarcity and protecting against the impacts of extreme weather events. These systems are vital for building climate resilience and securing a sustainable water future.

7.2.3 Resilience in Industry Sectors

The government of Cambodia has been encouraging diversified ventures in the field of electronics, automotive parts, and agro-processing to decrease reliance on garment manufacturing and export. Other initiatives include, for example, the Cambodia Industrial Development Policy 2015–2025 for competitiveness and investment in high-value industries. Meanwhile, superior energy-efficient technologies and renewable sources of energy are gaining greater momentum to decrease cost and environmental impact.

The garment industry has taken steps to build resilience. To save expenses and prevent pollution, some garment factories have set up solar panels to reduce their dependence on grid electricity and, correspondingly, carbon emissions. Many industries are adopting circular economy principles that involve waste materials being recycled and resources not being wasted. Initiatives like the Switch Garment Project by the EU and GIZ are promoting garment factories to apply energy-efficient practices with minimal environmental impact. The Cambodia Climate Change Alliance also encourages capacity-building processes for industries to adapt to climate risks. Below, some key projects and initiatives are outlined:

- **Factories are investing in renewable energy sources and energy-efficient equipment.** Recruiting manufacturers for free energy audits was a hurdle at the start of the EU-Switch Garment Project. Nevertheless, 22 factories are interested in spending USD 2.63 million putting the audit's recommendations into practice by the project's conclusion (EU Switch-asia, 2020).

  The Model Green Factory Program supports implementation of the National Energy Efficiency Policy (NEEP). **The Model Green Factory Program** by GGGI, provided energy recommendations and certification for energy audit verification by TAFTAC to garment factories and supports implementation of the National Energy Efficiency Policy (NEEP). The project provided capacity-building for 221 factory environmental team staff and other technical workers enabled to manage devices or electricity. With the renewable energy measures alone under the current regulations, factories can save electricity up to 35 percent of their total electricity consumption (GGGI, 2024). Evergreen Garment Co., Ltd can reduce firewood consumption by almost 20 percent by implementing the energy audit recommendations (EU Switch-asia, 2020). At present, some factories are reusing leftover steam in a water tank according to the advice given by the energy audit of Switch Garment.

By diversifying the industrial base, adopting green technologies, and fostering collaboration between stakeholders, Cambodia can create a more sustainable and resilient industrial sector capable of withstanding future shocks and contributing to long-term economic growth.

Climate-resilient architecture and design are also important for increasing resilience and adaptation in industry sectors. Passive cooling techniques play a crucial role in designing climate-resilient buildings. Passive cooling in industry contributes to a sustainable path toward energy consumption reduction and building resilience against climate variability. It uses natural processes, design strategies, and other techniques that maintain comfortable temperatures with limited reliance on mechanical cooling (IPCC, 2007). By smartly manipulating the design choices, passive cooling can reduce heat gain and increase heat loss, impacting comfort level and energy usage. There are several passive cooling techniques to cool down the industry building based on each context, location, and cost.

Natural Ventilation: Natural ventilation can be the most effective of all passive cooling techniques. This technique is implemented by using an arrangement of windows, vents, and other apertures so that air can flow naturally. As warm air can escape from the building while cool air can enter it, use of air conditioning may be considerably reduced. A combination of wide movable windows and ceiling vents permitting good cross-ventilation will provide suitable conditions indoors in industries. These systems can be used to save energy with increased thermal comfort and air quality indoors. By harnessing the natural breeze and cool air, buildings can be naturally cooled without the need for energy-intensive cooling systems. Implementing natural ventilation as part of passive cooling strategies is also particularly beneficial in regions with mild climates or during certain seasons (ACCO PAKISTAN, 2023).

Passive Solar Design: Passive solar design increases passive sunlight and reduces passive heat gain to promote appropriate energy efficiency and consumption. Passive solar design focuses on the principles of solar orientation to maximize reliance on natural light, along with minimizing the use of mechanical cooling systems. Building envelope optimization must include properly placed shading devices, materials with high thermal mass, proper insulation, and tight airtight envelopes. This maximizes natural ventilation through windows and ventilators, enabling cross-ventilation and removal of hot air, thereby passively cooling the space (ACCO PAKISTAN, 2023).

7.3 Nature-based Solutions

Nature-based Solutions (NbS) for climate resilience use the potential of natural ecosystems to dampen the effects of climate change and enhance the adaptability of communities and environments. Such solutions involve restoring and protecting natural habitats, including wetlands, forests, and coastal ecosystems that provide a buffer against extreme weather events. Urban agriculture and green spaces, such as parks and green roofs, cool cities, control stormwater runoff, and purify the air, thus making urban areas more livable and resilient to heat waves (OECD, 2024). In addition, practices such as agroforestry and sustainable watershed management protect soil health, water quality, and biodiversity, and help sequester carbon. NbS will enable the attainment of a multitude of goals: reducing disaster risks, conserving biodiversity, enhancing human well-being, and fostering sustainable development (IUCN, n.d.). This section considers some key NbS that can be implemented in Cambodia, including urban and community gardens, green roofs, street trees, rain gardens, and parks and urban space.

Urban farms and gardens have the potential to enhance climate resilience by mitigating the urban heat island effect, managing stormwater, and improving air quality (USDA, n.d.). Community gardens and urban agriculture present various advantages for food security and climate resilience by embedding food production within the urban ecology. It helps in the localization of food systems, reduce emissions from transportation, and provides fresh produce to urban centers. In Phnom Penh, urban gardening has already been widely adopted, with many urban residents having small garden spaces on sidewalks and rooftops.

Rooftop gardens take advantage of the space and create an area that otherwise would have been used merely for roofs, adding more access to food and clean air. Green roofs reduce the need for heating during winter and cooling during summer due to the natural insulation provided by the vegetation cover, helping building owners save money and use less energy. The vegetation layer reduces the heat island effect of urban areas and maintains a more constant inside temperature by reflecting and absorbing sunlight. Rain gardens are another urban solution that could benefit Cambodia's cities, where stormwater and runoff management are a challenge. Rain gardens help to mimic natural rainwater management in urban areas by absorbing rain and stormwater and preventing it from overloading urban drainage and stormwater systems. This reduces the burden on stormwater systems and decreases the risk of urban flooding. The plants and soil in rain gardens act as natural filters, removing pollutants such as oils, heavy metals, and chemicals from the water before it infiltrates the ground. Street trees can also help with rainwater management as well as providing shade and reducing surface and air temperatures, thereby acting to combat the urban heat island effect. Trees improve air quality through filtering of pollutants and sequestration of carbon dioxide.

Parks and open spaces can integrate all these NbS and are crucial to the resilience and well-being of communities. They are the lungs of cities, providing crucial ecosystem services such as the purification of air, temperature regulation, and management of stormwater. These green areas offer residents a place to relax, exercise, and connect with nature, which significantly enhances mental and physical health. According to City Hall, the capital had created and managed 121 public parks covering one million square meters as of 2022—up from around 50 parks reported in 2017 (Nhean, 2017). Prime Minister Hun Manet on April 7 reaffirmed his government's commitment to developing 70 hectares of land at Boeung Tumnup Kob Srov—also known as Boeung Ta Mok in Khan Prek Pnov—into a public park to serve the needs of local communities, reflecting broader government support for expanding green spaces nationwide.

7.4 Planning and Social Policy

7.4.1 Social Protection Systems

It has become increasingly clear that social protection systems are the foundation in building resilience and supporting communities to adapt to the worst impacts of climate change. Social protection systems include monetary or in-kind benefits and contributory or non-contributory schemes. Universal social protection can be used at a country level as an entry point for climate change adaptation in order to help vulnerable populations cope with extreme climatic events, loss of livelihoods, and other disruptions (FAO, 2023).

Social safety nets are crucial in supporting vulnerable populations during climate-related events. These systems provide financial assistance, food security, healthcare, and other essential services to those most affected by climate impacts, such as extreme weather events, droughts, and floods. In addition, they can support the development of more resilient communities, helping people to recover from shocks, and build a more sustainable future (FAO, 2023).

Key initiatives of social protection systems include (1) Financial Assistance, which refers to the cash transfers and unemployment benefits that help individuals and families cope with the economic shocks caused by climate-related events; (2) Food Security for supporting food production and supply chains(FAO, 2023); (3) Healthcare Services which allow vulnerable populations to receive the medical care they need during emergencies; (4) Disaster Preparedness and Response, which involves early warning systems, evacuation plans, and temporary shelters; and (5) Long-term Resilience, which contributes to long-term resilience by supporting education, job training, and community development.

These initiatives combine climate risk insurance with social protection to cushion farmer households from different risks. It applies four risk management strategies: reducing climate-related risk through nature-based solutions and improved agricultural practices; risk transfer through private insurance; risk retention through promoting group saving integrated with social protection systems; and promoting prudent-risk taking through a combination of capacity building in financing, livelihoods diversification, and easier access to credit (FAO, 2023). Insurance protects farmers against extreme climate events like droughts, while activities under the cash-for-work program help them build assets and invest in natural resources management (UNSSC, 2022).

Cambodia has made impressive gains in providing and extending social protection by reducing a high level of vulnerability to shocks threatening its economic and social stability by climate change. Social Protection initiatives are employed to build resilience and achieve Vision 2030 and Vision 2050 to become the upper-middle-income and a high-income country. Those initiatives include the family package of four core cash transfer programs, social safeguards, health coverage, and National Social Assistance Fund.

7.4.2 Climate, Emergency, and Disaster Risk Management

Climate, emergency, and disaster risk management build climate resilience by preparing communities to withstand and recover from adverse events. These management practices involve identifying potential hazards, assessing vulnerabilities, and implementing measures to mitigate risks. Effective risk management enhances the ability of communities to absorb shocks, maintain essential functions, and recover swiftly from disasters (FEMA, 2021). Climate, emergency and disaster risk management have roles in:

Risk Assessment and Early Warning Systems: Identifying and assessing risks allows for the development of early warning systems that can alert communities to impending disasters. This proactive approach enables timely evacuations and other protective measures, reducing the impact of disasters (FEMA, 2021).

Infrastructure and Building Codes: Implementing stringent building codes and resilient infrastructure designs can minimize damage during disasters. For example, constructing flood-resistant buildings and reinforcing critical infrastructure like bridges and roads can significantly reduce vulnerability (FEMA, 2021).

Community Engagement and Education: Educating communities about disaster preparedness and involving them in risk management planning fosters a culture of resilience. Community-based approaches ensure that local knowledge and needs are incorporated into disaster risk reduction strategies (FEMA, 2021).

Emergency Response and Recovery Plans: Developing comprehensive emergency response and recovery plans ensures that resources and procedures are in place to respond effectively to disasters. These plans include coordination among various agencies, resource allocation, and post-disaster recovery strategies.

Mainstreaming Risk Management: Integrating risk management into all stages of development planning ensures that potential risks are considered in policymaking, project design, and implementation (FEMA, 2021). This approach helps to avoid creating new vulnerabilities and reduces the overall risk profile of development projects.

Cross-Sectoral Collaboration: Effective risk management requires collaboration across different sectors, such as health, agriculture, and infrastructure. By working together, these sectors can develop comprehensive strategies that address multiple risks and enhance overall resilience (FEMA, 2021).

Policy and Regulatory Frameworks: Establishing robust policies and regulatory frameworks that mandate risk assessments and mitigation measures in development projects is crucial. These frameworks should be aligned with international standards and best practices to ensure consistency and effectiveness.

Investment in Resilient Infrastructure: Allocating resources for the development of resilient infrastructure is essential. This includes investing in flood defenses, earthquake-resistant buildings, and sustainable urban drainage systems. Such investments not only protect communities but also ensure the continuity of economic activities.

Capacity Building and Training: Strengthening the capacity of local governments, institutions, and communities to manage risks is vital. Training programs and workshops can enhance the skills and knowledge to implement effective risk management practices.

Integrating risk management into development planning can create more resilient communities that are better prepared to face the challenges posed by climate change and natural disasters.

7.4.3 Health Services

Resilient health services are essential to address the growing climate-related health risks, such as heatwaves, vector-borne diseases, and extreme weather events. Climate change exacerbates existing health challenges and introduces new ones, putting additional strain on health systems. To effectively manage these risks, health services must be adaptable, robust, and capable of responding to a wide range of climate impacts (WHO, 2021).

The following shows examples of health services adaptation initiatives in other countries:

- **Bangladesh's Climate-Resilient Health Infrastructure:** Bangladesh has implemented measures to make its health facilities more resilient to climate impacts. This includes elevating health centers in flood-prone areas and ensuring they have backup power supplies and water purification systems.
- **Ethiopia's Health Extension Program:** This program trains community health workers

to provide essential health services and educate communities about climate-related health risks. By decentralizing health services, Ethiopia enhances its capacity to respond to climate impacts at the local level.

Philippines' Early Warning Systems: The Philippines has developed early warning systems for extreme weather events, enabling health services to prepare and respond effectively. These systems include communication networks that alert health facilities and communities about impending disasters (WHO, 2021)**.**

7.4.4 Climate Change Education

Education is key for addressing the challenge of climate change. The Parties to the UNFCCC are called upon to educate the public about climate change, ensure the participation of the public in programs, and provide access to information on the subject. In addition to facilitating wise choices, education may incite people to change their attitudes and behavior. The young generation can be made aware of the impacts of global warming and climate change adaptation through schools. Education empowers all people, while young people are specially motivated to act. Being informed about the facts of an issue that is often presented with doom and gloom in the public sphere lessens the issue (UN, 2020).

Climate education is essential for building community awareness and resilience against the impacts of climate change. By equipping individuals with the knowledge, skills, and attitudes needed to understand and address climate issues, education empowers communities to take proactive steps towards sustainability and adaptation (UN, 2020). One key initiative is UNESCO's Climate Change Education for Sustainable Development program, which aims to "help people understand the impact of global warming today and increase climate literacy among young people" (UN, 2020). Key aspects of climate change education include:

Awareness and Understanding: Climate education helps people understand the causes and consequences of climate change. This awareness is crucial for fostering a sense of urgency and responsibility to act. Educated communities are more likely to support and engage in climate action initiatives.

Behavioral Change: Education can inspire individuals to adopt more sustainable lifestyles and practices. By learning about the environmental impact of their actions, people are more likely to make informed decisions that reduce their carbon footprint.

Community Resilience: Educated communities are better prepared to respond to climate-related events. Knowledge about local climate risks and adaptation strategies enables communities to develop and implement effective resilience plans.

Empowerment and Advocacy: Climate education empowers individuals to advocate for policy changes and participate in decision-making processes. This collective action is vital for driving systemic changes needed to address climate challenges.

7.4.5 Heritage Preservation

The World Heritage Centre identifies climate change as probably the most serious threat to world heritage. It can impair the Outstanding Universal Values, including the integrity and authenticity of many properties, and undermine the economic and social development as well as the quality of life for communities connected to World Heritage properties. In addition to the physical parameters, the impact of climate change on cultural heritage depends on the type of heritage, tangible or intangible. Figure 53 shows the UNESCO world heritage sites, 60 of which in danger due to climate change. Without the proper measures being taken, more world heritage sites will be in danger due to an increase in climate change impacts (EPRS, 2024).

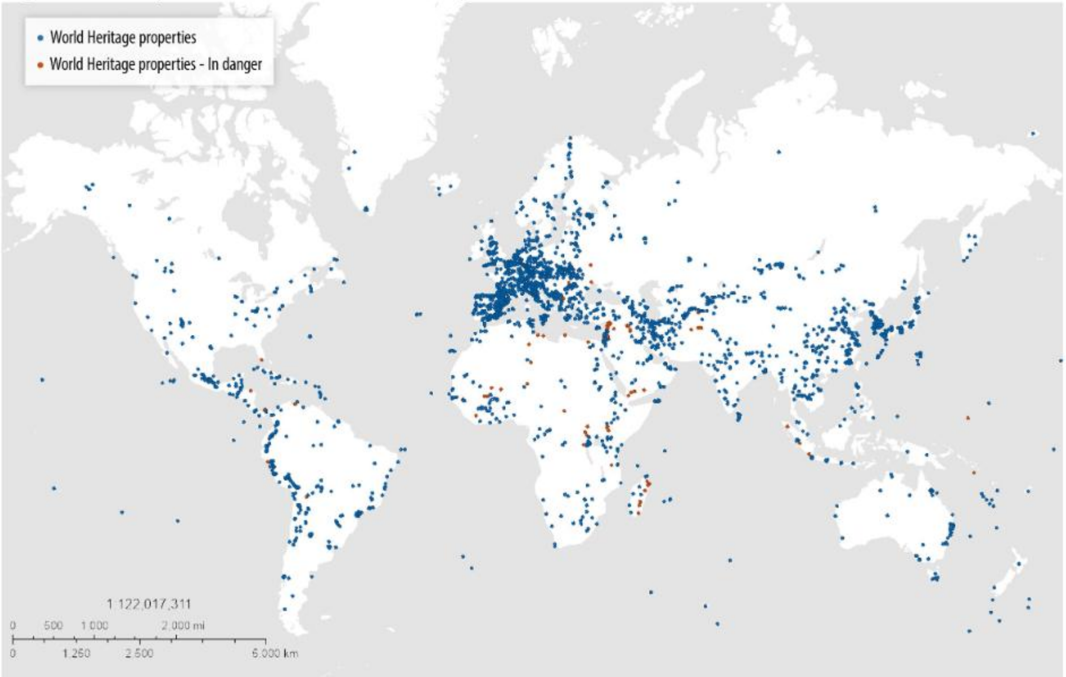


Figure 50: UNESCO world heritage sites.
Source: (EPRS, 2024)

Therefore, preserving cultural heritage sites is crucial as they embody the history, identity, and values of communities. Climate change poses significant threats to these sites through rising sea levels, increased flooding, and extreme weather events. Preserving these sites helps maintain cultural continuity and provides a sense of identity and belonging for future generations (UNESCO, 2023). As this very knowledge can help protect tangible cultural heritage, preserving it is all the more important. Pre-existing vulnerabilities deriving from physical, social, and cultural features increase the potential for cultural heritage to be adversely affected by climate change. Additionally, responses to climate change themselves constitute a hazard when badly conceived or implemented. For example, planting trees around historic temples may directly reduce effects of storms and heat, but those trees could also damage historic structures. Such circumstances can lead to damage or, in extreme cases, loss of tangible heritage. Climate change-related displacements of populations and disbanding of communities can lead to loss of intangible heritage, with detrimental knock-on effects for tangible heritage (EPRS, 2024).

World Heritage properties, through the carbon stored in their forest areas and the ecosystem benefits they provide, such as water and climate regulation, also provide opportunities for human civilization to adapt to and mitigate the impacts of climate change. Traditional knowledge preserved in cultural heritage contributes to resilience to future change and moving towards a more sustainable future.

Climate change may also affect indigenous peoples' and local communities' cultural heritage, landscapes, and traditional practices due to changes in the distribution of flora and fauna. Loss of livelihoods for communities living in and around the sites may also impact their livelihood, knowledge systems and their capacity to maintain the site. In addition, local knowledge and wisdom and traditional practice represent different knowledge systems that are key sources of information to inform mitigation and adaptation options to prepare communities for future climate risks (UNESCO, 2023).

7.4.6 Communication Strategy

From 1995 to 2015, climate and weather were responsible for nearly 90 percent of all major natural disasters reported. The catastrophes included heatwaves, droughts, floods, and storms (UNISDR , 2004). Additionally, the direct costs of such disasters have increased exponentially, surging from USD 75.5 billion in the 1960s to over a trillion dollars in the decade between 2007–2016 period (CRED, 2018). Communication strategies during climatic events and disasters, especially early warning systems, play an important role in building resilience and reducing the risks of climate change because they provide timely information accurately. For example, coordinated alerts through multiple channels ensure that even individuals without access to mobile phones receive timely warnings. Providing accurate and timely information reduces panic and confusion during emergencies. When people know what to expect and how to respond, they are more likely to remain calm and follow instructions, which can significantly reduce the impact of disasters (UNDP, 2018).

- **SMS Alerts:** Countries like Japan and Philippines use SMS alerts to notify residents about earthquakes, tsunamis, and typhoons. These messages provide critical information on the expected impact and recommended actions (UNDP, 2018).
- **TV and Radio Broadcasts:** In the United States, the Emergency Alert System (EAS) uses TV and radio broadcasts to disseminate emergency information. This system ensures that even those without access to mobile phones receive timely warnings (UNDP, 2018).
- **Sirens and Loudspeakers:** Coastal areas prone to tsunamis often use sirens and loudspeakers to alert residents. For example, Hawaii has a comprehensive siren system that warns people to move to higher ground in the event of a tsunami (UNDP, 2018).

By integrating these communication strategies into disaster risk management plans, communities can enhance their resilience, reduce the impact of disasters, and save lives.

Cambodia is highly vulnerable to the impacts of climate change, including increased frequency and intensity of floods, droughts, and extreme weather events. These challenges have prompted the country to develop and strengthen its communication strategy for climate change, especially early warning systems (EWS), to mitigate risks and enhance resilience (UNDP, 2018).

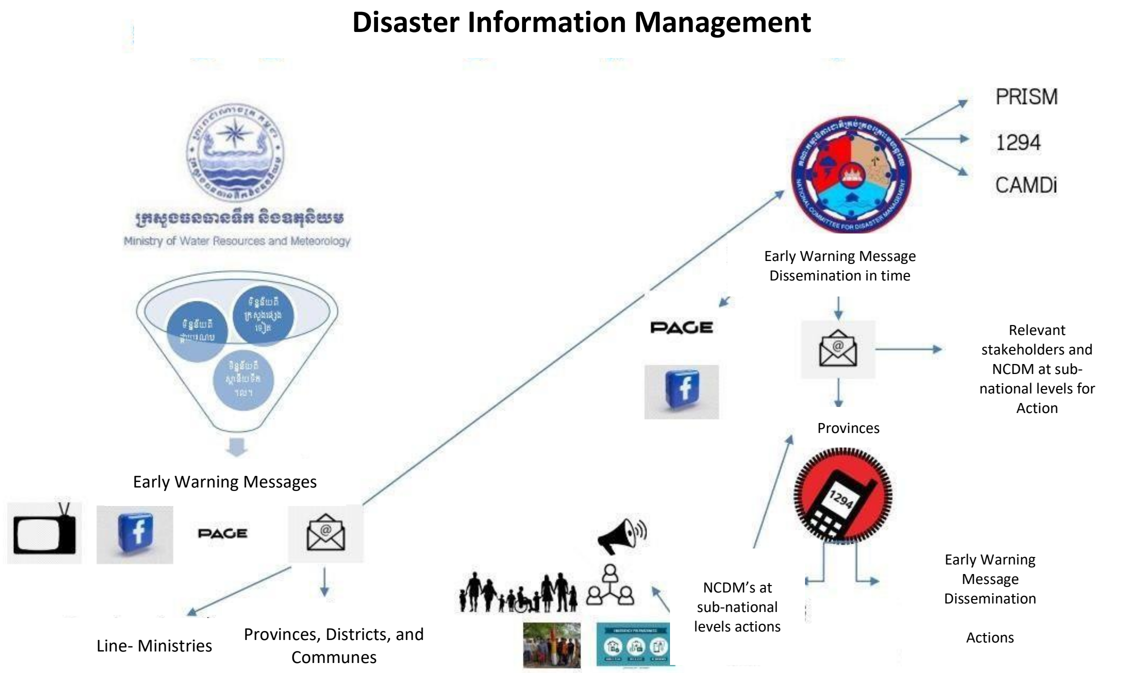


Figure 51: Disaster information management in Cambodia.
Source: (NCDM, 2023).

Early warning systems (EWS) have been incorporated into the broader adaptation plans for climate change in Cambodia. The National Adaptation Programme of Action has sought to increase resilience to climate change through strengthened early warning systems. The Climate Change Strategic Plan 2014–2023 identifies EWS as critical in disaster risk reduction. In community-based adaptation, the local communities were trained in deciphering early signals and taking appropriate precautionary measures, such as diversification of crops or construction of flood-resistant infrastructure. Examples of EWS in Cambodia include:

Flood Early Warning System: Cambodia collaborates with the Mekong River Commission (MRC) to monitor water levels and provide flood forecasts for the Mekong River Basin. Local communities are equipped with tools like water level gauges, radios, and mobile alerts to disseminate warnings. Satellite imagery, artificial intelligence, and hydrological models are used to predict floods and issue timely alerts (NCDM&WFP, 2024). Although there was still substantial damage to infrastructure and agriculture during the 2020 floods, the early warning system assisted in relocating thousands of people and decreased the number of fatalities.

Drought Early Warning System: The Ministry of Water Resources and Meteorology (MOWRAM) is preparing for droughts through rainfall and water level monitoring while giving advisories on methods of saving water and diversification of crops to farmers. Severe droughts in 2015-2016 affected more than 2.5 million people. Early warnings have allowed farmers to adjust planting schedules to reduce crop losses.

Weather and Climate Forecasting: The Cambodia Meteorological Department provides daily weather forecasts and seasonal climate predictions. Farmers use this information to plan planting and harvesting activities, reducing the risk of crop failure. In 2021, accurate weather forecasts helped farmers in Battambang Province avoid losses during unseasonal rain (NCSD, n.d).

Multi-Hazard Early Warning System: The National Committee for Disaster Management (NCDM) coordinates a multi-hazard early warning system that integrates flood, drought, and storm alerts. Mobile-based platforms, such as SMS alerts, are used to reach remote communities. Early Warning System (EWS) 1294, Cambodia's early warning system for natural disasters and related hazards, was designed based on the Climate Risk & Early Warning Systems (CREWS) checklist, an analytical framework published by the United Nations International Strategy for Disaster Reduction (UNISDR) in 2006, started in 2013 (Chowdhary, n.d). EWS 1294 effectively provides timely alerts to protect people from incoming natural disasters via different channels as such SMS, telegram, radio broadcasting, loudspeakers, and others for EWS 1294 to Cambodian including vulnerable groups (see Figure 54) (People in Need, 2022).

Cambodia's early warning systems play a critical role in addressing the impacts of climate change. While challenges remain, ongoing investments in technology, community engagement, and international collaboration are helping the country build resilience and reduce the risks associated with climate-related disasters. Cambodia needs to strengthen implementing frameworks of Disaster Risk Reduction (DRR), Early Warning for All (EW4All), Anticipatory Actions (AA), and Shock-Responsive Social Protection (SRSP). Artificial intelligence (AI) and geospatial technologies are the key to have regular and accurate monitoring with adequate budget support.

7.4.7 Equity, Responsibility, and Social Justice

The climate crisis Provides an opportunity to break down systems that have eroded equity and sustainability and remake them with an emphasis on well-being for both people and the planet. A people-centered framework acknowledges that the impacts of climate change are not evenly distributed, with historically marginalized groups often bearing the brunt. Ensuring equitable access to resources and opportunities is essential for fostering inclusive and just societies. Here are key strategies to achieve this goal (All4Ed, 2024):

Robust Infrastructure and Digital Access: Providing reliable infrastructure and ensuring digital access are fundamental. This includes expanding broadband internet to underserved areas, ensuring that all communities have access to essential services like healthcare, education, and transportation.

Equitable Resource Allocation: Resources should be distributed based on need, rather than equally. This approach involves directing more resources to underserved and marginalized communities to level the playing field and promote equity. For example, schools in low-income areas should receive additional funding to improve facilities and enhance educational outcomes.

Community Engagement and Participation: Engaging communities in decision-making processes ensures that policies and programs reflect their needs and priorities. This participatory approach fosters a sense of ownership and accountability, leading to more effective and sustainable outcomes.

Inclusive Leadership: Leaders at all levels should demonstrate a commitment to equity by promoting inclusive practices and policies. This includes setting clear goals for diversity and inclusion, providing training on unconscious bias, and holding individuals accountable for equitable outcomes.

Public-Private Partnerships: Collaborating with private sector organizations can help leverage additional resources and expertise to address equity challenges. These partnerships can support initiatives like affordable housing, job training programs, and community development projects.

Social Justice and Responsibility:

The story of anthropogenic climate change is a story of inequality. It is widely noted that the most vulnerable countries and communities have contributed relatively little to greenhouse gas emissions (Islam and Winkel, 2017). Wealthier nations may defend themselves far better against socio-environmental catastrophes by creating sturdier infrastructure, establishing sophisticated disaster management systems and giving substantial funds for post-disaster rehabilitation. The widespread use of inexpensive but polluting fossil fuels is what first made those countries affluent. Stated differently, the decreased susceptibility of climate change culprits is not a coincidence. 'Common but Differentiated Responsibilities' (CBDR) is a fundamental principle that underpins the Paris Climate Accords to cut global greenhouse gas emissions and prevent runaway climate change. It means that all countries share the same responsibility, but some must act more than others. Some key initiatives and goals include:

Equitable Resource Distribution: Climate resilience efforts must prioritize the equitable distribution of resources. Marginalized communities often face the greatest risks from climate change but have the least capacity to respond. Ensuring that these communities receive adequate support, such as funding for infrastructure improvements and access to clean water and healthcare, is essential for building resilience.

Inclusive Decision-Making: Effective climate resilience strategies require the active participation of all community members, including those from marginalized groups. Inclusive decision-making processes ensure that the voices of the most affected are heard and considered in planning and policy development. This leads to more comprehensive and effective resilience strategies.

Addressing Systemic Inequities: Climate change exacerbates existing social and economic inequalities. Addressing these systemic inequities is crucial for building resilience. This includes tackling issues such as poverty, lack of access to education, and inadequate healthcare, which can all hinder a community's ability to respond to climate impacts.

Empowerment and Capacity Building: Empowering vulnerable communities through education, training, and capacity-building initiatives enhances their ability to adapt to climate change. Programs that focus on skills development, leadership training, and community organizing can help build local resilience and foster a sense of agency and ownership over climate resilience efforts.

Legal and Policy Frameworks: Implementing legal and policy frameworks that protect the rights of vulnerable populations is essential for social justice in climate resilience. This includes enforcing environmental regulations, ensuring land rights, and providing legal support for communities affected by climate change.

By integrating social justice into climate resilience efforts, we can create more inclusive and effective strategies that ensure all communities are equipped to face the challenges posed by climate change.

7.4.8 Gender Equality, Disability, and Social Inclusion (GEDSI)

The GEDSI focuses on efforts to ensure that individuals disadvantaged based on age, sex, disability, race, ethnicity, religion, or other status are included in climate adaptation and NbS programs and benefits, enabling them to achieve their full potential in life (KIWA & PCCC, n.d). Incorporating GEDSI principles into climate resilience planning is crucial for supporting and protecting all community members, particularly the most vulnerable, against climate impacts. Climate resilience planning that integrates GEDSI principles play a key role in equitable resource distribution and addressing the specific needs of marginalized groups, including women, people with disabilities, and socially excluded communities.

GEDSI is a key to achieving sustainable development goals and economic development, especially it contributes to gender equality (SDG 5) and social equity in society (SDG 10). It also helps to achieve greater, and more effective, sustainable and equitable climate change results (SDG 13). GEDSI strengthens the ability and resilience of women and men in affected population groups to address climate change and ensures that women and men will equally contribute to and benefit from climate change action. GEDSI also contributes to reducing the gender and social gaps in climate change-exacerbated social, economic, and environmental vulnerabilities (ADB, 2023). Some examples of key GEDSI initiatives include:

Australia Pacific Climate Partnership: This initiative focuses on integrating GEDSI principles into climate and disaster resilience efforts in the Pacific region. It includes investments in income generation for women and people with disabilities, enhancing their livelihoods and economic stability. For instance, the redesign of the Luganville Market House in Vanuatu increased women's preparedness and recovery capacity after Tropical Cyclone Harold (UN Women, 2021).

SNV's GESI-Led Approach: SNV, a global development partner based in the Netherlands, prioritizes a GESI-led approach in its projects across the agri-food, water, and energy sectors. This approach identifies vulnerabilities and empowers marginalized groups to build resilience. For example, women in rural farming communities are supported through training and resources, enhancing their capacity to adapt to climate impacts.

UN Women's GEDSI Mainstreaming: UN Women promotes GEDSI mainstreaming in climate resilience projects by conducting vulnerability assessments, ensuring GEDSI participation in decision-making, and building the capacity of stakeholders and vulnerable groups. This approach has been implemented in various projects across the Asia-Pacific region (UN Women, 2021).

By incorporating GEDSI principles into climate resilience planning, we can create more inclusive, equitable, and effective strategies that ensure all community members are prepared to face the challenges posed by climate change.

7.4.9 Climate Data Management

There are many advantages of having a comprehensive and reliable national climate monitoring system. At the national level, accurate weather forecasting is invaluable for many sectors, particularly agriculture. In developing countries, where the main economic activity of a majority of the population is linked to agriculture, predictions about what environmental conditions can be expected during the year can have a huge impact on people's livelihoods and the national food supply. Decisions about what crops to plant, when to plant, and when to harvest are crucial, and the more accurate weather forecasts are, the better decisions can be made (NOAA, 2019).

The planting periods can be defined through the simulation of a climatic water balance using historical rainfall data, potential evapo-transpiration, the physiological characteristics of each crop, and water retention by the soil. As a result, agricultural losses can be reduced due to adverse climatic events while increasing agricultural productivity, which in some cases can guarantee profits for the producers. Monitoring systems enable the development of early warning systems for extreme weather events, such as hurricanes, floods, and heatwaves. These warnings can save lives and reduce economic losses by allowing timely preparation and response (NOAA, 2019).

One effect of climate change is the more frequent occurrence of extreme weather events. These include hurricanes, typhoons, unseasonal extremes of temperature, and heavy rains, which can lead to droughts, flooding, landslides, and other disasters. The sudden devastation these events can inflict on agricultural production highlights the invaluable role of improving prediction and planning capabilities. Given the complexity of global climate and weather systems, along with reliance on models based on historical data, regular measurements of specific variables through climate monitoring systems are essential for developing effective early warning systems (NOAA, 2019).

The availability of reliable data is crucial for supporting official agricultural planning and reducing government expenditure on agricultural loss recovery. Robust climate monitoring systems and effective data management are essential for informed decision-making, particularly in the context of climate resilience and adaptation. These systems provide accurate, timely, and comprehensive data, enabling policymakers, scientists, and communities to understand climate trends, predict future conditions, and develop effective mitigation and adaptation strategies (NOAA, 2019).

Climate monitoring data is also vital for scientific research, to improve climate models and forecasts. This supports innovation in climate resilience technologies and practices.

The following are the approaches, tools, and strategies for improving data collection, storing, and utilization (NOAA, 2019):

- **Enhanced Data Collection Methods:** Utilize a combination of traditional and modern data collection methods, such as satellite observations, ground-based sensors, and citizen science initiatives. This ensures comprehensive and high-quality data.
- **Data Integration and Standardization:** Integrate data from various sources and standardize it to ensure consistency and comparability. This involves using common formats and protocols for data collection and storage.
- **Advanced Data Management Tools:** Implement advanced data management tools and technologies, such as cloud storage, big data analytics, and machine learning. These tools enhance data processing, storage, and analysis capabilities.
- **Capacity Building and Training:** Invest in capacity building and training for data managers and analysts. This ensures that they have the skills and knowledge needed to effectively manage and utilize climate data.

- **Open Data Policies:** Promote open data policies that make climate data accessible to researchers, policymakers, and the public. This transparency fosters collaboration and innovation in climate resilience efforts.
- **Continuous Monitoring and Evaluation:** Establish mechanisms for continuous monitoring and evaluation of data management practices. This helps identify gaps and areas for improvement, ensuring that data systems remain effective and up-to-date.

7.5 Conclusion and Implications for Sustainable Development

7.5.1 Potential Risks to SDGs Achievements

The IPCC consistently highlights those human activities have warmed the atmosphere, ocean and land, leading to widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere. As a result, of climate change, the frequency of weather, climate and water-related disasters has increased by a factor of five over the past 50 years, causing over 2 million deaths and USD 3.64 trillion in losses (WMO, 2024). Climate change poses significant risks to achieving the Sustainable Development Goals (SDGs), as it can undermine progress across multiple areas.

Key climate indicators such as CO_2 Concentration, Ocean Acidification, Temperature Ocean Heat Content, Sea-Ice Extent, Glacier Mass Balance, and Sea-Level Rise also indicate risk to achieving SDGs (WMO, 2024). Because CO_2 concentration drives global climate change, it is indirectly responsible for risks related to the other climate indicators and nearly every single SDG (see figure 7.27). Therefore, reducing carbon emissions is one of the most effective and necessary climate-related actions for achieving the SDGs. Only 15 percent of SDGs are on track and some SDGs are off-track because of climate change disturbances.

In fact, progress made towards limiting global temperature increase would significantly ease the path to many other SDGs, such as those related to poverty, hunger, access to water, and terrestrial and marine ecosystems. Many of the SDGs and their targets can also be achieved in ways that would enable adaptive responses to climate change, for example those related to resilience in SDGs 9 and 11. Here are some key risks:

- **Poverty and Inequality (SDG 1 and SDG 10):** Climate change exacerbates poverty and inequality by disproportionately affecting the poorest and most vulnerable populations. Extreme weather events, such as floods and droughts, can destroy homes, livelihoods, and infrastructure, pushing more people into poverty.
- **Zero Hunger (SDG 2):** Changes in temperature and precipitation patterns can disrupt agricultural production, leading to food shortages and increased prices. This threatens food security and can exacerbate hunger and malnutrition, particularly in regions already facing food insecurity.
- **Good Health and Well-being (SDG 3):** Climate change impacts health through increased heatwaves, the spread of vector-borne diseases, and reduced air quality. These health risks can strain healthcare systems and reduce overall well-being.

- **Clean Water and Sanitation (SDG 6):** Altered rainfall patterns and increased frequency of extreme weather events can affect water availability and quality. This can lead to water scarcity, impacting drinking water supplies, sanitation, and hygiene.
- **Affordable and Clean Energy (SDG 7):** Climate change can disrupt energy production and distribution, particularly in regions that are reliant on hydropower. Extreme weather events can damage energy infrastructure, leading to power outages and increased energy costs.
- **Sustainable Cities and Communities (SDG 9 and SDG 11):** Urban areas are particularly vulnerable to climate impacts such as heatwaves, flooding, and sea-level rise. These challenges can strain urban infrastructure and services, making cities less sustainable and livable.
- **Life Below Water and Life on Land (SDG 14 and SDG 15):** Climate change affects ecosystems and biodiversity, both in marine and terrestrial environments. Ocean acidification, rising sea temperatures, and habitat loss threaten species and ecosystems, undermining conservation efforts.
- **Economic Growth and Employment (SDG 8):** Climate impacts can disrupt economic activities, particularly in sectors like agriculture, fisheries, and tourism. This can lead to job losses and reduced economic growth, affecting overall prosperity.

Integrating climate resilience into SDGs planning ensures that development efforts are sustainable and inclusive. Climate change poses significant risks to achieving the SDGs, and without incorporating resilience measures, progress can be easily undermined. Here are some key reasons why this integration is essential:

- **Protecting Development Gains:** Climate resilience safeguards progress towards the SDGs. For example, investments in infrastructure, health, and education can become ineffective if not designed to withstand climate impacts such as floods, heat waves, and storms.
- **Reducing Vulnerability:** Integrating climate resilience reduces community vulnerability to climate-related shocks. This is particularly important for marginalized and low-income populations, who are often the most affected by climate change. Considering climate risks in development projects help protect these communities and strengthen their adaptive capacity.
- **Enhancing Sustainability:** Climate resilience fosters sustainable development by promoting efficient resource use and protecting ecosystems. For instance, resilient agricultural practices can enhance food security while preserving soil health and biodiversity.
- **Fostering Inclusive Growth:** Integrating climate resilience into SDG planning ensures that all segments of society benefit from development efforts. This includes designing policies and programs that address the specific needs of women, children, people with disabilities, and other vulnerable groups, thereby promoting social equity and justice.
- **Supporting Long-Term Planning:** Climate resilience encourages long-term thinking and planning. By considering future climate scenarios, policymakers can develop strategies that are flexible and adaptive, ensuring that development goals remain achievable even in the face of changing climate conditions.

7.5.2 Research Gaps and Next Priorities

Current research on climate-resilient development has made significant strides, but several gaps remain that need to be addressed to enhance our understanding and implementation of effective resilience strategies. Here are some key gaps:

- **Climate Risk Data at the Local Level:** There is a lack of detailed climate risk data and models, especially at local and regional levels. More granular data is needed to understand the specific impacts of climate change on different communities and ecosystems. However, downscaling climate data and developing models require significant resources, which are often inaccessible to low-income countries. This limitation hinders their ability to predict climate impacts effectively and constrains their climate change planning and coping capacity.
- **Integration of Social Dimensions:** While there is growing recognition of the importance of social factors in climate resilience, research often lacks a comprehensive integration of social dimensions such as gender, disability, and social inclusion (GEDSI). More studies are needed to explore how these factors influence vulnerability and resilience, especially in low-income counties.
- **Long-Term Adaptation Strategies:** Much of the current research focuses on short-term adaptation measures. There is a need for more studies on long-term adaptation strategies that consider future climate scenarios and their potential impacts on development pathways.
- **Economic and Financial Mechanisms:** Research on economic and financial mechanisms to support climate-resilient development remains limited. This includes analyzing the costs and benefits of various adaptation measures and identifying sustainable financing options. Developing counties struggle to access the funds directly from climate funds or other sources, limiting their ability to build adaptation and resilience capacity.
- **Governance and Institutional Frameworks:** Effective governance and institutional frameworks are crucial for implementing climate resilience strategies. However, there is a lack of research on designing and operationalizing these frameworks, particularly in low-income and vulnerable regions
- **Monitoring and Evaluation:** There is a need for robust monitoring and evaluation systems to assess the effectiveness of climate resilience initiatives. Research should focus on developing indicators and methodologies to track progress and identify areas for improvement.

Advancing knowledge and practice in climate resilience requires addressing several key areas through future studies. Here are some suggested areas for research:

- **Localized Climate Risk Assessments:** More detailed and localized or downscaled climate risk assessments are needed to understand the specific impacts of climate change on different regions and communities. This includes developing high-resolution climate models and integrating local knowledge to improve accuracy and relevance.
- **Social Dimensions of Resilience:** Research should focus on the social dimensions of climate resilience, including gender, disability, and social inclusion (GEDSI). Understanding how these factors influence vulnerability and resilience is essential for designing inclusive and effective adaptation strategies, especially in low-income countries.

- **Long-Term Adaptation Strategies:** There is a pressing need for studies on long-term adaptation strategies that account for future climate scenarios and their potential impacts on development pathways. This includes exploring innovative approaches to urban planning, agriculture, and water management that can endure and adapt to long-term climate changes.
- **Economic and Financial Mechanisms:** Investigating economic and financial mechanisms to support climate-resilient development is crucial. This includes analyzing the costs and benefits of various adaptation measures, identifying sustainable financing options, and exploring the role of insurance and risk transfer mechanisms. Accesses to funds from Climate Funds and other sources need to be simplified and/or low-income counties should be supported in building the capacity to access these funds directly.
- **Governance and Institutional Frameworks:** Effective governance and institutional frameworks are essential for implementing climate resilience strategies. Research should focus on designing and operationalizing these frameworks, particularly in low-income and vulnerable regions.
- **Monitoring and Evaluation Systems:** Developing robust monitoring and evaluation systems to assess the effectiveness of climate resilience initiatives is vital. This includes creating indicators and methodologies to track progress and identify areas for improvement.
- **Nature-Based Solutions (NbS):** Research on NbS for climate resilience, such as wetland restoration, urban green spaces, and agroforestry, can provide valuable insights into sustainable and cost-effective adaptation strategies. Studies should explore the effectiveness, scalability, and co-benefits of NbS.
- **Community-Based Adaptation:** Investigating community-based adaptation strategies can provide practical insights into how local communities can enhance their resilience. This includes exploring participatory approaches, traditional knowledge, and local innovations in climate adaptation.
- **Technological Innovations:** Research on technological innovations, such as climate-smart agriculture, renewable energy, and advanced data analytics, can significantly support climate resilience efforts. Future studies should focus on the development, deployment, and scaling of these technologies across various sectors and geographic contexts.

Climate-resilient development in Cambodia has made significant progress, but several gaps need to be addressed to improve understanding and implementation of effective resilience strategies. Key gaps include a lack of detailed climate risk data at the local level and lack of comprehensive integration of social dimensions such as gender, disability, and social inclusion (GEDSI). While long-term adaptation strategies are already in places, considering future climate scenarios and their potential impacts on development pathways, economic and financial mechanisms to support climate-resilient development are limited, with developing counties such as Cambodia struggling to access funds directly from climate funds or other sources. Research on designing and operationalizing these frameworks, particularly in low-income and vulnerable regions, is needed to build an effective governance framework to execute climate resilience strategies, including monitoring and evaluation systems. Research should focus on localized climate risk assessments, social dimensions of resilience, long-term adaptation strategies, economic and financial mechanisms, governance and institutional frameworks, monitoring and evaluation systems, nature-based solutions (NbS), community-based adaptation, and technological innovations. In conclusion, addressing these gaps in climate-resilient development research is crucial for advancing knowledge and practice in this area. Future studies should focus on localized climate risk assessments, social dimensions of resilience, long-term adaptation strategies, and technological innovations to better understand and implement climate resilience strategies.

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