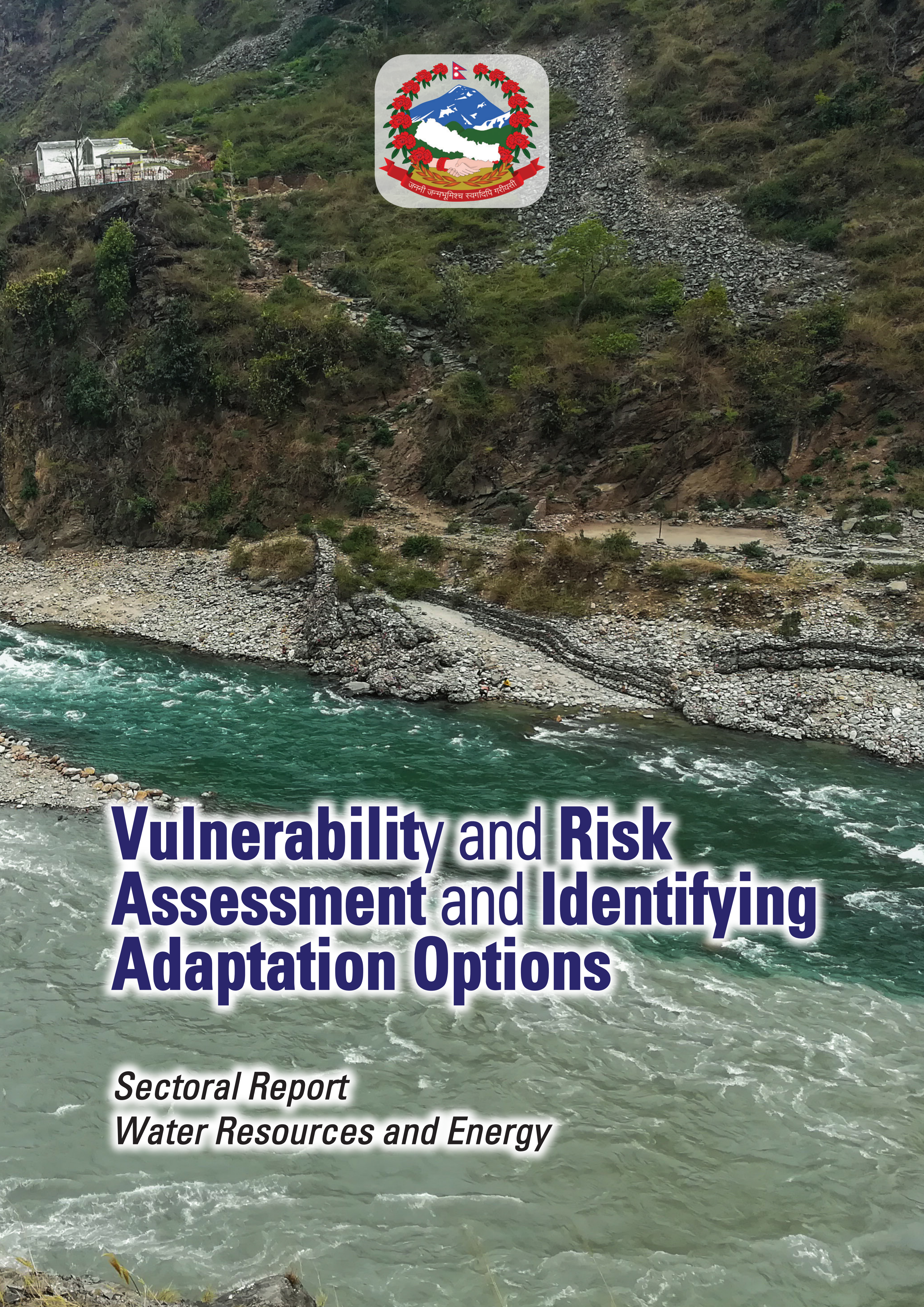

Vulnerability and Risk Assessment and Identifying Adaptation Options

Sectoral Report

Water Resources and Energy

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Foreword

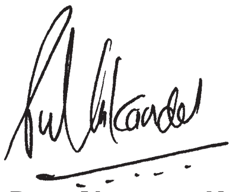
Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. The latest IPCC report confirms that human activities have changed our climate and led to the more frequent heatwaves, floods, droughts, and wildfires that we have seen recently. The evidence is incontrovertible. This highly influential report provides the evidence base and impetus to develop policy strategies and practices that will help people around the world and in Nepal live with and adapt to change.

Nepal has been a pioneer in the development and implementation of effective adaptation policies and practices. Nepal has made a strong commitment to updating a mid-long term National Adaptation Plan (NAP) every ten years, as well as conducting a National level Vulnerability and Risk Assessment every five years to inform climate resource allocation policies. Vulnerability and Risk Assessment (VRA) was initiated to assess vulnerability and risk at the national, physiographic, province, municipal, and sector levels to inform the Government of Nepal's current NAP formulation process.

I am pleased to see that the VRA report on Water resoruces and Energy was prepared by identifying sector-specific current vulnerability and future risk based on a solid scientific foundation and information. This report is the result of a thorough consultation process with national and provincial stakeholders and experts. This report, I believe, provides an opportunity for policymakers, decision-makers, and practitioners to make informed decisions about sector-specific vulnerability and risk to build a climate-resilient society and reduce the impacts of climate change at the local, provincial, and federal levels.

On behalf of the Ministry of Forests and Environment, I would like to thank the distinguished Chair - the Joint Secretary of the Ministry of Water Resources, Energy and Irrigation, and all the respected thematic group members who provided technical guidance to finalize this report. In addition, I gratefully acknowledge the assistance provided by the Climate Change Management Division, particularly Dr Radha Wagle and all technical committee members.

I also take this opportunity to acknowledge the funding and technical support of the British Embassy Kathmandu, and Policy and Institutions Facility (PIF) /Oxford Policy Management Limited.



Dr Pem Narayan Kandel
Secretary
Ministry of Forests and Environment (MoFE)

Acknowledgment

The National Climate Change Policy (2019) identifies eight thematic areas and four cross-cutting areas which will be impacted by climate change. As such, there is a pressing need to understand how public and private investments might be impacted. Without adequate information on risks and vulnerability, it will be difficult to translate policy into action. To plan and implement a successful adaptation strategy, it is vital to understand the likely impacts of climate change on different sectors and communities, and, in particular, how these may evolve in the future.

A National Adaptation Plan (NAP) needs to be developed based on a strong scientific foundation and reliable evidence. This includes data and information about how the climate has evolved in the recent past and how it may further change in the future. To realise this, the MoFE has carried out detailed Vulnerability and Risk Assessments (VRAs) of the thematic areas identified by the National Climate Change Policy at the municipal, district, and regional scales. The VRA framework and methodology presented in the report are based on the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and the NAP technical guidelines of the UNFCCC.

This VRA report contributes to the establishment of a strong baseline for climate change impacts, risks, and vulnerabilities in Nepal. In particular, it presents relevant information on social and structural vulnerabilities and risks triggered by the interaction of climate change and socio-economic, governance, political and cultural norms and practices. The report also offers a range of adaptation options for reducing root causes of vulnerability and risk, including enhancing social inclusion and reducing gender disparity.

On behalf of the Climate Change Management Division (CCMD), I would like to extend my appreciation to the chair, vice-chair, member secretary, and all the members of the Thematic Working Groups (TWGs) on Water Resources and Energy for providing guidance and input in the VRA process. Also, I acknowledge the input provided by federal, provincial, and local governments, national and international organizations, community-based organizations, and communities.

Special thank goes to the technical committee members Raju Sapkota, Dr Arun Prakash Bhatta, Srijana Shrestha, Hari Pandey, Dr Indira Kandel, Gyanendra Karki, and Dr Bimal Raj Regmi who supported and facilitated the VRA process. We would also like to thank Pabitra Gurung, Dinanath Bhandari, Bamshi Acharya, Basana Sapkota, Dr Shiba Banskota, Dr Nilhari Neupane, Apar Paudyal, Dr Ram Prasad Lamsal, Dr Pashupati Nepal, Dr Bhogendra Mishra, Regan Sapkota, Pratik Ghimire, Rojy Joshi, Goma Pandey, and Prashamsa Thapa, from the PIF, who provided technical insights and were involved in producing this report.

Besides, I also take this opportunity to acknowledge the funding and technical support of the British Embassy Kathmandu, and Policy and Institutions Facility (PIF) /Oxford Policy Management Limited.

Dr Radha Wagle
Joint Secretary
Climate Change Management Division
Ministry of Forests and Environment (MoFE)

List of Acronyms

ADPC	Asian Disaster Preparedness Centre
ADR	Adaptive Capacity Rank
AEPC	Alternative Energy Promotion Centre
AFS	Agriculture and Food Security
AGDP	Agriculture Gross Domestic Product
AR5	Fifth Assessment Report
CAF	Cancun Adaptation Framework
CBS	Central Bureau of Statistics
CDD	Consecutive Dry Days
CEEs	Climate Extreme Events
CIHs	Climate-Induced Hazards
COP	Conference of the Parties
CO-eq	Carbon Dioxide Equivalent
CSD	Cold Spell Duration
CSDI	Cold Spell Duration Index
CSOs	Civil Society Organizations
CWD	Consecutive Wet Days
DEM	Digital Elevation Model
DHM	Department of Hydrology and Meteorology
DJF	December, January, and February (Winter Season)
DNPWC	Department of National Parks and Wildlife Conservation
DOA	Department of Agriculture
DOED	Department of Electricity Development
DOFSC	Department of Forests and Soil Conservation
DOLIDAR	Department of Local Infrastructure Development and Agriculture Roads
DOR	Department of Roads
DOS	Department of Survey
DRRM	Disaster Risk Reduction and Management
DWIDM	Department of Water Induced Disaster Management
DWRI	Department of Water Resources and Irrigation
DWSSM	Department of Water Supply and Sewerage Management
EIA	Environmental Impact Assessment
EM-DAT	Emergency Events Database
ER	Exposure Rank
FBWM	Forests, Biodiversity and Watershed Management
FMIS	Farmer Managed Irrigation System
GDP	Gross Domestic Product

GESI	Gender Equality and Social Inclusion
Gg	Giga-gram
GHG	Green House Gas
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Flood
GON	Government of Nepal
GRDB	Groundwater Resource Development Board
HKH	Hindu Kush Himalaya
HR	Hazard Rank
H-WatSan	Health, Water and Sanitation
IBN	Investment Board Management
ICIMOD	International Centre for Integrated Disaster Management
ICT	Information and Communication Technology
IEE	Initial Environmental Examination
IITM	Indian Institute of Technology Madras
IOE	Institute of Engineering
IPCC	Intergovernmental Panel on Climate Change
IPPAN	Independent Power Producers' Nepal
IWMI	International Water Management Institute
JJAS	June, July, August, and September (Monsoon Season)
JMIS	Joint Management Irrigation System
KU	Kathmandu University
LBFC	Local Bodies Fiscal Commission
LDC	Least Developed Countries
LDOF	Landslides Dam Outburst Flood
LEG	LDC Expert Group
MAM	March, April, and May (Pre-monsoon Season)
masl	Metre above sea level
MAX	Maximum
MIN	Minimum
MOEWRI	Ministry of Energy Water Resources and Irrigation
MODIS	Moderate Resolution Imaging Spectroradiometer
MOF	Ministry of Finance
MOFAGA	Ministry of Federal Affairs and General Administration
MOFE	Ministry of Forests and Environment
MOHA	Ministry of Home Affairs
MOPE	Ministry of Population and Environment
MUS	Multiple Use System
NAP	National Adaptation Plan
NAPA	National Adaptation Programme of Action

NEA	Nepal Electricity Authority
NPC	National Planning Commission
NPR	Nepalese Rupees
P-ROR	Peaking Run-Of-River
ON	October and November (Post-monsoon Season)
OPM	Oxford Policy Management
PCP	Precipitation
PIF	Policy and Institutions Facility
PDGL	Potentially Dangerous Glacial Lake
PWD	People With Disability
ROR	Run-Of-River
RUS	Rural and Urban Settlements
RR	Risk Rank
RCPs	Representative Concentration Pathways
SDG	Sustainable Development Goal
SR	Sensitivity Rank
SREX	Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SWAT	Soil and Water Assessment Tools
TC	Technical Committee
TIPI	Transport, Industry, and Physical Infrastructure
TMP	Temperature
TNCH	Tourism, Natural and Cultural Heritage
TU	Tribhuvan University
TWG	Thematic Working Group
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UOG	University of Guelph
USGS	United States Geological Survey
VR	Vulnerability Rank
VRA	Vulnerability and Risk Assessment
WatRES	Water Resources and Energy Sector
WECS	Water and Energy Commission Secretariat
WIP	Water Poverty Index
WSD	Warm Spell Duration
WSDI	Warm Spell Duration Index
WUA	Water Users Association
WUCS	Water Users and Sanitation Committee
WUMP	Water Use Master Plan

Executive Summary

The Himalayan region is considered a water tower that plays a critical role in the livelihoods of people dependent on the glacier-fed river system. Nepal is endowed with abundant water resources with the potential to generate hydroelectric power, furnish water for irrigation, and supply water for domestic and industrial use. Over the years, observed climate variability and extreme events are found to have major impacts and higher economic costs in Nepal. Nepal is at high risk in the future from the adverse effects of climate change due to topographical diversity, fragile geological structure, sensitive ecosystems, and the diversity of climate and micro-climatic zones. Nepal is also the most vulnerable country to climate change compared to other least developed countries due to its limited adaptive capacity.

Vulnerability and Risk Assessment (VRA) is a crucial step in adaptation planning and implementation. The overall objective of this assessment is to assist Nepal's NAP process in assessing climate-related hazards and vulnerabilities and to identify practical adaptation options at the sectoral, local, provincial, and national levels in the Water Resources and Energy Sector (WatRES). The assessment adopted the Government of Nepal's national framework for the VRA, which is based on the IPCC–AR5. The IPCC framework considers risk as a function of hazard, exposure, and vulnerability. The national VRA framework assumes that the risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the exposure and vulnerability of human and natural systems. Changes in the climate system (trends and scenarios), the biophysical system, and socio-economic processes (including governance and adaptation and mitigation actions) are drivers of hazards, exposure, and vulnerability.

In this assessment, the water resources and energy have been analyzed separately as sub-sectors of WatRES. The district-wise data were collected from authentic sources, based on the indicators of the four VRA components: hazards, exposure, sensitivity, and adaptive capacity. The primary sources of the data were collected from government institutions followed by national and international institutions. The data has been collected at the district level and consolidated at the provincial and national levels. The assessment is integrated with cross-cutting areas, including (a) Gender Equality and Social Inclusions (GESI), (b) Socio-Economic Trends and Scenarios, and (c) Livelihood and Governance. The assessment has been carried out in consultation with the Thematic Working Group (TWG), Technical Committee (TC), and representatives of provincial stakeholders. In the provincial level meetings, TWG was led by the Ministry of Energy Water Resources and Irrigation (MOEWRI), and TC was led by the Ministry of Forests and Environment (MOFE).

As a part of the assessments, the multi-criteria decision-making approach was adopted in the analysis to identify the significance of the various indicators associated with the hazard, exposure, sensitivity, and adaptive capacity in the sector affected by climate change. The weightage of the indicators has been identified through sectoral experts. The experts were selected according to their contributions to the relevant WatRES sector and its sub-sectors i.e. TWG members, government officials, professors from national and international universities, and researchers from national and international research institutions.

The assessment used 20 indicators of hazard, 30 indicators of exposure, 35 indicators of sensitivity, and 20 indicators of adaptive capacity. These indicators were further categorized by elements based on their nature. Subsequently, there were 3 categories of hazard, 11 elements of exposure, 13 elements of sensitivity, and 8 elements of adaptive capacity. The data has been processed at the district level and consolidated at the province and physiographic levels. The processed data of the indicators have been normalized. The indicators are then composited element-wise by applying the weights received from the expert survey. Through this process, the rank of the districts, provinces, physiographic regions, subbasins, and watersheds have been determined separately for the VRA components, where the rank classes have been conducted using the 'Jenks Natural Breaks' method. The VRA components were consolidated to determine the vulnerability and risk ranks at the district, province, physiographic, subbasin and watershed level of the sector and sub-sectors. Based on the results of the vulnerability and risk rank, associated literature, and provincial consultation meetings, the possible adaptation options are identified and listed.

The observed impact of climate change in the water resources and energy sectors was found to be both physical as well as socio-economic. With the changes in temperature and precipitation, Nepal has already observed changes in the water balance, runoff, and the timing of water availability. There is evidence of changes in the snow and glacier melt pattern, rainfall variability, extreme weather events, streamflow and drought, soil erosion, mass-wasting, sediment deposition, changes in land cover, land use, and soil pattern, and ultimately altered water availability due to water-induced hazards. There are cases observed where extreme events damage or destroy the water services sector, hydropower plants, other infrastructures, and sources of alternative energy and caused the loss of human life and properties. The glacial lakes are formed behind moraine dams on loose and unconsolidated material and unstable lakes have resulted in the form of landslide dammed outburst floods and GLOFs to the downstream communities and damaged the infrastructure.

In the water resources and energy sector, Dang, Dhading, Dhanusha, Gorkha, Ilam, Jhapa, Kapilbastu, Kaski, Kathmandu, Morang, Rupandehi, Sankhuwasabha, Sindhupalchok, and Solukhumbu fall in the high exposure category in comparison to other districts of Nepal. The analysis shows that the dominant indicators for making the districts at higher exposure rank are the area of glaciers; water available at surface and ground; drainage length; the number of irrigation canals; the total area of agricultural lands, potential irrigable lands, and non-irrigated agricultural lands; total number of the male and female population; number of hydropower plants; length and capacity of both transmission and distribution lines; and household dependency on sources of traditional energy for cooking.

The sensitivity ranking was found high in Arghakhanchi, Baglung, Baitadi, Bajura, Dailekh, Dhading, Dolakha, Gorkha, Gulmi, Jumla, Kailali, Morang, Myagdi, Okhaldhunga, Sindhupalchok, Solukhumbu, and Western Rukum in comparison to other districts of Nepal. The analysis shows that the dominant indicators for making the districts at higher sensitivity ranks are the trend of change in groundwater flow and net water yields; drainage density; the average slope of the topography; area of loamy soils; area of the lake, river bed and snow cover; the trend of change in barren lands; households dependent on tube well/hand pump and covered well/kuwa; drinking water demand and supply status; irrigation water used from pond/lake; sex ratio; child population (boys and girls); the number of hydropower plants by capacity and by water conveyance systems; the number of under construction and under survey hydropower plants; the number of hydropower plants owned by the private sector; and the number of households dependent on wood/firewood for cooking.

High adaptive capacity was observed in Kaski, Kathmandu, and Sankhuwasabha, whereas the districts with very low adaptive capacity rank are Baitadi, Bajhang, Bajura, Dailekh, Darchula, Dolpa, Eastern Rukum, Humla, Jumla, and Okhaldhunga. The result shows that the dominant indicators for higher adaptive capacity ranks are the trends of reforestation/afforestation water conservation; trends of terrace farming for water retention; access to climate information; the number of wetlands conservation initiatives; total usable water for irrigation; number of bio-engineering practices; agricultural land with operational irrigation systems, Gender Development Index (GDI); and the electrification coverage status.

The vulnerability is determined by subtracting the composite adaptive capacity values of the districts from the composite sensitive value of respective districts. The overall result shows that the districts at very high vulnerability ranks are Arghakhanchi, Baglung, Baitadi, Bajhang, Bajura, Dailekh, Darchula, Dolpa, Eastern Rukum, Gulmi, Humla, Jumla, Okhaldhunga, and Western Rukum. On the contrary, the districts at very low vulnerability ranks are Achham, Banke, Bara, Bardiya, Bhaktapur, Dadeldhura, Dang, Dhankuta, Kathmandu, Parsa, Rautahat, Saptari, Sarlahi, Sindhuli, and Sunsari. In terms of vulnerability assessment of watersheds and sub-river basins, the findings show that most of the watersheds in Bagmati Province, Gandaki Province, Lumbini Province, Karnali Province, and Sudurpaschim Province are highly vulnerable. Furthermore, the result shows that the sub-basins of the Karnali river basin have a higher vulnerability to climate change impacts.

The overall result of climate change risk analysis shows that the districts at very high-risk rank are Chitwan, Dhading, Gorkha, Kailali, Morang, Sindhupalchok, and Solukhumbu. On the other side, the districts at very low-risk rank are Arghakhanchi, Bardiya, Bhaktapur, Dadeldhura, Dhankuta, Eastern Rukum, Kathmandu, Lalitpur, Parasi, Salyan, and Terhathum. Future projected scenarios show that Morang, Solukhumbu, Sindhupalchok, Dhading, Gorkha, and Kailali are the common districts in all four future projected scenarios – RCP 4.5 and RCP 8.5 in the 2030s and 2050s that are at very high-risk rank; whereas Dhankuta, Kathmandu, Bhaktapur, Salyan, Bardiya, and Dadeldhura are the common districts that are at very low-risk rank in comparison to other districts of Nepal.

In the watershed and sub-river basin, the baseline risk of climate change impact shows that few watersheds in Province 1, Bagmati Province, Gandaki Province, and Sudurpaschim Province are impacted by climate change. In addition, for sub-basin level risks, the findings show that Province 1, Gandaki Province, Karnali Province, and Sudurpashim Province are impacted. The watershed level risks analysis shows that in RCP 4.5 in 2030, except Karnali, all other provinces will be experiencing risks of climate change impact. The risks of climate change impact will be extending to all the provinces in RCP 8.5 in 2030. In 2050, the risks of climate change impact on watersheds will be severe. However, in RCP 8.5 in 2050, there will be a slight decrease in risks of climate change impact. In terms of sub-basin level risk, the findings show that in RCP 4.5 in 2030, the risks of climate change will be higher in Province 1, Bagmati Province, Gandaki Province, and Karnali Province. Besides, in RCP 8.5, the risks of climate change impact will be higher in additional provinces such as Province 2 and Lumbini Province. In 2050, under both scenarios, the risks of climate change impact will be higher in Province 2, Bagmati Province, Gandaki Province, Lumbini Province, Karnali Province, and parts of Sudurpaschim Province.

The adaptation options listed for the sub-sectors are proposed to address the adverse impact of climate change. The adaptation options were identified through policy review (water resource policy, white paper, fifteenth five-year plan, etc.), literature review, consultation with provincial and local level stakeholders, and suggestions from the experts and Thematic Working Group (TWG) members. The key priority adaptation strategies required for the water resources sector are – (a) promote Integrated River Basin Management (IRBM) approach and modalities for total available resource accounting, addressing climate adversities (high seasonal fluctuation of river flow; risks from climate-induced disasters; spatial and temporal water scarcity) and maximizing benefits (hydropower, food security, irrigation, and water supplies); (b) enrich the spatial coverage of the hydro-metrological measurements and monitoring stations in every district, particularly focused on the mountainous region of Nepal; (c) evaluate the water availability in every watershed, river basin, sub-basin and Palika with robust modelling activities and map the floods risk zoning for all the river systems of Nepal; (d) and promote and develop water recharge, retention, and reuse interventions to conserve/preserve and equitable distribution among the beneficiaries for the water security.

The energy sector is another important sector for generating adaptation and mitigation co-benefits and important for building resilience and security of the energy sector. The key adaptation strategies in the sector are: (a) enhance a more detailed understanding of changes in the hydrological cycle and its uncertainty. Also analyzing future risks on infrastructure (dams and hydropower plants, roads, and transmission lines); (b) ensure reservoir operation, to adjust rule curves by the climate change in different periods for the smooth operation and production. Similarly, increase the height of dams, reducing the annual sediment inflow to reservoirs, utilize unwanted spills, and modify existing spillways to increase discharge capacity fuse-gate/plugs; (c) diversify energy use opportunities by identifying relevant sources of energy based on geographical location, locally available resources, and minimizing environmental degradation; and (d) ensure public and private partnership for promoting renewable energy technologies and make them accessible to everyone and every corner.

One of the major challenges of climate-induced hazards will be potential implications for the hydropower and irrigation sector. Seasonal variability will impact hydropower efficiency and production. Besides, the government plan of river diversion might also be impacted by the fluctuations in the river flow. Climate-induced disasters such as floods, LDOF, landslides, GLOF will damage the infrastructure and impact energy generation and large-scale irrigation. To protect the huge development investment in the sector, there is an urgent need to increase awareness of hydropower developers/investors and the private sector as a whole. This needs to be supported with policy instruments such as regulations to in-build climate vulnerability and risk in the hydropower and irrigation design and adoption of necessary risk mitigation measures in the sector.

This VRA study had some limitations in terms of data access and analysis. The scale of the assessment was district-level in order to maintain uniformity. Due to the demand in the water resources and energy sector, the watershed and river-basin level analyses were considered despite major issues related to the availability of data. This study used an indicator-based approach, hence relied mostly on secondary data sources. New modelling and research work was not within the scope of this study. Hence, this study could not analyze seasonal water variability and its relationship with changing climate.

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Chapter 1

Background and Sectoral Context

1.1 Water Resources and Energy Sector of Nepal

The mountain regions of Nepal are the major sources of water storage, in the form of snow, ice, and glaciers; and in the natural lakes, wetlands, and groundwater aquifers. The water resource and energy sectors are important national assets, boosting the country's socio-economic development and national GDP through irrigation, energy production, and domestic and industrial uses (WECS, 2011). The water resource is the wealth that provides livelihood services to millions of people in Nepal and downstream countries. Nepal's water resources cover 395,000 ha (48%) area within 45,000 km in length of 6,000 rivers with 170 billion m^3 annual runoff and 45,610 MW feasible hydroelectricity generations.

The rivers of Nepal are primarily dominated by melted snow and glaciers that originate from higher than 5,000 m elevations of the great Himalayas, which flows towards less than 100 m of elevation within Nepal (Kansakar et al., 2004). According to Irrigation Master Plan 2019 (DWRI, 2019), Kankai, Koshi-Bagmati Province, East-Churia, Narayani/Gandaki, West-Curia, West Rapti, Babai, Karnali-Mohana, and Mahakali, are the river basins of Nepal (Figure 1). The river basins of Nepal contain a total of 6,200 glaciers (both clear ice and debris-cover ice) and have a total glaciated area of 7,141 km^2 with estimated ice reserves of about 611 km^3 (ICIMOD, 2011). The Irrigation Master Plan 2019 stated the Koshi river basin has about 6,945 million m^3 of renewable groundwater resources. Likewise, the Narayani and Karnali river basins have about 2,767 million m^3 and 3,359 million m^3 of renewable groundwater resources respectively. Considering these statistics, the rivers are sufficient to fulfill the water and energy demand of the country now and in the future.

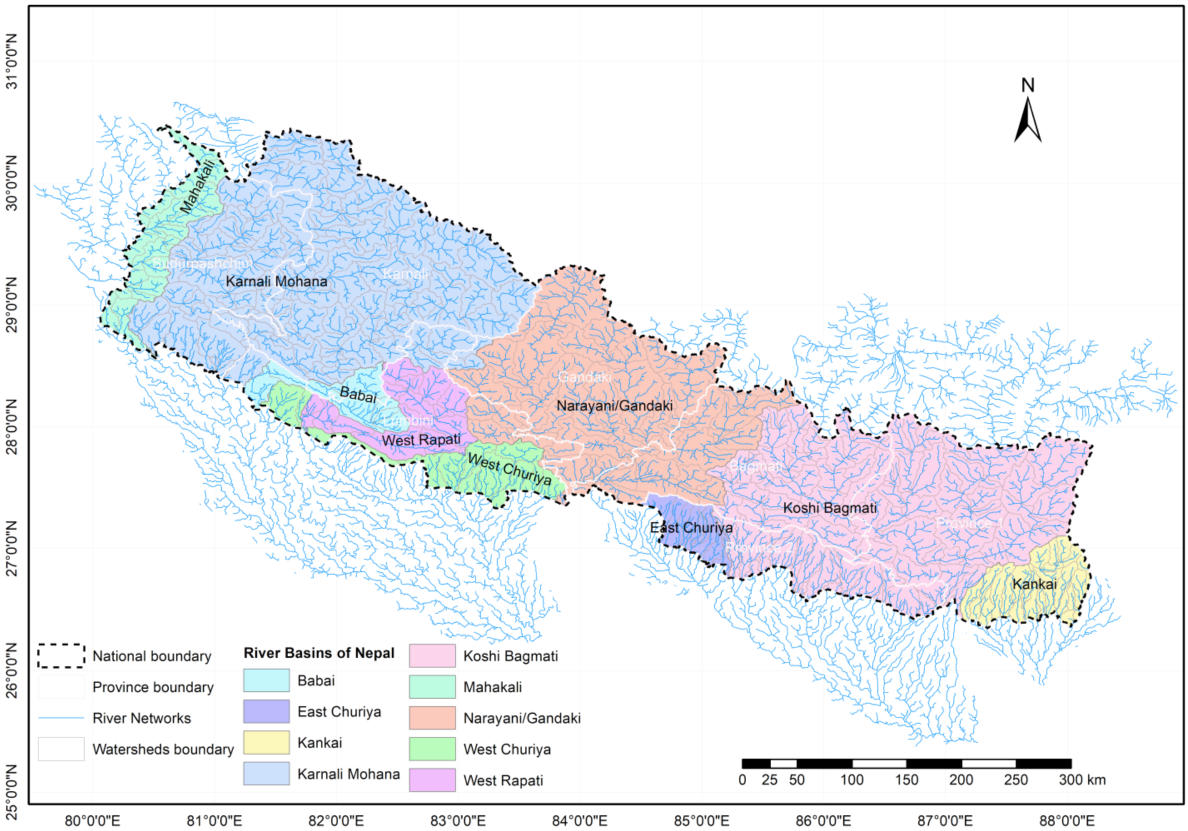


Figure 1: River basins of Nepal

1.1.1 Irrigation for agriculture development

In Nepal, approximately 40% of the total agricultural lands currently have irrigation facilities the Government of Nepal has ambitious goals to expand irrigated agricultural lands to meet the increasing demands for food over the next 25 years with additional investments (DWRI, 2019). According to the irrigation system inventory of the Department of Water Resources and Irrigation (DWRI), around 2,254 surface water irrigation systems are in operation which covers nearly 728,447 hectares of agricultural lands in Nepal (Figure 2). Among total surface water irrigated agricultural lands, the systems managed by Joint Managed Irrigation Systems (JMIS) cover nearly 357,053 hectares and by Farmer Managed Irrigation Systems (FMIS) cover nearly 371,394 hectares of agriculture lands; of which 81% of surface water irrigated agriculture lands are in Terai, 15% are in Hill and remaining 4% are in Mountain.

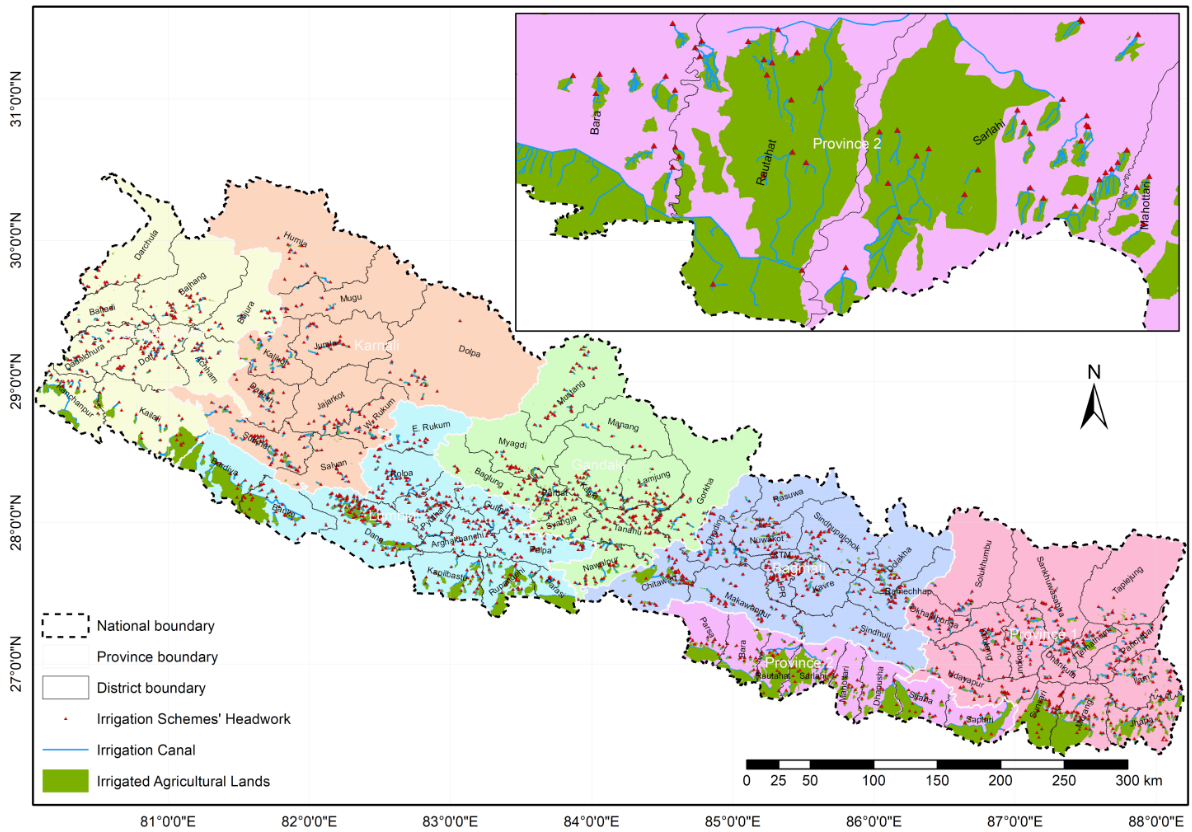


Figure 2: Irrigation schemes and irrigated agricultural lands

The livelihood of Nepal is mostly water-dependent: agriculture, forestry, fisheries, and energy. The agriculture sector (agriculture, forestry, and fisheries) is still the main source of livelihood for more than 65% of the population in Nepal, which contributes about 27% to the national Gross Domestic Product (GDP) (DWRI, 2019; MOF, 2019). Subsequently, the water footprint per dollar of AGDP (Agriculture GDP) is much higher. The changing climate and variability in climate extreme events may increase agricultural water demand in the future. Therefore, efforts should be made to streamline water usage without compromising livelihood outcomes in the near term. Nepal has higher per capita water availability (Luna Bharati et al., 2019; Ghimire et al., 2019; IWMI, 2019; Pandey et al., 2019, 2020; Pandit, 2020); however, its water resources have not been fully utilized (Chinnasamy et al., 2015) because the population is unable to invest in there use due to socio-economic constraints. For example, farmers rely on rain-fed irrigation but cannot afford water pumps to access water from rivers close by. Water scarcity is being driven by economic inaccessibility particularly in those communities that are below the poverty line. Likewise, a fishery is one of the water-dependent livelihood options which contribute to the national AGDP, however marginalized communities like Majhi and Hyau, who are socio-economically poor are not able to make it profitable due to their economic constraints.

1.1.2 Energy development

Water is critical for Nepal's power production as hydroelectric plants provide around 90% of the country's total electricity (MOSTE, 2013). The hydropower sector delivers a significant contribution of about 1.09% to the national GDP and its contribution will extend if it can reach its full potential capacity. It is one of the most prominent sectors and has the potential to extend its contribution towards national development. The total energy consumption in the fiscal year 2014/15 was about 500 million gigajoules, of which about 77.6% of the energy was from traditional fuels (wood, agriculture residue, and animal dung), 19.9% from commercial production (hydropower, coal, and petroleum), and 2.5% from renewable energy (solar, biogas and pico/micro/mini hydro). The sector can expand if it is allowed to utilize the water resources available.

Nepal's energy sector is undergoing a huge transformation as is illustrated by its new policies and regulations and white papers. It has been able to install hydropower plants with a capacity of 887 MW, which is only 1.7% of the total potential capacity of the country (MOPE, 2017a). Nepal plans to expand its electricity production by developing 580 hydroelectric projects. According to the data released by the Department of Electricity Development (DOED) on February 25, 2019, these 580 hydropower projects will be able to generate 32,396 MW of electric power in the future (WECS, 2017). DOED data of September 2021 shows that 115 hydropower plants are in operation, 140 are under construction and 225 are under survey, which includes hydropower plants owned by both government and the private sector.

Nepal's Terai plains contain large and mostly untapped reserves of renewable groundwater, which can be used to increase the water supply to irrigated agricultural land. This can be achieved primarily by introducing policies to promote the development of Nepal's hydropower potential to provide reliable and affordable energy for water pumping. The estimated direct economic gain from providing year-round irrigation to the unirrigated agricultural area in Terai is USD 1.1 billion, equivalent to 4.5% of Nepal's annual GDP in 2017 (Nepal et al., 2019) focusing on pathways to water security that originate in actions and policies related to other sectors. It identifies promoting development of Nepal's hydropower potential to provide energy for pumping as way to improve water security in agriculture. Renewable groundwater reserves of 1.4 billion cubic meters (BCM).

The white paper of the water and energy sector aims to generate 15,000 MW of electricity by 2030. It also aims to make major investments in the irrigation system and water conservation. According to the policy of the government, Nepal will be an energy-dependent country by 2022. The government intends to encourage all 753 local governments to install 500 kW solar and aims to increase 200 megawatts of solar energy by 2030. Moreover, Nepal also shows potential in wind energy development; however, this sector needs further study to map the actual scenarios that are economically sustainable.

1.1.3 Water-energy-food nexus

Marginalized and poor communities require financial support in order to have equitable access to the country's water resources. Despite prioritizing domestic requirements, conflicts regarding the amount of water used by hydropower, agriculture, fishery, and drinking water supply sectors continue. Studies could assist in developing an efficient water management plan by focusing on the Water Poverty Index (WPI), and the roles of marginalized groups and women in water management in the context of climate change (Thakur et al., 2017).

The demand for hydro and solar energy is increasing because it can help pump groundwater in the Terai, and lift water from the river to hills and mountains. It is becoming a common method in these regions and should be explored further so that its financial viability, practical use, and impact on the environment can be assessed.

The promotion of FMIS, Multiple Use System (MUS), and Water Use Master Plan (WUMP) would be good practices to improve water governance, gender participation, water use efficiency in energy and agriculture sectors in the socio-economic development (Rautanen et al., 2014; Rautanen & White, 2013) water-scarce and food-insecure regions, the Rural Village Water Resources Management Project has shown that integrated water resources management for both blue and green water is a must. Water use master plans (WUMPs).

1.2 Challenges in the Sector

Nepal is working with different kinds of challenges: it has problems within the water and energy sector that need to be addressed, and it is facing difficulties in developing its water and hydro-power sector. Within the water and energy sectors, the country is unable to fully capitalize on its freshwater resources and meet its growing electricity demand. When it comes to the development of the water and hydro-energy sector, it faces two major challenges: lack of appropriate hydro-climate data and the impact of climate change on (water) resources.

Nepal is unable to fully utilize its substantial freshwater resources for consumptive use in the water services area and energy development (Chinnasamy et al., 2015). The country is currently more focused on expanding irrigation coverage for agricultural lands, producing more hydroelectric power to meet its energy demands, and promoting the use of solar energy as a prominent source of alternative energy.

The estimated hydropower potential of Nepal is 83,000 MW. A recent study (WECS, 2017) has identified 114 projects with a total capacity of 45,610 MW as technically feasible and only 66 projects with a total capacity of 42,133 MW as economically feasible. Even though Nepal is endowed with large techno-economically feasible hydropower potential, the current generation is only around 1368 MW. With this installed capacity, Nepal is not able to fulfill the internal demand for electricity and depends on imports from India, particularly in the dry season (Upadhyay & Gaudel, 2018).

Attempts to develop its water and hydro-energy sector are stilted because Nepal does not have adequate and reliable hydro-climate data with well-distributed temporal and spatial coverage. There is a dearth of weather stations in the mountain regions of Nepal, and even fewer stations in its western region (DHM, 2017). The existing hydrological stations do not cover all the tertiary tributaries of the rivers of Nepal, and they are necessary for watershed planning and development. There is a lack of hydrological and meteorological stations in the rain-fed watershed where water security becomes a major challenge because of the adverse effects of extreme climate events.

Chapter 2

Objectives and Scopes

The impacts of climate change pose another challenge and they can be observed through the scarcity of water in the dry season and an excess of it during the monsoons (MOE, 2010). Water stress has directly impacted agricultural productivity, malnutrition, and human health and sanitation; excess water destroys human settlements, infrastructure, and farm fields (MOE, 2010). Climate change has led to the drying of water sources in the Middle Mountain region and floods in the Terai region of Nepal. Hydropower plants, especially the Run-of-River (ROR) types, are running under their capacity in the dry season and encounter too many sedimentation problems during the wet season. This is the major reason for the reduction in energy production from hydropower plants impacting the country's economy.

2.1 Objectives and Rationale

Vulnerability and Risk Assessment (VRA) is a critical step in the planning and implementation of adaptation strategies (IPCC, 2014), a key component of Element B of the Least Developed Countries (LDC) Expert Group (LEG) Technical Guidelines (UNFCCC, 2012). VRAs allow policy makers to make informed decisions; the goal of this VRA is to enhance adaptive capacity and build resilience among climate-vulnerable communities, geographical areas, physical infrastructure, and ecosystems in the water and energy sectors. Furthermore, it is to assist the process of Nepal's National Adaptation Plan (NAP) in assessing climate-related hazards and vulnerabilities and to identify practical adaptation options at sectoral, local, provincial, and national levels. These were its specific objectives:

- Assess water and energy sector's vulnerability to climate change, through applicable frameworks and ranking/categorizing associated climate risks and vulnerabilities.
- Identifying and categorizing adaptation options to these risks at multiple scales to address priority climate risks and vulnerabilities.

2.2 Scopes and Limitations

The VRA covers seven provinces, 77 districts, and five physiographic regions across Nepal. The district was the primary unit of analysis. The district-level results were clustered into the province-level analysis. Likewise, the physiographic region, watershed, and subbasin are another scale of analysis, whereby the risk and vulnerabilities of the five physiographic were categorized, analyzed, and presented. Based on the results and findings, districts, provinces, and physiographic regions are ranked and prioritized.

The VRA in the water and energy sector was based on secondary data and the indicators were selected depending upon their availability. The climate change VRA was introduced to identify the impacts and risks of climate change and adaptation options to support the policymakers, planners, and developers for sustainable climate-resilient development. Some key questions to limit the scope of the VRA were:

- Which systems, regions, or groups are exposed to climate change?
- What are the main climate vulnerabilities of those systems/regions/interest groups that demand climate risk management solutions to achieve their main development goals?
- What are the expected impacts of climate change: near-term (the 2030s) and medium-range (2050s) timelines based on the AR–5 projection scenarios?
- What are the most viable adaptation options to minimize climate impacts and maximize partnership and investment opportunities?

So the VRA process in this sector is primarily focused on addressing these questions. The scale of spatial analysis covers districts, provinces, and physiographic levels, which include the climate change projection scenarios of the 2030s and 2050s under RCP 4.5 and RCP 8.5 scenarios.

The sector is divided into two major sub-sectors: water resources and energy. These sub-sectors are further divided into 'water availability' and 'water services' under the water resources sub-sector and 'hydropower' and 'alternative energy' under the energy sub-sector (Figure 3). Based on this categorization, the indicators identified for the VRA are exposure, sensitivity, adaptive capacity, and hazards.

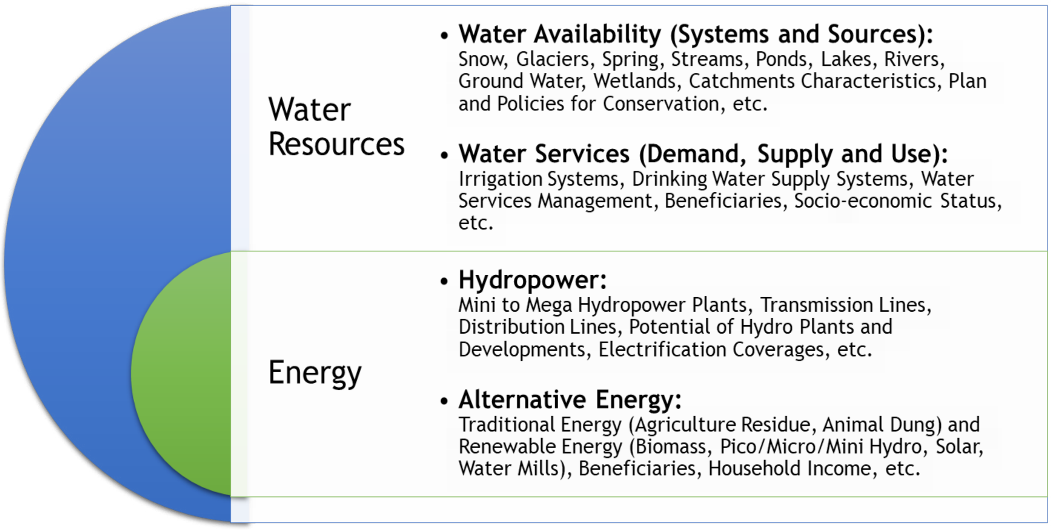


Figure 3: Subsectors considered in the assessment

This VRA study had some limitations in terms of data access and analysis. The scale of the assessment was district level to maintain uniformity in terms of carrying national-level risk and vulnerability assessment. Due to the demand in the water resources and energy sector, the watershed and river-basin level analysis were considered despite major issues related to the availability of data throughout the watersheds and river basins. This study used an indicator-based approach hence relied mostly on secondary data sources. New modelling and research work was not within the scope of this study. The study looked into the extreme events and the impact on water availability but could not analyze the seasonal water variability and its relationship with changing climate change including climate change impacts on extreme flow variations. The adaptation measures that have been listed are in a generic form which may vary for a particular specific river basin. For energy sectors, the specific adaptation measures for different hydropower project types could not be included in this study due to limitations in the scope of this assessment.

Methodology

3.1 The Framework of the Assessment

Nepal's NAP formulation process has developed a framework for the VRA based on the IPCC–AR5 and Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX). The IPCC framework considers risk as a function of hazard, exposure, and vulnerability. The developed framework unpacks the elements of risk and customizes them to the needs and applicability of the national context. Changes in the climate system (trends and scenarios), the biophysical system, and socioeconomic processes (including governance and adaptation and mitigation actions) are drivers of hazards, exposure, and vulnerability (IPCC, 2018).

This assessment is based on the climate change framework and the vulnerability and risk assessment framework of the Government of Nepal (MOPE, 2017b) (Figure 4). The analysis is based on measurable and quantifiable available secondary data.

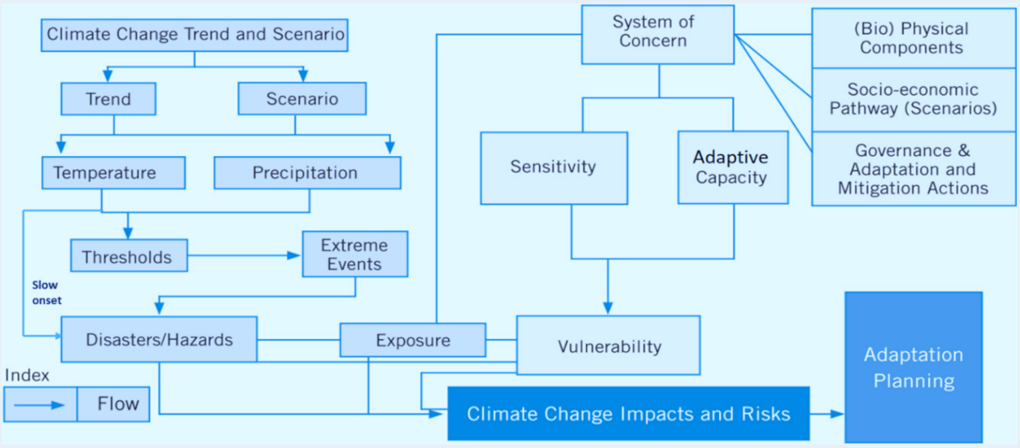


Figure 4: Climate Change Vulnerability and Risk Assessment Framework (MoPE, 2017b)

As described before, the key components of the VRA are hazards, exposure, sensitivity, adaptive capacity, vulnerability, and risk. According to the IPCC–AR5, vulnerability is a function of sensitivity and adaptive capacity (Equation 1) and the risk is a function of hazard, exposure, and vulnerability (Equation 2).

$V_{Index}=(S_{Index}-\ AC_{Index})$ ……………………..………. (Equation 1)

Where,
Vulnerability will justify, if $(S_{Index}-\ AC_{Index}) \geq 0$

And
$R_{Index}=(H_{Index}\ \times E_{Index}\ \times V_{Index})$ …………………… (Equation 2)

Where,
V_{Index} : Vulnerability Index;
E_{Index} : Exposure Index;
S_{Index} : Sensitivity Index;
H_{Index} : Hazard Index;
AC_{Index} : Adaptive Capacity Index; and
R_{Index} : Risk Index

Following the conceptual framework of the Government of Nepal, as well as Equation 1 and Equation 2, the methodological framework has been simplified further with additional information and steps. Figure 5 represents the overall methodological framework to assess climate change impacts and risks, which can be applied to all the sectors of the VRA process. Considering the Water Resources and Energy Sector (WatRES), the methodological framework for the identification of hazards, exposures, sensitivity, and adaptive capacity indexes are also explained further with additional information. This framework illustrates the cross-sectoral linkages and sources of data that need to be acquired. In the entire process, consultation within sectors, cross-cutting areas, thematic and technical teams, government line agencies, CSOs, and other sectors was the utmost priority to make the process acceptable for all.

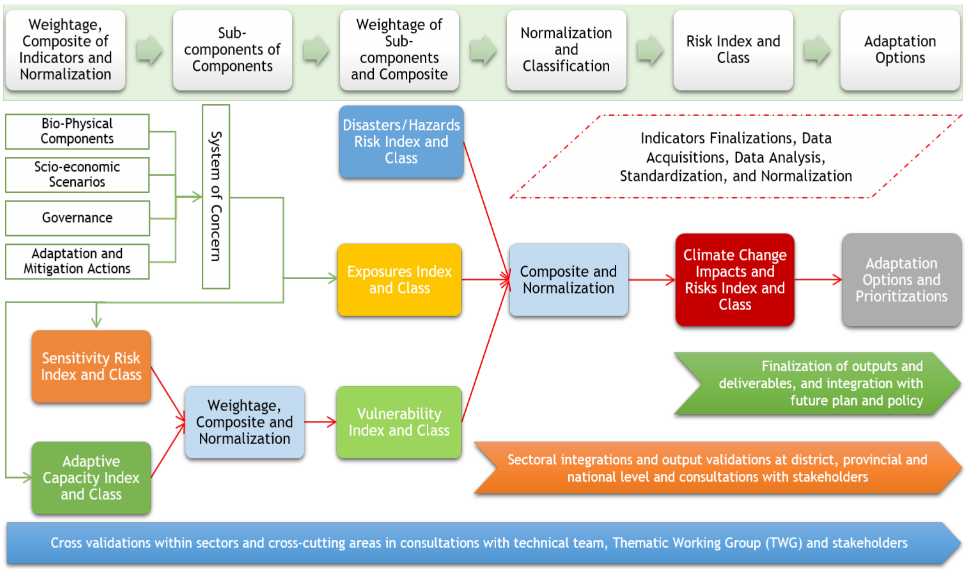


Figure 5: Process for VRA

3.2 Methodological Steps

There were nine detailed steps to the VRA assessment, as shown in Figure 6. The framework and the methodology of the VRA have been reviewed and updated according to the recent findings of the research and development in the water resources and energy sector. Required improvement has been conducted in consultation with the Thematic Working Group (TWG), Technical Committee (TC), and the VRA team members to have a common understanding and acceptance of everyone. The steps clearly explain the integration of Gender and Social Inclusion (GESI), livelihoods, and governance in the assessment.

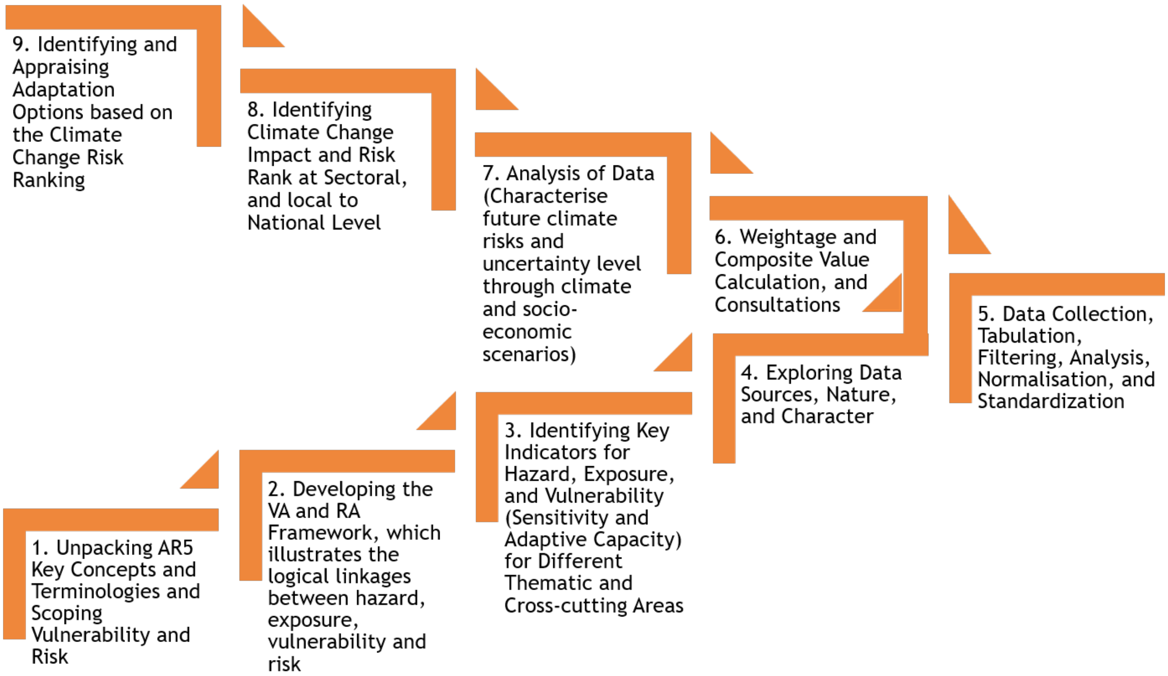


Figure 6: Detailed methodological steps of the assessment

As described in Figure 6, the steps of detailed methodology are - (1) Further description of the AR5 key concepts of the NAP and VRA processes, defining terminologies used and scoping the Vulnerability and Risk; (2) Develop the VRA frameworks and illustrating their logical linkages between the hazard, exposure, vulnerability and risk; (3) Identify the elements and indicators of hazard, exposure, sensitivity and adaptive capacity including the indicators that represent cross-cutting areas; (4) Explore authentic and reliable data sources and understanding their nature and linkage with changing climate; (5) Data collection and analysis for quality assurance, followed by the normalization and standardization of the collected data; (6) Identify the weightage of the elements, indicators and sub-sectors through expert survey and calculation of the indexes and consultation with TWG, TC and other line agencies at provinces; (7) Analysis of the data through the prospects of past trends of climate, future climate scenarios, its uncertainties and socio-economic scenarios; (8) Identify the climate change impact and risk in the sector at districts, provinces and physiographic level; and (9) Identify and appraising adaptation options according to the obtained climate impact and risk.

3.3 Data Analysis

This stage involves analyzing the data to identify trends in variables and highlight the ones that could be potentially useful in planning and decision-making. Data filtration and analysis are preceded simultaneously and cross-validated with other relevant sources. Figure 8 represents the different stages of data consolidation, filtration, normalization, analysis, composition, and production of final products. This step also involves characterizing broad future climate risks and levels of uncertainty through climate and socio-economic scenarios, with marginalized and vulnerable groups in mind. In this assessment, there are 18 members in the TWG and 31 experts for the indicators priority ranking, names, and designations of the members and experts are listed in Annex 2. Based on the priority ranking, the obtained weights of the indicators, elements, and sub-sectors of the VRA components are listed in Annex 3.

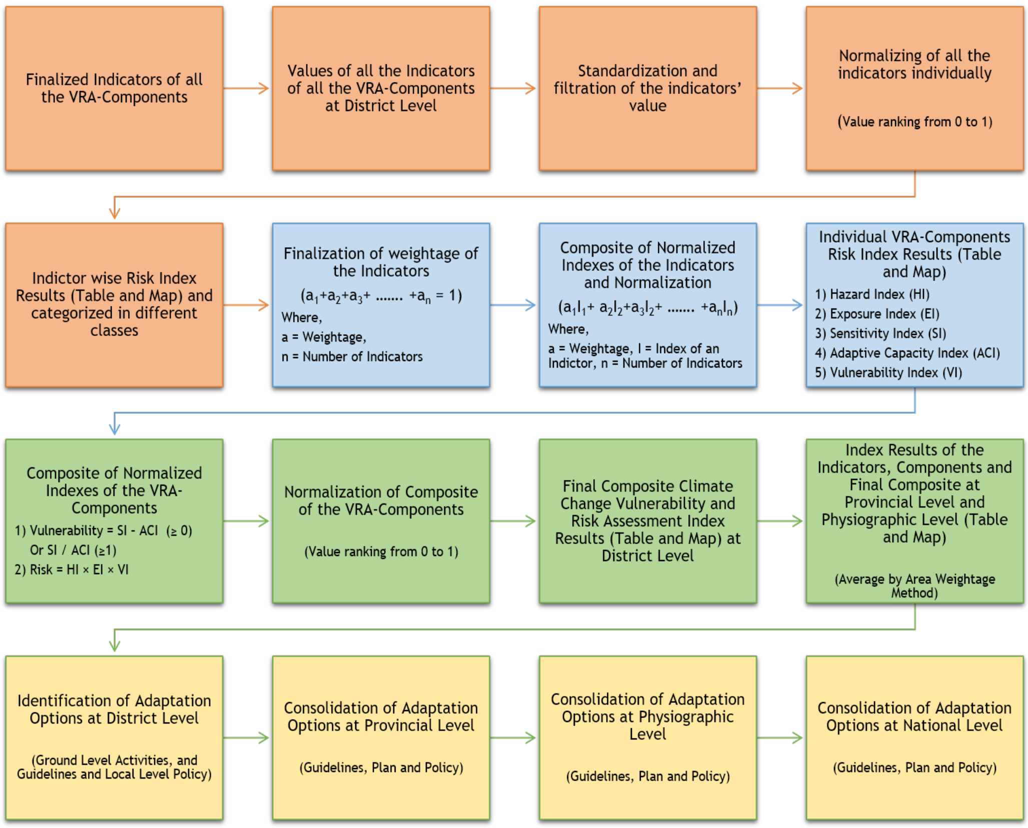


Figure 7: Stages of data acquisition, analysis, and overall risk rank results

3.3.1 Elements and indicators of the VRA components

According to MoPE (2017a), the exposure elements are grouped into four categories: water systems, hydropower, biomass energy, and energy demand. The elements of water systems that are exposed to change in climatic conditions are snow cover, glaciers, springs, groundwater, rivers, lakes, reservoirs, and wetlands. Similarly, the elements of hydropower that are exposed to change are hydropower plants and their transmission and distribution lines; and the beneficiaries of the water resources and energy. The degree of sensitivity of these exposed elements and the adaptive capacity of communities, physical infrastructure, and the natural system will define the scale of vulnerability. Thus the socio-economic status of the community, access to relevant technology, management practices, the capacity of the communities, and climate-resilient plans and policies need to improve to adapt to the impacts of climate change. Based on the elements and indicators defined by MOPE (2017b) as well as the literature review and status of data availability, the elements and indicators are further categorized according to the sub-sectors considered for the assessments. The elements/indicators of exposure, sensitivity, adaptive capacity, and hazards that were considered for the assessments are listed in Table 1, Table 2, Table 3, and Table 12 respectively.

Table 1: Elements and indicators of exposure

Sub-sector		Elements/Indicators		Units	Data Sources	Data Year
A. Water resources						
A.1	Water availability (systems and sources)	A.1.1	Water as snow cover and glaciers			
		a.	Snow cover area	km²	ICIMOD	2010
		b.	Number of glaciers	no.		
		c.	Area of glaciers	km²		
		d.	Area of glacier lakes	km²		
		A.1.2	Water as flowing/running water			
		a.	Ground water flow (as of springs/streams)	mm	DWRI, IWMI, UOG	1980-2012
		b.	Net water yields (as of larger streams)	mm		
		c.	Total water availability at rivers	MCM		
		d.	Drainage length	km	ICIMOD	2010
		A.1.3	Water as storage systems (lake/wetlands)			
		a.	Lakes and reservoirs area	km²	ICIMOD, MODIS	2001-2019
		b.	Wetlands area	km²		
A.2	Water service (demand, supply and use)	A.2.1	Irrigation systems and infrastructures			
		a.	Number of irrigation system	no.	DWRI	2019
		b.	Number of irrigation canal	no.		
		c.	Length of irrigation canal	km		
		A.2.2	Agriculture lands and irrigation status			
		a.	Total area of agriculture land	km²	DWRI, ICIMOD	2010, 2019
		b.	Potential area of irrigable land	km²		
		c.	Non-irrigated area of agriculture land	km²		
		A.2.3	Beneficiary of water services			
		a.	Total male population	no.	CBS	2011
		b.	Total female population	no.		
B. Energy						
B.1	Hydropower	B.1.1	Hydropower plants			
		a.	Number of hydropower plants	no.	DOED	2020
		b.	Total installed capacity	MW		
		B.1.2	Transmission lines			
		a.	Length of transmission lines	km	NEA	2020
		b.	The capacity of transmission lines	kV		
		B.1.3	Distribution (feeder) networks			
		a.	Length of distributions (feeder) networks	km	NEA	2020
		b.	The capacity of distributions (feeder) networks	kV		
B.2	Alternative energy (traditional and renewable)	B.2.1	The beneficiary of alternative energy			
		a.	Traditional energy for cooking[11]	HHs	CBS, AEPC	2011, 2020
		b.	Renewable energy for cooking[22]	HHs		
		c.	Renewable energy for lighting	HHs		
		B.2.2	Hydro as alternative energy			
		a.	Total number of pico/micro/mini hydro	no.	AEPC	2020
		b.	Total capacity of pico/micro/mini hydro	kW		
		c.	Improved water mills	no.		

Table 2: Elements and indicators of sensitivity

Sub-sector		Elements/Indicators		Units	Data Sources	Data Year
A. Water Resources						
A.1	Water availability (systems and sources)	A.1.1	Water as snow cover and glaciers			
		a.	Trend of change in snow cover area	km^2/year	MODIS	2001-2019
		A.1.2	Water as flowing/running water			
		a.	Trend of change in ground water flow (as of springs/streams)	mm/year	DWRI, IWMI, UOG	1980–2012
		b.	Trend of change in net water yields (as of larger streams)	MCM/year		
		c.	Trend of change in total water availability at river reaches	MCM/year		
		d.	Drainage density	km/km^2	ICIMOD	2010
		A.1.3	Water as storage systems (lake/wetlands)			
		a.	Trends of change in lakes and reservoirs area	km^2/year	MODIS	2001–2019
		b.	Trends of change in wetlands area	km^2/year		
		A.1.4	Catchment characteristics			
		a.	Slope/Topography	%	USGS	2014
		b.	[3]Soil Class (Texture) and Area	km^2	DOS, ICIMOD	2010
		c.	Trend of Change in [4]Land Use/Land Cover Area	km^2/year	MODIS	2001–2019
A.2	Water services (demand, supply and use)	A.2.1	Households dependency on main sources of drinking water			
		a.	Tap/piped water	%	CBS, DWSSM	2011–2015
		b.	Tube well/hand pump	%		
		c.	Covered well/kuwa	%		
		d.	Uncovered well/kuwa	%		
		e.	Spout water	%		
		f.	Rivers/stream	%		
		A.2.2	Water demand and supply (surplus or deficit) status			
		a.	Drinking water supply and demand	%	IWMI, UOG, CBS	1980–2012
		b.	Irrigation water supply and demand	%	DWRI, IWMI, UOG, CBS	1980–2019
		A.2.3	Irrigation systems and operations			
		a.	Average age of the irrigation system	Years	DWRI	2019
		b.	[5]Type of water sources used for irrigation	%		
		c.	[6]Functional status of irrigation systems	%		
		d.	[7]Irrigation scheme types by project size	%		
		A.2.4	GESI status of beneficiaries of water services			
		a.	Sex ratio (male/female)	%	CBS	2011
		b.	Trend of population growth	Person/Year		
		c.	People with disability (PWD, male and female)	%		
		d.	Female-headed households	%		
		e.	[8]Children and senior citizen	%		
		f.	[9]Ethnicity	%		
B. Energy						
B.1	Hydropower	B.1.1	Types of hydro plants (total capacity)			
		a.	[10]Types of hydro plants by capacity/power	% of Total MW	NEA, DOED	2020
		b.	[11]Types of hydro plants by water conveyance			
		B.1.2	[12]Operational status of hydro plants			
		B.1.3	Ownership types (private hydro plants)			

1 Traditional energy: firewood, agriculture residue, animal dung
2 Renewable energy: biomass, pico/micro/mini hydro, solar, wind
1 Soil class (texture): loamy, loamy skeletal, loamy boulder, fragmental sandy, lake area, river bed, snow cover area
2 Land use/land cover type: agriculture land, barren land, forests, grassland, savannas
3 Type of water sources used for irrigation: perennial, pond/lake, local stream
4 Functional status of irrigation systems: operational, under construction, defunct systems
5 Irrigation scheme types by project size: major, large, medium, small projects
6 Children and senior citizen: boys and girls (below 19 years), male/female senior citizen (above 60 years)
7 Ethnicity: dalit (male and female), janajati (male and female)
8 Types of hydropower plants by capacity: mini/small/medium/mega hydro plants
9 Types of hydropower plants by water conveyance systems: run-of-river (ror), peaking run-of-river (p-ror), storage
10 Operational status of hydro plants: under construction and under survey hydro plants
11 Electricity: pico/micro/mini hydro plants

Sub-sector		Elements/Indicators		Units	Data Sources	Data Year
B.2	Alternative energy (traditional and renewable)	B.2.1	Households dependency on sources of alternative energy			
		a.	Depend on wood/firewood for cooking	%	AEPC, CBS	2011, 2020
		b.	Depend on [13]electricity for lighting	%		
		B.2.2	Biomass supply and demand (surplus or deficit status)	%	CBS, ICIMOD	2010-2011

Table 3: Elements and indicators of adaptive capacity

Sub-sector		Elements/Indicators		Units	Data Sources	Data Year
A. Water Resources						
A.1	Water availability (systems and sources)	A.1.1	Water Recharge, Retention, and Reuse Interventions			
		a.	Trends of Reforestation/Afforestation to conserve water (Change in forest cover)	km²/year	MODIS	2001–2019
		b.	Trends of Terrace Farming for Water Retention (Change in agriculture cover)	km²/year		
		A.1.2	Disaster Prevention Measures			
		a.	Draining of glacier lakes and monitoring plan	Station No.	DHM	2020
		b.	Access to climate information	Station No.	DHM	
		A.1.3	Conservation/Management Plans and Investments			
		a.	Number of wetland conservation initiatives	No.	MOFE	2020
		b.	Number of management of conservation pond and reservoir	No.		
		c.	Environment/Climate Change Relevant Budget	NPR	MOFAGA	
A.2	Water services (demand, supply and use)	A.2.1	Water Conservation Practices			
		a.	Total Usable Water for Irrigation (Water-Use Potentials)	MCM	DWRI, IWMI, UOG	1980–2012
		b.	Total Usable Water for Drinking Water (Water-Use Potentials)	mm		
		c.	Number of bioengineering practices (Bio-Engineering applications)	No.	MOFE	2020
		A.2.2	Water Service Systems Management			
		a.	Registration of Water Users Association (WUA) of Irrigation Systems	%	DWRI	2019
		b.	Turnover of Water Users Association (WUA) of Irrigation Systems	%		
		c.	Gross Command Area Covered by Operational Irrigation Systems	ha		
		d.	No. of Well-functional Drinking Water Supply Schemes	No.	DWSSM	2015
		e.	Gender Development Index (GDI)	Fraction	NPC	2014
B. Energy						
B.1	Hydropower	B.1.1	Operation Status of Hydro Plants (Operating Plan and Strategy)			
		a.	Hydropower Potentials (Total Generation Capacity)	MW	DOED	2020
		b.	Electrification Coverage Status	%	NEA	
B.2	Alternative energy (traditional and renewable)	B.2.1	Access to Technology of Alternative Energy			
		a.	Bio-gas Plants Coverage by Households	% of HHs	AEPC, CBS	2011, 2020
		b.	Solar Plants Coverage by Households			
		B.2.2	Household Income/Per Capita Income	NPR	CBS, NPC	2014

3.3.2 Climate change vulnerability and risk maps

Through the assessments, impact and risks maps are produced based on climate trends and scenarios, observed and projected impacts, and elements of the VRA components. The products are vulnerability and risk assessment indexes and classes of the VRA components, sub-sectors, and sectors which integrate cross-cutting issues. It will rank climate change impacts and risks at the sectoral, ecosystem, and national levels. The ranking and classification have been finalized in consultative meetings with TWG, TC, and provincial key stakeholders. The class break values of all VRA components at the district, provincial, and physiographic levels. Table 4 represents the levels at which the results have been produced.

Table 4: Output products of the VRA[1]

Vulnerability and Risk Index and Class			District Level	Province Level	Physiographic Regions	Subbasin Level	Watershed Level
Hazard Indexes	Climate Extreme Events Trends	Sub-sectors	Yes	Yes	Yes	Yes	Yes
		Sector	Yes	Yes	Yes	Yes	Yes
	Climate-Induced Disaster	Sub-sectors	Yes	Yes	Yes	Yes	Yes
		Sector	Yes	Yes	Yes	Yes	Yes
	Climate Extreme Events Scenarios	Sub-sectors	Yes	Yes	Yes	Yes	Yes
		Sector	Yes	Yes	Yes	Yes	Yes
Indexes of Water Resources Energy Overall Sector	Exposure	Sub-sectors	Yes	Yes	Yes	Yes	Yes
		Sector	Yes	Yes	Yes	Yes	Yes
	Sensitivity	Sub-sectors	Yes	Yes	Yes	Yes	Yes
		Sector	Yes	Yes	Yes	Yes	Yes
	Adaptive Capacity	Sub-sectors	Yes	Yes	Yes	Yes	Yes
		Sector	Yes	Yes	Yes	Yes	Yes
	Vulnerability	Sub-sectors	Yes	Yes	Yes	Yes	Yes
		Sector	Yes	Yes	Yes	Yes	Yes
	Risk	Baseline	Yes	Yes	Yes	Yes	Yes
		Future Scenarios	Yes	Yes	Yes	Yes	Yes

3.3.3 Identification and appraisal of adaptation options

Identified adaptation options are aligned with the National Climate Change Policy (2019) of WatRES, which states that "water and energy security will be ensured by promoting multiple uses of water resources and production of low carbon energy." The policy has recommended eight strategies and the working policies in WatRES are described in Figure 8. As adaptation options and mitigation plans for climate change impacts, these strategies and working policies promote (a) promotion of recharge, retention, and re-use of water; (b) Multiple Use System (MUS) for the effective and efficient use of water; (c) Rain Water Harvesting for groundwater recharge and sustainable use of groundwater; (d) production of renewable energy and efficient use; (e) environmental protection and climate-resilient technologies; (f) maintaining river ecosystems and water level in glacial lakes; and (g) installation of new weather stations in various geographical location to have evenly distributed climate information that could represent both slope and expects.

1 'Yes' means the maps are produced.

(I) Water, Storage, Reuse, and Multiple Use System (MUS)	• Technologies for storage, multiple use and efficient use of water will be developed and promoted in risk-prone areas and settlements considering the effects of climate change on availability of, and access to, water.
(II) Water Recharge and Rain Water Harvesting	• Rainwater harvesting ponds will be constructed for groundwater recharge and their multiple use.
(III) Sustainable Use of Ground Water	• Standards will be developed and implemented for sustainable use of groundwater resources in urban areas.
(IV) Renewable Energy and Efficient Technology	• Production and use of renewable energy and use of energy efficient technologies will be encouraged.
(V) Environment and Climate Friendly Technology	• Selection of environment friendly sites will be made and climate friendly technologies will be used while constructing infrastructures including that of hydroelectricity, drinking water and irrigation.
(VI) Maintaining River Ecosystems	• Measures to mitigate adverse impacts on river ecosystems will be adopted while generating hydroelectricity.
(VII) Reducing Glacial Lake Outburst Risks	• Safe outlet will be managed by decreasing the water level for reduction of glacial lake outburst risks.
(VIII) Expanding Spatial Coverage of Hydro-meteorological Stations	• Dissemination of information relating to weather will be systematized by expanding Hydro meteorological stations in various geographical regions and their capacity will be enhanced.

Figure 8: Strategies and working policy of national climate change (2019)

In the assessment, the adaption options are recommended to meet the outcomes in short-term (1–5 years), medium-term (1–10 years), and long-term (1–30 years) periods, which are based on the structural/physical, social, and institutional prospects (Table 5) to strengthen the resilience of systems for water resources and energy management. The adaptation options are identified based on the recommendation of government white papers, literature reviews, and suggestions from the provincial meetings.

- To enhance the resilience of systems for water resources management in the future and to overcome the issues of water scarcity due to the impact of climate change
- To ensure the safety of water management facilities and to minimize the risk of climate-induced hazards due to extreme climate events
- To reduce the impact of periodic water scarcity and extreme climate events in the energy sector, particularly hydro-electric production
- To promote the use of alternative energy and to diversify the use of renewable energy

Table 5: Category and period of recommended adaptation options[2]

Adaptation Options		Short-term (1–5 Year)	Medium-Term (1–10 Years)	Longer-Term (1–30 Years)
Water Resources	Structural/Physical	Yes	Yes	Yes
	Social	Yes	Yes	Yes
	Institutional	Yes	Yes	Yes
Energy	Structural/Physical	Yes	Yes	Yes
	Social	Yes	Yes	Yes
	Institutional	Yes	Yes	Yes

2 ‘Yes’ means the adaptation options are identified.

Observed Climate Change Impacts

4.1 Observed impacts on the sector

Climate change presents physical and socio-economic challenges in the water and energy sector. The effects of changes in temperature and precipitation are expected to change the water balance, runoff, and timing of water availability. The changes also add uncertainties to water availability as it brings changes in the snow and glacier melt pattern, rainfall variability, extreme weather events, streamflow, and drought.

Most of the elements of hazard listed in WatRES (refer to Table 12) will cause changes either in the land use pattern or soil class/patterns or both. This change can increase surface runoff and evaporation and decrease groundwater recharge within the watershed. Most of the time it will change the vegetation and topography and affect the water balance of the watersheds. Furthermore, surface soil erosion, mass-wasting, and sediment deposition occur due to water-induced hazards, which change the land cover and land use, and soil pattern within the watershed ultimately altering water availability.

The changing climate may further exacerbate the water stress already occurring in Nepal due to the monsoon-dominated climate. Climate change would further increase this seasonal imbalance: - too much water during the rainy season and too little of it duringthe dry seasons (Chaulagain, 2009).Water resources, especially springs, are being depleted rapidly across the Hindu Kush Himalaya (HKH) region (Tiwari & Joshi, 2012b). Although the causes are not yet clear, a range of factors are thought to be responsible, including reduced infiltration and increased runoff, changes in land use (e.g. mixed forest to plantation, shrubs and barren land to forest, forest to agriculture, agriculture to infrastructure, wetlands encroachments and drying out), changes in agricultural practices (leading to soil degradation), and changes in precipitation patterns (e.g. from snow to rain, increase in cloudbursts and extreme events) (Gautam

& Andersen, 2017; Tiwari & Joshi, 2012a, 2012b). In the two watersheds of the Kavrepalanchok district of Nepal, 15–30% of the springs have dried up in the last decade. This is likely due to a combination of factors such as climate change, biophysical, technical, and socio-economic factors (ICIMOD, 2015; Poudel & Duex, 2017; Sharma et al., 2016).

The changes in climate variables and land use pattern have not only impacted the water availability, particularly in seasonal water availability to meet water demands of all the sectors (L. Bharati et al., 2014; Luna Bharati et al., 2019)especially in regions such as the Koshi Basin in the Himalayas; where CC impacts are still uncertain. This paper recommends targeting adaptation strategies by focusing on changes in variability between the past and future climates at smaller scales. The Soil and Water Assessment Tool (SWAT but has also had an impact on the quantity of freshwater reservoir in the mountains of Nepal, particularly due to glaciers retreat (Shrestha & Aryal, 2010). Also, it impacts the access and usage of water particularly increasing vulnerability and marginalization. A recent study (IWMI, 2019) about techno-social interventions based on the socio-economic and biophysical settings in the river basins of Western Nepal (Karnali, Mahakali, and Mohana), suggested that access to sustainable water resources require mitigation and prevention against land degradation, which is also connected to land-use practices. Table 6 represents the findings of climate change impact on WatRES; which are summarized from the studies mentioned in this assessment.

The changes in precipitation and temperature pattern, including extreme weather events (such as floods and droughts), affect water availability and timing and cause water-related disasters. Due to the monsoon-dominated seasons in Nepal, floods, flash floods, and landslides are very common in hilly areas. These water-related hazards will increase (e.g. frequency, magnitude) in the context of global climate change. Different forms of drought (such as agriculture, meteorological droughts) have a direct impact on various sectors.

Table 6: Climate change impacts in watres

Medium Confidence with Limited Evidence	Climate change will intensify the sectoral competition for water use.
Medium Confidence with Medium Evidence	In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality.
	Glacier retreats are affecting runoff and water resources downstream.
	In presently dry regions, drought frequency will likely increase by the end of the 21st century under RCP 8.5.
	Climate change may influence the integrity and reliability of pipelines and electricity grids.
High Confidence with Medium Evidence	Glaciers continue to shrink almost worldwide due to climate change.
	Climate change is causing permafrost warming and thawing in high latitude regions and high-elevation regions.
	Rising water temperatures, due to global warming, will lead to shifts in freshwater species distributions and worsen water quality problems, especially in those systems experiencing high anthropogenic loading of nutrients.
	Climate change is projected to reduce raw water quality and pose risks to drinking water quality even with conventional treatment, due to interacting factors: increased temperature; increased sediment, nutrient, and pollutant loadings from heavy rainfall; increased concentration of pollutants during droughts; and disruption of treatment facilities during floods.

High Confidence with Robust Evidence	Freshwater-related risks of climate change increase significantly with increasing greenhouse gas concentrations.
	Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions.
	Climate change is projected to reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors.
	Climate change will affect different energy sources and technologies differently, depending on the resources (water flow, wind, and insolation), the technological processes (cooling), or the locations (coastal regions, floodplains) involved. Gradual changes in various climate attributes (temperature, precipitation, windiness, cloudiness, etc.) and possible changes in the frequency and intensity of extreme weather events will progressively affect operation over time.
	The impact of the increase/decrease in average water availability will lead to increased/reduced power outputs. The changes in seasonal and inter-annual variation in inflows (water availability) will shift in seasonal and annual power output; floods and lost output in the case of higher peak flows. Likewise, the extreme precipitation causing floods will have direct and indirect (by debris carried from flooded areas) damage to dams and turbines, lost output due to releasing water through bypass channels.

The hydropower sector in the Hindu Kush Himalayas suffers from the twin challenges of societal pressure and climate change. The sector faces major challenges due to glacial melt induced by climate change. Glaciers across the region, except in the Karakoram (Bolch et al., 2017) based on 1973 Hexagon KH-9, ~ 2009 ASTER and the SRTM DTM, we show that glaciers in the Hunza River basin (central Karakoram, are retreating, leading to changes in future hydrological regimes. At the same time, the risk of glacial lake outbursts floods (GLOFs), and landslides are increasing, putting both existing and planned hydropower plants at risk. Glacial lakes are formed behind moraine dams on loose and unconsolidated material. These unstable lakes pose a threat to downstream communities and infrastructure in the event of GLOFs. For example, a GLOF in 1985 in the Dudh Koshi River Basin damaged the nearly completed Namche Small Hydroelectric Project and caused other damage further downstream (ICIMOD, 2011). Similarly, in recent years, landslides and landslides blocking rivers causing Landslide Dam Outburst Flood (LDOF) have become common, such as the Sunkoshi dam landslide in 2014. Landslides attributable to intense rainfall, land degradation, and development activities are disturbing springs in the middle hills.

Soil erosion and sedimentation are very common during the monsoon and affect irrigation canals, dams, and hydropower plant reservoirs (both storage and run-of-the-river). Excessive sedimentation shortens the life span of reservoirs and decreases the efficiency of power plants. Rising temperatures can cause glaciers to shrink and enhance glacier melt. There is also more rainfall than snow due to high temperatures in high-altitude areas. It is likely that due to climate change, runoff from glaciated areas will increase in the short term, but in the long run, it is expected to decrease when glacier storage diminishes (Bates et al., 2008; Eriksson et al., 2009).

4.2 Climate change impact on the hydrology of Nepal

The impact of climate change on the hydrology of Nepal is evident. According to basin-level studies (Luna Bharati et al., 2019; Ghimire et al., 2019; IWMI, 2019; Pandey et al., 2019, 2020; Pandit, 2020) in Nepal on the impact of climate change in water availability (Table 7), the total water availability at river basins of Nepal will increase in both the near future and the medium future scenarios of RCP 4.5 and RCP 8.5. However, there are variations in seasonal and sub-basin level projected water availability. The future changes of flow in the non-monsoon seasons

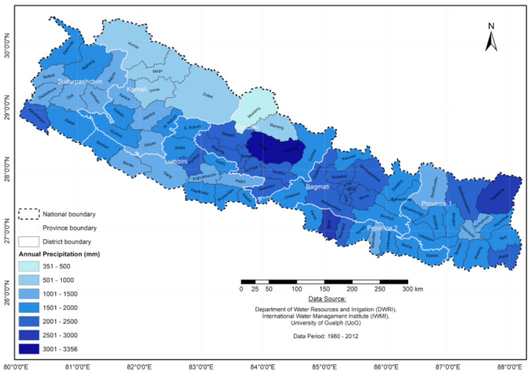
(October to May) will be within the past ranges, whereas, the future changes of flow in the monsoon (June to September) will be higher than in the past. This will have adverse effects on the water demands of people, as well as the ecosystem due to the high demand for energy and industrial development. Figure 9 represents the district-wise hydrological parameters: Precipitation (in mm), Ground Water Flow (in mm), Net Water Yield (in mm), and Total Water Volume (in MCM) at the baseline period.

Based on the results of the studies (Table 7) including analysis included in the Irrigation Master Plan 2019 (DWRI, 2019), the impact of climate change scenario on water resources has been further analyzed for the near future (the 2030s) and medium future (2050s) projection of scenarios RCP 4.5 and RCP 8.5 at the district level. Table 8 represents the percentage of changed scenarios due to climate change impact on the amount of annual groundwater flow, the amount of annual net water yield, and the amount of annual total water volume (discharge) available at districts.

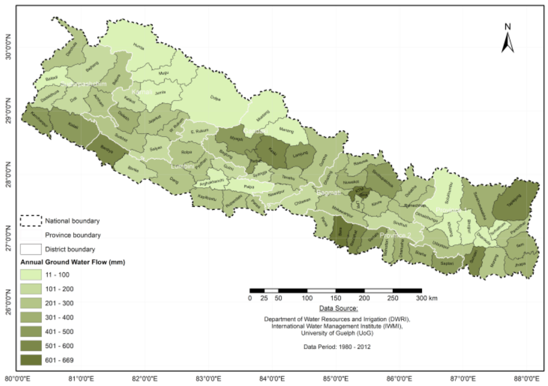
Table 7: Change in total annual water availability

Basin/Sub-basin	RCP 4.5		RCP 8.5		Reference
	2030s	2050s	2030s	2050s	
Koshi-Bagmati	-	+7.25%	-	+11.29%	(Luna Bharati et al., 2019)
Narayani (Gandaki)	+2.60%	+10.87%	+5.40%	+5.24%	(Ghimire et al., 2019; Pandit, 2020)
Karnali-Mohana	+0.60%	+6.40%	+1.90%	+4.20%	(IWMI, 2019; Pandey et al., 2020)
Chamelia in Mahakali	+8.20%	+12.20%	-	-	(Pandey et al., 2019)

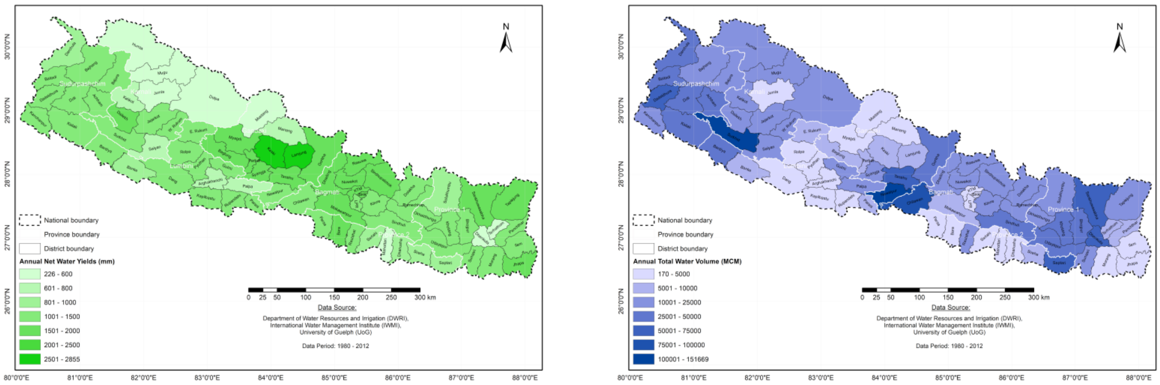
According to the climate change projection scenarios (Table 8), the annual water availability parameters will increase in most of the districts in the future, while decreasing in some districts. However, the spatial imbalance and temporal variabilities of water availability do exist. The change in the ground-water flow which contributes to the flow of springs and local streams will primarily have an impact on the community level water demands such as drinking water, pico/micro hydropower, biomass production, and micro-irrigation. Whereas the change in net water yield, which contributes to the larger flow of streams, will primarily have an impact on the water demands of small-scale water services, such as urban water supply, mini/small hydropower, small irrigations, and small industries. Similarly, the change in total water volume (discharge) of the river will have an impact on the larger scale water demands, such as medium/mega hydropower, medium/large/major irrigation, and mega water supply projects. Results of the above studies show that climate change has a direct impact on water availability, which is the key exposure unit of the water resources and energy sector.



(a) Precipitation



(b) Ground Water Flow



(c) Net Water Yields (d) Total Water Volume

Figure 9: District-wise hydrological water balance parameters

Table 8: Range of change in water availability parameters

Parameter of Annual Water Availability	Change in Near Future (2030s)					
	RCP 4.5			RCP 8.5		
	Change Range	No. of Districts		Change Range	No. of Districts	
		Increasing	Decreasing		Increasing	Decreasing
Ground Water Flow	-81.3% to +634.5%	57	20	-84.4% to +639.9%	61	16
Net Water Yield	-134.8% to +230.3%	55	22	-138.0% to +241.0%	59	15
Total Water Volume	-38.6% to -27.2%	34	43	-39.4% to +27.3%	46	31
	Change in Medium Future (2050s)					
Ground Water Flow	-73.1% to +637.9%	61	16	-89.5% to +646.5%	62	15
Net Water Yield	-148.8% to +236.1%	58	19	-165.2% to +250.7%	64	13
Total Water Volume	-38.6% to +27.2%	50	27	-51.6% to +46.1%	50	27

4.3 Climate change impact on the energy sector

The study initiated by the government of Nepal shows that climate variability also affects hydroelectric production. Hydroelectric plants are dependent on predictable run-off patterns, and thus sensitive to climate variability (OECD, 2003). The impact of an increase/decrease in average water availability will lead to increased/reduced power outputs. Nepal's electricity generation relies mostly on the run-of-river hydropower plants, and some river flows are insufficient to operate important plants during the dry season, which will worsen due to climate change. The changes in seasonal and inter-annual variation in inflows (water availability) will shift in seasonal and annual power output; floods and lost output in the case of higher peak flows. Likewise, the extreme precipitation causing floods will have direct and indirect (by debris carried from flooded areas) damage to dams and turbines, lost output due to releasing water through bypass channels. The impact of climate variability on electricity production indicates that economic costs could be equivalent to 0.1% of GDP per year on average, and 0.3% in very dry years (IDS-Nepal et al., 2014)released this week by the Climate and Development Knowledge Network (CDKN).

Studies show that rising temperatures will affect snow hydrology and glacier melt and may impact hydro plants with substantial catchments above the snow line (i.e. the winter snow line of > 3000m elevation and the year-round snow line > 5000m elevation) but will have little or negligible impact on plants at lower elevations. Also, hydropower plants that are located within 50–100 km downstream of potential glacier lakes are expected to be more affected by potential GLOF events. This is because the peak discharge generated by GLOF events within such distances can be higher than the design flood values of the hydro plants. The higher monsoon peak flows could increase the risks of extreme flows and floods, leading to damage of hydroelectricity plants, with the costs of repair and lost revenues. As an example, there have been recent losses of smaller hydro plants (e.g. Khudi hydropower plant) due to floods (CDKN, 2017).

They are also subject to the risks of floods and droughts, including risks from Glacial Lake Outburst Floods (GLOFs). Incidentally, there was a loss of a multi-million dollar hydropower facility in 1985 due to a GLOF event (OECD, 2003) and a more recent loss of micro-hydro plants from floods (Paudyal, 2011). The Zhangzangbo GLOF (July 11, 1981) caused substantial damage to the diversion weir of the Sun Koshi Hydropower Plant, the Friendship Bridge at the Nepal-China border, two other bridges, and extensive road sections of the Arniko Highway. These amounted to a total loss of more than US$ 3 million. Similarly, the Dig Tsho GLOF (4 August 1985) in the Khumbu region (eastern Nepal) destroyed, over a distance of 42 km, the Namche small hydroelectric plant with an estimated loss of US$ 1.5 million, 14 bridges, 30 houses, trails, farmlands and the properties of many families, including three human lives. On 3 September 1998, the Tam Pokhari GLOF in the Dudh Koshi Basin (eastern Nepal) destroyed 6 bridges and farmlands (with an estimated loss of US$ 2 million), including two human lives.

The heavy sediments and debris flow from GLOFs can create problems in these downstream projects. Breaching of glacial lake dams from a close distance poses high risks to hydro projects; a case in point is the flood damage in Bhote Koshi Project on 5 July 2016 from a GLOF originating from Tibet, China. Recently, there have been cases of landslide-induced damming and impounding of a large volume of water behind these dams (for example, the Jure landslide in Sun Koshi River in August 2014) impacting hydro plants downstream. Nearly 10% of the nation's hydropower capacity, some 67 MW, was severed by the landslide, submerging a 5 MW power plant and disconnection of the power supply with Bhotekoshi hydropower (45MW) and Sunkoshi hydropower (10 MW) and washed out over 400 houses, killing over 200 people. The landslide-induced dam breached catastrophically but, fortunately, no human casualties occurred. The impact of hydropower projects downstream is not known. The higher monsoon peak flows could increase the risks of extreme flows and floods, leading to damage of hydroelectric plants, with the costs of repair and lost revenues. As an example, there have been recent losses of smaller hydro plants (e.g. Khudi hydropower plant) due to floods.

Climate change influences the integrity and reliability of electricity grids. In Nepal, floods, landslides, snowstorms, and other hazards damage the electricity grids, transmission lines, and powerhouses. Although there is no actual assessment of how much is lost annually through the disasters, there are common views that the loss and damage are huge and will increase in the future. The consultations at the provinces revealed that transmissions in Terai are in threat of flood while in the mountains mostly landslides pose the damage.

Chapter 5

Climate Induced Hazards

The effects of climate change are apparent in Nepal, especially in the high mountains. The increase in temperature is evident whereas there is extreme variability in rainfall patterns. Recent studies show that temperatures are rising all over Nepal but becoming particularly high in the mountain areas. The precipitation patterns are changing: there is a short duration of rainfall but a more intensive and heavier pour.

According to MoPE (2017), extreme climate events such as extreme precipitation; annual minimum and maximum temperatures; summer maximum and winter minimum temperatures; consecutive hot, dry, and wet days; and the number of rainy days are the elements of hazards for the WatRES. Similarly, climate-induced hazards are landslides, flood and flash floods, Glacial Lake Outbursts (GLOFs), Landslides Dam Outburst Floods (LDOFs), heavy rainfall, and snowstorm. Also, the sediment transport and deposit, which has changed the land cover and land use, are some water sector-specific hazards. These elements are major drivers which have an impact on the water balance of the watershed. As a result, the hydrological processes of the respective watersheds are altered evident through changes in the surface runoff, groundwater recharge, and evapotranspiration.

5.1 Trends and change scenarios of climate in Nepal

DHM (2017) reported that there were significant positive trends in the annual and seasonal maximum temperature, however, these significant positive trends of minimum temperature were observed only in monsoon. There were no significant trends observed in the annual and seasonal precipitation. According to the observed climate data of Nepal, the annual minimum and maximum temperatures have increased by 0.02°C and 0.56°C respectively per decade. Table 9, Table 10, and Table 11 represent the generic trends of temperature, precipitation, and climate extremes by seasons, districts, and physiographic regions.

Table 9: Seasonal temperature and precipitation trends

Season	Generic Trends			Trend in Districts		
	Temperature		Precipitation	Temperature		Precipitation
	Minimum	Maximum		Minimum	Maximum	
Winter	[14]↓	[15]↑	↑	Significant	Significant	Insignificant
Pre-monsoon	↓	↑	↓	Significant	Significant	Significant
Monsoon	↑	↑	↑	Significant	Significant	Significant

Table 10: Temperature and precipitation trends in physiographic regions

Physiographic Region	Generic Trends		
	Temperature		Precipitation
	Minimum	Maximum	
High Himalaya	Insignificant (↕) (in winter – '↓')	Significant (↑)	Significant (in pre-monsoon – '↓')
High Mountain	Insignificant (↕)	Significant (↑)	Insignificant (↕)
Middle Mountain	Insignificant (↕)	Significant (↑)	Insignificant (↕)
Siwalik	Significant (↑)	Significant (↑), (in winter – '↓')	Insignificant (↕)
Terai	Significant (↑)	Significant (↑) (in pre-monsoon & winter – '↓')	Insignificant (↕)

MOFE (2019), the annual mean temperature will increase in the future by 0.9°C to 1.1°C in the 2030s (near future) and by 1.3°C to 1.8°C in the 2050s (medium future) regarding the period 2010s (baseline). Likewise, the annual mean precipitation will also increase in the future by 2–6% in the 2030s and by 8–12% in the 2050s. This shows that the climate will be significantly warmer and wetter in the future; however, there will be seasonal variability, such as decreasing precipitation during pre-monsoon seasons and a likelihood of stronger monsoons in the future. This will increase the chances of occurrence of extreme climate events in the future and will have an impact on the hydrological water balance and water availability for the sector including all other sectors. The stronger monsoon will increase the risks of monsoon-related disasters, such as landslides and floods/flash floods in the future.

Table 11: Climate extreme general trends

Climate Extreme Events	Generic Trend in Districts		
	Decreasing (↓)	Increasing (↑)	Insignificant (↕)
Temperature (TMP)			
Warm Days		Majority	
Warm Nights		Majority	
Warm Spell Duration (WSD)		Majority	
Cold Days	Majority		
Cold Nights	Few South-eastern	Northern & Few North-western	
Cold Spell Duration (CSD)		Sudurpashchim Province	
Precipitation (PCP)			
No. of Rainy Days		North-western	
Very Wet Days	Northern		
Extremely Wet Days	Northern		
Consecutive Dry Days (CDD)	North-western of Karnali Province		
Consecutive Wet Days (CWD)		Northern of Karnali Province; and Central parts of Gandaki Province and Province 1.	

'↓' – Significant Decreasing Trend
'↑' – Significant Increasing Trend

5.2 Climate change stressors

The climatic variables used in this sector are annual, monsoon, and winter precipitation; and minimum, maximum, and average temperature. Whereas the extreme climate events that have been considered are extreme and very wet days, consecutive wet and dry days, several rainy days, warm days and nights, and warm spell duration. The climate-induced hazards that have been considered in the assessment of these sub-sectors are heavy rainfall, snowstorm, landslides, flood/ flash floods, Glacial Lake Outburst Floods (GLOFs), and an avalanche. Based on the availability of quality data, the impact of the hazard that has been considered for the assessment is the number of human casualties, property loss, and the number of affected families. The hazard and its impact data were acquired from the Ministry of Home Affairs (MOHA). The elements and indicators that have been considered for the sector are listed in Table 12. The respective rank analysis can be found below sections.

Table 12: Elements and indicators of hazards/disasters

Category		Elements/Indicators		Units and Data Nature	Data Sources	Data Year
A. Climate and Climate Extreme Events						
A.1	Historical Trends	A.1.1	Climatic Variables			
		a.	Annual Precipitation	mm/year	DHM	1971-2014
		b.	Monsoon Precipitation			
		c.	Winter Precipitation			
		d.	Maximum Temperature	°C/year		
		e.	Minimum Temperature			
		A.1.2	Climate Extreme Events			
		a.	Extreme Wet Days	Days/year or Nights/year	DHM	1971-2014
		b.	Very Wet Days			
		c.	Consecutive Wet Days			
		d.	Consecutive Dry Days			
		e.	Number of Rainy Days			
		f.	Warms Days			
		g.	Warm Nights			
		h.	Warm Spell Duration			
A.2	Climate Change Future Scenarios	A.2.1	Climatic Variables			
		a.	Annual Precipitation	RCP 4.5 & RCP 8.5 Scenarios Near Future 2030s Medium Future 2050s Precipitation related changes are in % Temperature related changes are in ⁰C	MOFE	1981-2010
		b.	Average Temperature			
		A.2.2	Climate Extreme Events			
		a.	Extreme Wet Days	RCP 4.5 & RCP 8.5 Scenarios Near Future 2030s Medium Future 2050s Climate extreme events are in %	MOFE	1981-2010
		b.	Very Wet Days			
		c.	Consecutive Wet Days			
		d.	Consecutive Dry Days			
		e.	Number of Rainy Days			
		f.	Warm Days			
		g.	Warm Nights			
		h.	Warm Spell Duration			

Category		Elements/Indicators		Units and Data Nature	Data Sources	Data Year
B. Climate-Induced Hazard						
B.1	Hazard Events	B.1.1	Heavy Rainfall: Occurrences	No.	MOHA	1971-2019
		B.1.2	Snow Storm			
		a.	Occurrences	No.	MOHA	1971-2019
		b.	Snowy Area	km^2		
		B.1.3	Landslides			
		a.	Occurrences	No.	MOHA	1971-2019
		b.	Prone Area	km^2		
		B.1.4	Flood/Flash Floods			
		a.	Occurrences	No.	MOHA	1971-2019
		b.	Prone Area	km^2		
		B.1.5	Glacial Lake Outburst Floods (GLOFs)			
		a.	Occurrences	No.	MOHA	1971-2019
		b.	Potentially Dangerous Glacier Lakes	No.		
		c.	Distance from Glacier Lakes	km^2		
		B.1.6	Avalanche: Occurrences	No.	MOHA	1971-2019
B.2	Loss And Damage	B.2.1	Number of People/Family			
		a.	Death People	No.	MOHA	1971-2019
		b.	Injured People	No.		
		c.	Affected Family	No.		
		B.2.2	Property Loss (Monetary Value)	NPR	MOHA	1971-2019

Landslides are common in Nepal (Salike & Fee, 2015) since 80% of the total area is mountainous. According to the climate projection scenarios (Luna Bharati et al., 2019), the high flows are outside the past range in all the months except January and September, which signifies that flood occurrences will increase in the future. The glacier areas have been lost by 25% between 1980–2010, and more loss of glacier mass is to be expected in the future (Bajracharya et al., 2014a). This glacier retreat will lead to changes in the hydrological regimes in the future (Bolch et al., 2017) based on 1973 Hexagon KH-9, 2009 ASTER and the SRTM DTM, we show that glaciers in the Hunza River basin (central Karakoram). These climate-induced hazards have directly or indirectly impacted the people, their settlement, infrastructures, and Natural resources in the past. The GLOFs and landslides are a prevalent risk to the planned and operating hydropower plants. According to MOPE (2017b), the estimated total direct economic cost of water-induced disasters is USD 270 million per year, and damages caused by floods are about 5% of the national GDP. Similarly, the impact of climate variability on electricity production and planned interruptions has lost and damaged the equivalent of 0.1% GDP every year on average and is equivalent to 0.3% in very dry years (IDS-Nepal et al., 2014) released this week by the Climate and Development Knowledge Network (CDKN).

5.2.1 Climate extreme events

The change in climatic variables such as precipitation, temperature (minimum and maximum), relative humidity, solar radiation, and wind speed will affect hydrological systems and ultimately affect water resources and their subsectors, such as water system and sources, water use/

demand (water service), hydropower development and alternative energy sources. Climate extreme events such as heatwaves, prolonged periods of drought, and intense rainfall will have an impact on the functioning of hydropower systems and production (MOPE, 2017b).

5.2.2 Major climate-induced hazards in the sector

Landslides

Landslides are common in Nepal because 80% of the total area is mountainous (Salike & Fee, 2015). Natural phenomena such as heavy rainfall, fragile geology, steep and rugged topography, deforestation, and disturbance in hill slopes are the major causes of landslides in Nepal. Landslides occurrence—which is high in the hills and mountain regions of Nepal—has had a direct or indirect impact on people, their settlement, infrastructures, and natural resources. The proximity of these exposed elements will distinguish the degree of sensitivity of the exposure. The infrastructures that are damaged or destroyed by landslides can affect water availability and also alter the water and energy demand, supply, and consumption. More importantly, the disturbance in soil and vegetation will affect water availability and might dry up the springs and stream sources of the watershed.

Floods/Flash Floods

According to a study (Luna Bharati et al., 2019) based on projected climate and hydrological modeling of the Koshi basin, the range of the projected high flows is outside the past range in all months except January and September, which has further suggested that the peak flows will increase in the future. Therefore, flooding occurrences are expected to increase with the changing climate in the future. The Koshi river basin is found to be a high potential for hydropower and irrigation development due to its high water availability. Some of them are in operation and many of them are in the design phase. However, the impact of climate change has not been considered in their design. Therefore, these infrastructures are under the threat of flooding. In the same way that a landslide causes destruction, floods have also damaged and destroyed the lives of people and their livelihoods and natural resources. Communities that live near the flooding area and the communities living in flood plains will be sensitive to the susceptibility of floods. Floods will also change the land-use pattern because of soil mass movement and loss of vegetation, which will alter the hydrological system of the respective watersheds.

Glacier Lake Outburst Floods (GLOFs)

The study in the Dudh Koshi basin from eastern Nepal (Shea et al., 2014, 2015) suggested a loss of glaciers mass in the Everest region by this century according to RCP 4.5 and RCP 8.5 climate projections. Similarly, Bajracharya et al. (2014) reported the loss of glacier areas of 23% in Bhutan and 25% in Nepal between 1980 and 2010. Glaciers across the region except in the Karakoram (Bolch, 2017; Bolch et al., 2017) are retreating, leading to changes in future hydrological regimes. Forty-seven glacial lakes were identified as potentially dangerous. These include 42 lakes in the Koshi, three in the Gandaki, and two in the Karnali basins. Of these, 25 potentially dangerous glacial lakes (PDGLs) are in the TAR, China, and flow across the border into Nepal, 21 PDGLs are situated in Nepal (Table 13), and one is located in India. The table shows the PDGLs by river basin and sub-basin. At the same time, the risk of GLOFs and landslides are increasing, putting both existing and planned hydropower plants at risk. The sub-sector, such as hydropower, is facing major challenges due to the glacial melt caused by climate change. Therefore, climate change has become an additional challenge to the hydropower sector along with the existing challenges.

Table 13: Potentially dangerous glacial lakes in Nepal

River Basin	Sub-basin	Potentially Dangerous Glacial Lakes (PDGLs)
Koshi	Tamor	4
	Arun	4
	Dudh Koshi	9
	Tama Koshi	1
Gandaki/Narayani	Trishuli	1
	Marsyangdi	1
Karnali	Humla	1

In the assessment, the other climate-induced hazards that have been considered are heavy rainfalls, snowstorms, and avalanches. These hazards also have a considerable impact on the water resources and energy sector.

According to the MOHA database, 3,787 landslides, 3,443 floods/flash floods, 14 GLOFs, 822 heavy rainfalls, 179 snowstorms, and 126 avalanches have occurred from 1971 to 2019. These disasters have killed nearly 31,692 people and injured nearly 57,990 people, affected around 6,357 thousand households, and destroyed properties equivalent to NPR 71.36 billion. The data shows that the occurred snow storms have covered nearly 3,663 km^2 and the occurred landslides and floods/flash floods covered nearly 87,102 km^2 and 11,246 km^2 respectively.

5.3 Trends of climatic variables and climate extreme events

The historical trends of climatic variables and climate extreme events related to the sector are also analyzed. The summary trends presented in Table 9, Table 10, and Table 11 reflect seasonal, physiographic level, and climate extreme events general trends in the country. Based on the DHM (2017) trends analysis data of climate variables and climate extremes events (the list in A.1 of Table 12), the hazard rank analysis has been conducted (Figure 11) and the class group-wise list of the districts are included in Table 14.

The hazard rank analysis was carried out by normalizing the indicators and their composition based on the individual weightage to see the composite impacts. In general, the rank has shown that the western parts and north-eastern parts of the country were highly vulnerable in the past. Among the 77 districts, there are 6 districts in ‘Very High’, 16 in ‘High”, 22 in ‘Moderate’, 23 in ‘Low’ and 10 in ‘Very Low’ class groups (Table 14). The dominant indicators that contributed to a higher rank of hazardous classes are trends of annual, monsoon, and winter precipitation; trends of maximum temperature; trends of very wet days; and trends of warm days.

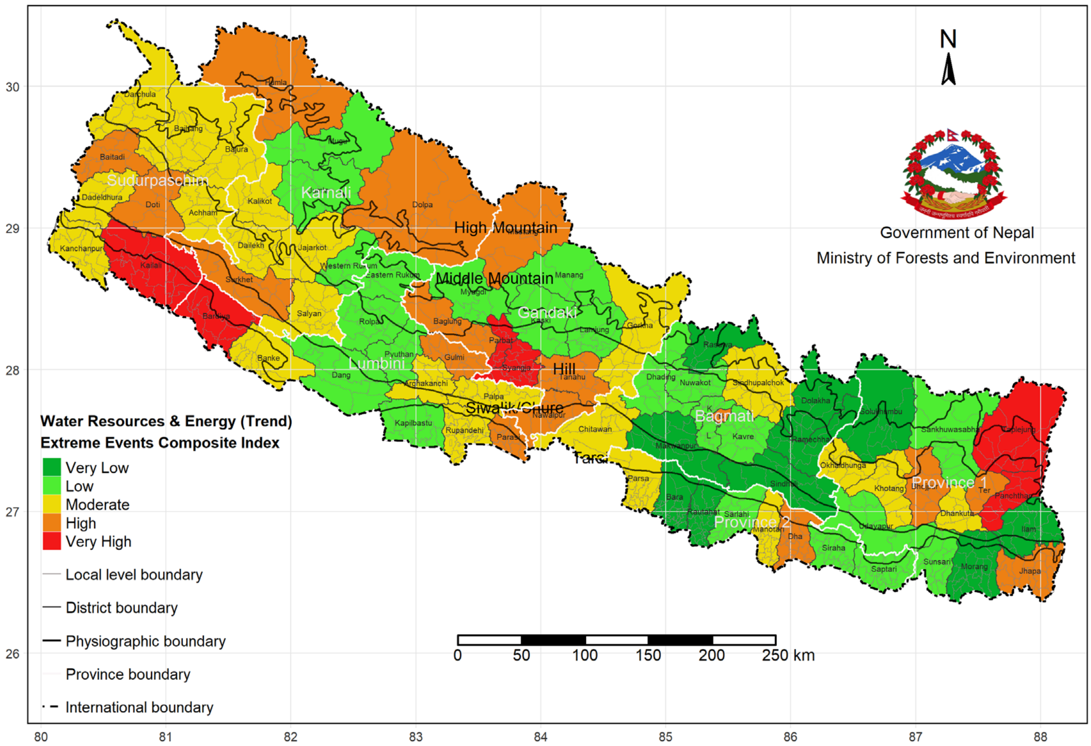


Figure 10: Hazard rank due to past trends of climate extreme events

Table 14: Hazard rank due to trends of climate extreme events

Hazard Rank	District
Very High (0.815 – 1.000)	Bardiya, Kailali, Panchthar, Parbat, Syangja, Taplejung
High (0.612 – 0.814)	Baglung, Baitadi, Bhaktapur, Bhojpur, Dhanusha, Dolpa, Doti, Gulmi, Humla, Jhapa, Mustang, Nawalpur, Parasi, Surkhet, Tanahu, Terhathum
Moderate (0.473 – 0.611)	Achham, Arghakhanchi, Bajhang, Bajura, Banke, Chitawan, Dadeldhura, Dailekh, Darchula, Dhankuta, Gorkha, Jajarkot, Kalikot, Kanchanpur, Khotang, Mahottari, Okhaldhunga, Palpa, Parsa, Rupandehi, Salyan, Sindhupalchok
Low (0.242 – 0.472)	Dang, Dhading, Eastern Rukum, Jumla, Kapilbastu, Kaski, Kathmandu, Kavrepalanchok, Lalitpur, Lamjung, Manang, Mugu, Myagdi, Nuwakot, Pyuthan, Rolpa, Sankhuwasabha, Saptari, Sarlahi, Siraha, Sunsari, Udayapur, Western Rukum
Very Low (0.000 – 0.241)	Bara, Dolakha, Ilam, Makawanpur, Morang, Ramechhap, Rasuwa, Rautahat, Sindhuli, Solukhumbu

5.4 Climate-induced hazards (baseline)

The indicators under climate-induced hazards and loss/damage due to climate-induced hazards (the list in B.1 and B.2 of Table 12) of the past are normalized and composited for the hazard ranking for the understanding of the impact of climate-induced hazards presented in Figure 12 and the list of the districts are included in Table 15. This rank is a historical scenario of the hazards; thus, it has been considered as the baseline status of the hazards in the sector and sub-sectors.

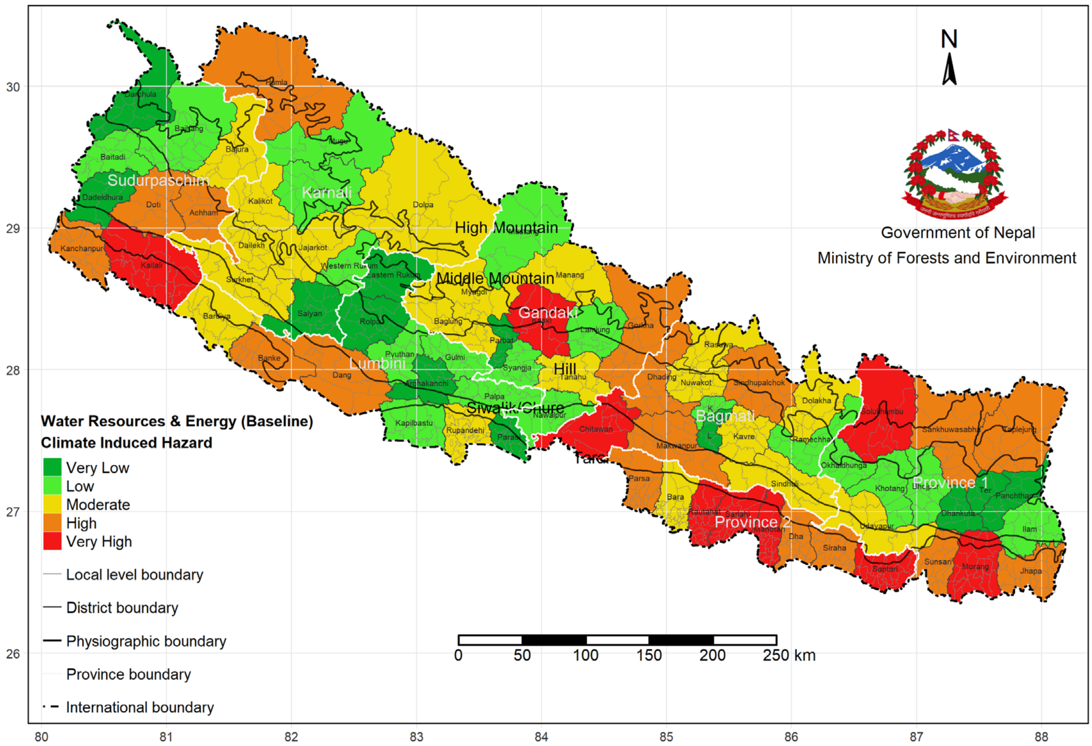


Figure 11: Hazard rank due to climate-induced hazards

Table 15: Hazard rank due to climate-induced hazards (baseline)

Hazard Rank	District
Very High (0.748 – 1.000)	Chitwan, Kailali, Kaski, Mahottari, Morang, Rautahat, Saptari, Sarlahi, Solukhumbu
High (0.496 – 0.747)	Achham, Banke, Dang, Dhading. Dhanusha, Doti, Gorkha, Humla, Jhapa, Kanchanpur, Makawanpur, Parsa, Sankhuwasabha, Sindhupalchok, Siraha, Sunsari, Taplejung
Moderate (0.287 – 0.495)	Baglung, Bajura, Bara, Bardiya, Dailekh, Dolakha, Dolpa, Jajarkot, Kalikot, Kavrepalanchok, Manang, Myagdi, Nuwakot, Rasuwa, Rupandehi, Sindhuli, Surkhet, Tanahu, Udayapur
Low (0.154 – 0.286)	Baitadi, Bajhang, Bhojpur, Gulmi, Ilam, Jumla, Kapilbastu, Kathmandu, Khotang, Lamjung, Mugu, Mustang, Nawalpur, Okhaldhunga, Palpa, Pyuthan, Ramechhap, Syangja, Western Rukum
Very Low (0.000 – 0.153)	Arghakhanchi, Bhaktapur, Dadeldhura, Darchula, Dhankuta, Eastern Rukum, Lalitpur, Panchthar, Parasi, Parbat, Rolpa, Salyan, Terhathum

In general, the composite rank of climate-induced hazards has been highly dominated by historical events of floods in the Terai, landslides in the Hill region, and GLOFs in the Mountain region. The floods were prevalent in Terai's Districts and GLOFs are in Kaski and Solukhumbu districts. Among the 77 districts, there are 9 districts in 'Very High', 17 in 'High', 19 in 'Moderate', 19 in 'Low', and 13 in the very Low' class group (Table 15). The dominant indicators that contributed towards a higher rank of hazardous classes are the occurrences of floods/flash floods and their prone area; occurrences of GLOFs and their proximity to the districts; and the number of human death caused by climate-induced disasters.

5.5 Future scenarios of the climate extreme events

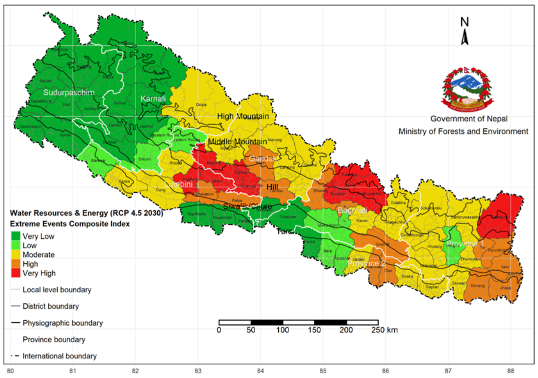
The most relevant 10 elements (the list in A.2 of Table 12) of climatic variables and climate extreme events for this assessment were selected from the 13 elements reported by MOFE (2019). These selected elements have been normalized and composited to figure out the composite impact of climate change in the future of the sector. Figure 12 represents the district-wise plots of future scenarios due to the composite effects of projected change in climatic variables and climate extreme events. The future projected scenarios are RCP 4.5 and RCP 8.5 in the period 2030s and 2050s.

Table 16: Hazard rank due to change in climate extreme events

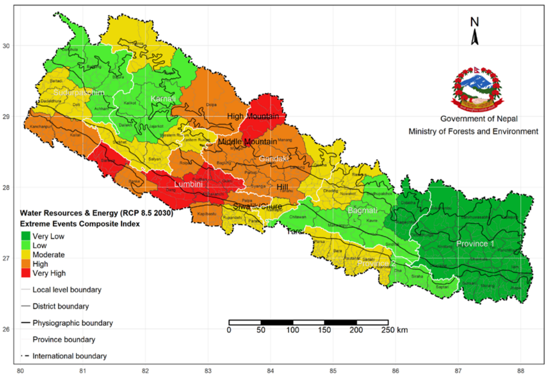
Hazard Rank		Number of Districts			
	RCP 4.5		RCP 8.5		
	2030s	2050s	2030s	2050s	
Very High	(0.845 – 1.000)	9	9	6	7
High	(0.696 – 0.844)	14	12	15	11
Moderate	(0.507 – 0.695)	23	20	20	16
Low	(0.235 – 0.506)	9	18	20	23
Very Low	(0.000 – 0.234)	22	18	16	20

Projected Scenarios	Districts in 'Very High' Rank	
	2030s	2050s
RCP 4.5	Baglung, Gulmi, Nuwakot, Parbat, Pyuthan, Rasuwa, Sindhupalchok, Syangja, Taplejung	Baglung, Dolpa, Gulmi, Kaski, Mustang, Myagdi, Parbat, Pyuthan, Syangja
RCP 8.5	Arghakhanchi, Bardiya, Dang, Gulmi, Mustang, Pyuthan	Arghakhanchi, Banke, Bardiya, Kailali, Kanchanpur, Mustang, Pyuthan
	Dominant Hazardous Climate Extreme Events	
	2030s	2050s
RCP 4.5	Change in Precipitation and Consecutive Dry Days	Change in Precipitation, Extreme Wet Days and Very Wet Days
RCP 8.5	Change in Consecutive Wet Days, Number of Rainy Days	Change in Precipitation, Temperature, Extreme Wet Days, Very Wet Days, Consecutive Wet Days

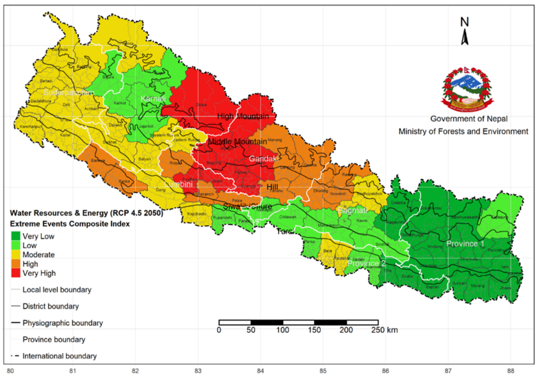
Under the RCP 4.5 scenario, the middle and eastern part of Nepal will be more impacted than the western part in the 2030s, whereas, it will be just the opposite in 2050s (refer to figures (a) and (c) of Figure 12). This represents the higher risk of climate extreme events that will shift from east to west according to the near to medium-range of projections. Whereas under the RCP 8.5 scenario in both 2030s and 2050s projections, the Gandaki Province and Lumbini Province, some parts of Karnali Province, and the western Terai will be comparatively more impacted than other parts of the country. The number of districts in the hazard rank classes is presented in Table 16 separately for both projected scenarios and periods. The table also includes the name lists of the districts under the 'Very High' class rank and the list of the dominant climatic variables and climate extreme events which are the consequences of higher hazardous districts in the future.



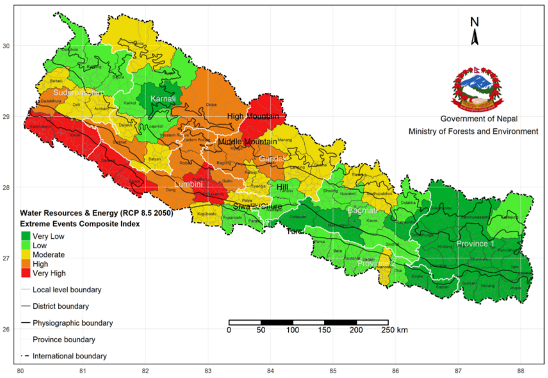
(a) RCP 4.5 in 2030s



(b) RCP 8.5 in 2030s



(c) RCP 4.5 in 2050s



(d) RCP 8.5 in 2050s

Figure 12: Hazard rank of projected change in climate extreme events

5.6 Climate hazard scenarios

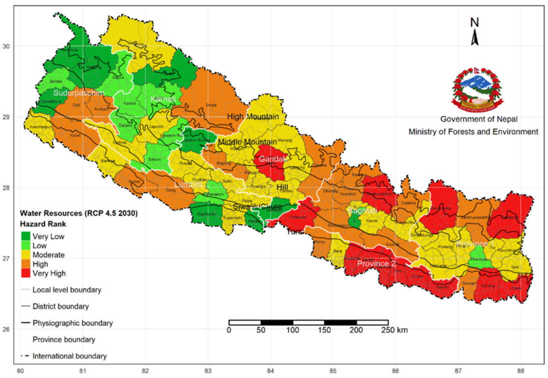
The hazard rank of future scenarios has been further analysed separately for the sub-sectors and then analysed for the overall scenario of the sector. For the analysis, the elements and indicators of the hazards/disasters listed in Table 12 are grouped by sub-sector-wise relevancy, which is listed in Table 17. As described before, the hazard rank scenarios due to historical climate-induced hazards have been taken as the baseline for the future projections, and the future scenarios of hazard rank have been considered by compositing the climate-induced hazards with the future change scenarios of climatic variables and climate extreme events. The climatic variables (change in precipitation and temperature), the six climate-induced hazards (heavy rainfall, snowstorm, landslides, floods/flash floods, GLOFs, and avalanches), and loss and damage due to climate-induced hazards (number of death and injured people, property loss and number of the affected family) are common for both sub-sectors; water resources and energy. Whereas all the eight climate extreme events (listed in Table 12) are considered for the water resources sub-sector; however, only two climate extreme events (change in extreme wet days and warm spell duration) are considered for the energy sub-sector.

Table 17: Sub-sector wise breakdown of hazard/disaster's elements

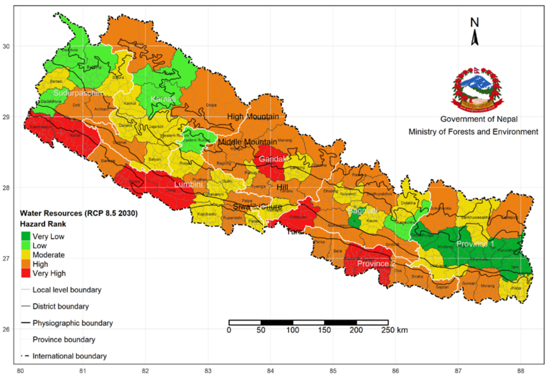
	Water Resources	Energy
Climatic Variables	Change in Precipitation (%) Change in Temperature (ºC)	
Climate Extreme Events	Change in Extreme and Very Wet Days (%) Change in Number of Rainy Days (%) Change in Consecutive Wet and Dry Days (%) Change in Warm Days and Nights (%) Change in Warm Spell Duration (%)	Change in Extreme Wet Days (%) Change in Warm Spell Duration (%)
Climate-Induced Hazard	Heavy Rainfall (Occurrences) Snow Storm (Occurrences and Snow Area) Landslides (Occurrences and Prone Area) Floods/Flash Floods (Occurrences and Prone Area) GLOFs (Occurrences, Potential Danger and its Proximity) Avalanche (Occurrences)	
Loss and Damage	Number of people dead and injured people Property loss Number of affected family	

5.6.1 Climate hazards scenarios in water resources

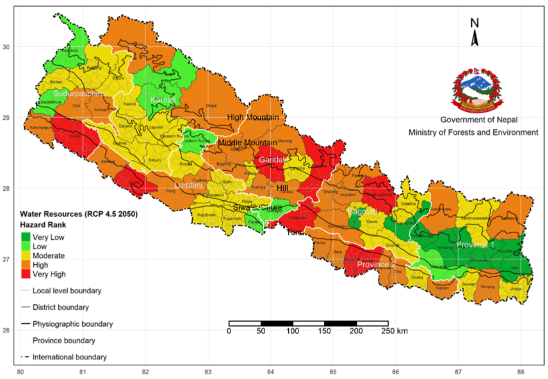
Of the hazards and disaster elements listed in Table 17, the future impact on the water resources sub-sector has been analyzed and the maps are presented in Figure 13, which include both projected scenarios (RCP 4.5 and RCP 8.5) of the periods the 2030s and 2050s. Region-wise, there are no specific locations where the impact of disasters will be more significant in the future. However, the results of both projection scenarios for both future periods in the context of water resources availability and its service areas show the comparatively less hazard-prone area to be the hilly part of Province 1.



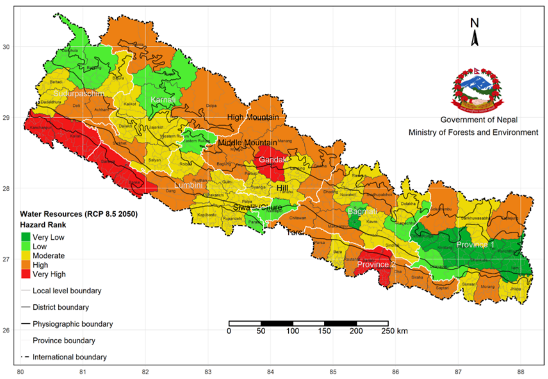
(a) RCP 4.5 in 2030s



(b) RCP 8.5 in 2030s



(c) RCP 4.5 in 2050s



(d) RCP 8.5 in 2050s

Figure 13: Hazard rank of future projection scenarios (water resources)

The numbers of districts in the hazard rank classes of the water resources sub-sector are presented in Table 18 separately for both projected scenarios and the periods. The table also includes the names of the districts under the 'Very High' rank and the list of the dominants climatic variables, climate extreme events, and climate-induced hazards which are the consequences of higher hazardous districts in the future.

Table 18: Hazard rank due to change in CEEs (water resources)

Hazard Rank		Number of Districts			
	RCP 4.5		RCP 8.5		
	2030s	2050s	2030s	2050s	
Very High	(0.748 – 1.000)	13	8	9	7
High	(0.496 – 0.747)	17	26	30	24
Moderate	(0.287 – 0.495)	28	25	22	27
Low	(0.154 – 0.286)	10	8	7	10
Very Low	(0.000 – 0.153)	9	10	9	9

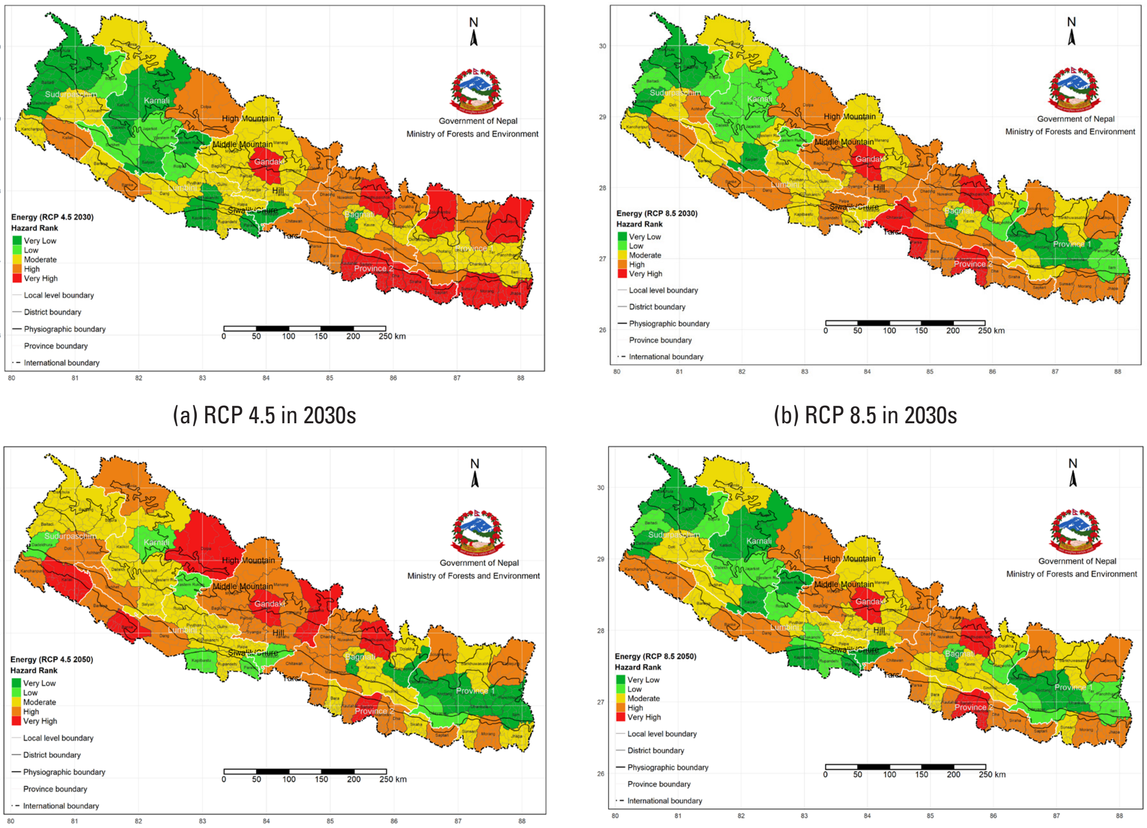
Projected Scenarios	Districts in 'Very High' Rank		
	2030s		2050s
RCP 4.5	Chitawan, Dhanusha, Jhapa, Kaski, Mahottari, Morang, Rautahat, Saptari, Sarlahi, Sindhupalchok, Siraha, Solukhumbu, Taplejung		Banke, Chitawan, Gorkha, Kailali, Kaski, Rautahat, Sarlahi, Sindhupalchok
RCP 8.5	Banke, Chitawan, Dang, Kailali, Kanchanpur, Kaski, Mahottari, Rautahat, Sarlahi		Banke, Bardiya, Kailali, Kanchanpur, Kaski, Mahottari, Sarlahi
		Dominant Hazardous Climate-Induced Hazards and Climate Extreme Events	
		2030s	2050s
RCP 4.5	CEEs[1]	Change in Consecutive Dry Days	Change in Very Wet Days
	CIHs[2]	Snow Storm Area, Landslide Occurrences, Floods/ Flash Floods, GLOFs, Number of People Death	Landslide Occurrences, Floods/Flash Floods Prone Area, GLOFs, Number of People Death
RCP 8.5	CEEs	Change in Consecutive Wet Days, Number of Rainy Days	Change in Precipitation, Temperature, Extreme Wet Days, Consecutive Wet Days, Number of Rainy Days, Warm Nights
	CIHs	Floods/Flash Flood Prone Area, Number of Death and Injured People	Flood/Flash Floods Prone Area, GLOFs, Number of People Death

5.6.2 Climate hazards scenarios in energy

Of the elements of hazards and disasters in Table 17, the hazard rank of the energy sub-sector has been conducted for the RCP 4.5 and RCP 8.5 scenarios in the period of 2030s and 2050s; the district-wise maps are presented in Figure 14. Similar to the above table, Table 19 represents the numbers of districts that fall under the five hazard rank classes in the stated projected scenarios and periods of the Energy sub-sector. Also, the table includes a list of districts in the 'Very High' rank class and elements of hazards and disasters which have dominants roles to become comparatively hazardous districts in the future.

1 Climate extreme events

2 Climate-induced hazards



(a) RCP 4.5 in 2030s

(b) RCP 8.5 in 2030s

(c) RCP 4.5 in 2050s

(d) RCP 8.5 in 2050s

Figure 14: Hazard rank of future projection scenarios (energy)

In the energy sub-sector, the major reasons behind the 'Very High' rank of the districts; such as Kaski and Sindhupalchok, are due to the existence of glacier lakes in the districts and due to the number of GLOFs that have occurred in the past. The 'Very High' rank of the districts in the Terai is due to the occurrences of floods and losses/damage caused by climate-induced disasters.

Table 19: Hazard rank of future projection scenarios (energy)

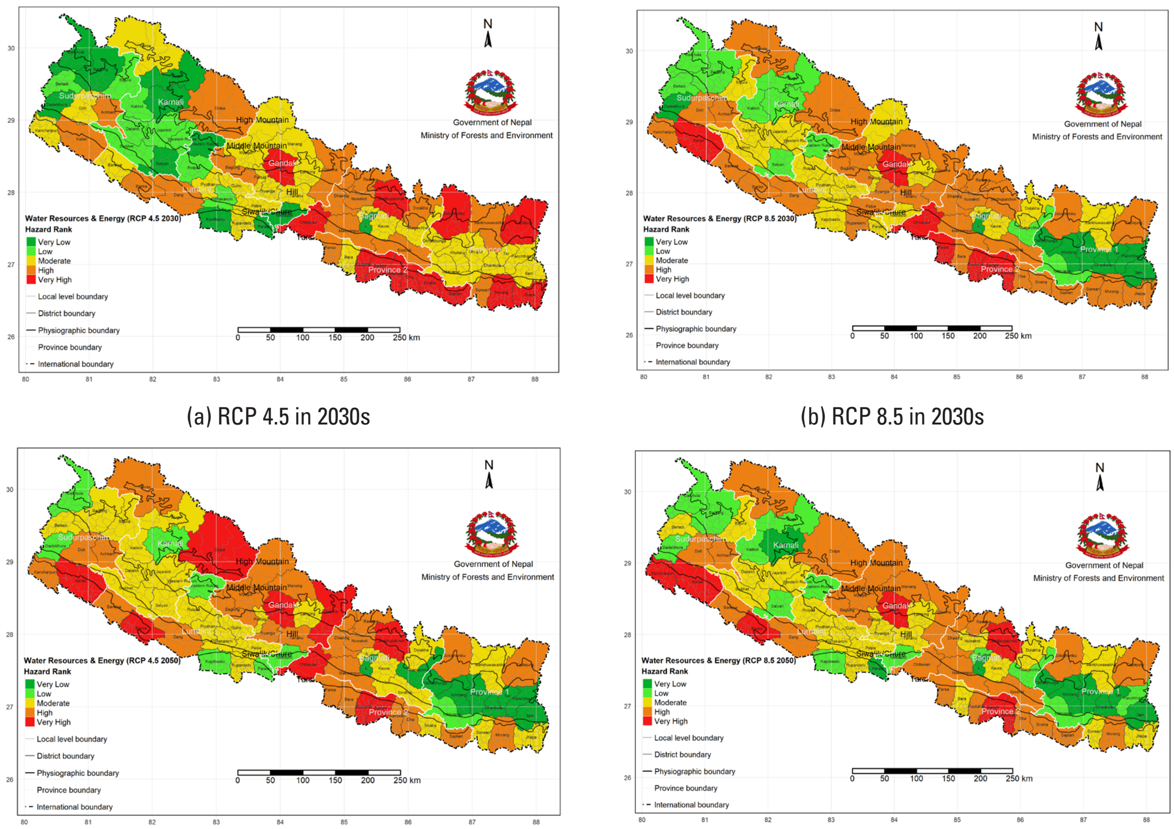
Hazard Rank		Number of Districts			
	RCP 4.5		RCP 8.5		
	2030s	2050s	2030s	2050s	
Very High	(0.748 – 1.000)	13	7	6	4
High	(0.496 – 0.747)	15	28	27	21
Moderate	(0.287 – 0.495)	28	25	22	21
Low	(0.154 – 0.286)	5	7	12	14
Very Low	(0.000 – 0.153)	16	10	10	17

Projected Scenarios	Districts in 'Very High' Rank	
	2030s	2050s
RCP 4.5	Dhanusha, Jhapa, Kaski, Mahottari, Morang, Rautahat, Saptari, Sarlahi, Sindhupalchok, Siraha, Solukhumbu, Sunsari, Taplejung	Banke, Dolpa, Gorkha, Kailali, Kaski, Sarlahi, Sindhupalchok
RCP 8.5	Chitawan, Kaski, Mahottari, Parsa, Sarlahi, Sindhupalchok	Kaski, Mahottari, Sarlahi, Sindhupalchok
	Dominant Hazardous Climate-Induced Hazards and Climate Extreme Events	
	2030s	2050s

RCP 4.5	CEEs	Change in Consecutive Dry Days	Change in Very Wet Days
	CIHs	Snow Storm Area, Landslide Occurrences, Floods/Flash Floods, GLOFs, Number of People Death	Landslide Occurrences, Floods/Flash Floods Prone Area, GLOFs, Number of People Death
RCP 8.5	CEEs	Change in Number of Rainy Days	Change in Precipitation, Temperature, Extreme and Very Wet Days, Warm Nights
	CIHs	Landslide Occurrences, Floods/Flash Floods Prone Area, GLOFs, Number of People Death	Landslide Occurrences, Floods/Flash Floods Prone Area, GLOFs

5.6.3 Overall climate hazards scenarios in the sector

Similarly, the hazard rank results of the overall sector are included in Figure 15 and the number of districts under hazards ranks classes are in Table 20. The table also includes the list of the districts in the 'Very High' hazard rank class and the dominant elements that are the reason for the comparatively hazardous districts in the country.



(a) RCP 4.5 in 2030s

(b) RCP 8.5 in 2030s

(c) RCP 4.5 in 2050s

(d) RCP 8.5 in 2050s

Figure 15: Overall hazard rank of future projection scenarios

In the water resources and energy sectors under the RCP 4.5 scenario, Province 1, Province 2, Bagmati Province, and Gandaki Province will be comparatively affected than other provinces by climate change based on the considered change in climatic variables, climate extreme events, and historical records of climate-induced hazards in the 2030s; and the higher impact of climate change will be shifted towards the west and the hills region of Province 1 will have comparatively less impact in the 2050s. Likewise, the impact of climate change and climate-induced hazards throughout the country under RCP 8.5 in the 2030s and 2050s will have a similar impact to RCP 4.5 in the 2050s.

As described before, the analysis is based on the downscaled data of change in climatic variables and climate extreme events at the district level and the composite results have shown that some less hazard-prone districts in the 2030s will be more hazard-prone in the 2050s and vice versa. This would be justifiable while comparing the overall hazard rank analysis (Figure 15) with the climate-induced hazards analysis (Figure 11) and climate extreme events analysis (Figure 12). It is due to the overall hazard risk scenarios in the sector, and the composite effect of associated hazards and disasters that occurred in the past and the future scenarios of the climatic variables and climate extreme events.

Table 20: Overall hazard rank due to change in climate extreme events

Hazard Rank		Number of Districts			
	RCP 4.5		RCP 8.5		
	2030s	2050s	2030s	2050s	
Very High	(0.748 – 1.000)	13	9	7	7
High	(0.496 – 0.747)	16	24	31	24
Moderate	(0.287 – 0.495)	27	26	19	23
Low	(0.154 – 0.286)	9	8	10	13
Very Low	(0.000 – 0.153)	12	10	10	10

Projected Scenarios	Districts in 'Very High' Rank		
	2030s		2050s
RCP 4.5	Chitawan, Dhanusha, Jhapa, Kaski, Mahottari, Morang, Rautahat, Saptari, Sarlahi, Sindhupalchok, Siraha, Solukhumbu, Taplejung		Banke, Chitawan, Dolpa, Gorkha, Kailali, Kaski, Rautahat, Sarlahi, Sindhupalchok
RCP 8.5	Chitawan, Kailali, Kaski, Mahottari, Parsa, Rautahat, Sarlahi		Banke, Kailali, Kanchanpur, Kaski, Mahottari, Sarlahi, Sindhupalchok
		Dominant Hazardous Climate-Induced Hazards and Climate Extreme Events	
		2030s	2050s
RCP 4.5	CEEs	Change in Consecutive Dry Days,	Change in Very Wet Days
	CIHs	Snow Storm Area, Landslides Occurrences, Floods/Flash Floods, GLOFs, Number of People Death	Landslide Occurrences, Floods/Flash Floods Prone Area, GLOFs, Number of People Death
RCP 8.5	CEEs	Change in Consecutive Wet Days, Number of Rainy Days	Change in Precipitation, Temperature, Extreme and Very Wet Days, Consecutive Wet Days, Number of Rainy Days, Warm Nights
	CIHs	Floods/Flash Floods Prone Area, GLOFs, Number of People Death	Landslide Occurrences, Flood/Flash Floods Prone Area, GLOFs, Number of Death People

Chapter 6

Climate Change Exposure

The identified exposure indicators (Table 1) are primarily based on the Ministry of Population and Environment Report (MOPE, 2017c), which is further synthesized by reviewing other governmental reports and literature (the details are mentioned in Annex 3) and validated through consultations with TWGs and experts. There are 30 indicators altogether that have been adopted as exposure indicators for the sector; among them, 18 are in Water Resources and 12 are in Energy. The indicators have been grouped into 11 elements (six in Water Resources and five in Energy). Water in the form of snow and glaciers, water as flowing/running water, water as storage/reservoirs (pond, lakes, and wetlands), irrigation systems and infrastructures, agricultural lands and irrigations, and the beneficiaries of the water services have been taken as elements of the water resources sub-sector. The hydropower plants, transmission lines, distribution lines/feeder networks, beneficiaries of alternative energy, and hydro as alternative energy have been taken as elements of the Energy sub-sector. As described in the methodology section, the actual value of the indicators is normalized at the beginning, which is then consolidated to element-wise and sub-sector-wise based on the weightage received from experts (Annex 3). The composite results of the exposure rank at element, sub-sector, and sector are defined in the sections below.

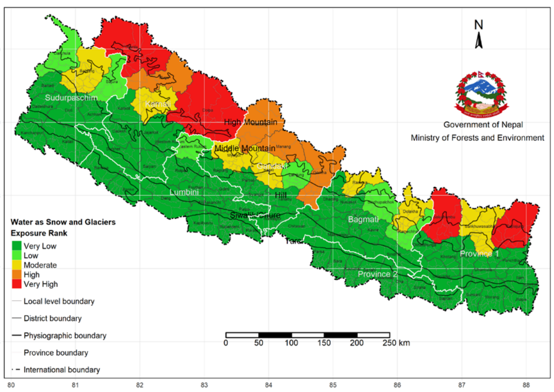
6.1 Exposure ranks of the elements

Figure 16 represents the individual maps of the six elements of the Water Resources sub-sector. The indicators related to water as snow and glaciers; snow-covered area, the number and area of glaciers, and area of glacier lakes; all exist in the middle and high mountain region of Nepal. Therefore, the composite exposure rank map of the element ‘water as a snow and glaciers’ shows that the districts in those regions are highly exposed than the districts in the hills and Terai [Figure 16 (a)]. Among the mountainous districts, the highly exposed districts are Humla, Dolpa, Solukhumbu, and Taplejung.

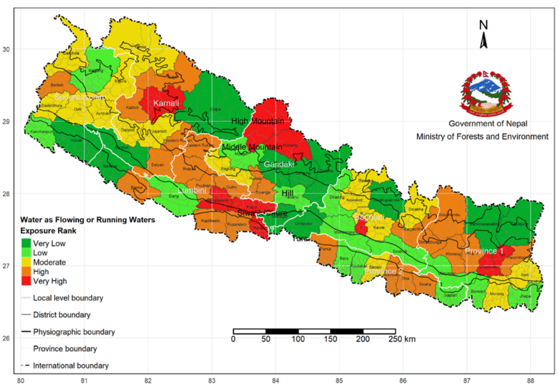
Figure 16(b) represents the exposure rank map of the element 'water as flowing/running water', which includes the indicators: groundwater flow, net water yields (routed flow of the district), total water availability at rivers, and the drainage length. While analyzing the exposure rank, a lower rank has been given to the higher water availability and larger drainage lengths taking into consideration the issues of water security. While considering all the indicators of this element; Jumla, Mustang, Manang, Arghakhanchi, Palpa, Parasi, Lalitpur, and Terhathum are comparatively highly exposed than other districts in the context of water availability and usage for water service areas.

Figure 16(c) represents the exposure rank map of element 'water as storage/reservoirs', which includes the indicators: total area of lakes and wetlands that present in the districts. Based on the existence of these indicators, the districts, Mugu, Kaski, and Sankhuwasabha are highly exposed in comparison to other districts. Many districts have little to no coverage of lakes and wetlands and fall under a very low rank in the exposure index.

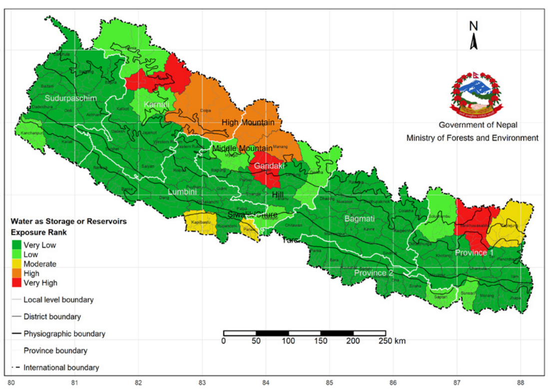
Figure 16(d) represents the exposure rank map of the element 'irrigation systems and infrastructures', which includes indicators, such as the number of the irrigation system in operation, and the number and length of irrigation canals within the districts. These have been taken as exposure units considering the number of losses and damage caused by climate-induced hazards. Majorly, the districts in Terai have a higher chance of exposure due to the presence of a larger number of irrigation systems and infrastructures. Comparatively, Dang, Morang and Jhapa are at a higher exposure than other districts.



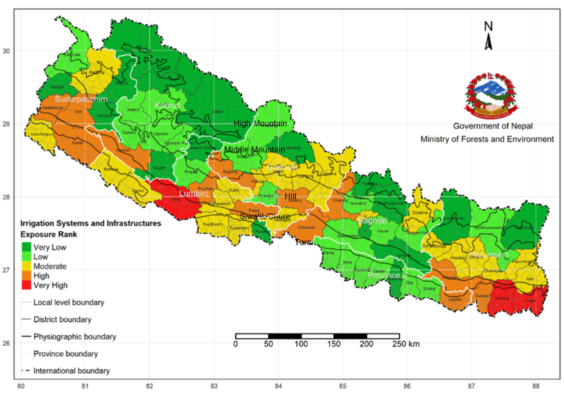
(a) Water as Snow and Glaciers



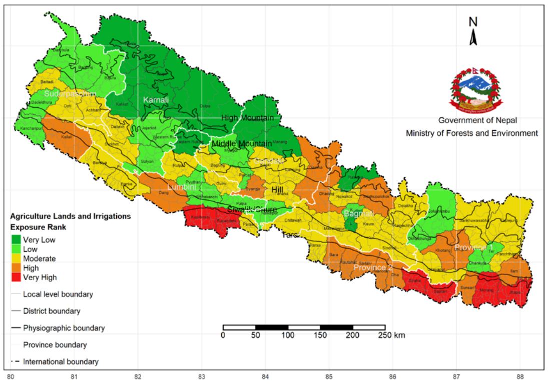
(b) Water as Flowing/Running Water



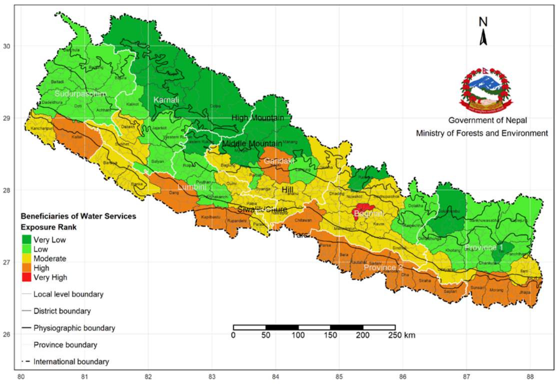
(c) Water as Storage/Reservoirs



(d) Irrigation Systems and Infrastructures



(e) Agriculture Lands and Irrigations

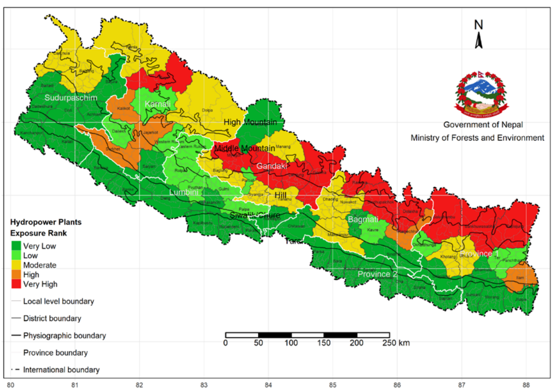


(f) Beneficiaries of Water Services

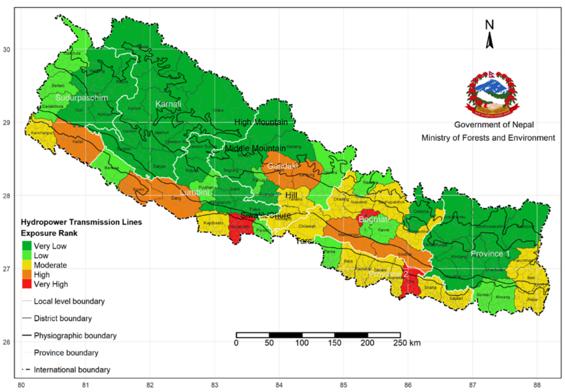
Figure 16: Exposure ranks of the elements (water resources)

Figure 16(e) represents the exposure rank map of the element 'agricultural lands and irrigation management, which includes indicators such as the total area of agricultural lands, potential irrigable area, and non-irrigated lands within the districts. These have been taken as exposure units considering either the irrigation facilities of agricultural lands or the rain-fed systems, as the climate change will adversely affect the agricultural production and their livelihoods due to climate-induced hazards such as floods and droughts. The districts in the Terai, and hills and middle mountain regions of Province 1, Bagmati Province, and Gandaki Province are comparatively at higher exposure than other regions. For this element, Kapilbastu, Rupandehi, Siraha, Saptari, Morang, and Jhapa are at higher exposure than other districts.

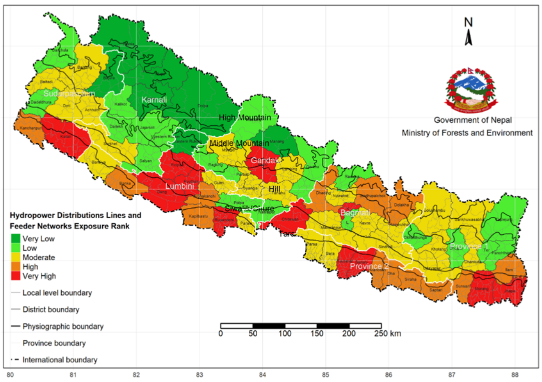
Figure 16(f) represents the exposure rank map of element 'beneficiaries of water services, which includes the total male and female population separately in the districts. The male and female populations are separately analysed. The findings show that in districts where the higher number of female populations are present, the exposure is higher. This is an integration of GESI in this assessment through the consideration that females are more vulnerable than their male counterparts. The average weightage received for the female is 0.506 and 0.494 for the male. The most vulnerable districts will be where there is a higher number of female populations. Therefore, most of the districts in Terai are at a higher exposure, with the inclusion of a non-Terai district Kathmandu among the 77 districts of Nepal.



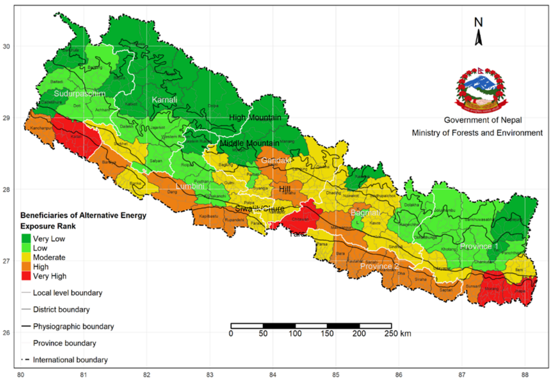
(a) Hydropower Plants



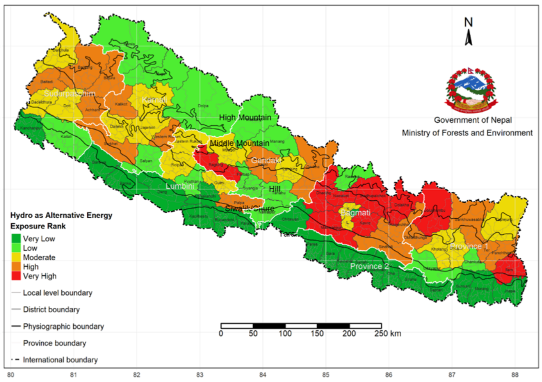
(b) Transmission Lines



(c) Distribution (Feeder) Networks



(d) Beneficiary of Alternative Energy



(e) Hydro as Alternative Energy

Figure 17: Exposure ranks of the elements (energy)

Figure 17 represents a similar exposure rank map of the five elements of the Energy sub-sector. In the element 'hydropower plants' [Figure 17(a)], the number of hydropower plants and their installed capacity has been taken as indicators. The hydropower plants that are currently in operation, under construction (confirmed to be completed in the next few years), and under detailed survey have been considered in the assessment. Considering the possible loss and damage due to the changing climate and climate induced-hazards, the districts with the existence of a higher number of hydropower plants and total installed capacity are highly exposed. The results show that the districts of Mugu, Myagdi, Kaski, Lamjung, Gorkha, Rasuwa, Sindhupalchok, Dolakha, Solukhumbu, Sankhuwasabha, and Taplejung are highly exposed compared to other districts.

Figure 17(b) represents the exposure rank map of the element 'transmission lines' and Figure 17(c) represents the exposure rank map of the element 'distribution lines' (feeder network). Both elements include the total length of the electric line network and their capacity in kilovolts (kV). These have also been considered by the impact of loss and damage due to the changing climate and associated hazards. For the transmission lines, the higher exposure districts are Rupandehi, Kathmandu, and Dhanusha in comparison to other districts. Similarly, for the distribution lines, the higher exposure districts are Kailali, Dang, Rolpa, Pyuthan, Rupandehi, Kaski, Chitawan, Kathmandu, Rautahat, Sarlahi, Morang, and Jhapa.

Figure 17(d) represents the exposure rank map of the element 'beneficiary of alternative energy, which includes indicators such as the number of households that depend on traditional energy for cooking and renewable energy for cooking and lighting. Based on the statistics, a high number of households in the Terai region, and Bagmati Province and Gandaki Province are using alternative energy for cooking and lighting in comparison to other regions in Nepal. Kailali, Chitwan, Morang, and Jhapa are at high exposure in comparison to other districts

Figure 17(e) represents the exposure rank map of element 'hydro as alternative energy, which includes the indicators: number of pico/micro/mini hydropower plants and their total installed capacity, and number of improved water-mills within the districts. Similar to other elements, the loss and damage in the system of this element due to the changing climate and associated disasters will put the districts at high exposure. Additionally, a higher number of pico/micro/ mini hydropower and water-mills in the districts will also put the districts at high exposure. Therefore, the hills and both middle and high mountain regions of Province 1, and Bagmati Province Province in the east; and hills and middle mountain regions of Gandaki Province, Lumbini Province, Karnali Province, and Sudurpashchim Province in the west are comparatively at high exposure. The highly exposed districts are Baglung, Dhading, Nuwakot, Makawanpur, Sindhupalchok, Kavrepalanchok, Dolakha, Solukhumbu, and Ilam.

6.2 Exposure ranks of the sub-sectors

The composite rank of the six elements, described above and mentioned in Figure 16, is the exposure rank for the water resources sub-sector. The composite exposure rank map is presented in Figure 18. The composite exposure rank shows that the eastern Terai districts of Province 1, Province 2, and Lumbini Province, and Mugu, Kaski, Kathmandu, and Dolakha are comparatively at higher exposure than other districts for the water resources sub-sector. The dominant elements that resulted in the higher exposure in Terai are the existence of higher irrigation systems and infrastructures, agricultural lands and irrigation status, and the higher number of people residing in the districts. In general, the mountainous districts are in moderate to high rank of exposure due to the existence of water as snow, glaciers, and glacier lakes.

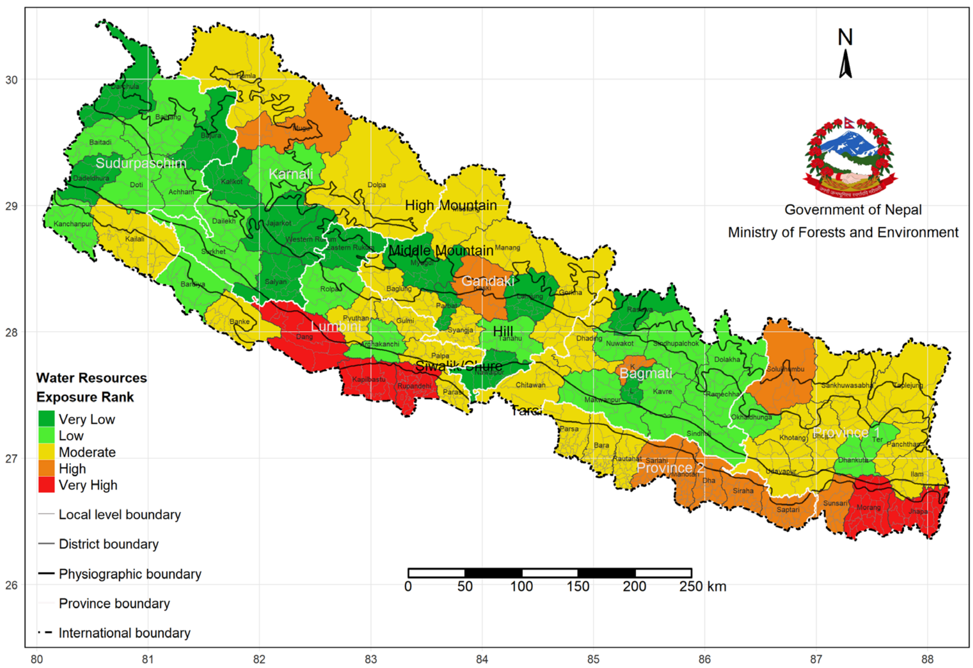


Figure 18: Exposure rank of the water resources sub-sector

Table 21: Exposure ranks of the water resources sub-sector

Exposure Rank	District
Very High (0.660 – 1.000)	Dang, Jhapa, Kapilbastu, Morang, Rupandehi
High (0.477 – 0.659)	Dhanusha, Kaski, Kathmandu, Mahottari, Mugu, Saptari, Sarlahi, Siraha, Solukhumbu, Sunsari
Moderate (0.310 – 0.476)	Baglung, Banke, Bara, Bhojpur, Chitawan, Dhading, Dolpa, Gorkha, Gulmi, Humla, Ilam, Kailali, Khotang, Manang, Mustang, Palpa, Panchthar, Parasi, Parsa, Pyuthan, Rautahat, Sankhuwasabha, Syangja, Taplejung, Udayapur
Low (0.174 – 0.309)	Achham, Arghakhanchi, Baitadi, Bajhang, Bardiya, Dailekh, Dhankuta, Dolakha, Doti, Jumla, Kanchanpur, Kavrepalanchok, Makawanpur, Nuwakot, Okhaldhunga, Ramechhap, Rolpa, Sindhuli, Sindhupalchok, Surkhet, Tanahu, Terhathum
Very Low (0.000 – 0.173)	Bajura, Bhaktapur, Dadeldhura, Darchula, Eastern Rukum, Jajarkot, Kalikot, Lalitpur, Lamjung, Myagdi, Nawalpur, Parbat, Rasuwa, Salyan, Western Rukum
Dominant Indicators for the Higher Exposure Ranks	
Water availability as groundwater flow, net water yields, and total water at rivers; Drainage length; Area covered by lakes and reservoirs; Number of irrigation canals; Total area of agricultural lands, potential irrigable lands, and non-irrigated agricultural lands; Total number of the male and female population.	

Table 21 represents the list of districts based on the exposure rank classes of the water resources sub-sector. Among the 77 districts of Nepal, the exposure rank classes are as follows - 5 districts are in 'Very High', 10 are in 'High', 25 are in 'Moderate', 22 are in 'Low', and 15 are in 'Very Low'. The table also includes the list of the indicators which play a dominant role in the higher exposure of the districts due to higher magnitudes in comparison to other districts. Most importantly, the assessment is based on current infrastructures developed until 2019.

The exposure rank for the energy sub-sector is obtained from the composite result of the five elements described in the above section and also mentioned in Figure 17. The obtained exposure rank map is presented in Figure 19. The rank result shows that the districts in Province 1, Province 2, Bagmati Province, and Gandaki Province are at higher exposure than the western provinces. In general, the indicators of the elements—the existence of hydropower plants, distribution/feeder networks of the electric lines, and hydro as alternative energy are predominant in making the districts at higher exposure as an exposure rank. As described before, these kinds of ranking processes are a composite effect of all the indicators (there are 12 indicators for energy in this assessment) and the given weightage to them is in an aggregating process.

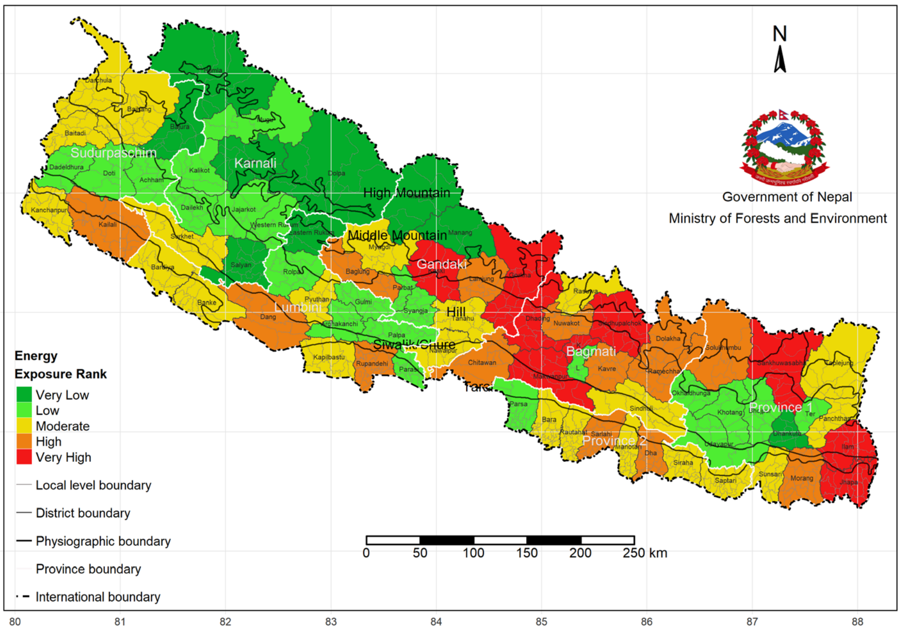


Figure 19: Exposure Rank of the Energy Sub-sector

Similar to the water resources sub-sector, the infrastructures in operations and under construction can only be considered for this assessment of the energy sub-sector as exposure units. Looking at the ranking, almost all districts of Karnali Province—eastern Rukum, Mustang, and Manang, and the hills of Province 1, are at lower exposure in comparison to other districts. This shows that these districts have fewer infrastructures for energy development, which means that either the districts have comparatively few opportunities to develop the energy sector, or they have little to no access to developed energy sources.

Table 22 represents the list of districts based on the exposure rank classes of the Energy sub-sector. Among the 77 districts the exposure rank classes are as follows - 9 districts are in 'Very High', 14 are in 'High', 22 are in 'Moderate', 23 are in 'Low', and 9 are in 'Very Low'. The table also includes the list of indicators that will predominantly influence the districts to become a higher exposure in comparison to other districts.

Table 22: Exposure Ranks of the Energy Sub-sector

Exposure Rank	District
Very High (0.743 – 1.000)	Dhading, Gorkha, Ilam, Jhapa, Kaski, Kathmandu, Makawanpur, Sankhuwasabha, Sindhupalchok
High (0.539 – 0.742)	Baglung, Chitwan, Dang, Dhanusha, Dolakha, Kailali, Kavrepalanchok, Lamjung, Morang, Nuwakot, Ramechhap, Rupandehi, Sarlahi, Solukhumbu
Moderate (0.327 – 0.538)	Baitadi, Bajhang, Banke, Bara, Bardiya, Darchula, Kanchanpur, Kapilbastu, Mahottari, Myagdi, Nawalpur, Panchthar, Pyuthan, Rasuwa, Rautahat, Saptari, Sindhuli, Siraha, Sunsari, Surkhet, Tanahu, Taplejung
Low (0.140 – 0.326)	Achham, Arghakhanchi, Bhaktapur, Bhojpur, Dadeldhura, Dailekh, Doti, Gulmi, Jajarkot, Kalikot, Khotang, Lalitpur, Mugu, Okhaldhunga, Palpa, Parasi, Parbat, Parsa, Rolpa, Syangja, Terhathum, Udayapur, Western Rukum
Very Low (0.000 – 0.139)	Bajura, Dhankuta, Dolpa, Eastern Rukum, Humla, Jumla, Manang, Mustang, Salyan
Dominant Indicators for the Higher Exposure Ranks	
Several hydropower plants and their installed capacity; Length and capacity of both transmission and distribution lines; Households dependency on sources of traditional energy for cooking; Number of improved water-mills.	

6.3 Overall exposure ranks of the sector

The overall exposure rank map of the sector has been obtained by compositing its two sub-sectors – water resources and energy, presented in Figure 20. The overall exposure rank shows that the Terai and Mountain districts of Province 1 are at 'High' to 'Very High' exposure rank, whereas the hills districts are 'Moderate' to 'Low' exposure rank while inter-comparing between the 77 districts of Nepal. Similarly, the districts in Province 2 are at 'Moderate' to 'Very High' exposure rank. In Bagmati Province, the districts are at 'Very Low' to 'Very High' exposure rank; where Bhaktapur is at 'Very Low' and Gorkha, Kathmandu and Sindhupalchok are at 'Very High' exposure rank. Similarly, in Gandaki Province, the districts are also at 'Very Low' to 'Very High' exposure; where Manang is at 'Very Low' and Kaski and Gorkha are at 'Very High' exposure rank. The districts of Lumbini Province are also at 'Very Low' to 'Very High' exposure; where Eastern Rukum is at 'Very Low' and Dang, Kapilbastu and Rupandehi are at 'Very High' exposure rank. The districts of Karnali Province are at 'Very Low' to 'Moderate' exposure rank and the districts of Sudurpashchim Province are at 'Very Low' to 'High' exposure rank in the inter-comparison among 77 districts of Nepal. In general, the eastern part is comparatively at higher exposure than the western part of Nepal, except for western areas in the Terai region.

Looking at the overall exposure rank, Karnali Province and Sudurpashchim Province are at lower exposures when inter-comparing with other provinces. As described before in the sub-sector sections, this is due to the existence of water services and energy-related infrastructure, which represents the presence of lesser development infrastructure in these provinces in comparison to other provinces. Overall the composite exposure rank, the dominant indicators to obtain the higher exposure rank are mentioned in Table 23, which are identical with the dominant indicators for the sub-sectors mentioned in Table 21 and Table 22. The mountainous districts, such as Gorkha and Solukhumbu, are highly exposed due to the presence of additional exposure indicators related to glaciers. Similarly, Kathmandu district is at high exposure due to the highest population and hydro-electric transmission lines; Sankhuwasabha is at exposure due to the presence of maximum wetlands area and the maximum installed capacity of hydropower plants; Dang, Jhapa, and Morang are at exposure due to the presence of a higher number of irrigation systems and canals, and agricultural lands, and so on.

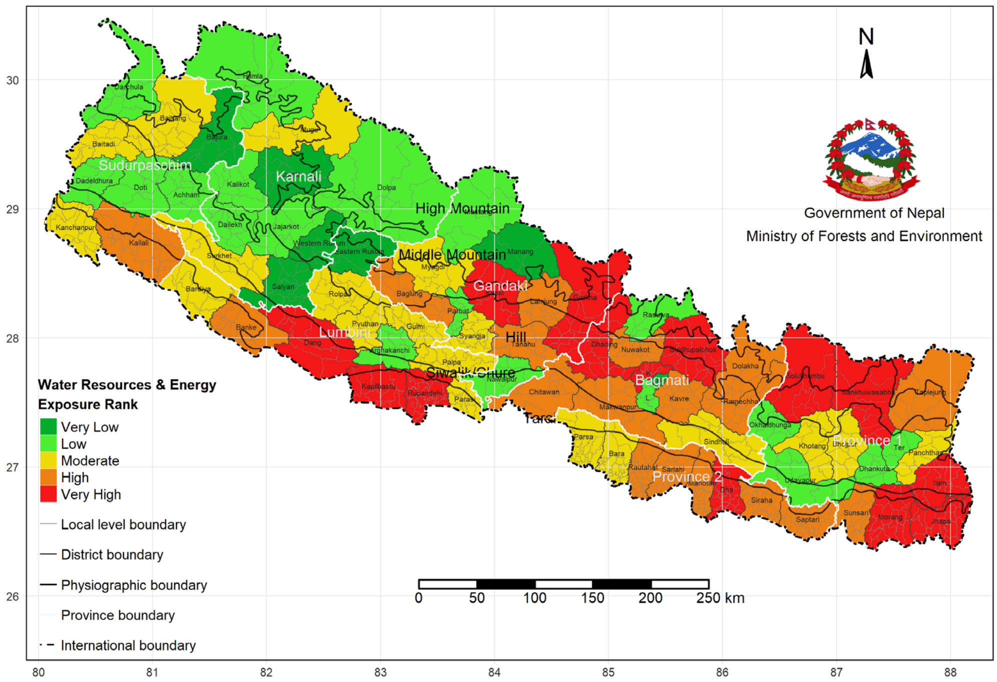


Figure 20: Overall exposure rank of the sector

Table 23: Overall exposure ranks of the sector

Exposure Rank	District
Very High (0.649 – 1.000)	Dang, Dhading, Dhanusha, Gorkha, Ilam, Jhapa, Kapilbastu, Kaski, Kathmandu, Morang, Rupandehi, Sankhuwasabha, Sindhupalchok, Solukhumbu
High (0.444 – 0.648)	Baglung, Banke, Chitwan, Dolakha, Kailali, Kavrepalanchok, Lamjung, Mahottari, Makawanpur, Nuwakot, Ramechhap, Rautahat, Saptari, Sarlahi, Siraha, Sunsari, Tanahu, Taplejung
Moderate (0.276 – 0.443)	Baitadi, Bajhang, Bara, Bardiya, Bhojpur, Gulmi, Kanchanpur, Khotang, Mugu, Myagdi, Palpa, Panchthar, Parasi, Parsa, Pyuthan, Rolpa, Sindhuli, Surkhet, Syangja
Low (0.157 – 0.275)	Achham, Arghakhanchi, Dadeldhura, Dailekh, Darchula, Dhankuta, Dolpa, Doti, Humla, Jajarkot, Kalikot, Lalitpur, Mustang, Nawalpur, Okhaldhunga, Parbat, Rasuwa, Terhathum, Udayapur
Very Low (0.000 – 0.156)	Bajura, Bhaktapur, Eastern Rukum, Jumla, Manang, Salyan, Western Rukum
Dominant Indicators for the Higher Exposure Ranks	
Area of Glaciers; Water availability as groundwater flow, net water yields, and total water at rivers; Drainage length; Number of irrigation canal; Total area of agricultural lands, potential irrigable lands, and non-irrigated agricultural lands; Total number of the male and female population; Number of hydropower plants; Length and capacity of both transmission and distribution lines; Households dependency on sources of traditional energy for cooking.	

Overall, 14 districts are at 'Very High', 18 are at 'High', 19 are at 'Moderate', 19 are at 'Low' and 7 are at 'Very Low' exposure rank classes (Table 23).

Observed Climate Change Vulnerability

As explained before, the vulnerability of climate change is a function of sensitivity and adaptive capacity. The sensitivity, adaptive capacity, and vulnerability ranks are separately explained below in detail by elements, sub-sectors, and sector-wise.

7.1 Sensitivity ranks and indexes

Overall, 35 indicators (Table 2) have been considered for the sensitivity component,among the 35, the water resources sub-sector has 28 indicators under the eight elements and the energy sub-sector has seven indicators under the five elements. The eight elements of the water resources sub-sector are water as snow and glaciers, water as flowing/running water, water as storage/reservoirs, catchment characteristics, dependency on drinking water sources, water demand and supply status, irrigation system and operations, and GESI status [Table 2(a)]. The five elements of the energy sector are the type of hydropower plants, the operational status of hydro plants, ownership types of hydro plants, dependency on alternative energy, and biomass supply and demand status [Table 2(b)]. There is only a single indicator under some elements. The indicators are primarily based on the report of the Ministry of Population and Environment (MoPE, 2017b) and further refined based on the literature review and the nature of available data.

7.1.1 Sensitivity ranks of the elements

The sensitivity rank maps of the elements of the water resources and energy sub-sectors are presented in Figure 21 and Figure 22. These element-wise sensitivity ranks have been obtained by composing the respective indicators (Table 2) of the elements and respective weightage received from the expert survey (refer to Annex 3 for the weightage of individual indicators, elements, and sub-sectors).

Figure 21(a) represents the water resources sub-sector sensitivity rank map of the element 'water as snow and glaciers', which includes an indicator related to the trend of change in snow-covered areas. The degree of sensitivity is measured according to the status of the snow areas either in decreasing or in increasing trends. Similar trend information of glaciers and glaciers lakes were also planned to be included in the beginning, however, this was not possible due to the unavailability of the respective data, which is also considered to be a limitation of this assessment. Among the 77 districts of Nepal, only 24 districts have snow-covered areas with analyzed trends. The remaining 53 districts are not applicable for these indicators, subsequently these districts are to be categorized as 'Very Low' insensitivity. According to data from 2001 to 2019, the snow-covered areas of Darchula, Bajhang, Humla, and Mugu districts are in a decreasing trend in comparison to the 24 districts with snow-covered areas. The snow, ice, and glaciers in the mountains of Nepal are freshwater storage that feeds the rivers of Nepal, and the decreasing trends in their coverage will lead to a water security issue in the future. Therefore, the districts and regions, the existence of higher decreasing trends of snow and ice-covered areas are more sensitive to the water-related socio-economic development.

Figure 21(b) represents the water resources sub-sector sensitivity rank map of the element 'water as flowing/running water', which includes the indicators of the trend of change in water balance parameters such as groundwater flow, net water yields, and total water at rivers; and drainage density. The trends of change in groundwater parameters have been analysed through the hydrological model data used in the Irrigation Master Plan 2019, in which trends are analysed considering the change in the parameter in the future, concerning the present scenario. In the analysis, the decreasing trends in water balance parameters and the existence of lesser drainage density have been considered as a higher risk in terms of water security of the districts in the future. According to these considerations and respective data analysis, Kaski and Nuwakot districts are at a 'Very Low' sensitivity rank in comparison to other districts. In general, most of the districts, except for a few hill districts of Province 1, Bagmati Province, and Gandaki Province, are comparatively lower in the sensitivity rank.

Figure 21(c) represents the water resources sub-sector sensitivity rank map of the element 'water as storage/reservoirs'. This element includes the indicators such as trends of change in lakes and wetland areas. Among the 77 districts, both lakes and wetlands are present in 17 districts. Dolpa, Gorkha, Kaski, Manang, Mugu, Mustang, Myagdi, Sankhuwasabha, Saptari, Solukhumbu, Sunsari, and Taplejung is the common district for the existence of both lakes and wetlands. While, Baitadi, Humla, Jumla, Rasuwa, and Udayapur districts only have lakes, Chitwan, Kanchanpur, Kapilbastu, Nawalpur, and Sindhupalchok districts only have wetlands. Most of these districts are from high and middle mountain regions and few are from the Terai region. The trends of change in these parameters analysis have been conducted with the data from 2001 to 2019. For this assessment, the remaining 55 districts are considered to be not applicable for these parameters and taken as 'Very Low' sensitivity rank. Comparatively, the higher sensitivity rank districts are Mugu, Solukhumbu, and Sankhuwasabha.

Figure 21(d) represents the water resources sub-sector sensitivity rank map of the element 'catchment characteristics', which includes the indicators—slopes of the topography, soil class based on texture and covered area, and trend of change in land use land cover area. In this analysis, the higher slope of topography is considered highly sensitive because of the high possibility of occurrences related to water-induced disasters such as landslides and floods due to high surface runoff. Similarly, the high sensitivity in soil texture of the top layer is considered based on high hydraulic conductivity, which leads to high interflow and few chances of groundwater recharge. Soil types based on the texture that has been considered in this assessment are loamy, loamy-skeletal, loamy-boulder, fragmental-sandy, river-bed, and snow-covered. Likewise, the decreasing trends of change in agricultural land and forests coverage; and the increasing trends of change in a barren land, grasslands, and savannas have been taken as highly sensitive due to their adverse effect on hydrological retention. Comparatively, the districts of the Terai and Siwalik regions, as well as, Mustang and Solukhumbu districts are at a lesser sensitivity rank.

Figure 21(e) represents the water resources sub-sector sensitivity rank map of the element 'water as flowing/running water', which includes the indicators of the trend of change in water balance parameters such as groundwater flow, net water yields, and total water at rivers; and drainage density. The trends of change in groundwater parameters have been analyzed through the hydrological model data used in the Irrigation Master Plan 2019, in which trends are analyzed considering the change in the parameter in the future, concerning the present scenario. In the analysis, the decreasing trends in water balance parameters and the existence of lesser drainage density have been considered as a higher risk in terms of water security of the districts in the future. According to these considerations and respective data analysis, Kaski and Nuwakot districts are at a 'Very Low' sensitivity rank in comparison to other districts. In general, most of the districts, except for a few hill districts of Province 1, Bagmati Province, and Gandaki Province, are comparatively lower in the sensitivity rank.

Figure 21(c) represents the water resources sub-sector sensitivity rank map of the element 'water as storage/reservoirs'. This element includes the indicators such as trends of change in lakes and wetland areas. Among the 77 districts, both lakes and wetlands are present in 17 districts. Dolpa, Gorkha, Kaski, Manang, Mugu, Mustang, Myagdi, Sankhuwasabha, Saptari, Solukhumbu, Sunsari, and Taplejung is the common district for the existence of both lakes and wetlands. While, Baitadi, Humla, Jumla, Rasuwa, and Udayapur districts only have lakes, Chitwan, Kanchanpur, Kapilbastu, Nawalpur, and Sindhupalchok districts only have wetlands. Most of these districts are from high and middle mountain regions and few are from the Terai region. The trends of change in these parameters analysis have been conducted with the data from 2001 to 2019. For this assessment, the remaining 55 districts are considered to be not applicable for these parameters and taken as 'Very Low' sensitivity rank. Comparatively, the higher sensitivity rank districts are Mugu, Solukhumbu, and Sankhuwasabha.

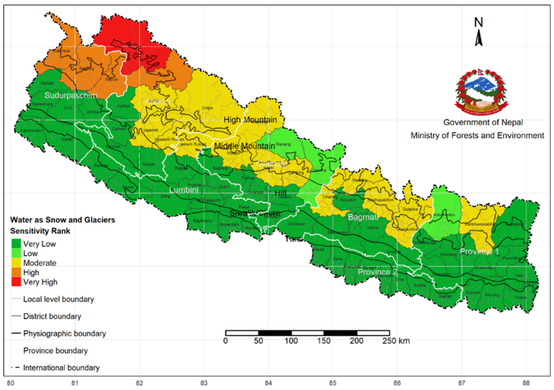
Figure 21(d) represents the water resources sub-sector sensitivity rank map of the element 'catchment characteristics', which includes the indicators—slopes of the topography, soil class based on texture and covered area, and trend of change in land use land cover area. In this analysis, the higher slope of topography is considered highly sensitive because of the high possibility of occurrences related to water-induced disasters such as landslides and floods due to high surface runoff. Similarly, the high sensitivity in soil texture of the top layer is considered based on high hydraulic conductivity, which leads to high interflow and few chances of groundwater recharge. Soil types based on the texture that has been considered in this assessment are loamy, loamy-skeletal, loamy-boulder, fragmental-sandy, river-bed, and snow-covered. Likewise, the decreasing trends of change in agricultural land and forests coverage; and the increasing trends of change in barren land, grasslands, and savannas have been taken as highly sensitive due to their adverse effect on hydrological retention. Comparatively, the districts of the Terai and Siwalik regions, as well as, Mustang and Solukhumbu districts are at a lesser sensitivity rank.

Figure 21(e) represents the water resources sub-sector sensitivity rank map of the element 'dependency on drinking water sources, which includes the number of households who have access to drinking water from the tap/piped water, tube well/hand pump, covered and uncovered well/kuwa, spout water and rivers/streams sources. The degree of sensitivity is determined based on access to safe drinking water. For this assessment, the water from the tap/piped water, tube well/hand pump, and covered well/kuwa have been taken as safe water and the water from uncovered well/kuwa, spout water, and rivers/streams sources have been taken as unsafe water to drink. Comparatively, the districts of the western region, particularly that of Karnali Province and Sudurpashchim Province as well as Sindhuli district is at a higher sensitive rank.

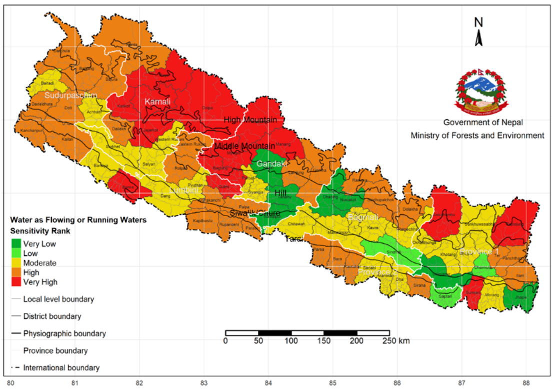
Figure 21(f) represents the water resources sub-sectors sensitivity rank map of the element 'water supply and demand status', which includes both drinking water and irrigation water requirement and supply. The districts with a higher demand deficit have been taken as high sensitive districts in terms of meeting the consumptive demand from the available water in the districts. This demand and supply status is completely reliant on the population size for the drinking water and the agricultural land size for the irrigation water demand concerning total water availability for consumptive use. According to this assessment, the higher sensitive districts are from the Terai, Siwalik, and Hills regions of Province 1, and Lumbini Province; Kathmandu Valley; and Province 2. In general, the Terai to Hills regions is sensitive to water security and scarcity status.

Figure 21(g) represents the water resources sub-sectors sensitivity rank map of the element 'irrigation systems and operations, which includes parameters—age of operational irrigation schemes, type of water sources used for irrigation (perennial, pond/lake, and local stream), functional status of irrigations systems (operational, under construction and defunct) and sizes of irrigation scheme (major, large, medium and small). The districts which have a higher number of older irrigation schemes, irrigation systems from local streams, under construction and defunct irrigation schemes, and irrigation schemes by size, have been taken as highly sensitive in this assessment. In general, the eastern Terai districts are highly sensitive, which includes Achham, Baglung, Arghakhanchi, Rasuwa, Lalitpur, Dhanusha, Solukhumbu, and Okhaldhunga districts are at high sensitivity; and Baitadi, Parbat, and Kaski districts are less sensitive.

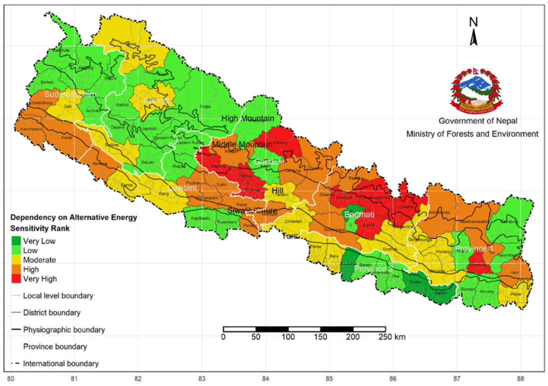
Figure 21(f) represents the water resources sub-sectors sensitivity rank map of the element 'water supply and demand status', which includes both drinking water and irrigation water requirement and supply. The districts with a higher demand deficit have been taken as high sensitive districts in terms of meeting the consumptive demand from the available water in the districts. This demand and supply status is completely reliant on the population size for the drinking water and the agricultural land size for the irrigation water demand concerning total water availability for consumptive use. According to this assessment, the higher sensitive districts are from the Terai, Siwalik, and Hills regions of Province 1, and Lumbini Province; Kathmandu Valley; and Province 2. In general, the Terai to Hills regions is sensitive to water security and scarcity status.



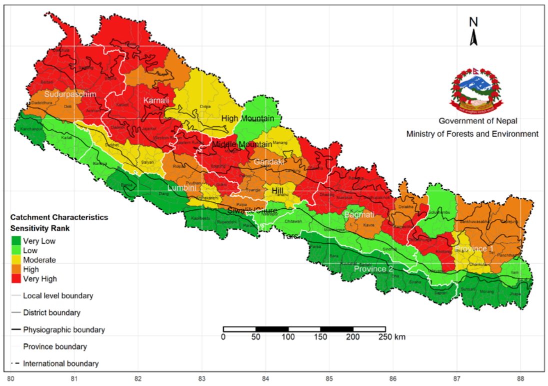
(a) Water as Snow and Glaciers



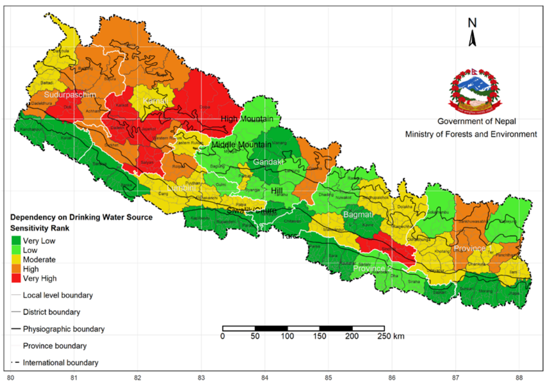
(b) Water as Flowing/Running Water



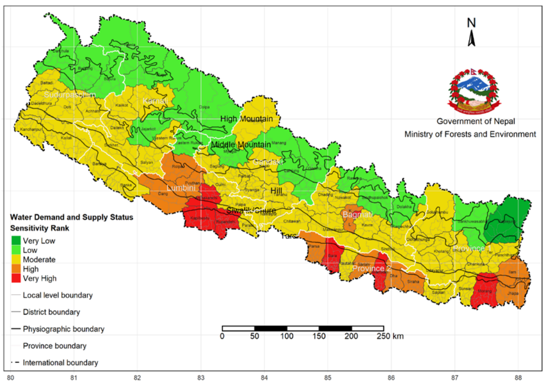
(c) Water as Storage/Reservoirs



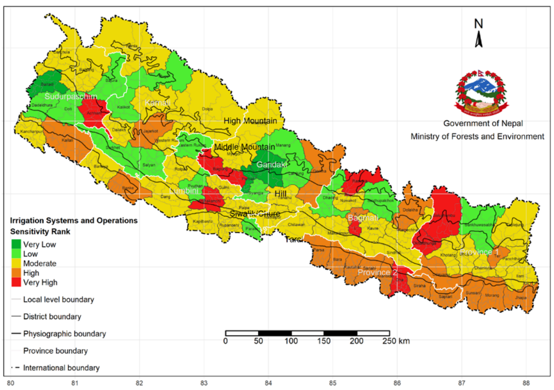
(d) Catchment Characteristics



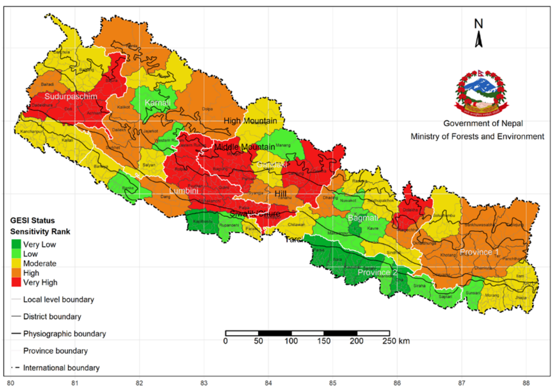
(e) Dependency on Drinking Water Sources



(f) Water Demand and Supply Status



(g) Irrigation Systems and Operations



(h) GESI Status

Figure 21: Sensitivity rank of the elements (water resources)

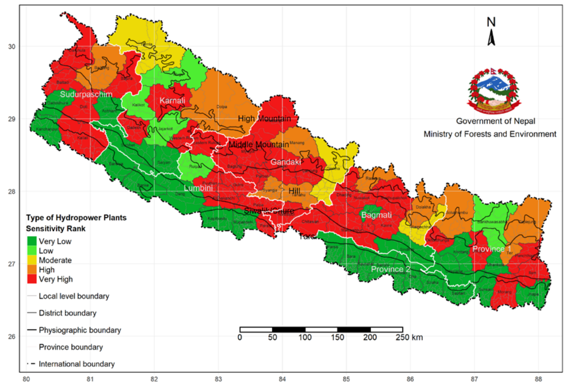
Figure 21(g) represents the water resources sub-sectors sensitivity rank map of the element 'irrigation systems and operations, which includes parameters—age of operational irrigation schemes, type of water sources used for irrigation (perennial, pond/lake, and local stream), functional status of irrigations systems (operational, under construction and defunct) and sizes of irrigation scheme (major, large, medium and small). The districts which have a higher number of older irrigation schemes, irrigation systems from local streams, under construction and defunct irrigation schemes, and irrigation schemes by size, have been taken as highly sensitive in this assessment. In general, the eastern Terai districts are highly sensitive, which includes Achham, Baglung, Arghakhanchi, Rasuwa, Lalitpur, Dhanusha, Solukhumbu, and Okhaldhunga districts are at high sensitivity; and Baitadi, Parbat, and Kaski districts are less sensitive.

Figure 21(h) represents the water resources sub-sectors sensitivity rank map of the element 'GESI status', which includes sensitivity indicators – sex ratio (male by female), the trend of population growth, male and female number of people with disability (PWD), number of female-headed households, number of children population (boys and girls), number of senior citizens (male and female), Dalit population (male and female) and Janajati population (male and female). The districts where the existence of higher concentration of women, children, girls, number of PWD, senior citizens, and ethnic groups; have been taken as higher sensitive districts. By the composition of these indicators, Dadeldhura, Doti, Achham, Bajura, Eastern Rukum, Rolpa, Pyuthan, Baglung, Myagdi, Parbat, Gulmi, Arghakhanchi, Palpa, Nawalpur, Lamjung, Gorkha, and Dolakha districts are highly sensitive in comparison to other districts.

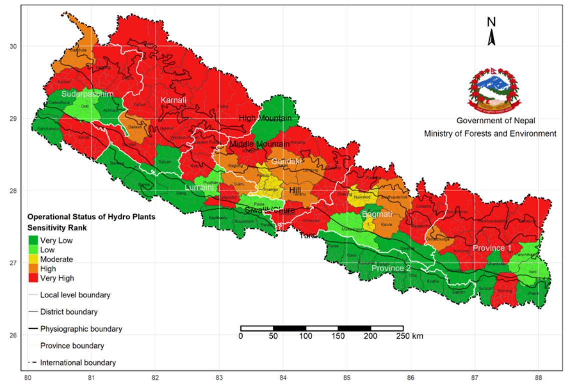
Figure 22(a) represents the energy sub-sectors sensitivity rank map of the element's number and type of hydropower plants by capacity (mini, small, and medium) and by water conveyance systems (Run-Of-River (ROR) and Peaking Run-Of-River (P-ROR))'. The mega and storage type of hydropower have not been taken into this assessment, as the mega and storage type hydropower plants are designed for peaking with storage capacity and rely on larger river systems - thus found little sensitive. However, the mini, small and medium hydropower plants are ROR and PROR types, many of them rely on tributaries from major river systems and are sensitive to the changing climate. Among the 77 districts of Nepal, 52 districts have hydropower in operation, under construction or survey. The remaining 25 districts are not applicable for this analysis and are found to be very less sensitive.

Figure 22(b) represents the energy sub-sectors sensitivity rank map of the element 'operational status of hydropower plants (under construction and survey)'. The operational hydropower plants are considered as very less sensitive as they have been in operation for many years, have already generated the required revenue, and are well-functioning as designed. The hydropower plants that are under construction or survey are still not in operation and will take a few more years to operate. There is an enormous amount of investment in the hydropower plants that are under construction and survey thus these have been taken as more sensitive due to climate change and associated disasters.

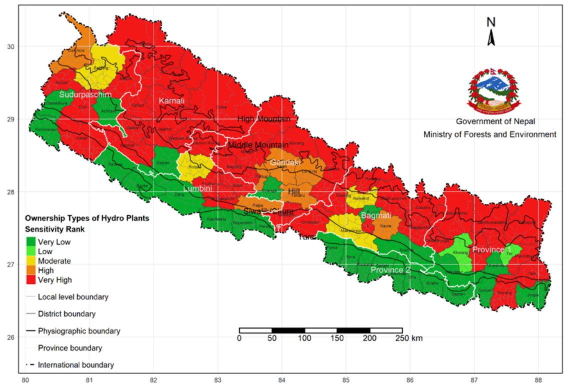
Figure 22(c) represents the energy sub-sectors sensitivity rank map of the element 'ownership types of the hydropower plants' (government and private sector). The governmental institutions that own the hydropower projects are large and well set up. Therefore, the government can have multiple back-ups in terms of financial leverage in case some of the hydropower projects are not able to function as well or result in their operations being halted by climate change and its associated disasters. In case of similar incidents, the private sector will have fewer coping mechanisms as most private sectors only own single hydropower, with limited financial leverage - thus, private sectors are more sensitive than governmental institutions.



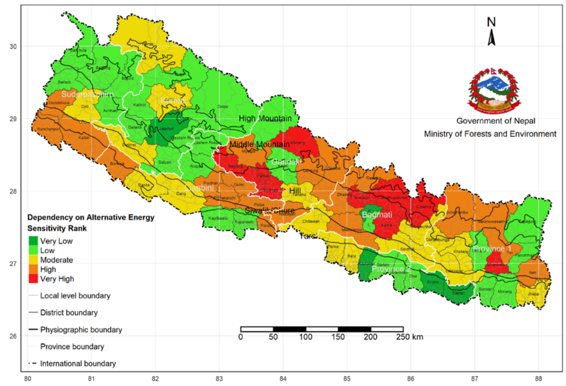
(a) Type of Hydropower Plants



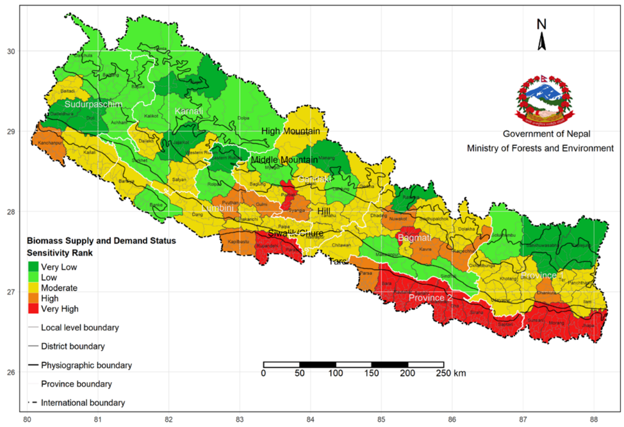
(b) Operational Status of Hydro Plants



(c) Ownership Types of Hydro Plants



(d) Dependency on Alternative Energy



(e) Biomass Supply and Demand Status

Figure 22: Sensitivity of the elements (energy)

Figure 22(d) represents the energy sub-sectors sensitivity rank map of the element's dependency on alternative energy, which includes the number of households dependent on wood/firewood for cooking and pico/micro/mini hydropower plants for lighting. These indicators are based on the sources of alternative energy for cooking and lighting. The excessive use of firewood will create high chances of deforestation and the loss of forest will also impact the daily household activities that rely on firewood for cooking. Likewise, the pico/micro/mini hydropower is dependent on the local stream, which will highly affect by the change in a small amount of water availability and have chances to destroy completely by single events of climate-induced disasters. Therefore, the higher numbers of households in the districts who depend on the firewoods for cooking and these hydropower plants for lighting are taken as more sensitive districts for this assessment. In general, the western Terai, Bagmati Province, and Gandaki Province, and some districts of Province 1 and Lumbini Province. Interestingly, Karnali Province and Hills and Mountain regions of Sudurpashchim Province are less sensitive for the analysis of this element. It is because very few households of this region are depended on pico/micro/mini hydropower plants for lighting.

Figure 22(e) represents the energy sub-sectors sensitivity rank map of the element 'biomass supply and demand status', which includes surplus and deficit status of biomass to consume at households as a source of alternative energy for cooking. Higher deficit or fewer surpluses has been taken as highly sensitive in this assessment. The biomass availability is based on the forest coverage and biomass demand of the population. Therefore, the districts which have a high concentration of people are more sensitive in comparison to other districts.

7.1.2 Sensitivity ranks of the sub-sectors

Figure 23 represents the sensitivity rank map of the water resources sub-sector, which has been obtained by compositing the eight elements mentioned in Table 2 and Figure 21, considering the relevant weightage of elements listed in Annex 3. The composite rank result shows that the western part of Nepal (excluding some Terai districts) and the eastern mountainous region are more sensitive in comparison to other districts. The dominant elements for the higher sensitivity rank of the water resources sub-sector are water as flowing/running water [Figure 21 (b)], catchment characteristics [Figure 21 (d)], dependency on sources of drinking water [Figure 21 (e)], and GESI status [Figure 21 (h)] among the eight elements.

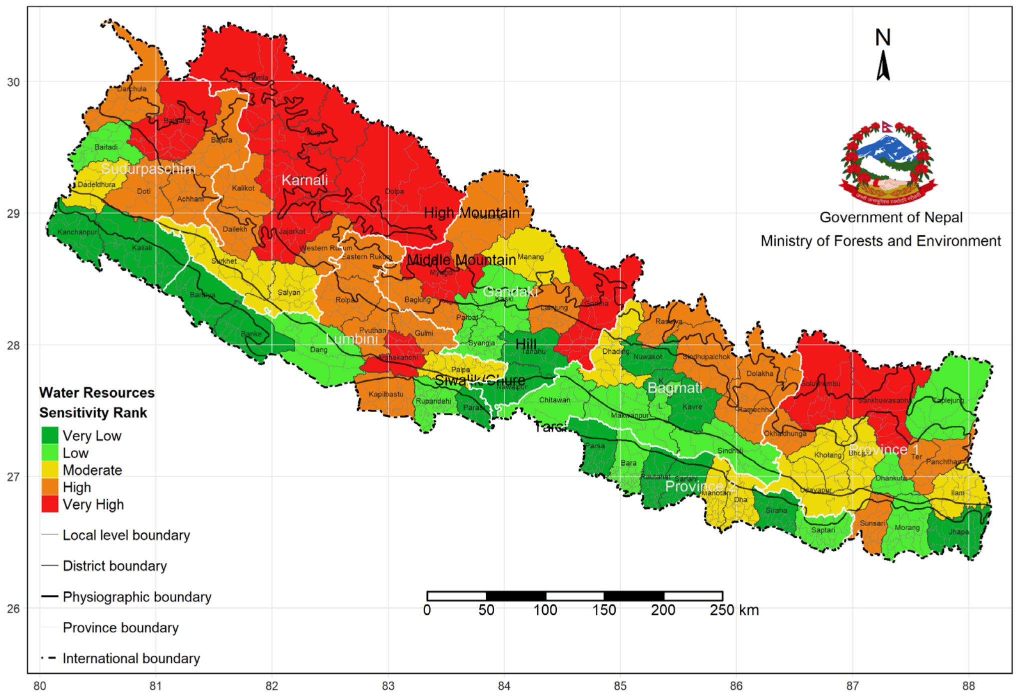


Figure 23: Sensitivity rank of the water resources sub-sector

Table 24 represents the list of districts based on the sensitivity rank classes for the water resources sub-sector and the list of the dominant indicators which are more prevalent to make districts high sensitive. There are 11 districts at 'Very High', 23 districts at 'High', 12 districts at 'Moderate', 16 districts at 'Low', and 15 districts at 'Very Low' sensitivity rank in the water resources sub-sector.

Table 24: Sensitivity ranks of the water resources sub-sector

Sensitivity Rank	District
Very High (0.497 – 1.000)	Arghakhanchi, Bajhang, Dolpa, Gorkha, Humla, Jajarkot, Jumla, Mugu, Myagdi, Sankhuwasabha, Solukhumbu
High (0.312 – 0.496)	Achham, Baglung, Bajura, Dailekh, Darchula, Dolakha, Doti, Eastern Rukum, Gulmi, Kalikot, Kapilbastu, Lamjung, Mustang, Okhaldhunga, Panchthar, Pyuthan, Ramechhap, Rasuwa, Rolpa, Sindhupalchok, Sunsari, Terhathum, Western Rukum
Moderate (0.211 – 0.311)	Bhojpur, Dadeldhura, Dhading, Dhanusha, Ilam, Khotang, Mahottari, Manang, Palpa, Salyan, Surkhet, Udayapur
Low (0.127 – 0.210)	Baitadi, Bara, Bhaktapur, Chitwan, Dang, Dhankuta, Kaski, Lalitpur, Makawanpur, Morang, Parbat, Rupandehi, Saptari, Sindhuli, Syangja, Taplejung
Very Low (0.000 – 0.126)	Banke, Bardiya, Jhapa, Kailali, Kanchanpur, Kathmandu, Kavrepalanchok, Nawalpur, Nuwakot, Parasi, Parsa, Rautahat, Sarlahi, Siraha, Tanahu
Dominant Indicators for the Higher Sensitivity Ranks	
The trend of change in groundwater flow, net water yields and total water availability; Drainage density; Average slope of the topography; Area of loamy and loamy-boulder soils; Area of the lakes, river bed and snow cover; Trend of change in barren lands, forests and savannas; Households depend on tube well/hand pump and covered well/kuwa; Drinking water demand and supply status; Average age of irrigation systems; Irrigation water used from pond/lake; Sex ratio (male by 100 female); People with disability (male and female); Children population (boys and girls); Dalit population (Male)	

Figure 24 represents the sensitivity rank map of the energy sub-sector, which has been obtained by the composition of the five elements of the energy sub-sector mentioned in Table 2 and Figure 22. In the composition, the weightage of elements considered was received from the expert survey (Annex 3). The composite result shows that all Terai and Siwalik districts except Kailali, Nawalpur, Chitwan, and Morang are at a lower sensitivity in comparison to other districts of Nepal. The districts in Gandaki Province and Bagmati Province, and Baitadi, Western Rukum, and Okhaldhunga are highly sensitive. The dominant elements for the higher sensitivity are the type of hydropower plants [Figure 22 (a)], the operational status of hydropower plants [Figure 22 (b)], and the ownership type of the hydropower plants [Figure 22 (c)].

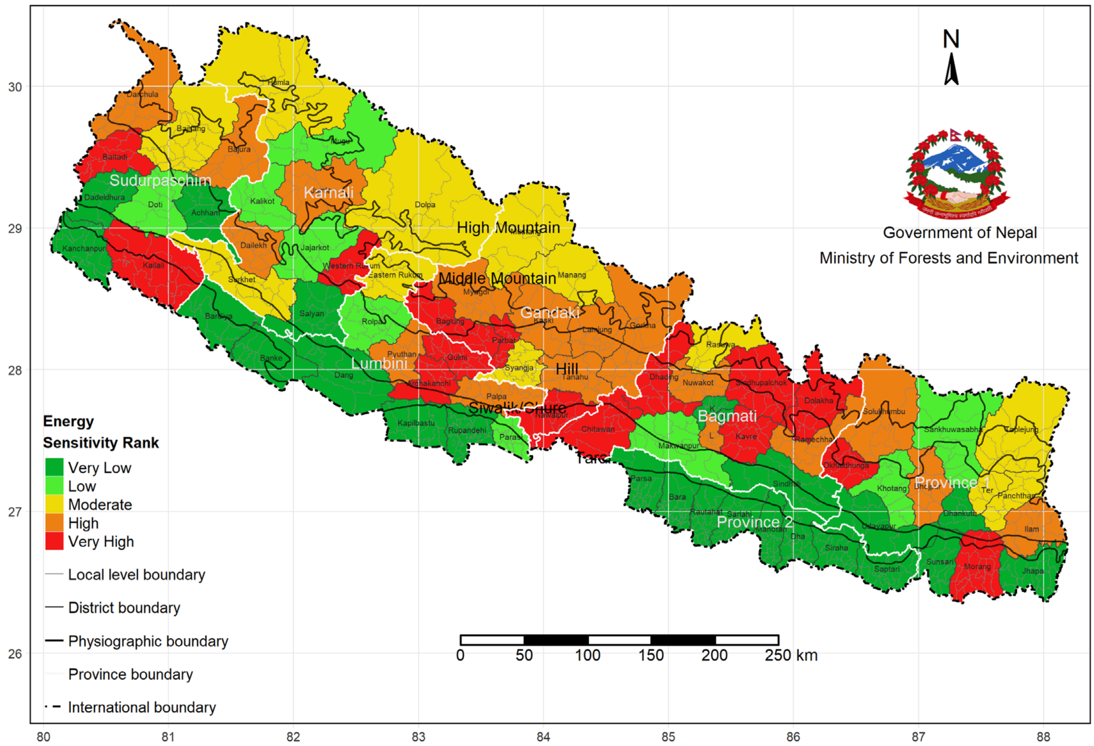


Figure 24: Sensitivity rank of the energy sub-sector

Table 25: Sensitivity ranks of the energy sub-sector

Sensitivity Rank	District
Very High (0.873 – 1.000)	Arghakhanchi, Baglung, Baitadi, Chitwan, Dhading, Dolakha, Gulmi, Kailali, Kavrepalanchok, Morang, Nawalpur, Okhaldhunga, Parbat, Sindhupalchok, Western Rukum
High (0.718 – 0.872)	Bajura, Bhojpur, Dailekh, Darchula, Gorkha, Ilam, Jumla, Kaski, Lalitpur, Lamjung, Myagdi, Nuwakot, Palpa, Pyuthan, Ramechhap, Solukhumbu, Tanahu
Moderate (0.587 – 0.717)	Bajhang, Dolpa, Eastern Rukum, Humla, Manang, Mustang, Panchthar, Rasuwa, Surkhet, Syangja, Taplejung, Terhathum
Low (0.312 – 0.586)	Doti, Jajarkot, Kalikot, Khotang, Makawanpur, Mugu, Parasi, Rolpa, Sankhuwasabha
Very Low (0.000 – 0.311)	Achham, Banke, Bara, Bardiya, Bhaktapur, Dadeldhura, Dang, Dhankuta, Dhanusha, Jhapa, Kanchanpur, Kapilbastu, Kathmandu, Mahottari, Parsa, Rautahat, Rupandehi, Salyan, Saptari, Sarlahi, Sindhuli, Siraha, Sunsari, Udayapur
Dominant Indicators for the Higher Sensitivity Ranks	
Number of ROR hydropower plants; Number of under construction and survey hydropower plants; Number of hydropower plants owned by the private sector; Number of households depend on wood/firewood for cooking	

Table 25 represents the list of districts based on the sensitivity rank classes for the energy sector and dominant indicators which are more prevalent to make districts highly sensitive. In the energy sub-sector, there are 15 districts at 'Very High', 17 districts at 'High', 12 districts at 'Moderate', 9 districts at 'Low', and 24 districts at 'Very Low' sensitivity rank.

7.1.3 Overall sensitivity ranks of the sector

The overall sensitivity rank of the sector (Figure 26) has been obtained by compositing the sub-sectors ranks presented in Figure 23 and Figure 24. The composition is based on the weightage of sub-sectors received from the expert survey, which can be found in Annex 3. The sensitivity rank sub-sectors have been well reflected in the overall sensitivity rank. The sensitivity rank result shows that all the districts of Terai and Siwalik, except Kailali and Morang, are comparatively at a lower sensitivity to climate change. The districts in the hills of Gandaki Province and Lumbini Province, and Baitadi, Dailekh, Kavrepalanchok, and Okhaldhunga are comparatively high sensitive. Similarly, most of the districts in the middle and high mountains are also comparatively high in sensitivity to climate change.

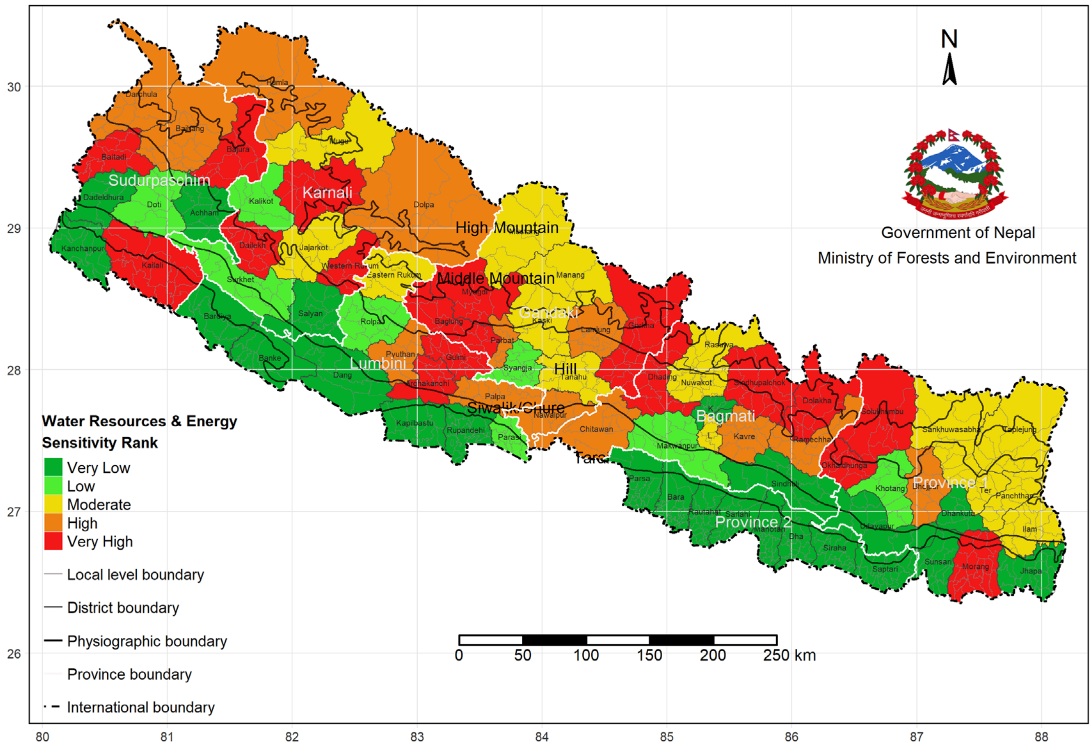


Figure 25: District wise overall sensitivity rank of the sector

Table 26 represents the list of districts according to the overall sensitivity rank of the sector, in which 17 districts are at 'Very High', 13 districts are at 'High', 15 districts are at 'Moderate', 8 districts are at 'Low' and 24 districts are at 'Very Low'. The table also includes the list of indicators, which predominantly affect the districts to become a higher sensitivity rank. These indicators are identical with the indicators mentioned in the sub-sectors sections above; however, it is dependent on the class break values of sub-sectors and sectors.

Table 26: Overall sensitivity rank of the sector

Sensitivity Rank	District
Very High (0.825 – 1.000)	Arghakhanchi, Baglung, Baitadi, Bajura, Dailekh, Dhading, Dolakha, Gorkha, Gulmi, Jumla, Kailali, Morang, Myagdi, Okhaldhunga, Sindhupalchok, Solukhumbu, Western Rukum
High (0.699 – 0.824)	Bajhang, Bhojpur, Chitwan, Darchula, Dolpa, Humla, Kavrepalanchok, Lamjung, Nawalpur, Palpa, Parbat, Pyuthan, Ramechhap
Moderate (0.551 – 0.698)	Eastern Rukum, Ilam, Jajarkot, Kaski, Lalitpur, Manang, Mugu, Mustang, Nuwakot, Panchthar, Rasuwa, Sankhuwasabha, Tanahu, Taplejung, Terhathum
Low (0.262 – 0.550)	Doti, Kalikot, Khotang, Makawanpur, Parasi, Rolpa, Surkhet, Syangja
Very Low (0.000 – 0.261)	Achham, Banke, Bara, Bardiya, Bhaktapur, Dadeldhura, Dang, Dhankuta, Dhanusha, Jhapa, Kanchanpur, Kapilbastu, Kathmandu, Mahottari, Parsa, Rautahat, Rupandehi, Salyan, Saptari, Sarlahi, Sindhuli, Siraha, Sunsari, Udayapur
Dominant Indicators for the Higher Sensitivity Ranks	
The trend of change in groundwater flow and net water yields; Drainage density; Average slope of the topography; Area of loamy soils; Area of the lakes, river bed and snow cover; Trend of change in barren lands; Households depend on tube well/hand pump and covered well/kuwa; Drinking water demand and supply status; Irrigation water used from pond/lake; Sex ratio (male by 100 female); Children population (boys and girls); Number of hydropower plants by capacity and by water conveyance systems; Number of under construction and under survey hydropower plants; Number of hydropower plants owned by the private sector; Number of households depend on wood/firewood for cooking	

Besides, the analysis of the watershed and sub river basin data shows that the sensitivity is higher in the mid-hills and mountainous regions of Nepal. In watersheds, the sensitivity is higher in Bagmati Province, Gandaki Province, Lumbini Province, Karnali Province, and Sudurpaschim Province (Figure 26 a). Besides, except Province 2 and Sudurpaschim Province, all other Provinces have a higher sensitivity to climatic stressors in the sub-basin level assessment (Figure 26 b). Since the majority of the hydropower plants are constructed in these provinces, the future risk of climate change will be higher.

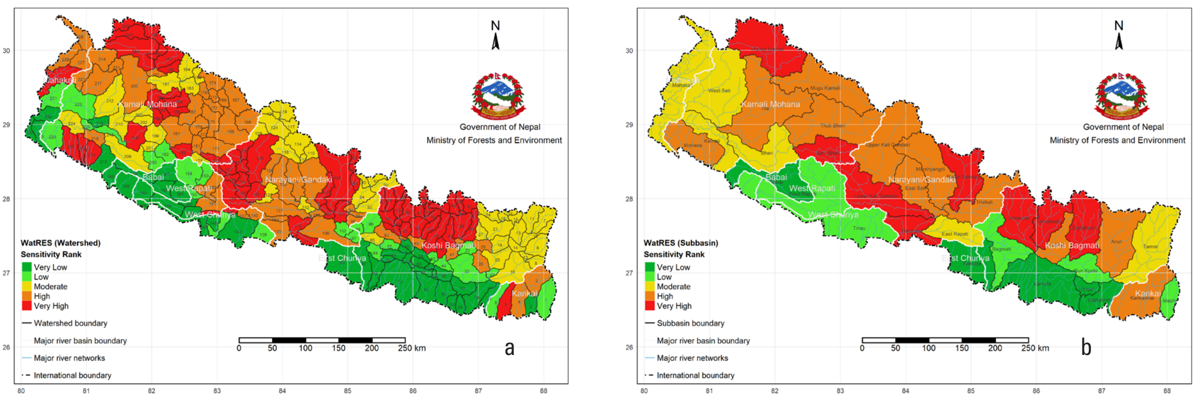


Figure 26: Sensitivity Rank of the a) Watershed, b) Sub-river basin

7.2 Adaptive capacity ranks and indexes

There are 20 indicators for the adaptive capacity ranking, which mainly focuses on the existing practices and knowledge that are relevant to the technology; prevention, protection, and conservation practices in disaster risk reduction; water conservation and water services management practices; diversity in energy used and electrification status; adoption of solar technology and economic status of households. Among the 20 indicators of adaptive capacity, 15 are for the water resources and five are for the energy sub-sector (Table 3). These indicators have been grouped into five elements in water resources and three elements in the energy sub-sector. The five elements of the water resources sub-sector are water recharge, retention, and reuse interventions; disaster prevention measures; conservation plans and investments; water conservation plans; and systems management of water services. Likewise, the three elements of the energy sub-sector are the operation status of hydro plants; access to alternative energy technology; and household income. The adaptive capacity rank maps of the elements can be found in Figure 27 and Figure 28 for the water resources and energy sub-sectors, respectively.

7.2.1 Adaptive capacity ranks of the elements

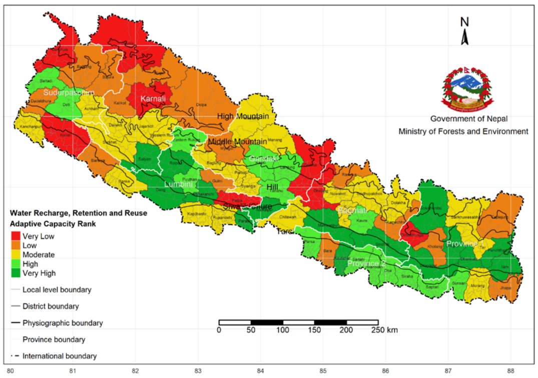
The adaptive capacity rank maps of the elements of water resources and energy sub-sector presented in Figure 27 and Figure 28 have been obtained by compositing respective indicators of the elements (Table 3) based on the weights received from the expert survey (refer to Annex 3 for the weightage of individual indicators, elements, and sub-sectors).

Figure 27 (a) represents the water resources sub-sector adaptive capacity rank of the element 'water recharge, retention and reuse direct or indirect interventions', which includes the trends of change in reforestation/afforestation to conserve water and trends of change in terrace farming for water retention, in this assessment. The decreasing trends of these indicators show a lower adaptive capacity of respective districts. In general, the districts in Karnali Province and Sudurpashchim Province, and Palpa, Gorkha, Dhading, and Okhaldhunga have lower adaptive capacity than other districts.

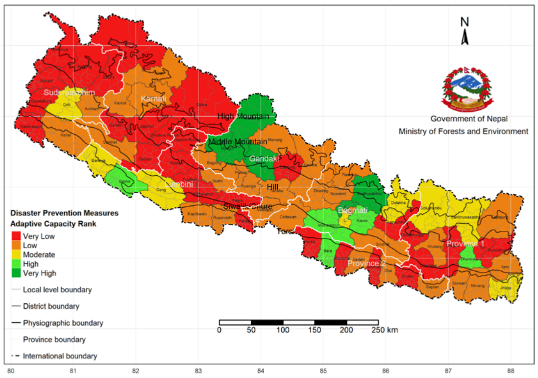
Figure 27 (b) represents the water resources sub-sectors adaptive capacity rank of the element – disaster preventions measures; such as draining of glacier lakes and monitoring plan, and access to climate information. The existence of a higher number of stations to monitor glaciers and measure climatic data in the districts are taken as the higher adaptive capacity of the respective districts. According to such status of having monitoring; Banke, Mustang, Myagdi, Kaski, Kathmandu, Makawanpur, Bara, Sindhupalchok, Kavrepalanchok, and Dhankuta districts have the high adaptive capacity, and remaining all other districts have the less adaptive capacity. Figure 27 (c) represents the water resources sub-sector adaptive capacity rank of the element 'conservation plans and investments', which includes the number of wetland conservation initiatives, the management of conservation pond and reservoir, and allocation of environment/climate change relevant budget by the local government. The districts with a higher number of provisions for conservation and management plans have a higher adaptive capacity in the respective districts. In this assessment, Achham, Pyuthan, Kaski, Gorkha, Kathmandu, Dolakha, Sarlahi, and Dhanusha districts have a higher adaptive capacity.

Figure 27 (d) represents the water resources sub-sector adaptive capacity rank of the element 'water conservation practices, which includes water usage potential such as total usable water for irrigation and drinking water, and the number of bio-engineering practices. Similar to above, the presence of higher numbers of water conservation practices in districts has a higher adaptive capacity. In this assessment, the districts in western hills and Terai, in hills and Siwalik region of Gandaki Province, and some districts of Province 2 and Bagmati Province have the higher adaptive capacity.

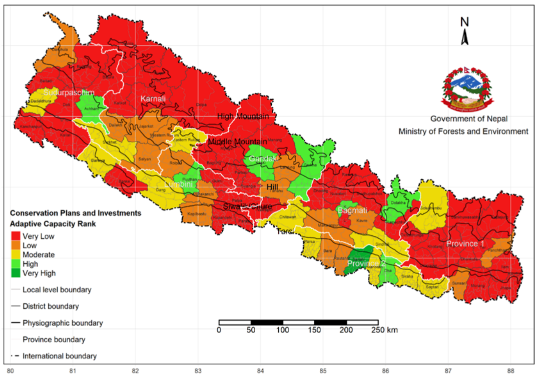
Figure 27 (e) represents the water resources sub-sector adaptive capacity rank of the element 'water systems management, which includes registration and financial turnover status of the Water Users Association (WUA), agricultural land with operation irrigation systems, number of functional drinking water schemes and the Gender Development Index (GDI). The districts with a higher number of these systems and better management status of the water services have a higher adaptive capacity. In general, the Terai and Siwalik districts of Nepal have a higher adaptive capacity.



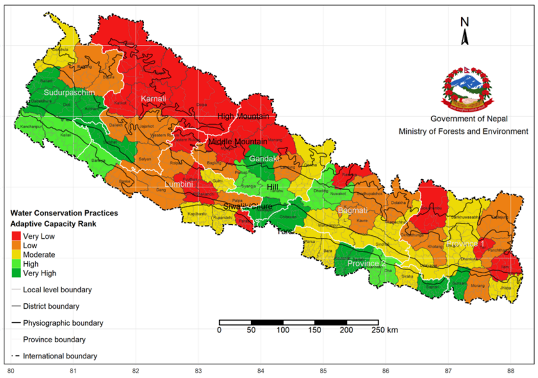
(a) Water Recharge, Retention, and Reuse



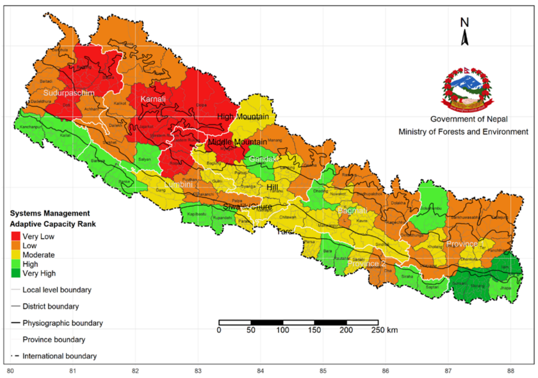
(b) Disaster Prevention Measures



(c) Conservation Plans and Investments



(d) Water Conservation Practices



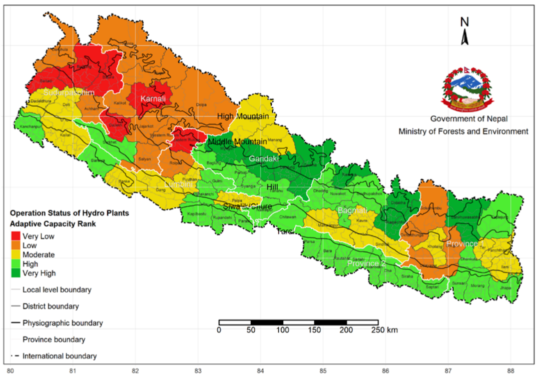
(e) Systems Management of Water Services

Figure 27: Adaptive capacity of the elements (water resources)

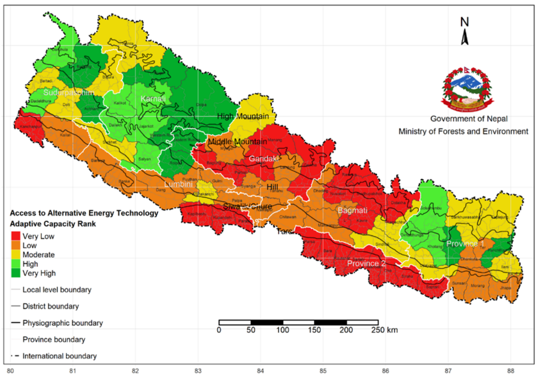
Figure 28 (a) represents the energy sub-sector adaptive capacity rank of the element's operational status of hydropower plants, which includes hydropower potentials in districts and the status of electrification coverage of the districts. The better status of these indicators represents the higher adaptive capacity. In this assessment, the districts of the hills and mountain region of Sudurpashchim Province, the districts of Karnali Province, and some western districts of Province 1 have a lower adaptive capacity in comparison to the other regions and districts.

Figure 28 (b) represents the energy sub-sector adaptive capacity rank of the element's access to alternative energy technology, which includes households that have bio-gas plants and solar plants. The districts with the better status of coverage of biogas and solar plants have a higher adaptive capacity. These technologies are recommended worldwide and practiced as adaption options for climate change. The adaptive rank map shows that there are no significant scenarios region-wise as it entirely depends on the knowledge and economic status of the people and access to resources and places for installation.

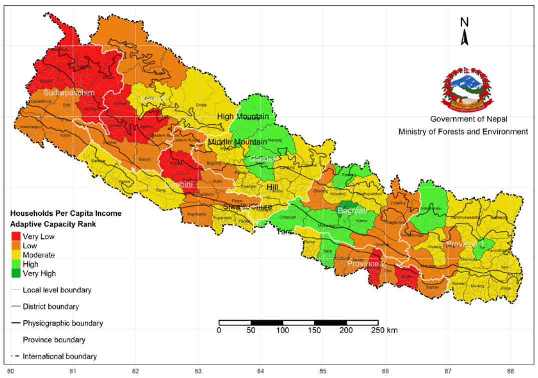
Figure 28 (c) represents the energy sub-sector adaptive capacity rank of the element 'economic status of the households' such as per capita income in the districts. The districts with higher per capita income have a higher adaptive capacity. This adaptive capacity ranking is based on the current per capita income of the districts, which can change in the future according to changes in the economic status of the people and households.



(a) Operation Status of Hydro Plants



(b) Access to Alternative Energy Technology



(c) Households/Per Capita Income

Figure 28: Adaptive capacity of the elements (energy)

7.2.2 Adaptive capacity ranks of the sub-sectors

The adaptive capacity rank of the water resources sub-sector is analyzed by compositing the five elements mentioned in Figure 27 and the corresponding weightage of the elements during the composite processes (Annex 3). Figure 29 represents the adaptive capacity rank of the water resources sub-sector. The predominant elements to have composite adaptive capacity ranking are water recharge, retention and reuse interventions, water conservation practices, and system management of water services among five elements. In general, the districts in the hills and mountains of the western region, in the mountainous region of the mid, and hills and mountains of the eastern region have a lower adaptive capacity rank.

Table 27 represents the list of districts based on the adaptive capacity rank classes in the water resources sub-sector, where 5 districts have 'Very High', 18 districts have 'High', 21 districts have 'Moderate', 17 districts have 'Low' and 16 districts have 'Very Low' adaptive capacity rank. The table also includes the list of individual indicators that are the reasons for having the higher adaptive capacity.

Similarly, the adaptive capacity rank of the energy sub-sector (Figure 30) is analyzed by compositing the three elements mentioned in Figure 28. The weightage of the elements (Annex 3) has been taken while compositing the elements. The predominant element is the operational status of hydropower plants. In general, the districts in hills and mountain regions of the western region, and Mahottari, Siraha, Sindhuli, Udayapur, and Okhaldhunga districts have a lower adaptive capacity in comparison to other districts.

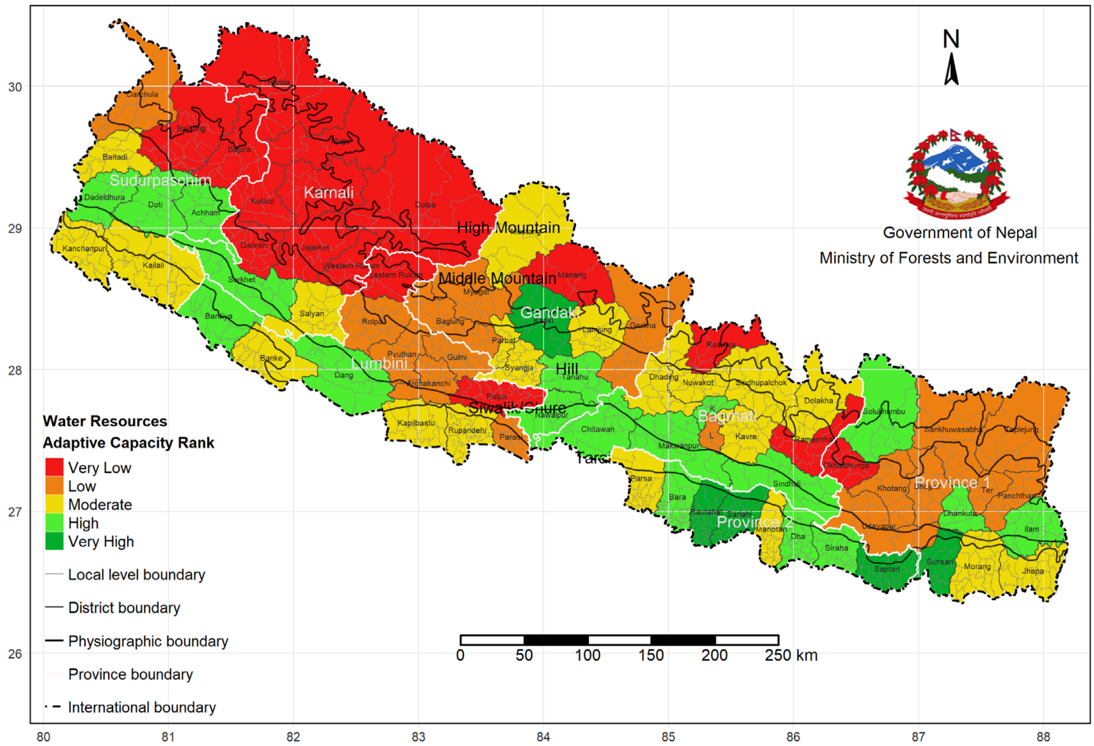


Figure 29: Adaptive capacity rank of the water resources sub-sector

Table 27: Adaptive capacity ranks of the water resources sub-sector

Adaptive Capacity Rank	District
Very High (0.660 – 1.000)	Kaski, Rautahat, Saptari, Sarlahi, Sunsari
High (0.479 – 0.659)	Achham, Bara, Bardiya, Chitwan, Dadeldhura, Dang, Dhankuta, Dhanusha, Doti, Ilam, Kathmandu, Makawanpur, Nawalpur, Sindhuli, Siraha, Solukhumbu, Surkhet, Tanahu
Moderate (0.334 – 0.478)	Baitadi, Banke, Bhaktapur, Dhading, Dolakha, Jhapa, Kailali, Kanchanpur, Kapilbastu, Kavrepalanchok, Lamjung, Mahottari, Morang, Mustang, Nuwakot, Parbat, Parsa, Rupandehi, Salyan, Sindhupalchok, Syangja
Low (0.185 – 0.333)	Arghakhanchi, Baglung, Bhojpur, Darchula, Gorkha, Gulmi, Khotang, Lalitpur, Myagdi, Panchthar, Parasi, Pyuthan, Rolpa, Sankhuwasabha, Taplejung, Terhathum, Udayapur
Very Low (0.000 – 0.184)	Bajhang, Bajura, Dailekh, Dolpa, Eastern Rukum, Humla, Jajarkot, Jumla, Kalikot, Manang, Mugu, Okhaldhunga, Palpa, Ramechhap, Rasuwa, Western Rukum
Dominant Indicators for the Higher Adaptive Capacity Ranks	
The trend of reforestation/afforestation to conserve water; Trends of terrace farming for water retention; Access to climate information; Number of wetlands conservation initiatives; Number of bio-engineering practices; Registration status of Water Users Association (WUA); Agricultural land with operational irrigation systems, Gender Development Index	

Table 28 represents the list of districts based on the adaptive capacity rank classes in the energy sub-sector, where 8 districts have 'Very High', 21 districts have 'High', 25 districts have 'Moderate', 15 districts have 'Low' and 8 districts have 'Very Low' adaptive capacity rank. The table also includes the list of individual indicators that are the reasons for having the higher adaptive capacity.

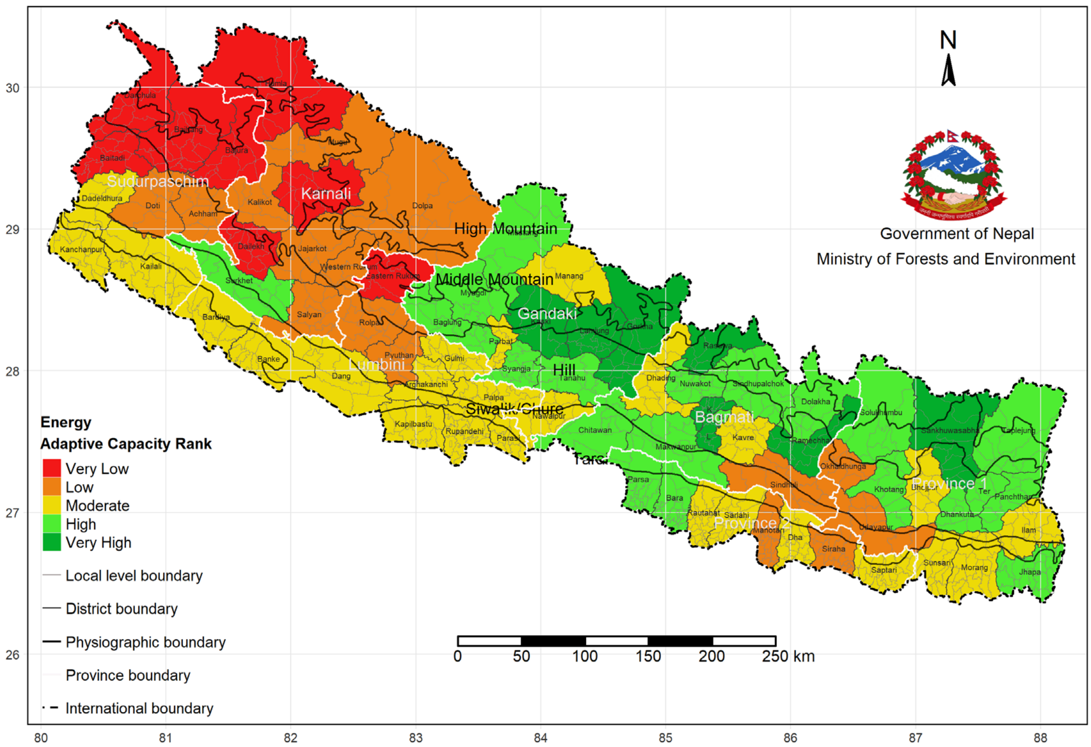


Figure 30: Adaptive capacity rank of the energy sub-sector

Table 28: Adaptive capacity ranks of the energy sub-sector

Adaptive Capacity Rank	District
Very High (0.678 – 1.000)	Gorkha, Kaski, Kathmandu, Lalitpur, Lamjung, Ramechhap, Rasuwa, Sankhuwasabha
High (0.549 – 0.677)	Baglung, Bara, Bhaktapur, Chitwan, Dhankuta, Dolakha, Jhapa, Khotang, Makawanpur, Mustang, Myagdi, Nuwakot, Panchthar, Parsa, Sindhupalchok, Solukhumbu, Surkhet, Syangja, Tanahu, Taplejung, Terhathum
Moderate (0.446 – 0.548)	Arghakhanchi, Banke, Bardiya, Bhojpur, Dadeldhura, Dang, Dhading, Dhanusha, Gulmi, Ilam, Kailali, Kanchanpur, Kapilbastu, Kavrepalanchok, Manang, Morang, Nawalpur, Palpa, Parasi, Parbat, Rautahat, Rupandehi, Saptari, Sarlahi, Sunsari
Low (0.266 – 0.445)	Achham, Dolpa, Doti, Jajarkot, Kalikot, Mahottari, Mugu, Okhaldhunga, Pyuthan, Rolpa, Salyan, Sindhuli, Siraha, Udayapur, Western Rukum
Very Low (0.000 – 0.265)	Baitadi, Bajhang, Bajura, Dailekh, Darchula, Eastern Rukum, Humla, Jumla
Dominant Indicators for the Higher Adaptive Capacity Ranks	
Electrification coverage status; Households come/per capita income	

7.2.3 Adaptive capacity rank of the sector

Overall, the adaptive capacity rank of the sector presented in Figure 31 is a composite of the adaptive capacity rank of sub-sectors, included in Figure 29 and Figure 30 respectively. In this assessment, the overall adaptive capacity rank is equally affected by both the sub-sectoral ranks. In general, the districts in the hills and mountain region of Lumbini Province, Karnali Province, and Sudurpashchim Province; and Manang, Palpa, Okhaldhunga, and Udayapur districts have a comparatively lower adaptive capacity rank.

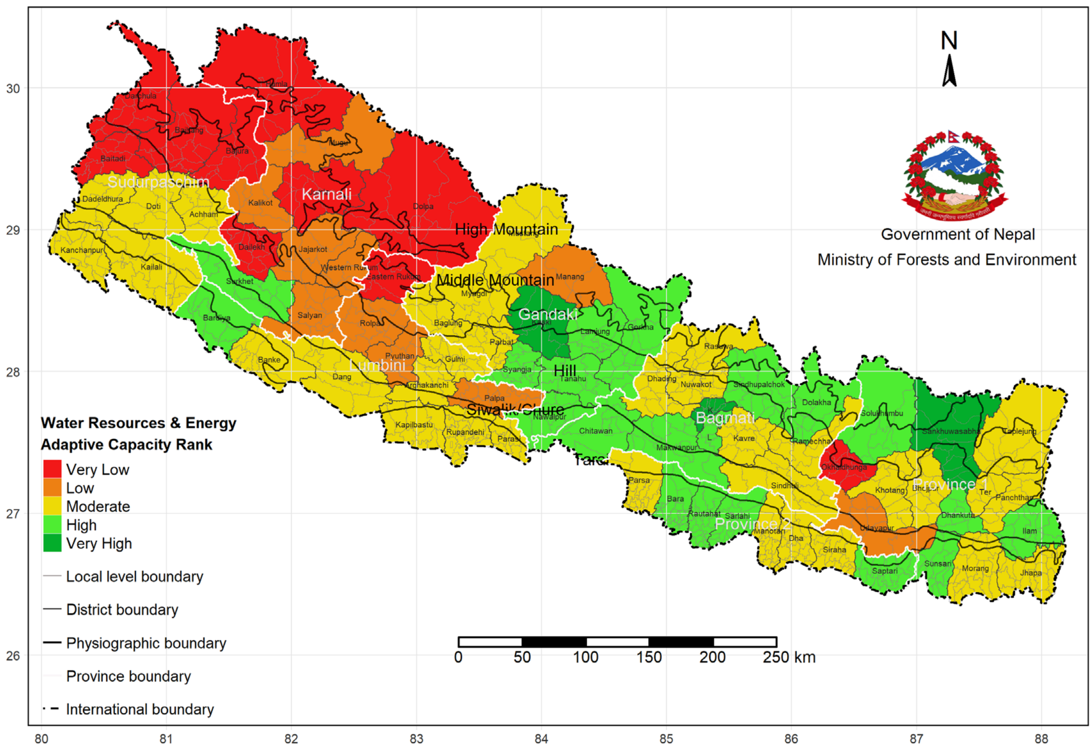


Figure 31: Overall adaptive capacity rank of the sector

Table 29: Overall adaptive capacity ranks of the sector

Adaptive Capacity Rank	District
Very High (0.765 – 1.000)	Kaski, Kathmandu, Sankhuwasabha
High (0.618 – 0.764)	Bara, Bardiya, Bhaktapur, Chitwan, Dhankuta, Dolakha, Gorkha, Ilam, Lalitpur, Lamjung, Makawanpur, Nawalpur, Rautahat, Saptari, Sarlahi, Sindhupalchok, Solukhumbu, Sunsari, Surkhet, Syangja, Tanahu
Moderate (0.434 – 0.617)	Achham, Arghakhanchi, Baglung, Banke, Bhojpur, Dadeldhura, Dang, Dhading, Dhanusha, Doti, Gulmi, Jhapa, Kailali, Kanchanpur, Kapilbastu, Kavrepalanchok, Khotang, Mahottari, Morang, Mustang, Myagdi, Nuwakot, Panchthar, Parasi, Parbat, Parsa, Ramechhap, Rasuwa, Rupandehi, Sindhuli, Siraha, Taplejung, Terhathum
Low (0.281 – 0.433)	Jajarkot, Kalikot, Manang, Mugu, Palpa, Pyuthan, Rolpa, Salyan, Udayapur, Western Rukum
Very Low (0.000 – 0.280)	Baitadi, Bajhang, Bajura, Dailekh, Darchula, Dolpa, Eastern Rukum, Humla, Jumla, Okhaldhunga
Dominant Indicators for the Higher Adaptive Capacity Ranks	
The trend of reforestation/afforestation to conserve water; Trends of terrace farming for water retention; Access to climate information; Number of wetlands conservation initiatives; Total usable water for irrigation; Number of bio-engineering practices; Agricultural land with operational irrigation systems, Gender Development Index (GDI); Electrification coverage status	

Table 29 represents the list of districts based on the overall adaptive capacity rank classes in the sector; where 3 districts have 'Very High', 21 districts have 'High', 33 districts have 'Moderate', 10 districts have 'Low' and 10 districts have 'Very Low' adaptive capacity rank. The table also includes the list of individual indicators, which are the reasons for having a higher adaptive capacity. These indicators are identical with the predominant indicators mentioned in the sub-sectors; however, it depends on the class break values of the sub-sectors and sectors.

7.3 Vulnerability ranks and indexes

As described before, the vulnerability is determined by subtracting the composite adaptive capacity value of the districts from the composite sensitive value of respective districts (Equation 1). The vulnerability rank of the sub-sectors and sectors is described in the sections below.

7.3.1 Vulnerability rank of the sub-sector

Water resources

Figure 32 is the vulnerability rank of the water resources sub-sector and Table 30 is the list of districts based on the vulnerability rank classes. This vulnerability rank map has been determined by subtracting the adaptive capacity rank map (Figure 29) from the sensitivity rank map (Figure 23) of the water resources sub-sector. Looking at the analysis scenario of vulnerability, the hills and mountain regions of western Nepal are highly sensitive to climate change, whereas the adaptive capacity of the region is very low. Thus, the region is highly vulnerable. In the water resources sub-sector, there are 7 districts at 'Very High', 18 districts at 'High', 16 districts at 'Moderate', 29 districts at 'Low', and 7 districts at 'Very Low' vulnerability ranks.

In water resources, five northern districts (Eastern Rukum, Rolpa, Pyuthan, Arghakhanchi, and Palpa) of Lumbini Province (except Gulmi), all the districts of Karnali Province (except Surkhet and Salyan), and three northern districts (Darchula, Bajhang, and Bajura) of Sudurpashchim Province are at high to very high vulnerability rank. In Gandaki Province, the districts boarding with Karnali and Lumbini Province (Myagdi and Baglung) and four northern districts (Mustang, Manang, Lamjung, and Gorkha) are at moderate to high vulnerability rank. In Bagmati Province, five northern districts (Dhading, Rasuwa, Sindhupalchok, Dolakha, and Ramechhap) and Lalitpur in Kathmandu Valley are at moderate to high vulnerable rank. In Province 2, Mahottari district is at a moderate vulnerability rank in comparison to all the districts of Nepal, but this district is at a higher vulnerability rank in comparison to the other 7 districts of this province. In general, the districts of Province 1 are less vulnerable in comparison to the other districts of Nepal. In Province 1, except the district in the Terai region, Sunsari, Morang, and Jhapa, and the hill districts, Dhankuta and Ilam, all other nine districts are at moderate to high vulnerability rank.

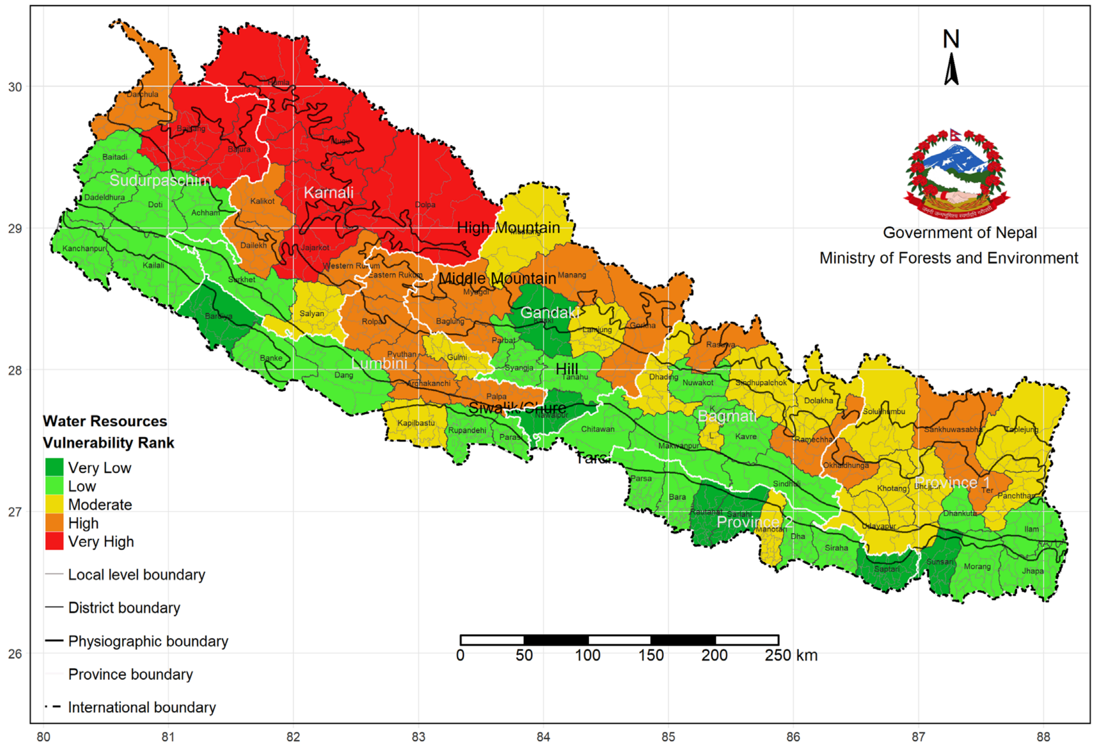


Figure 32: Vulnerability rank of the water resources sub-sector

Table 30: Vulnerability ranks of the water resources sub-sector

Vulnerability Rank	District
Very High (0.684 – 1.000)	Bajhang, Bajura, Dolpa, Humla, Jajarkot, Jumla, Mugu
High (0.535 – 0.683)	Arghakhanchi, Baglung, Dailekh, Darchula, Eastern Rukum, Gorkha, Kalikot, Manang, Myagdi, Okhaldhunga, Palpa, Pyuthan, Ramechhap, Rasuwa, Rolpa, Sankhuwasabha, Terhathum, Western Rukum
Moderate (0.382 – 0.534)	Bhojpur, Dhading, Dolakha, Gulmi, Kapilbastu, Khotang, Lalitpur, Lamjung, Mahottari, Mustang, Panchthar, Salyan, Sindhupalchok, Solukhumbu, Taplejung, Udayapur
Low (0.179 – 0.381)	Achham, Baitadi, Banke, Bara, Bhaktapur, Chitwan, Dadeldhura, Dang, Dhankuta, Dhanusha, Doti, Ilam, Jhapa, Kailali, Kanchanpur, Kathmandu, Kavrepalanchok, Makawanpur, Morang, Nuwakot, Parasi, Parbat, Parsa, Rupandehi, Sindhuli, Siraha, Surkhet, Syangja, Tanahu
Very Low (0.000 – 0.178)	Bardiya, Kaski, Nawalpur, Rautahat, Saptari, Sarlahi, Sunsari

Similarly, Figure 33 represents the vulnerability rank map of the energy sub-sector, and the list of districts according to the vulnerability rank classes is presented in Table 31. This vulnerability rank map of the energy sector is determined from the sensitivity (Table 25) and adaptive capacity (Table 28) analysis of the energy sector. In the energy sub-sector, as described before, most of the districts in the Terai region are less sensitive due to a lack of presence of energy-related infrastructures and are at moderate to high adaptive capacity. On the contrary, most of the hills and mountainous districts are highly sensitive and are at moderate to very low adaptive capacity. These scenarios have been reflected in the vulnerability rank of the energy sub-sector. In the energy sector, there are 15 districts at each 'Very High', 'High' and 'Low' vulnerability rank classes, and the other 20 districts are at 'Moderate' and the remaining 12 districts are at 'Very Low' vulnerability rank classes.

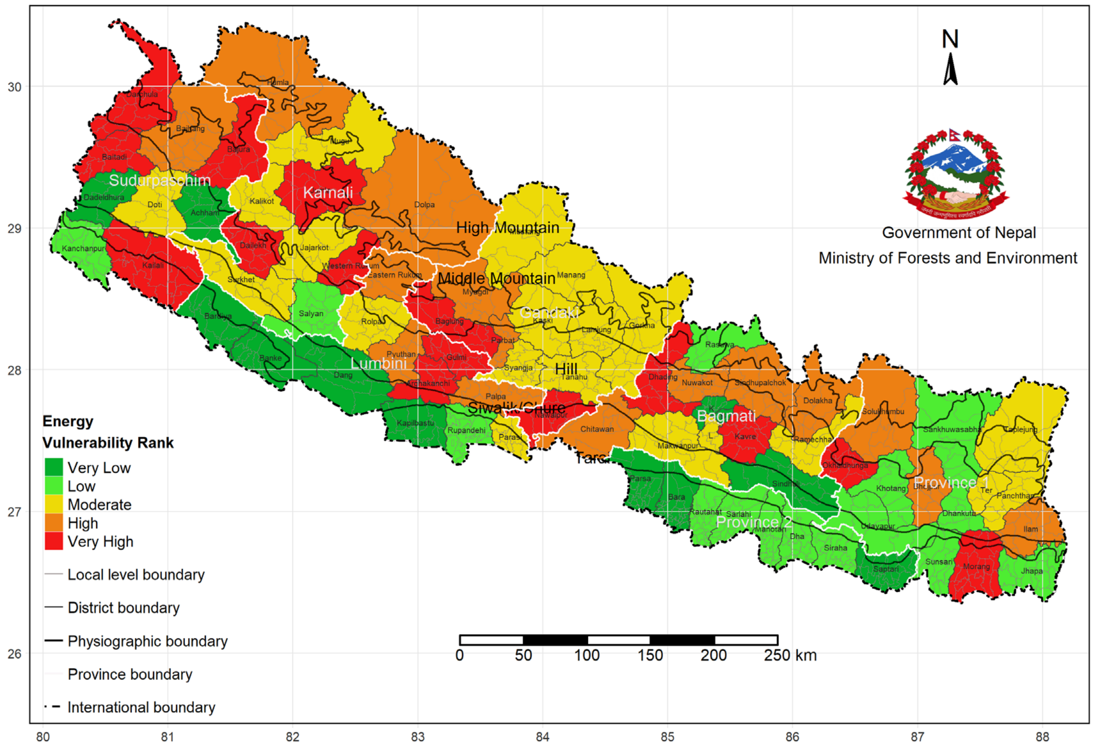


Figure 33: Vulnerability rank of the energy sub-sector

Table 31: Vulnerability ranks of the energy sub-sector

Vulnerability Rank	District
Very High (0.750 – 1.000)	Arghakhanchi, Baglung, Baitadi, Bajura, Dailekh, Darchula, Dhading, Gulmi, Jumla, Kailali, Kavrepalanchok, Morang, Nawalpur. Okhaldhunga, Western Rukum
High (0.594 – 0.749)	Bajhang, Bhojpur, Chitwan, Dolakha, Dolpa, Eastern Rukum, Humla, Ilam, Myagdi, Nuwakot, Palpa, Parbat, Pyuthan, Sindhupalchok, Solukhumbu
Moderate (0.392 – 0.593)	Doti, Gorkha, Jajarkot, Kalikot, Kaski, Lalitpur, Lamjung, Makawanpur, Manang, Mugu, Mustang, Panchthar, Parasi, Ramechhap, Rolpa, Surkhet, Syangja, Tanahu, Taplejung, Terhathum
Low (0.221 – 0.391)	Dhankuta, Dhanusha, Jhapa, Kanchanpur, Khotang, Mahottari, Rasuwa, Rautahat, Rupandehi, Salyan, Sankhuwasabha, Sarlahi, Siraha, Sunsari, Udayapur
Very Low (0.000 – 0.220)	Achham, Banke, Bara, Bardiya, Bhaktapur, Dadeldhura, Dang, Kapilbastu, Kathmandu, Parsa, Saptari, Sindhuli

The vulnerability rank of the energy sub-sector shows that Ilam, Morang, Khotang, Okhaldhunga, and Solukhumbu in Province 1; Dolakha, Kavrepalanchok, Sindhupalchok, Nuwakot, Gorkha and Chitwan in Bagmati Province; Nawalpur and Baglung in Gandaki Province; Palpa, Gulmi, Arghakhanchi, and Eastern Rukum in Lumbini Province; Western Rukum, Dolpa, Jumla, Dailekh, and Humla in Karnali Province; and Kailali, Baitadi, Darchula, Bajhang and Bajura in Sudurpashchim Province are highly vulnerable considering their sensitivity and adaptive capacity statuses. The existence of a higher number with the larger capacity of energy-related infrastructure in the districts are the reasons for having a higher degree of sensitivity and this leads them to be more vulnerable.

7.3.2 Vulnerability ranks of the sector

Figure 34 is the overall vulnerability rank map of the sector, which is a composite result of the vulnerability rank of water resources (Figure 32) and energy (Figure 33) sub-sectors. Table 32 represents the list of districts based on the overall vulnerability rank classes of the sector. According to these classes, there are 14 districts each at 'Very High', 'Moderate' and 'Low' vulnerability rank classes, 20 districts are at 'High' and the remaining 15 districts are at 'Very Low' vulnerability rank classes. The predominant elements and indicators for being highly vulnerable are described in the respective sections of sensitivity and adaptive capacity analysis above, and also listed in Table 26 and Table 29 respectively.

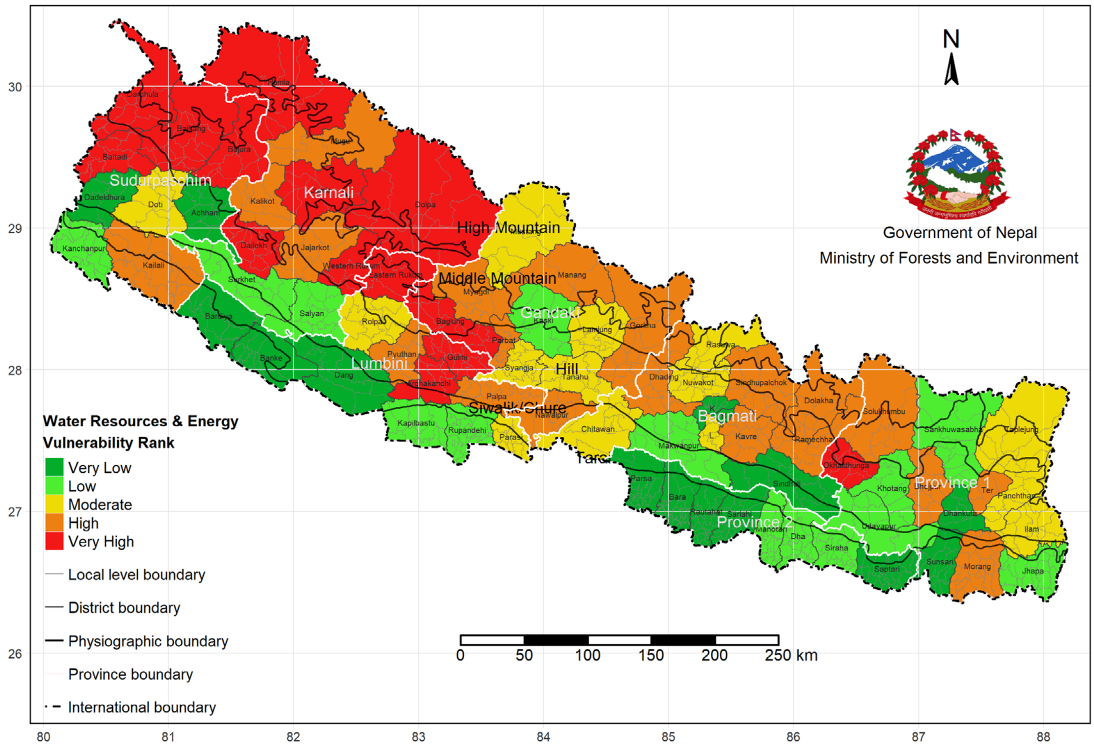


Figure 34: Overall vulnerability rank of the sector

The result of the overall composite vulnerability rank classes shows that, in general, the hills and mountains of western and middle regions are highly vulnerable in comparison to other regions of Nepal. Morang, Terhathum, Khotang, Solukhumbu, and Okhaldhunga districts in Province 1; Dolakha, Ramechhap, Kavrepalanchok, Sindhupalchok, and Dhading districts in Bagmati Province; Gorkha, Nawalpur, Manang, Parbat, Myagdi, and Baglung districts in Gandaki Province; Palpa, Gulmi, Arghakhanchi, Pyuthan, and Eastern Rukum districts in Lumbini Province; all the districts except Salyan and Surkhet in Karnali Province; and Bajura, Bajhang, Darchula, Baitadi, and Kailali districts of Sudurpashchim Province are highly vulnerable (high to very high-rank class).

Table 32: Overall vulnerability ranks of the sector

Vulnerability Rank	District
Very High (0.721 – 1.000)	Arghakhanchi, Baglung, Baitadi, Bajhang, Bajura, Dailekh, Darchula, Dolpa, Eastern Rukum, Gulmi, Humla, Jumla, Okhaldhunga, Western Rukum
High (0.560 – 0.720)	Bhojpur, Dhading, Dolakha, Gorkha, Jajarkot, Kailali, Kalikot, Kavrepalanchok, Manang, Morang, Mugu, Myagdi, Nawalpur, Palpa, Parbat, Pyuthan, Ramechhap, Sindhupalchok, Solukhumbu, Terhathum
Moderate (0.389 – 0.559)	Chitwan, Doti, Ilam, Lalitpur, Lamjung, Mustang, Nuwakot, Panchthar, Parasi, Rasuwa, Rolpa, Syangja, Tanahu, Taplejung
Low (0.220 – 0.388)	Dhanusha, Jhapa, Kanchanpur, Kapilbastu, Kaski, Khotang, Mahottari, Makawanpur, Rupandehi, Salyan, Sankhuwasabha, Siraha, Surkhet, Udayapur
Very Low (0.000 – 0.219)	Achham, Banke, Bara, Bardiya, Bhaktapur, Dadeldhura, Dang, Dhankuta, Kathmandu, Parsa, Rautahat, Saptari, Sarlahi, Sindhuli, Sunsari

In terms of vulnerability assessment of the watershed and sub-river basin, the findings show that most of the watersheds in Bagmati Province, Gandaki Province, Lumbini Province, Karnali Province, and Sudurpaschim Province are highly vulnerable (Figure 35a). Furthermore, the result shows that the sub-basins of the Karnali river basin have a higher vulnerability to climate change impacts (Figure 35 b).

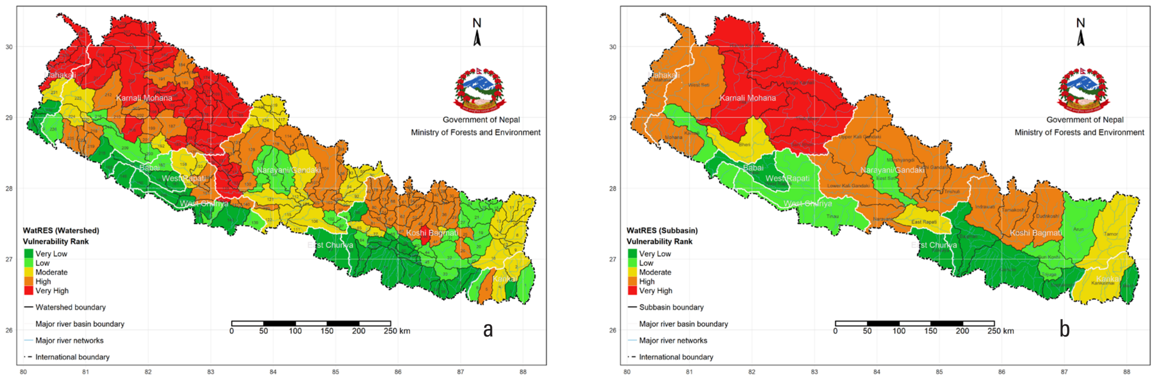


Figure 35: Vulnerability rank of the a) watershed b) sub-river basin

Chapter 8

Climate Change Risks

As explained before, the risk is a function of hazard, exposure, and vulnerability (Equation 2). Therefore, the risk ranking is entirely based on the analysis carried out for the hazard, exposure and vulnerability, explained in their respective sections above. Based on the analysis, the obtained risk ranks of the sub-sectors and sectors have been explained in the sections below.

8.1 Risk rank scenarios of water resources

Figure 36 represents the baseline risk rank map of the water resources sub-sector; which has been obtained from the composition of climate-induced hazards (Figure 11), exposure (Figure 18), and vulnerability (Figure 32). The baseline is based on the historical data of the indicators. Table 33 represents the list of districts according to the baseline risk rank classes, with eight districts at 'Very High', 19 districts at 'High', 17 districts at 'Moderate', 19 districts at 'Low', and 14 districts at 'Very Low' risk rank classes (Table 33). The risk rank results are the composite result of all the indicators of exposure, sensitivity, adaptive capacity, and hazards.

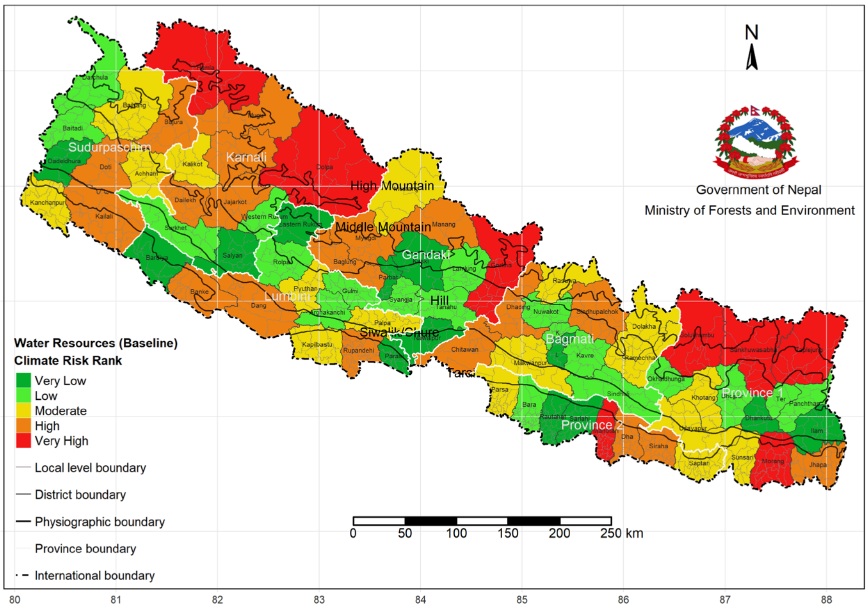
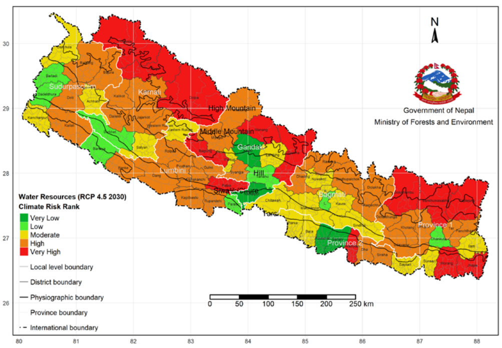


Figure 36: Risk rank of the water resources sub-sector at baseline

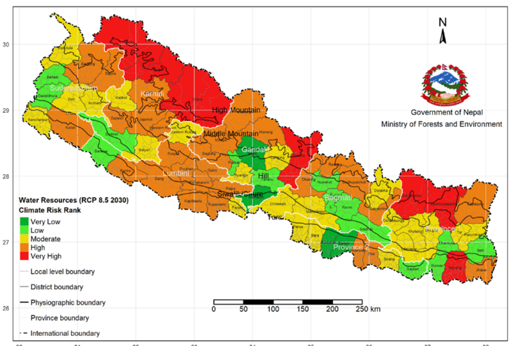
In Province 1, the Terai and Mountain districts (except Sunsari) are at higher risk rank (high to very high); whereas the hill districts of the province are at lesser risk in comparison to other districts of Nepal. In Province 2, Mahottari, Dhanusha, and Siraha districts are at higher risk rank; whereas, Bara, Rautahat, and Sarlahi are at lower risk rank. In Bagmati Province, Sindhupalchok, Dhading, and Chitwan are at higher risk rank, and Sindhuli, Kavrepalanchok, Lalitpur, Bhaktapur, Kathmandu, and Nuwakot are at lower risk rank. In Gandaki Province, Gorkha, Manang, Myagdi and Baglung districts are at higher risk rank and Nawalpur, Tanahu, Lamjung, Syangja, Parbat and Kaski districts are at lower risk rank. In Lumbini Province, Rupandehi, Dang, and Banke districts are at higher risk rank and Parasi, Arghakhanchi, Gulmi, Rolpa, Eastern Rukum, and Bardiya districts are at lower risk rank. In Karnali Province, all the mountainous districts (except Kalikot), and Dailekh and Jajarkot districts are at higher risk rank, whereas, Western Rukum, Salyan, and Surkhet districts are at lower risk rank. In Sudurpashchim Province, Bajura, Doti, and Kailali districts are at a higher risk tank, whereas, Darchula, Baitadi, and Dadeldhura districts are at lower risk rank in comparison to other districts of the province. Considering these scenarios of baseline, Karnali Province is at higher risk so far in comparison to other districts of Nepal.

Table 33: Districts in risk ranks of the water resources sector

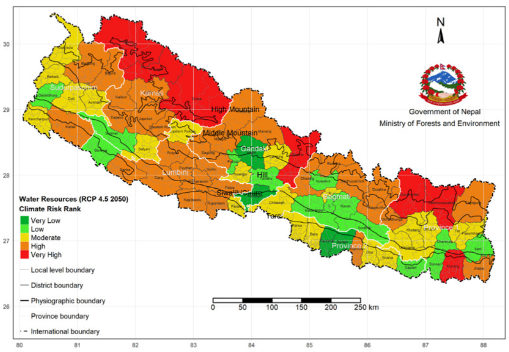
Risk Rank	District
Very High (0.578 – 1.000)	Dolpa, Gorkha, Humla, Mahottari, Morang, Sankhuwasabha, Solukhumbu, Taplejung
High (0.368 – 0.577)	Baglung, Bajura, Banke, Chitwan, Dailekh, Dang, Dhading, Dhanusha, Doti, Jajarkot, Jhapa, Jumla, Kailali, Manang, Mugu, Myagdi, Rupandehi, Sindhupalchok, Siraha
Moderate (0.253 – 0.367)	Achham, Bajhang, Dolakha, Kalikot, Kanchanpur, Kapilbastu, Khotang, Makawanpur, Mustang, Palpa, Parsa, Pyuthan, Ramechhap, Rasuwa, Saptari, Sunsari, Udayapur
Low (0.138 – 0.252)	Arghakhanchi, Baitadi, Bara, Bhojpur, Darchula, Gulmi, Kathmandu, Kavrepalanchok, Lamjung, Nuwakot, Okhaldhunga, Panchthar, Rolpa, Sindhuli, Surkhet, Syangja, Tanahu, Terhathum, Western Rukum
Very Low (0.000 – 0.137)	Bardiya, Bhaktapur, Dadeldhura, Dhankuta, Eastern Rukum, Ilam, Kaski, Lalitpur, Nawalpur, Parasi, Parbat, Rautahat, Salyan, Sarlahi



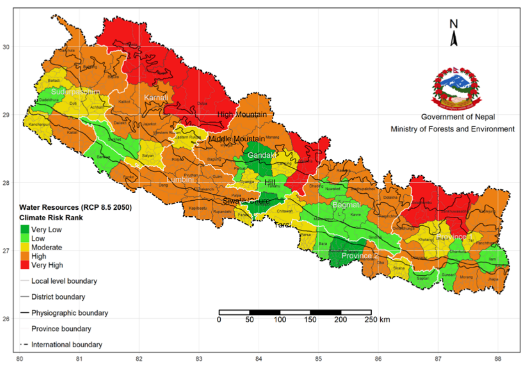
(a) RCP 4.5 in 2030s



(b) RCP 8.5 in 2030s



(c) RCP 4.5 in 2050s



(d) RCP 8.5 in 2050s

Figure 37: Risk rank of future change scenarios (water resources)

Figure 37 represents the risk rank map of the water resources sub-sector of the future. Based on the future projection scenarios of climatic hazards (Figure 13), these include four different future scenarios under RCP 4.5 and RCP 8.5 in the projection periods the 2030s and 2050s. Table 34 includes the number of districts in the risk rank classes at baseline and for both future projection scenarios of both projected periods. The future scenarios of risk rank show that the numbers of higher risk rank districts will increase in the future in both periods of both projected scenarios. Kaski, Nawalpur, Rautahat, and Sarlahi districts are at very low-risk rank in the future too in comparison with other districts, however, this does not mean that these districts will not be imposed by the changing climate and its associated disasters.

Table 34: No. of districts in risk rank classes (water resources)

Risk Rank Baseline		Number of Districts				
		RCP 4.5		RCP 8.5		
		2030s	2050s	2030s	2050s	
Very High	(0.578 – 1.000)	8	13	7	7	6
High	(0.368 – 0.577)	19	33	30	28	35
Moderate	(0.253 – 0.367)	17	18	21	22	15
Low	(0.138 – 0.252)	19	9	15	16	17
Very Low	(0.000 – 0.137)	14	4	4	4	4

8.2 Risk rank scenarios of energy

Figure 39 represents the baseline risk rank map of the energy sub-sector, which has been obtained by the composition of climate-induced hazards (Figure 11), exposure (Figure 19), and vulnerability (Figure 33) analysis of the energy sub-sector that is driven by historical climatic hazards. Table 35 represents the list of districts based on the baseline risk rank classes for the energy sector and Table 36 represents the number of districts at baseline and in RCP 4.5 and RCP 8.5 projection scenarios of the projected periods of the 2030s and 2050s. This risk rank analysis is based on the elements and indicators of the exposure, sensitivity, adaptive capacity, and hazards components, therefore, the higher dominant indicators of these components lead to becoming the higher risk rank.

Table 35: Districts in risk ranks of the energy sector

Risk Rank	District
Very High (0.629 – 1.000)	Chitwan, Dhading, Kailali, Kaski, Morang, Sindhupalchok
High (0.340 – 0.628)	Baglung, Dolakha, Gorkha, Kavrepalanchok, Makawanpur, Solukhumbu, Taplejung
Moderate (0.170 – 0.339)	Baitadi, Bajhang, Dailekh, Dhanusha, Doti, Ilam, Jajarkot, Jhapa, Kalikot, Kanchanpur, Lamjung, Mahottari, Myagdi, Nawalpur, Nuwakot, Pyuthan, Ramechhap, Rautahat, Sankhuwasabha, Saptari, Sarlahi, Siraha, Sunsari, Surkhet, Tanahu
Low (0.078 – 0.169)	Achham, Bajura, Banke, Bara, Bardiya, Bhojpur, Dang, Darchula, Dolpa, Gulmi, Humla, Jumla, Khotang, Mugu, Okhaldhunga, Palpa, Panchthar, Parbat, Parsa, Rasuwa, Rolpa, Rupandehi, Sindhuli, Syangja, Western Rukum
Very Low (0.000 – 0.077)	Arghakhanchi, Bhaktapur, Dadeldhura, Dhankuta, Eastern Rukum, Kapilbastu, Kathmandu

In Province 1, Morang, Taplejung, and Solukhumbu districts are at higher risk rank and the hill districts are at lower risk rank in comparison to other districts of the province. In Province 2, all the districts are at a very low to moderate risk rank. In Bagmati Province, Dolakha, Sindhupalchok, Kavrepalanchok, Dhading, Makawanpur, and Chitwan districts are at higher risk rank, and Sindhuli, the three districts of Kathmandu Valley and Rasuwa districts are at lower risk rank. In Gandaki Province, Gorkha, Kaski, and Baglung districts are at higher risk rank, whereas, Mustang, Manang, Parbat, and Syangja districts are at lower risk rank. In the Lumbini Province and Karnali Province, all the districts are at very low to moderate risk rank. In Sudurpashchim Province, Kailali district is at very risk rank, whereas, Bajura, Achham, Darchula, and Dadeldhura districts are at lower risk rank. As explained before, the energy sub-sector analysis has been entirely based on the development of energy infrastructures and the existence of relevant plans thus the future development of the energy sub-sector will affect the obtained risk rank. In this assessment, the exposure rank of the energy sub-sector has been found more prevalent for the obtained risk rank of this sub-sector.

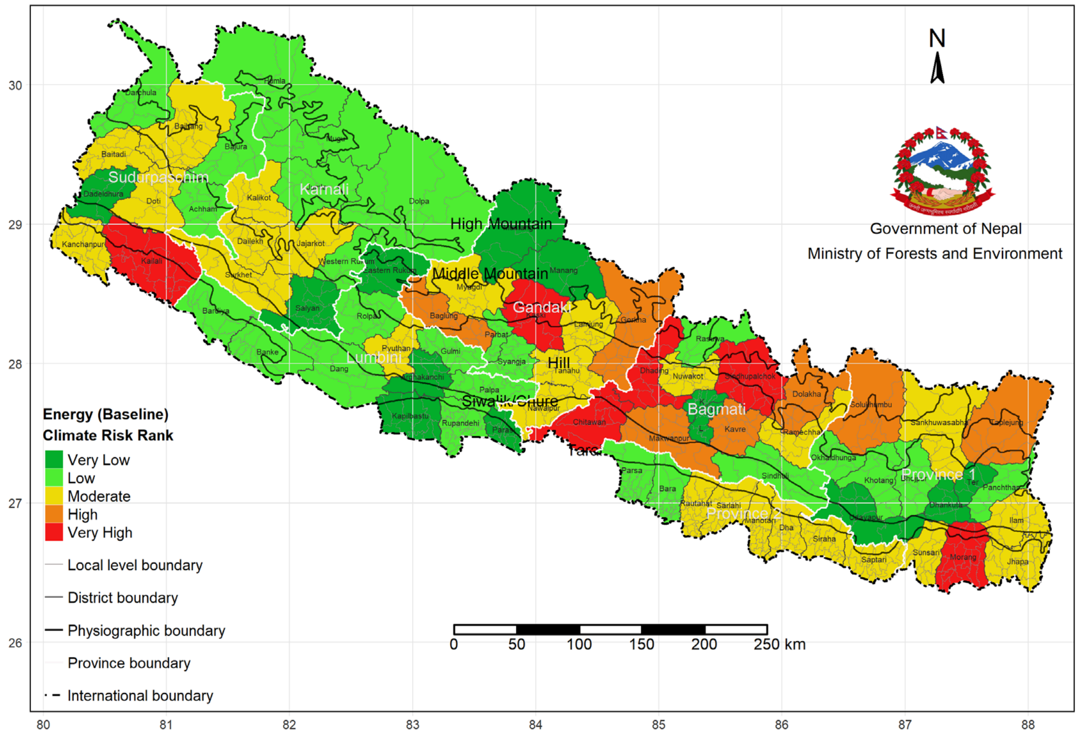
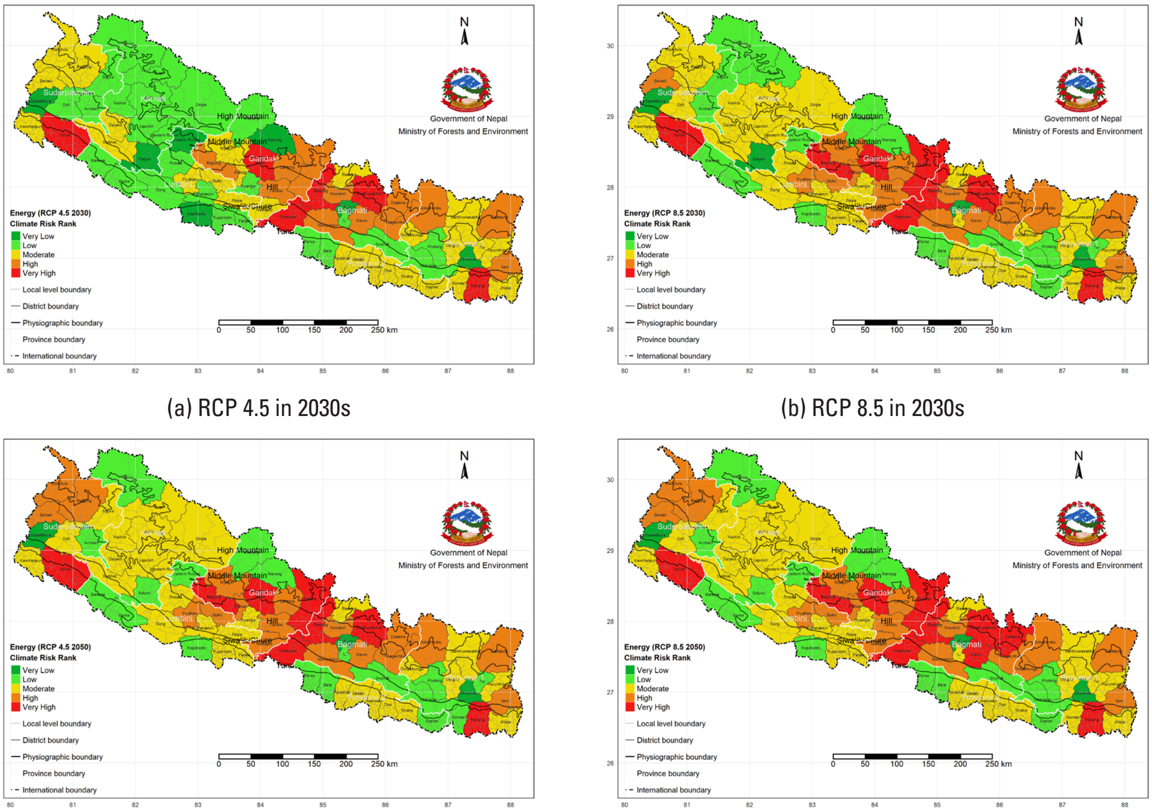


Figure 38: Risk rank of the energy sub-sector at baseline

Figure 39 represents the risk rank maps of future scenario changes of the energy sub-sector. This includes the risk rank maps of the projection scenarios RCP 4.5 and RCP 8.5 of the projection periods of the 2030s and 2050s based on the future projection scenarios of climatic hazards (Figure 14). According to the projection scenarios, the number of higher-risk rank districts will increase in the future, when the number of districts at baseline is compared with the 2030s and 2050s (Table 36). This shows that climate change will increase the risk in the energy sub-sector in the future and the scenario will be different with the development of additional energy infrastructures. Comparatively, Dadeldhura, Kathmandu, Bhaktapur, and Dhankuta are common districts that are at very low-risk rank, whereas, Kailali, Kaski, Chitwan, Gorkha, Sindhupalchok, and Morang are common districts which are at the very high-risk rank for all four future scenarios. However, this is just an inter-comparative risk scenario of all 77 districts of Nepal, where the districts at lower risk rank also have a considerable impact due to the changing climate and its associated disasters.

Table 36: No. of districts in risk rank classes (energy)

Risk Rank Baseline		Number of Districts				
		RCP 4.5		RCP 8.5		
		2030s	2050s	2030s	2050s	
Very High	(0.629 – 1.000)	6	6	8	8	10
High	(0.340 – 0.628)	7	12	18	16	17
Moderate	(0.170 – 0.339)	25	26	29	31	31
Low	(0.078 – 0.169)	25	25	18	17	15
Very Low	(0.000 – 0.077)	14	8	4	5	4



(a) RCP 4.5 in 2030s

(b) RCP 8.5 in 2030s

(c) RCP 4.5 in 2050s

(d) RCP 8.5 in 2050s

Figure 39: Risk rank of future change scenarios (energy)

8.3 Overall risk rank scenarios of the sector

Figure 40 represents the overall baseline risk rank map of the sector, which is also the final product of this assignment including the projected overall risk rank maps (Figure 41). This overall baseline risk rank map has been obtained by composing the risk rank maps of the water resources (Figure 36) and the energy (Figure 38) sub-sectors. Similarly, the projected overall risk rank maps under RCP 4.5 and RCP 8.5 of the projected periods the 2030s and 2050s have been obtained by compositing the projected respective risk rank maps of the water resources (Figure 37) and energy (Figure 39) sub-sectors.

Table 37 represents the list of districts following the overall baseline risk rank classes and Table 38 includes the number of districts under the baseline and future projections scenarios of overall risk ranks of the sector. Overall, the number of districts in higher risk ranks is increasing for the future scenarios of the 2030s and 2050s when being compared with the baseline (refer to a total number of districts at the very high and high-risk rank class of Table 38). The number of districts in lower-risk ranks is also decreasing in the future (refer to the total number of districts at the very low and low-risk rank class of Table 38).

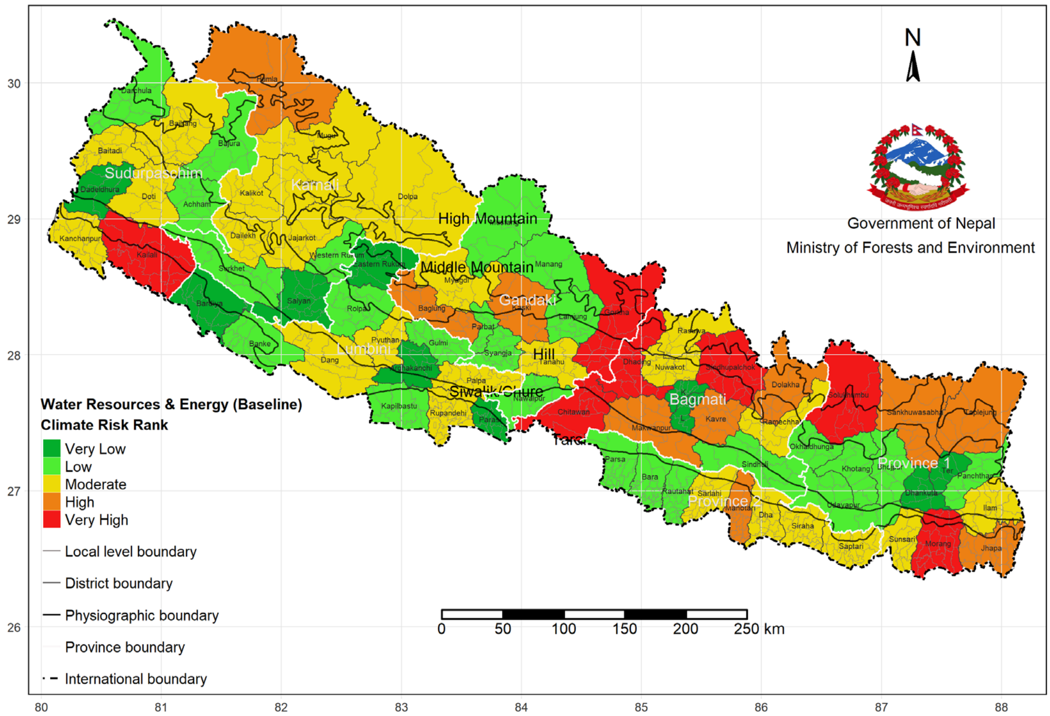


Figure 40: Overall risk rank of the sector

Table 37: Districts in overall risk ranks of the sector

Risk Rank	District
Very High (0.591 – 1.000)	Chitwan, Dhading, Gorkha, Kailali, Morang, Sindhupalchok, Solukhumbu
High (0.322 – 0.590)	Baglung, Dolakha, Humla, Jhapa, Kaski, Kavrepalanchok, Mahottari, Makawanpur, Sankhuwasabha, Taplejung
Moderate (0.196 – 0.321)	Baitadi, Bajhang, Dailekh, Dang, Dhanusha, Dolpa, Doti, Ilam, Jajarkot, Jumla, Kalikot, Kanchanpur, Mugu, Myagdi, Nuwakot, Palpa, Pyuthan, Ramechhap, Rasuwa, Rupandehi, Saptari, Sarlahi, Siraha, Sunsari, Tanahu
Low (0.096 – 0.195)	Achham, Bajura, Banke, Bara, Bhojpur, Darchula, Gulmi, Kapilbastu, Khotang, Lamjung, Manang, Mustang, Nawalpur, Okhaldhunga, Panchthar, Parbat, Parsa, Rautahat, Rolpa, Sindhuli, Surkhet, Syangja, Udayapur, Western Rukum
Very Low (0.000 – 0.095)	Arghakhanchi, Bardiya, Bhaktapur, Dadeldhura, Dhankuta, Eastern Rukum, Kathmandu, Lalitpur, Parasi, Salyan, Terhathum

In Province 1, Jhapa, Morang, Taplejung, Sankhuwasabha, and Solukhumbu districts are at higher risk and the hill districts at a lower risk. In Province 2, Mahottari district is at higher risk rank, whereas, Parsa, Bara, and Rautahat districts at a lower risk. In Bagmati Province, Dolakha, Sindhupalchok, Kavrepalanchok, Makawanpur, and Chitwan districts are at higher risk rank, whereas, Sindhuli, Kathmandu, Bhaktapur, and Lalitpur are at lower risk rank. In Gandaki Province, Gorkha, Kaski, and Baglung districts are at higher risk rank, whereas, Nawalpur, Lamjung, Manang, Mustang, Parbat, and Syangja districts are at lower risk rank. In Lumbini Province, all the districts are at moderate to very low-risk rank. In Karnali Province, the Humla district is at a higher risk rank, whereas, Western Rukum, Salyan, and Surkhet are at a lower risk rank. In Sudurpashchim Province, Kailali district is at a higher risk rank, whereas, Bajura, Achham, Darchula, and Dadeldhura districts are at a lower risk rank in comparison to other districts of Nepal. However, the provincial ranks are identical with the district level rank, where the district indexes are classified.

Besides, the baseline risk of climate change impact in the watershed and sub-river basin is analyzed. The findings show that few watersheds in Province 1, Bagmati Province, Gandaki Province, Sudurpaschim Province are impacted by climate change (Figure 41 a). In addition, for sub-basin level risks, the findings show that Province One, Gandaki Province, Karnali Province, and Sudurpashim Province are impacted (Figure 41 b).

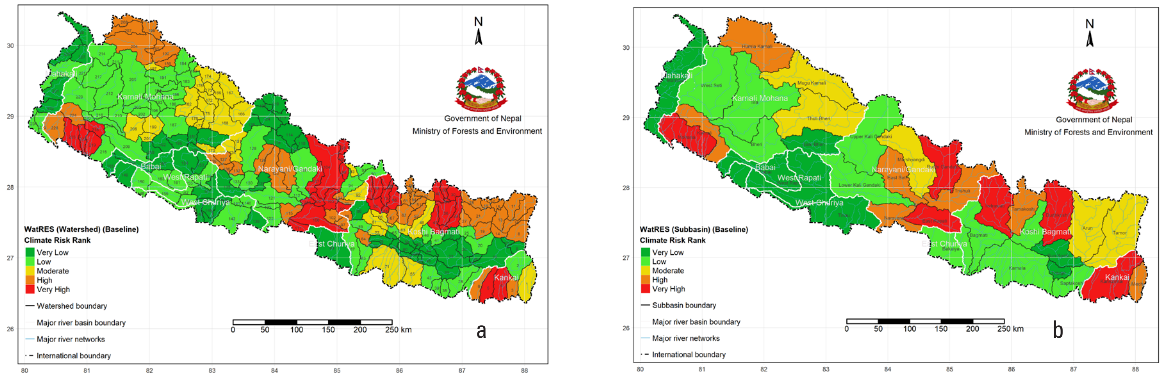
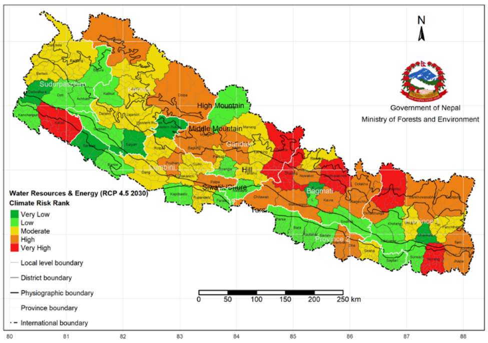


Figure 41: Risk rank of baseline scenarios a) watersheds b) sub-basin

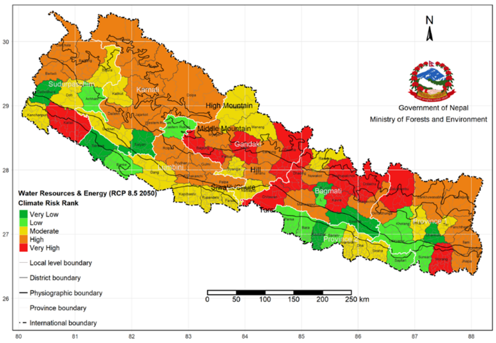
The watershed level risks analysis shows that in RCP 4.5 in 2030, except Karnali, all other Provinces will be experiencing risks of climate change impact. The risks of climate change impact will be extending to all the Provinces in RCP 8.5 in 2030. Besides, in 2050, the risks of climate change impact on watersheds will be severe. However, in RCP 8.5, in 2050, there will be a slight decrease in risks of climate change impact.

In terms of sub-basin level risk, the findings show that in RCP 4.5 in 2030, the risks of climate change will be higher in Province One, Bagamati Province, Gandaki Province, and Karnali Province. Besides, in RCP 8.5, the risks of climate change impact will be higher in additional Provinces such as Province 2 and Lumbini Province. In 2050, under both scenarios, the risks of climate change impact will be higher in Province 2, Bagmati Province, Gandaki Province, Lumbini Province, Karnali Province, and parts of Sudurpaschim Province.

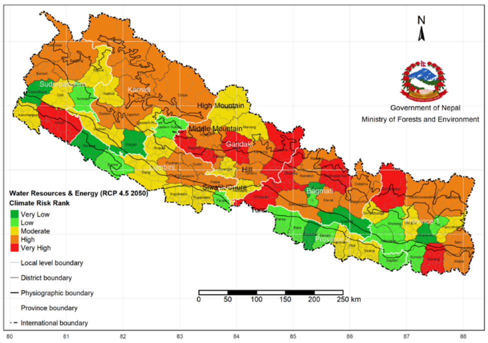
As explained before, Figure 42 represents the projected overall risk rank maps of the sector under the projected scenarios RCP 4.5 and RCP 8.5 of the projection periods of the 2030s and 2050s, the number of districts at higher risk due to climate change will increase in the future. This shows that the impact of climate change will increase the risk in the sector. In this sector, Morang, Solukhumbu, Sindhupalchok, Dhading, Gorkha, and Kailali are the common districts in all four future projected scenarios that are at very high-risk rank classes; whereas, Dhankuta, Kathmandu, Bhaktapur, Salyan, Bardiya, and Dadeldhura are the common districts that are at very low-risk rank classes in comparison to the other districts of Nepal.



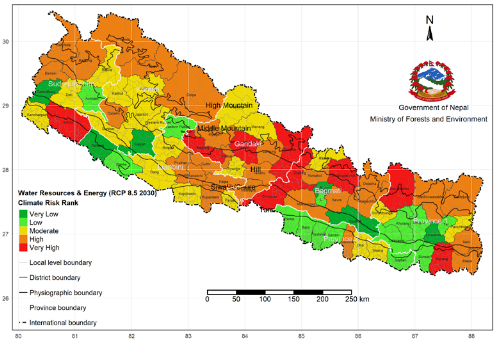
(a) RCP 4.5 in 2030s



(b) RCP 8.5 in 2030s



(c) RCP 4.5 in 2050s



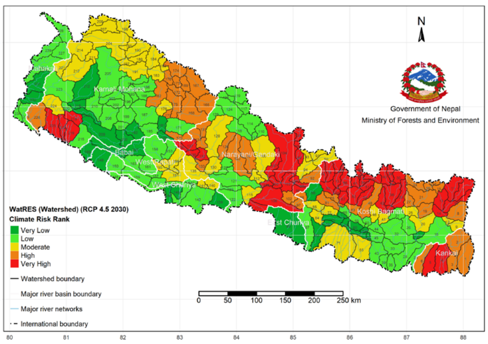
(d) RCP 8.5 in 2050s

Figure 42: Overall risk rank of future change scenarios

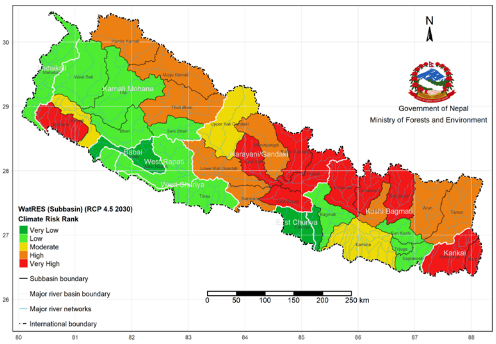
Table 38: No. of districts in overall risk rank classes

Risk Rank	Number of Districts				
	Baseline	RCP 4.5		RCP 8.5	
		2030s	2050s	2030s	2050s
Very High (0.591 – 1.000)	7	6	9	9	11
High (0.322 – 0.590)	10	20	27	27	28
Moderate (0.196 – 0.321)	25	22	20	20	19
Low (0.096 – 0.195)	24	22	13	14	11
Very Low(0.000 – 0.095)	11	7	8	7	8

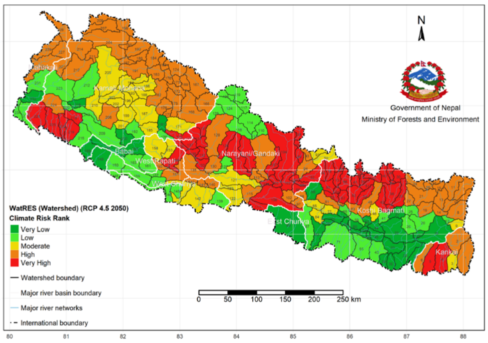
Likewise, Figure 43 and Figure 44 represent the RCP4.5 and RCP8.5 projected scenarios of the overall risk ranks respectively of the period 2030s and 2050s at the watershed and subbasin level. In the future, most of the watersheds and subbasins in the hills, Middle Mountain and High Mountain are comparatively at higher risk including the watersheds and subbasins at Kankai and Mohan river basins.



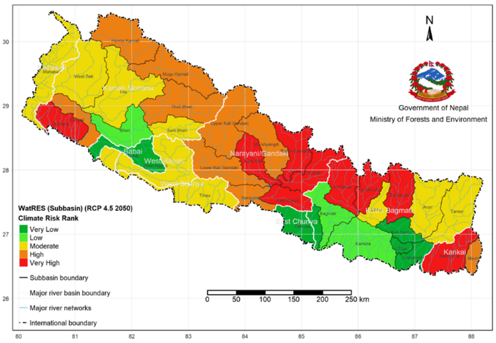
(a) RCP4.5 in 2030s of the Watersheds



(b) RCP4.5 in 2030s of the Subbasins

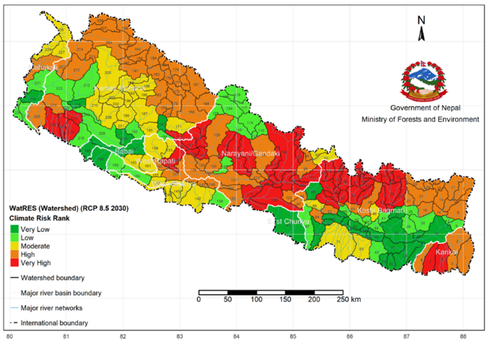


(c) RCP4.5 in 2050s of the Watersheds

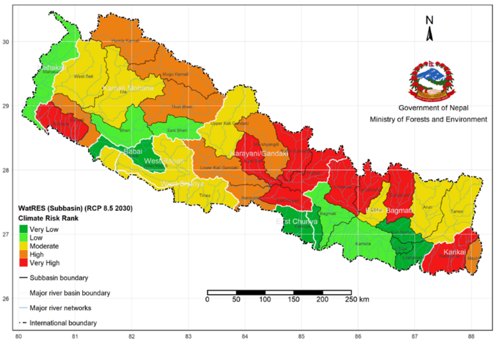


(d) RCP4.5 in 2050s of the Subbasins

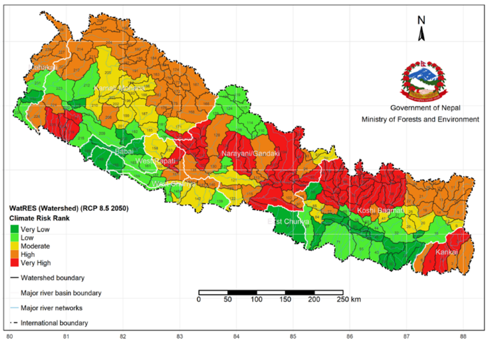
Figure 43: RCP4.5 scenarios of overall risk rank of the watersheds and subbasins



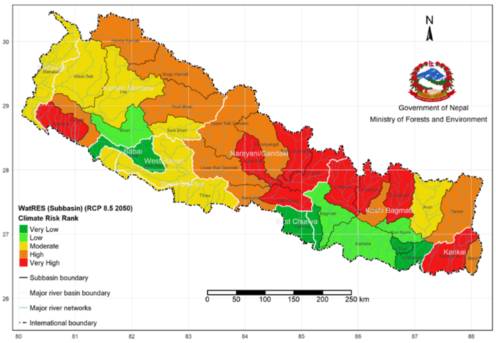
(a) RCP8.5 in 2030s of the Watersheds



(b) RCP8.5 in 2030s of the Subbasins



(c) RCP8.5 in 2050s of the Watersheds



(d) RCP8.5 in 2050s of the Subbasins

Figure 44: RCP8.5 scenarios of overall risk rank of the watersheds and subbasins

In summary, the findings show that the risks of climate change impact will be higher throughout Nepal in 2030 and 2050 in both the RCP scenarios. This implies that climate extreme events will have major implications for water and energy security in the future. Precipitation is projected to increase along with climate extreme events such as the number of rainy days. This has implications of too much water during monsoon which will bring extreme flooding, landslide, and landslide induced flood. The extreme variability observed in the precipitation will lead to an impact on water storage, river runoff, groundwater recharge, and water availability as a whole. This has implications for the drinking water, irrigation, hydropower, and other services derived from water resources. The increased temperature will lead to glacier melting and the risks of water flow in snow-fed rivers will be high. The hydropower sector which is one of the major sources of energy generation in Nepal will suffer from the seasonal water fluctuation and variability and the consequences of climate-induced disasters in the energy infrastructure and services. Besides, the large dam, reservoir, and river diversion plans will be impacted due to the seasonal variability (too much water and too little water).

Chapter 9

Adaptation Options in the Sector

Water availability, supply, distribution, use, and conservation are directly dependent on climatic variabilities, naturally stored freshwater and spatial coverage of water availability. Besides the domestic, agricultural, and industrial demand, the ecological water demand also needs to be fulfilled to maintain the ecosystems, as they also completely rely on the spatial coverage of water availability. Strengthening the water resources management is crucial in adopting adaptation measures to combat the projected climate change and related changes in terms of rainfall, snowfall, glaciers, water use patterns, and water quality.

The strategic priority areas on adaptation proposed for this sector is aligned with the water resource policy of the government of Nepal, the white paper, and the fifteenth five-year plan along with other strategic policy priorities on implementing the master plan on integrated river basin management, integrated water resource management, and mitigating the risks of climate-induced disasters. The storage capacity of water resources needs to be increased naturally and artificially to meet the seasonal water scarcity caused by climate change and to meet the scattered demand of water service areas. These adaptation options can be implemented by the development and deployment of new technologies targeting short-term to long-term solutions. Re-adjusting the individual structure and service areas according to the availability of water resources and energy sources could be a viable option. Renewable energy itself is identified as an adaption option to diversify the use of energy and to deal with seasonal variability of water availability for hydropower plants. Most importantly, the socio-economic implications need to be considered while implementing the adaptation options for the changing climate. The four priority actions required as adaptation strategies are described in Table 39 and the detailed list based on three categories of the water resources and energy sub-sectors are described in Table 40 and Table 41 respectively.

Table 39: Strategic Priority areas on Adaptation in the Water Resources and Energy

Water Resources	Energy
• Promote Integrated River Basin Management (IRBM) approach and modalities for total available resource accounting, addressing climate adversities (high seasonal fluctuation of river flow; risks from climate-induced disasters; spatial and temporal water scarcity) and maximizing benefits (hydropower, food security, irrigation, and water supplies) • Enrich the spatial coverage of the hydro-metrological measurements and monitoring stations in every watershed, river basin, sub-basin, and Palika, particularly focused on the mountainous region of Nepal • Evaluate the water availability in every Palika, watershed, river basin, and district with robust modelling activities and map the floods risk zoning for all the river systems of Nepal • Promote and develop water recharge, retention, and reuse interventions to conserve/preserve and equitable distribution among the beneficiaries for the water security	• Enhance a more detailed understanding of changes in the hydrological cycle and its uncertainty. Also, analyzing future risks on infrastructure (dams and hydropower plants, roads, and transmission lines) • Ensure reservoir operation, to adjust rule curves by the climate change in different periods for the smooth operation and production. Similarly, increase the height of the dam, reducing the annual sediment inflow to the reservoir, utilize the unwanted spill, and modify existing spillways to increase discharge capacity Fuse-gate/ plugs. • Diversify the energy use opportunities by identifying relevant sources of energy based on the geographical location, locally available resources and minimizing the environmental degradation • Ensure the public and private partnership for promoting renewable energy technologies and make them accessible to everyone and every corner
Provision of relevant plans, policies, and guidelines based on the watersheds to implement the priority actions effectively and relevant capacity development activities	

The climate change adaptation options for the sector include water security and thereby energy security. Adaptation measures should maintain the reliable and sustainable quantity and quality of water for health, livelihoods, agricultural production, and energy development. Since climate change impacts will increase gaps in water availability and demand, it will also alter the energy production and supply, therefore, the water resources management and diversification of alternative energy use should be strengthened. Water management strengthening should include increasing water storage capacity with water retention and recharge plan; adapting advanced technology for the water quality treatment and re-use; promoting multiple water use systems to improve the efficiency of productive water use; promoting to use of hydro-electric and renewable energy, including the households appliances; improving the system and diversifying the energy consumption and power generation; developing a watershed and river-basin management plan and relocating of upstream human habitats to control the pollutant load; and readjusting the industrial structure which requires a huge amount of water.

One of the major challenges of climate-induced hazards will be potential implications for the hydropower sector. The seasonal variability (too much and too little water) will impact hydropower efficiency and production. Climate-induced disasters such as floods, LDOF, landslides, GLOF will damage the infrastructure and impact energy generation. To protect the huge development investment in the sector, there is an urgent need to increase awareness of hydropower developers/investors and the private sector as a whole. This needs to be supported with policy instruments such as regulations to in-build climate vulnerability and risk in the hydropower design and adoption of necessary risk mitigation measures in the sector.

The climate change adaptation options recommended in this assessment are based on the climate change impact, risk, and vulnerability in the sub-sectors, which have been drawn from the literature and consultative meetings in the provinces (Annex 1). The list of recommended adaptation options for the Water Resources and Energy Sub-sector is included separately in Table 40 and Table 41.

Table 40: Lists of Adaptation Options for Water Resources Sub-sector

Risk and Vulnerabilities	Short-term (1-5 years)	Medium-term (1-10 years)	Longer-term (1-30 years)
		Structural/Physical	
• Climate change is projected to reduce renewable surface water and groundwater resources, intensifying competition for water among sectors • Changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality • Sustained mass loss from glaciers in the Everest region through the 21st century based on RCP 4.5 and RCP 8.5 climate projections • Climate change is projected to reduce raw water quality and pose risks to drinking water quality even with conventional treatment, due to interacting factors: increased temperature; increased sediment, nutrient, and pollutant loadings from heavy rainfall; increased concentration of pollutants during droughts; and disruption of treatment facilities during floods	• Assess the seasonal variability of water resources and their implications in water storage, river runoff, and water usages • Develop EBA strategies to address the risk and vulnerabilities of critical river basins, watersheds, springsheds, and other water bodies • Assess the groundwater resources quantity and quality throughout the country and study the impacts of climate change • Assess the current facilities and storage options according to future water availability. And, evaluate future options to enhance the water storage (particular focus on the recharging groundwater aquifer) • Enhance integrated and resilience approach to municipal services in water supply and sanitation, faecal sludge management, and multiple water use systems • Document and promote climate-resilient indigenous practices of water management and integrate them into advanced technology and practices	• Help to implement integrated river basin master plan including integrated water resource management policy and strategies. • Promote efficient domestic water use practices (rainwater harvesting, and multiple water use systems) at the household and community level • Improve maintenance of existing reservoirs at villages (to improve the efficiency of water conveyance system and rehabilitation of water storage in the villages with treatment facilities) • Promote efficient irrigation technologies and practices such as lined irrigation canals and well-buried water supply pipelines to prevent water leakage and loss • Enhance water recharge and retention technologies; such as recharging pit and wells and terrace farming practices, afforestation, etc. • Increase the efficiency of water use and reduce water losses from irrigation system (re-use of drainage/wastewater; water-saving irrigation applications: micro-irrigation and drip irrigation; efficient use of groundwater: production wells, boreholes; rainwater harvesting, solar lifting) • Design flood control infrastructure (protection to riverbank erosion, improvement of cross-drainage structure) • Expand hydrological and meteoroidal network to improve spatial coverage (particular focus to more stations in mountainous watersheds and river basins) of hydro-climatic information • Adopt adaptive land use management (particular focus on flood plain farming and farming according to change in agro-ecological regions) • Develop glaciers and glaciers lake monitoring infrastructures/ mechanisms throughout the mountainous regions of Nepal lake monitoring infrastructures/ mechanisms throughout the mountainous regions of Nepal	• Develop large-scale water infrastructure that will provide the needed buffering capacity, robustness, and resilience to withstand variability of climate change • Promote water diversion to ensure efficient water use while minimizing the negative impact on freshwater biodiversity, including cultural and social values • Develop and implement climate-resilient watershed management plans for critical watersheds and river basins • Reinforce bio-engineering and engineered road construction to minimize the risk of landslides and loss and soil • Promote effective and efficient irrigation (drip irrigation, terrace farming to conserve water in the watershed) • Promote ecological restoration programme (particular focus on wetland and floodplain conservation and restoration) • Launch afforestation and reforestation activities to increase the canopy coverage in the catchment area of irrigation, water supply, and hydropower • Integrate all the forms of water cycles in technological interventions (surface and groundwater, freshwater storage as snow and glaciers, water quantity and quality, land use systems, soil class, topography, ecosystems, etc.) • Launch initiatives to drain glacier lakes particularly of all the vulnerable and risky glaciers • Scale-up community-based water resources management to address the issues of water security and equip the communities with technology and practices to manage the too much and too little water

Risk and Vulnerabilities	Short-term (1-5 years)	Medium-term (1-10 years)	Longer-term (1-30 years)
Policy, Institutional, and Capacity building			
	• Develop capacity to adopt improved impact-based forecasting systems in risk-prone water bodies (glacier, rivers, streams) and Improve access to early warning systems and response systems • Develop institutional capacity to carry out systematic monitoring of hazards using remote sensing tools and support to improve the climate forecast system • Develop network-based communication systems (priority to radio, mobile phone, and internet) to provide timely information on the potential threat and risks from climate-induced hazards • Develop guidelines for regular repair and maintenance of water services and infrastructures • Improve access of local and provincial governments to hazard and vulnerability mapping Enhance knowledge using appropriate climate change projection downscaling tools • Ensure compliance of water tariffs to sustain financially the water users committee and improve their access to water management • Adopt and promote disaster planning and preparedness programs and disaster contingencies funds • Establish the water management agencies in every watershed and river basin to monitor the activities in the watershed /river basin	• Encourage local government, the provincial government, and relevant stakeholders to develop and implement climate-resilient watershed, wetland, and river basin management plans. Examples include promoting community/ecosystem-based adaptation plans at various scales • Build capacity of water user groups, soil, and water management group, community forestry group to integrate climate resilience in their optional plan, annual plan, etc. • Design safe shelters in flood-prone areas (elevated permanent shelters – priority to poor people) based on the flood risk mapping • Ensure data collection and sharing on availability of water resources (rainfall, snowfall, reservoir storage, river discharges, groundwater potential and levels, water quality, etc.) • Reinforce water use regulations and agreements between the water users and local governments • Regularize plan and policy for groundwater utilization at the municipal level and to control over the extraction • Establish a mechanism for upstream and downstream linkages and knowledge sharing • Implement the integrated river basin management strategy and plan • Develop bankable projects for accessing the fund, including UNFCCC funds (GCF, AF, LDCF) on addressing climate change issues	• Raise awareness in gender equity and climate change impact on water resources through education and other events • Provide financial incentives for the water users (tax reduction and provision of subsidies) • Ensure water right trading system at the local level (establish the rules to share water among water users and support to those who suffer from water scarcity by compensation, insurance, and cross-subsidies provision) • Promote insurance including index-based weather insurance schemes, catastrophe bonds, and revolving funds • Develop investment plan for efficient use of existing and future water storage options • Promote integrated water resource management plan and programme implementation considering all water-related sectors (flood control, water supply, and sewerage, irrigation water, industrial water, water for power generation, water for environment improvement, etc.) • Ensure provision of payment for ecosystem services in programme design and implementation • Establish a climate change research center as per climate change policy to foster research and development on climate change issues, impact, and adaptation solutions in the context of mountain ecosystems

Table 41: Lists of Adaptation Options for Energy Sub-sector

Risks and Vulnerabilities	Short term (2025)	Medium-term (2030)	Long Term (2050)
• Glaciers across Nepal, are retreating, leading to changes in future hydrological regimes. • The risk of glacial lake outburst floods (GLOFs) and landslides are increasing, putting both existing and planned hydropower plants at risk • The impact of increase/decrease in average water availability will lead to increased/ reduced power outputs • The changes in seasonal and inter-annual variation in inflows (water availability) will shift in seasonal and annual power output; floods and lost output in the case of higher peak flows • The extreme precipitation causing floods will have direct and indirect (by debris carried from flooded areas) damage to dams and turbines, lost output due to releasing water through bypass channels • Socio-economic disparity further restricts poor and marginalized households to access clean energy sources thus increases the sensitivity of the population	• Enhance a more detailed understanding of changes in the hydrological cycle and its uncertainty. Also analyzing future risks on infrastructure (dams and hydropower plants, roads, and transmission lines) • Sensitize private sector, investors, developers, and respective technical staffs and workers of hydropower sector on potential risks and vulnerabilities of climate change on hydropower • Improve the efficiency and coverage of transmission and distributions line systems to minimize the electricity losses • Enhance and improve the early warning systems for water/climate-induced disasters • Amend/improve EIA guidelines to include climate risk and vulnerability assessment and suggestion of adaptation options • Support in developing disaster risk management and climate change adaptation plans for vulnerable areas surrounding hydro-plants • Promote second-generation biofuels (particular focus on non-food biomass) and other clean energy sources	• Promote underground distributions system of hydroelectric lines • Promote flood modelling, dam-break modelling, and extreme values analysis techniques using appropriate tools to protect the hydro-electric plants • Develop dam safety plans and promote the use of safety measures and equipment • Diversify the energy mix by the use of renewable energy sources and technologies: Biomass, Solar, Wind and Water Mills • Ensure the climate-resilient design and construction of energy facilities, including good site selection for energy infrastructure, effective permitting, licensing, standards regulation regimes, and enforcement • Establish the off-grid solar systems and roof-top solar systems in institutions and homes • Enforce the energy-efficiency standards and regulations for electrical appliances/ cookstoves, licensing, permitting, monitoring, and regulation of energy projects • Develop low head, peaking run-of-river hydroelectricity schemes. • Create "green" buffers around transmission and distribution infrastructure to reduce tree contacts with sagging lines due to extreme temperatures • Support in setting up high-resolution climatic and hydro-meteorological scenarios for each dam site and for the river basin they belong to, in a way that they can be easily accessed and understood by the electric utilities' management and by all other users within the basin. • Support in the design of specific climate services to provide accurate projections of the relevant indicators in an accessible format	• Minimize the seasonal fluctuation of hydropower generation potential through improvements in system management (implement the watershed management plan and use of weather forecasts) • Ensure reservoir operation, to adjust rule curves by the climate change in different periods for the smooth operation and production. Similarly, climate-proof infrastructure by increasing the height of the dam, reducing the annual sediment inflow to the reservoir, utilizing the unwanted spill, and modification of existing spillways to increase discharge capacity Fuse-gate/ plugs • Explore alternatives for maximizing the use of hydropower facilities (particular focus on the potential of Pump-Storage Hydroelectricity (PHP)) • Maintain ecological corridors (particular focus on the enhancement of fish passage in hydropower dams • Identify the spots for a reservoir in every river basin and develop relevant infrastructure to control the sediment and regularize the river flows • Promote the set of engineering options to manages dam spills. Spillways design shapes include chute spillways, stepped spillways, bell-mouth spillways, syphon spillways, ogee crests, side channels, labyrinth spillways, and piano-key weirs (PKW). • Ensure the Gated systems are part of the dam design which are a series of gates installed along the dam wall or around bell-mouth spillways that can be opened to manage the reservoir's water level and in particular to release downstream excess water volume in case of flooding

Risks and Vulnerabilities	Short term (2025)	Medium-term (2030)	Long Term (2050)
Policy, Institutional, and capacity			
	• Raise awareness of stakeholders and help to prepare a plan for responding to the impacts of climate change in terms of increased climate-induced hazards (floods, sediments, GLOFs, LDOFs) • Design capacity building training for sources, production, and use of renewable energy (particular focus on biomass, solar, and wind) • Develop legal measures to encourage insurance of infrastructure, property, and people • Enhance disaster contingencies funds for addressing climate change issues in the energy sector • Conduct studies on the impacts of climate change on alternative energy sources and the benefit of renewable energy to reduce climate change • Consider climate change into long-term power generation plans	• Enhance the capacity of women and marginalized groups in the selection of alternative energy and energy-efficient technology to support livelihoods • Define property rights and land tenure security for the hydropower producers and biomass production • Promote the implementation of the renewable energy programme at the municipal level, and build capacity at the local level • Develop guidelines for biomass use as renewable energy without affecting the forest and ecosystem; and use of agricultural residue • Develop climate-resilient guidelines in the energy sector to ensure climate change is considered of hydropower plants, dams, transmission lines, and other infrastructures	• Implement ecosystem-based adaptation management plan and programme to enhance renewable energy use and restore water resources • Conduct studies on dam break analysis and flooding in hydropower and make a preparedness plan accordingly • Incentivize consumers through reduction of electricity unit price and promote the use of electrical appliances in households • Integrate the climate risk into energy planning and decision-making processes, improve climate data collection and management, strengthen capacity for forecasting and climate risk analysis

Risks and Vulnerabilities	Short term (2025)	Medium-term (2030)	Long Term (2050)
• Glaciers across Nepal, are retreating, leading to changes in future hydrological regimes. • The risk of glacial lake outburst floods (GLOFs) and landslides are increasing, putting both existing and planned hydropower plants at risk • The impact of increase/decrease in average water availability will lead to increased/reduced power outputs • The changes in seasonal and inter-annual variation in inflows (water availability) will shift in seasonal and annual power output; floods and lost output in the case of higher peak flows • The extreme precipitation causing floods will have direct and indirect (by debris carried from flooded areas) damage to dams and turbines, lost output due to releasing water through bypass channels • Socio-economic disparity further restricts poor and marginalized households to access clean energy sources thus increases the sensitivity of the population	• Enhance a more detailed understanding of changes in the hydrological cycle and its uncertainty. Also analyzing future risks on infrastructure (dams and hydropower plants, roads, and transmission lines) • Sensitize private sector, investors, developers, and respective technical staffs and workers of hydropower sector on potential risks and vulnerabilities of climate change on hydropower • Improve the efficiency and coverage of transmission and distributions line systems to minimize the electricity losses • Enhance and improve the early warning systems for water/climate-induced disasters • Amend/improve EIA guidelines to include climate risk and vulnerability assessment and suggestion of adaptation options • Support in developing disaster risk management and climate change adaptation plans for vulnerable areas surrounding hydro-plants • Promote second-generation biofuels (particular focus on non-food biomass) and other clean energy sources	• Promote underground distributions system of hydroelectric lines • Promote flood modelling, dam-break modelling, and extreme values analysis techniques using appropriate tools to protect the hydro-electric plants • Develop dam safety plans and promote the use of safety measures and equipment • Diversify the energy mix by the use of renewable energy sources and technologies: Biomass, Solar, Wind and Water Mills • Ensure the climate-resilient design and construction of energy facilities, including good site selection for energy infrastructure, effective permitting, licensing, standards regulation regimes, and enforcement • Establish the off-grid solar systems and roof-top solar systems in institutions and homes • Enforce the energy-efficiency standards and regulations for electrical appliances/ cookstoves, licensing, permitting, monitoring, and regulation of energy projects • Develop low head, peaking run-of-river hydroelectricity schemes. • Create “green” buffers around transmission and distribution infrastructure to reduce tree contacts with sagging lines due to extreme temperatures	• Minimize the seasonal fluctuation of hydropower generation potential through improvements in system management (implement the watershed management plan and use of weather forecasts) • Ensure reservoir operation, to adjust rule curves by the climate change in different periods for the smooth operation and production. Similarly, climate-proof infrastructure by increasing the height of the dam, reducing the annual sediment inflow to the reservoir, utilizing the unwanted spill, and modification of existing spillways to increase discharge capacity Fuse-gate/plugs • Explore alternatives for maximizing the use of hydropower facilities (particular focus on the potential of Pump-Storage Hydroelectricity (PHP)) • Maintain ecological corridors (particular focus on the enhancement of fish passage in hydropower dams • Identify the spots for a reservoir in every river basin and develop relevant infrastructure to control the sediment and regularize the river flows

Risks and Vulnerabilities	Short term (2025)	Medium-term (2030)	Long Term (2050)
Policy, Institutional, and capacity			
	• Raise awareness of stakeholders and help to prepare a plan for responding to the impacts of climate change in terms of increased climate-induced hazards (floods, sediments, GLOFs, LDOFs) • Design capacity building training for sources, production, and use of renewable energy (particular focus on biomass, solar, and wind) • Develop legal measures to encourage insurance of infrastructure, property, and people • Enhance disaster contingencies funds for addressing climate change issues in the energy sector • Conduct studies on the impacts of climate change on alternative energy sources and the benefit of renewable energy to reduce climate change • Consider climate change into long-term power generation plans	• Enhance the capacity of women and marginalized groups in the selection of alternative energy and energy-efficient technology to support livelihoods • Define property rights and land tenure security for the hydropower producers and biomass production • Promote the implementation of the renewable energy programme at the municipal level, and build capacity at the local level • Develop guidelines for biomass use as renewable energy without affecting the forest and ecosystem; and use of agricultural residue • Develop climate-resilient guidelines in the energy sector to ensure climate change is considered of hydropower plants, dams, transmission lines, and other infrastructures	• Implement ecosystem-based adaptation management plan and programme to enhance renewable energy use and restore water resources • Conduct studies on dam break analysis and flooding in hydropower and make a preparedness plan accordingly • Incentivize consumers through reduction of electricity unit price and promote the use of electrical appliances in households • Integrate the climate risk into energy planning and decision-making processes, improve climate data collection and management, strengthen capacity for forecasting and climate risk analysis

Chapter 10

Conclusions and Recommendations

10.1 Conclusions

The Climate Change Vulnerability and Risk Assessment (VRA) was conducted according to the conceptual framework of IPCC–AR5 and the Government of Nepal. In this, the risk of climate change is the function of hazard, exposure, and vulnerability; and the vulnerability is the inverse relationship between the degree of sensitivity and adaptive capacity. In the analysis, the biophysical and socio-economic processes (including GESI and governance) have been considered as cross-cutting issues. Thus hazard, exposure, sensitivity, adaptive capacity, vulnerability, and risk are the six components of the VRA process. In the assessment, the impact of climate change on the water resources sector of Nepal has been analyzed based on published reports and journal articles and the findings have been triangulated with other findings. After which the most relevant indicators were identified.

The studies show an increase in temperature, as stated by the trend analysis of the past observed data; however, there were no significant trends in precipitation. The future downscaled climate data have shown an increase in both temperature and precipitation under RCP 4.5 and RCP 8.5 scenarios, Similarly, water availability is projected to increase in the future by both projected scenarios RCP 4.5 and RCP 8.5. However, water availability at some sub-basins will decrease in the future, which will impact water security at the local level

Considering the impact of climate change in the sub-sectors, the indicators of exposure, sensitivity, and adaptive capacity have been identified by taking the indicators. In this assessment, there are 20 indicators in hazard, 30 indicators in exposure, 35 indicators of insensitivity, and 20 indicators in adaptive capacity. All the data for the indicators, including the sub-indicators, have been collected at the district level. The primary sources of data are governmental agencies, particularly from the departments and divisions of the Ministry of Energy Water Resources and Irrigation (MOEWRI) and other governmental line agencies.

The processed data of the indicators are normalized by scaling from 0 to 1 to the original values of the indicators. The indicators are then composited element-wise by applying the weights received from the expert survey; then composited to sub-sector-wise and to the overall sector for the VRA components separately. In this way, the rank of the districts, provinces, and physiographic regions are determined separately for the VRA components, where the rank classes have been conducted using the 'Jenks Natural Break' method. Based on the results of vulnerability and risk rank, associated literature, and provincial consultation meetings, the possible adaptation options have been identified and listed in this final report.

For the hazard rank analysis, two climatic variables - change in precipitation and temperature; eights climate extreme events - change in extreme and very wet days, in the number of rainy days, consecutive wet and dry days, warm days and nights, and warm spell duration; Overall, the result shows that the dominant climate-induced hazards for making higher risk are snowstorm areas, landslide occurrences, floods/flash floods occurrences, and prone areas, and GLOFs. The districts at very high hazard rank at baseline scenario are Chitwan, Kailali, Kaski, Mahottari, Morang, Rautahat, Saptari, Sarlahi, and Solukhumbu.

The districts at very high exposure ranks are Dang, Dhading, Dhanusha, Gorkha, Ilam, Jhapa, Kapilbastu, Kaski, Kathmandu, Morang, Rupandehi, Sankhuwasabha, Sindhupalchok, and Solukhumbu in comparison to other districts of Nepal. Overall, the result shows that the dominant indicators for making the districts at higher exposure rank are an area of glaciers; water availability as groundwater flow, net water yields and total water at rivers; drainage length; the number of irrigation canals; the total area of agricultural lands, potential irrigable lands and non-irrigated agricultural lands; total number of the male and female population; the number of hydropower plants; length and capacity of both transmission and distribution lines; and households dependency on sources of traditional energy for cooking.

The districts at a very high sensitivity rank are Arghakhanchi, Baglung, Baitadi, Bajura, Dailekh, Dhading, Dolakha, Gorkha, Gulmi, Jumla, Kailali, Morang, Myagdi, Okhaldhunga, Sindhupalchok, Solukhumbu, and Western Rukum in comparison to other districts of Nepal. Overall, the result shows that the dominant indicators for making the districts at higher sensitivity ranks are trends of change in groundwater flow and net water yields; drainage density; the average slope of the topography; area of loamy soils; area of the lake, river bed and snow cover; the trend of change in barren lands; households depend on tube well/hand pump and covered well/kuwa; drinking water demand and supply status; irrigation water used from pond/lake; sex ratio (male by 100 female); children population (boys and girls); the number of hydropower plants by capacity and by water conveyance systems; the number of under construction and under survey hydropower plants; the number of hydropower plants owned by the private sector; and many households depend on wood/firewood for cooking.

The districts with very high adaptive capacity rank are Kaski, Kathmandu, and Sankhuwasabha, whereas the districts are very low adaptive capacity rank are Baitadi, Bajhang, Bajura, Dailekh, Darchula, Dolpa, Eastern Rukum, Humla, Jumla, and Okhaldhunga in comparison to other districts of Nepal. Overall, the result shows that the dominant indicators for making the districts at higher adaptive capacity ranks are trends of reforestation/afforestation for water conservation; trends of terrace farming for water retention; access to climate information; the number of wetlands conservation initiatives; total usable water for irrigation; number of bio-engineering practices; agricultural land with operational irrigation systems, Gender Development Index (GDI); and electrification coverage status.

The vulnerability rank analysis has been carried out by subtracting the composite adaptive capacity value from the districts from the composite sensitive value of respective districts. Thus, the vulnerability analysis is entirely based on the analysis results of sensitivity and adaptive capacity ranks. The overall result shows that the districts at very high vulnerability ranks are Arghakhanchi, Baglung, Baitadi, Bajhang, Bajura, Dailekh, Darchula, Dolpa, Eastern Rukum, Gulmi, Humla, Jumla, Okhaldhunga, and Western Rukum; whereas the districts at very low vulnerability ranks are Achham, Banke, Bara, Bardiya, Bhaktapur, Dadeldhura, Dang, Dhankuta, Kathmandu, Parsa, Rautahat, Saptari, Sarlahi, Sindhuli and Sunsari in comparison to the districts of Nepal.

The vulnerability assessment of the watershed and sub-river basin shows that most of the watersheds in Bagmati Province, Gandaki Province, Lumbini Province, Karnali Province, and Sudurpaschim Province are highly vulnerable. Furthermore, the result shows that the sub-basins of the Karnali river basin have a higher vulnerability to climate change impacts

The risk rank analysis was carried out by compositing the hazard, exposure, and vulnerability value of respective districts; thus the risk analysis is based on the analysis results of hazards, exposure, and vulnerability ranks. The overall result shows that the districts at very high-risk rank are Chitwan, Dhading, Gorkha, Kailali, Morang, Sindhupalchok, and Solukhumbu; whereas the districts at very low-risk rank are Arghakhanchi, Bardiya, Bhaktapur, Dadeldhura, Dhankuta, Eastern Rukum, Kathmandu, Lalitpur, Parasi, Salyan, and Terhathum. The projected scenarios show that Morang, Solukhumbu, Sindhupalchok, Dhading, Gorkha, and Kailali are the common districts in all four future projected scenarios—RCP 4.5 and RCP 8.5 in the 2030s and 2050s—that are at very high-risk rank; whereas, Dhankuta, Kathmandu, Bhaktapur, Salyan, Bardiya, and Dadeldhura are the common districts that are at very low-risk rank in comparison to other districts of Nepal.

The baseline risk of climate change impact In the watershed and sub-river basin shows that few watersheds in Province 1, Bagmati Province, Gandaki Province, Sudurpaschim Province are impacted by climate change. In addition, for sub-basin level risks, the findings show that Province One, Gandaki Province, Karnali Province, and Sudurpashim Province are impacted. The watershed level risks analysis shows that in RCP 4.5 in 2030, except Karnali Province, all other provinces will be experiencing risks of climate change impact. The risks of climate change impact will be extending to all the provinces in RCP 8.5 in 2030. Besides, in 2050, the risks of climate change impact on watersheds will be severe. However, in RCP 8.5, in 2050, there will be a slight decrease in risks of climate change impact. In terms of sub-basin level risk, the findings show that in RCP 4.5 in 2030, the risks of climate change will be higher in Province One, Bagamati Province, Gandaki Province, and Karnali Province. Besides, in RCP 8.5, the risks of climate change impact will be higher in additional provinces such as Province 2 and Lumbini Province. In 2050, under both scenarios, the risks of climate change impact will be higher in Province 2, Bagmati Province, Gandaki Province, Lumbini Province, Karnali Province, and parts of Sudurpaschim Province.

The adaptation options listed for the sub-sectors are proposed to address the adverse impact of climate change. The adaptation options were identified through literature review, consultation with provincial and local level stakeholders, and suggestions from the experts and Thematic Working Group (TWG) members.

The key priority adaptation strategies required for the water resources sector are – a) promote Integrated River Basin Management (IRBM) approach and modalities for total available resource accounting, addressing climate adversities (high seasonal fluctuation of river flow; risks from climate-induced disasters; spatial and temporal water scarcity) and maximizing benefits (hydropower, food security, irrigation, and water supplies); b) enrich the spatial coverage of the hydro-metrological measurements and monitoring stations in every district, particularly focused on the mountainous region of Nepal; c) evaluate the water availability in every watershed, river basin, sub-basin and Palika with robust modelling activities and map the floods risk zoning for all the river systems of Nepal; d) and promote and develop water recharge, retention, and reuse interventions to conserve/preserve and equitable distribution among the beneficiaries for the water security.

The energy sector is another important sector for generating adaptation and mitigation co-benefits and important for building resilience and security of the energy sector. The key adaptation strategies in the sector are:

- Enhance a more detailed understanding of changes in the hydrological cycle and its uncertainty. Also analyzing future risks on infrastructure (dams and hydropower plants, roads, and transmission lines);
- Ensure reservoir operation, to adjust rule curves by the climate change in different periods for the smooth operation and production. Similarly, increase the height of the dam, reducing the annual sediment inflow to the reservoir, utilize the unwanted spill, and modify existing spillways to increase discharge capacity fuse-gate/plugs;
- Diversify the energy use opportunities by identifying relevant sources of energy based on the geographical location, locally available resources and minimizing the environmental degradation; and
- Ensure the public and private partnership for promoting renewable energy technologies and make them accessible to everyone and every corner.

One of the major challenges of climate-induced hazards will be potential implications for the hydropower and irrigation sector. The seasonal variability (too much and too little water) will impact hydropower efficiency and production. Besides, the government plan of river diversion might also be impacted by the fluctuations in the river flow. Climate-induced disasters such as floods, LDOF, landslides, GLOF will damage the infrastructure and impact energy generation and large-scale irrigation. To protect the huge development investment in the sector, there is an urgent need to increase awareness of hydropower developers/investors and the private sector as a whole. This needs to be supported with policy instruments such as regulations to in-build climate vulnerability and risk in the hydropower and irrigation design and adoption of necessary risk mitigation measures in the sector.

10.2 Recommendations

The following actions should be considered in the future, particularly to improve the VRA assessments by eliminating the gaps listed below:

- Increase the hydro-climate stations to have spatial and temporal (daily and hourly) hydrological and meteorological data, which will help identify water availability more precisely in air, land, and soil
- Improve the data recording and management systems in a more disaggregated way based on the nature of the data and according to the district, municipality, and ward level; which will help conduct the VRA from a local context and will support the LAPA preparation
- Improve the mechanism to access data for this kind of study, which will help expedite the study works
- The subsurface hydro-geological study should be conducted through the country to have more precise and spatially well-covered information of groundwater level and quantity, and to have soil classes with heterogeneous information including soil properties
- Improve the information on snow, ice, glaciers, and glacier lakes by numbers, covered area and volume to the quantity, and study of retreat trends; to help conduct the study of the mountain region more precisely to evaluate the climate change impact and status of freshwater storage in the mountains
- Conduct a rigorous and robust study on bio-mass availability, on its sources and consumption pattern in the country, which will help enhance this VRA assessment of the renewable energy sub-sector by considering the climate change

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Annexes

Annex 1: Summary findings of provincial consultation

Province 1

Mountain: The participants during consultations and the communities during field visits identified that snowfall, irregular rainfall, and flood, melting of snow and glaciers, drying of water springs, are the most common climatic extreme events in this province and region. Impacts on water resources: drying leading to unavailability of water resources which led to the migration of communities and failure of the infrastructures related to water resources services are the major impact due to climate change.

Suggested adaptation options:

- Protection of water resources
- Develop necessary policy and regulations to respond effectively to climate change in a mountainous region
- Promote water conservation technologies for the mountains

Hill: Temperature is in increasing trend leading to drought, extreme rainfall, and variability with increased flood and landslide are most common stressors in the regions. The impact can be seen as increasing energy demand, drying of water sources, impact on infrastructure (hydropower stations, transmission lines, water pipes), and an increase in water demand is contrary to the declining water yield and availability are the major impacts on this region.

Suggested adaptation options:

- Protect spring sheds and water bodies for drinking water
- Promote soil and water management schemes
- Promote water conservation and storage system (conservation ponds, water collection ponds, water recharge system, water reservoirs)
- Develop longer-term sustainable water management plan in the context of climate change
- Invest in big water storage and water recharge system in the hills to rejuvenate and recharge the springs
- Carry out plantation activities

Terai: Temperature rise, Rainfall variability, and Disasters: flood, inundation, have been observed throughout the year. The major impacts can be seen in the form of Water services are disrupted: groundwater pollution, impact on water table: lower in many districts. Flood is taking life and damaging infrastructure, agriculture is worse impacted due to damage to the irrigation system.

Suggested adaptation options:

- Formulate water regulatory policy and provisions
- Promote water-efficient technologies and water-saving schemes
- Promote water-efficient irrigation technologies

Province 2

The participants during consultations and the communities during field visits identified that the Water table is low due to degradation of churiya, Drying of water sprigs, and other water sources e.g. streams, ponds, well, etc. Heavy rainfall in short duration, Increasing flood incidence, Increasing temperature, and Massive loss of life and property are the most common climatic extreme events in this province and region. Impacts on water resources: The drought is impacting the agriculture sector production due to damage to the irrigation system and less water, Depletion of water resources and lowering of the water table, rising of the river bed, Massive loss of life and properties due to flooding and its damage on human life, settlements, infrastructure, and services and the water demand is higher and access to water is low are the most common impacts in this province due to climatic stressors.

Suggested adaptation options:

- Promote flood early warning systems
- Ensure proper drainage system Promote water conservation technologies for the mountains
- Promote churiya and watershed conservation in an integrated manner
- Establish water harvesting ponds, check dam spur and embankment
- Promote sustainable water management program targeting to conserve and manage water

Bagmati Province

The participants during consultations and the communities during field visits identified that the Temperature increase leading to avalanches, GLOF, Changes in the growth cycle of crop and plant species, Flooding and inundation, landslide and soil erosion, Drought, Emergence of new diseases, Increasing extreme events are the most common climatic extreme events in this province and region. Drying off of water resources, Damage to wetlands, Impact irrigation infrastructure, lowering of the water table, rising of the river bed, damage, and failure of hydropower due to extreme events are the most common impacts in this province due to climate change.

Suggested adaptation options:

- Implement early warning systems – fire, flash flood, and landslide if possible
- Promote climate-resilient watershed management plans
- Draining of dangerous GLOF
- Promote rainwater harvesting and other water conservation technologies
- Promote alternative energy practices
- Promote the management of wetlands
- Ensure infrastructure development follow climate resilience standards and codes
- Promote water-efficient irrigation technologies

Gandaki Province

The participants during consultations and the communities during field visits identified that the Rainfall variability leading to drying of water sources, Temperature rise leading to snow melting – too much and too little water are an increasing trend and are observed changes due to climate stressors in the past few years. With the temperature rise, increasing observation of loss of snow in mountains, Decline in water resources leading toward declining water cycle, Decline in the number of water resources available impacting irrigation potential, Changing pattern of rainfall is leading toward the declining capacity of soil moisture absorption, Impact on hydropower potential and solar energy production, Loss and damage of energy and infrastructure due to Flood, landslide, and inundation is the most commonly observed impacts due to climate change throughout the year in this province within the sector.

Suggested adaptation options:
- Conservation of forest and biodiversity
- Planned irrigation plan formulation and its implementation
- Raise awareness on climate change and its impact on the public
- Ensure all policy-related provisions are systematically implemented

Lumbini Province
The participants during consultations and the communities during field visits identified that the Landslide and floods, Increase in temperature, Rainfall variability is the most commonly observed climatic stressors within the sector in this province. Drying of wetlands, less water in the watersheds and catchment areas, Damages to irrigation facilities, Damage to hydropower infrastructures, Damage to water sources, Damage to other infrastructures such as transmission lines, irrigation canals, roads, suspension bridges, water catchment areas, ponds are the major observed impacts due to climate change throughout the year in this province within the sector.

Suggested adaptation options:
- Promote wetland and watershed rehabilitation programs
- Implement conservation of water through efficient technologies
- Implement bioengineering and other sustainable soil and water management practices
- Promote rainwater harvesting and other water conservation technologies
- Conserve and manage water resources and other critical infrastructures
- Protect water sources and arrange alternative drinking water
- Invest in research and development particularly understanding water demand and other issues impacted by climate change
- Implement guidelines for making water resources and energy production infrastructure more climate-resilient

Karnali Province
The participants during consultations and the communities during field visits identified that the Increase temperature, Extreme weather events, Off seasonal snowfall, More rainfall, Drought, Increased - Avalanche, GLOF, Flood-landslide, Epidemics, Cold waves, Thunderbolt and Intense rainfall are the most commonly observed climatic stressors within the sector in this province. Increased snowmelt rate, Geo-hazard increase, Depletion of water sources are the Spring drying up, Spring relocation, Depletion of groundwater level are the major observed impacts due to climate change throughout the year in this province within the sector.

Suggested adaptation options:
- Plantation of suitable plants.
- Research, development, and training to the local level
- Bio-fencing
- Multi-purpose water management
- Lift/alternative irrigation facilities
- Drought resistance cropping
- Dike construction

- Tree plantation
- Develop long term policy and programs
- Rainwater harvesting (common – pond and private in HH)
- Policy to use the underground water resources.
- Increase the electricity production

Sudurpashchim Province

The participants during consultations and the communities during field visits identified that the Increase in river flow due to the melting of snow, GLOF, Increase in temperature, Landslide, Fire, Soil erosion, flood and inundation, Drought is the most commonly observed climatic stressors within the sector in this province. Drying up of water sources used for drinking water and irrigation, Depletion of groundwater level, Increase in land/air/water/noise pollution are the major observed impact due to climate change throughout the year in this province within the sector.

Suggested adaptation options:

- Use of lift irrigation system in the hilly region on river basin area
- Promotion of sugarcane farming than rice farming in the flood-prone area
- Awareness campaign
- Formulation of regulation for balanced and proper utilization of groundwater
- Effective implementation of environmental impact assessment (EIA)
- Afforestation
- Conservation of Chure area to preserve groundwater of terai area
- Conservation of water sources
- Construction of conservation pond
- Promotion of alternative energy

Annex 2: Thematic Working Group (TWG) Members and Sectoral Experts for Priority Ranking

SN	Name	Designation of TWG	Associated Institutions	Position at Associated Institutions
1	Ram Gopal Kharbuja	Coordinator	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Joint Secretary
2	Chatur Bahadur Shrestha	Co-coordinator	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Senior Divisional Engineering Geologist (SDEG)
3	Dinesh Shrestha	Member Secretary	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Engineer
4	Baburaja Adhikari	Member	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Senior Divisional Engineer (SDE)
5	Khilanath Dahal	Member	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Senior Divisional Hydro-Geologist (SDHG)
6	Sujana Timilsina	Member	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Hydropower Engineer
7	Madhav Dev Aacharya	Member	Water Energy Commission Secretariat (WECS)	Senior Divisional Engineering Geologist (SDEG)
8	Hari Bahadur Khatri	Member	Department of Electricity Development (DoED)	Senior Divisional Engineer (SDE)
9	Milan Dahal	Member	Nepal Electricity Authority (NEA)	Manager
10	Ananta Man Singh Pradhan	Member	Water Resource Research and Development Centre (WRRDC)	Senior Divisional Engineering Geologist (SDEG)
11	Surendra Man Shakya	Member	Groundwater Resources Development Board (GRWB)	Senior Divisional Hydro-Geologist (SDHG)
12	Subash Tuladhar	Member	Department of Hydrology and Meteorology (DHM)	SDH
13	Rana Bahadur Thapa	Member	Alternative Energy Promotion Centre (AEPC)	Programme Officer
14	Tejendra Bahadur G.C.	Member	Jalsrot Vikas Sanstha (JVS)	Manager
15	Neha Basnet	Member	Jalsrot Vikas Sanstha (JVS)	Programme Officer
16	Sailendra Guragain	Member	Independent Power Producers' Association Nepal (IPPAN)	Chairman
17	Subash Ghimire	Member	Kathmandu University (KU)	Department Head and Assistant Professor
18	Devendra Adhikari	Member	Expert	Independent Consultant

Experts for Priority Ranking of the Elements/Indicators

SN	Name	Associated Institutions	Position at Associated Institutions
1	Dr Aseem Sharma	Natural Resources Canada	Research Scientist
2	Dr Khila Nanda Dulal	Hillside College of Engineering	Associate Professor
3	Dr Luna Bharati	International Water Management Institute (IWMI)	Principal Researcher
4	Dr Maheshor Shrestha	Water Resource Research and Development Centre (WRRDC)	Executive Director
5	Dr Nirman Shrestha	International Water Management Institute (IWMI)	Researcher
6	Dr Rocky Talchabhadel	Texas A&M AgriLife Research Center at El Paso/ Texas A&M University	Postdoctoral research associate
7	Dr Santosh Nepal	ICIMOD	Climate and Hydrology Group Leader
8	Dr Saroj Karki	Ministry of Physical Infrastructure Development, Province-1, Nepal	Senior Engineer
9	Dr Soni Pradhanang	University of Rhode Island	Associate Professor
10	Dr Subash Ghimire	Kathmandu University (KU)	Department Head and Assistant Professor
11	Dr Sujan Koirala	Max Planck Institute for Biogeochemistry	Senior Scientist
12	Dr Vishnu Pandey	International Water Management Institute (IWMI)	Researcher (Now Prof. at Institute of Engineering, Pulchowk)
13	Mr. Ajay Adhikari	Department of Water Resources and Irrigation (DWRI)	Project Director
14	Mr. Ananta Man Singh Pradhan	Water Resource Research and Development Centre (WRRDC)	Senior Divisional Engineering Geologist (SDEG)
15	Mr. Devendra Adhikari	Independent Expert	Independent Consultant
16	Mr. Dinesh Shrestha	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Engineer
17	Mr. Hari Bahadur Khatri	Department of Electricity Development (DoED)	Senior Divisional Engineer (SDE)
18	Mr. Jebin Tamrakar	MoEWRI	Senior Divisional Engineer
19	Mr. Khilanath Dahal	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Senior Divisional Hydro-Geologist (SDHG)
20	Mr. Manish Shrestha	ICIMOD	Hydrologist
21	Mr. Milan Dahal	Nepal Electricity Authority (NEA)	Manager
22	Mr. Rana Bahadur Thapa	Alternative Energy Promotion Centre (AEPC)	Programme Officer
23	Mr. Subash Tuladhar	Department of Hydrology and Meteorology (DHM)	SDH
24	Mr. Surendra Man Shakya	Groundwater Resources Development Board (GRWB)	Senior Divisional Hydro-Geologist (SDHG)
25	Mr. Suresh Marahatta	Tribhuvan University	Assistant Professor
26	Mr. Tejendra Bahadur G.C.	Jalsrot Vikas Sanstha (JVS)	Manager
27	Mr. Utsav BhatTerai	Water Modeling Solutions Pvt. Ltd.	Senior Water Resources Modeler
28	Ms. Aakanchya Budhathoki	Asian Institute of Technology	Researcher
29	Ms. Anjana Timilsina	Institut Charles Quentin	Teacher
30	Ms. Neha Basnet	Jalsrot Vikas Sanstha (JVS)	Programme Officer
31	Ms. Sujana Timilsina	Ministry of Energy Water Resources and Irrigation (MOEWRI)	Hydropower Engineer

Annex 3: Weightage of the Indicators, Elements, and Sub-sectors

Weights in the Exposure Component

SN	Indicator	Weight	Element	Weight	Sub-sector			Weight
1	Snow Cover Area	0.262	Water as Snow Cover and Glaciers	0.326	Water Availability (Systems and Sources)	0.500	Water Resources	0.532
2	Number of Glaciers	0.242						
3	Area of Glaciers	0.242						
4	Area of Glacier Lakes	0.254						
5	Ground Water Flow (as of Springs/ Streams)	0.265	Water as Flowing Water	0.348				
6	Net Water Yields (as of Larger Streams)	0.257						
7	Drainage Length	0.223						
8	Total Water Availability at Rivers	0.255						
9	Lakes and Reservoirs Area	0.515	Water as Storage Systems (Lake/ Wetlands)	0.326				
10	Wetlands Area	0.485						
11	Number of Irrigation System	0.348	Irrigation Systems and Infrastructures	0.335	Water Services (Demand, Supply, and Use)	0.500		
12	Number of Irrigation Canal	0.329						
13	Length of Irrigation Canal	0.323						
14	Total Area of Agriculture Land	0.342	Agriculture Lands and Irrigation Status	0.338				
15	Potential Area of Irrigable Land	0.345						
16	Non-Irrigated Area of Agriculture Land	0.313						
17	Total Male Population	0.494	The beneficiary of Water Services	0.327				
18	Total Female Population	0.506						
19	Number of Hydropower Plants	0.485	Hydropower Plants	0.360	Hydro-power	0.520	Energy	0.468
20	Total Installed Capacity	0.515						
21	Length of Transmission Lines	0.493	Transmission Lines	0.323				
22	Capacity of Transmission Lines	0.507						
23	Length of Distributions (Feeder) Networks	0.493	Distribution (Feeder) Networks	0.317				
24	Capacity of Distributions (Feeder) Networks	0.507						
25	Beneficiaries of Traditional Energy for Cooking	0.330	The beneficiary of Alternative Energy	0.501	Alternative Energy (Traditional and Renewable)	0.480		
26	Beneficiaries of Renewable Energy for Cooking	0.337						
27	Beneficiaries of Renewable Energy for Lighting	0.333						
28	Total Number of Pico/Micro/Mini Hydropower	0.333	Hydro as Alternative Energy	0.499				
29	Total Capacity of Pico/Micro/Mini Hydropower	0.341						
30	Improved Water Mills	0.326						

Weights in the Sensitivity Component

SN	Indicator			Weight	Element	Weight	Sub-sector	Weight		
1	Trend of Change in Snow Cover Area				Water as Snow Cover and Glaciers	0.252	Water Availability (Systems and Sources)	0.500	Water Resources	0.532
2	Trend of Change in Ground Water Flow (as of Springs/Streams)			0.260	Water as Flowing Water	0.263				
3	Trend of Change in Net Water Yields (as of Larger Streams)			0.250						
4	Drainage Density			0.228						
5	Trend of Change in Total Water Availability at Rivers			0.262						
6	Trends of Change in Lakes and Reservoirs Area			0.515	Water as Storage Systems (Lake/ Wetlands)	0.248				
7	Trends of Change in Wetlands Area			0.485						
8	Slope/Topography			0.335	Catchment Characteristics	0.237				
9	Loamy	0.147	Soil Class (Texture) and Area	0.319						
	Loamy Skeletal	0.135								
	Loamy Boulder	0.135								
	Fragmental Sandy	0.136								
	Lake Area	0.147								
	River Bed	0.145								
	Snow Cover Area	0.155								
10	Agriculture Land	0.217	Trend of Change in Land Use/Land Cover Area	0.346						
	Barren Land	0.188								
	Forests	0.211								
	Grassland	0.198								
	Savannas	0.186								
11	Tap/Piped Water			0.169	Households Dependency on Main Sources of Drinking Water	0.262	Water Service (Demand, Supply and Use)	0.500		
12	Tube Well/Hand Pump			0.168						
13	Covered Well/Kuwa			0.161						
14	Uncovered Well/Kuwa			0.160						
15	Spout Water			0.169						
16	Rivers/Stream			0.173						
17	Drinking-Water Supply and Demand Status			0.511	Demand and Supply (Surplus or Deficit) Status	0.254				
18	Irrigation Supply and Demand Status			0.489						
19	Average Age of the Irrigation System			0.241	Irrigation Systems and Operations	0.252				
20	Perennial	0.344	Type of Water Sources used for Irrigation	0.258						
	Pond/Lake	0.317								
	Local Stream	0.339								
21	Operational	0.380	Functional Status of Irrigation Systems	0.261						
	Under Construction	0.338								
	Defunct	0.282								
22	Major	0.256	Irrigation Scheme Types by Project Size	0.240						
	Large	0.252								
	Medium	0.254								
	Small	0.238								

<table>
<tr><th>SN</th><th colspan="3">Indicator</th><th>Weight</th><th>Element</th><th>Weight</th><th>Sub-sector</th><th>Weight</th><th></th><th></th></tr>
<tr><td>23</td><td colspan="3">Sex Ratio (Male/Female)</td><td>0.136</td><td rowspan="5">GESI Status of Beneficiaries of Water Services</td><td rowspan="5">0.232</td><td rowspan="5"></td><td rowspan="5"></td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>24</td><td colspan="3">Trend of Population Growth</td><td>0.142</td></tr>
<tr><td>25</td><td colspan="3">PWD Male</td><td>0.151</td></tr>
<tr><td>26</td><td colspan="3">PWD Female</td><td>0.152</td></tr>
<tr><td>27</td><td colspan="3">Female-Headed Households</td><td>0.145</td></tr>
<tr><td rowspan="4">28</td><td>Boys (Below 19 years)</td><td>0.237</td><td rowspan="4">Children and Senior Citizen</td><td rowspan="4">0.150</td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8"></td></tr>
<tr><td>Girls (Below 19 years)</td><td>0.244</td></tr>
<tr><td>Senior Citizen (Male)</td><td>0.258</td></tr>
<tr><td>Senior Citizen (Female)</td><td>0.261</td></tr>
<tr><td rowspan="4">29</td><td>Dalit (Male)</td><td>0.246</td><td rowspan="4">Ethnicity</td><td rowspan="4">0.124</td></tr>
<tr><td>Dalit (Female)</td><td>0.262</td></tr>
<tr><td>Janajati (Male)</td><td>0.239</td></tr>
<tr><td>Janajati (Female)</td><td>0.253</td></tr>
<tr><td>30</td><td colspan="3">Types of Hydro Plants by Capacity</td><td>0.500</td><td rowspan="2">Type of Hydro plants (Total Capacity)</td><td rowspan="2">0.346</td><td rowspan="4">Hydropower</td><td rowspan="4">0.520</td><td rowspan="7">Energy</td><td rowspan="7">0.468</td></tr>
<tr><td>31</td><td colspan="3">Types of Hydro Plants by Water Conveyance Systems</td><td>0.500</td></tr>
<tr><td>32</td><td colspan="5">Operational Status of Hydro Plants (Under Construction/Under Survey)</td><td>0.358</td></tr>
<tr><td>33</td><td colspan="5">Ownership Types (Capacity of Private Hydro Plants)</td><td>0.296</td></tr>
<tr><td>34</td><td colspan="3">Households Depend on Wood/Firewood for Cooking</td><td>0.510</td><td rowspan="2">Dependency on Sources of Alternative Energy</td><td rowspan="2">0.507</td><td rowspan="3">Alternative Energy (Traditional and Renewable)</td><td rowspan="3">0.480</td></tr>
<tr><td>35</td><td colspan="3">Households Depend on Electricity for Lighting</td><td>0.490</td></tr>
<tr><td>36</td><td colspan="5">Biomass Supply and Demand (Surplus or Deficit)</td><td>0.493</td></tr>
</table>

Weights in the Adaptive Capacity Component

SN	Indicator	Weight	Element	Weight	Sub-sector			Weight
1	Trends of Reforestation/ Afforestation to conserve water (Change in forest cover)	0.505	Water Recharge, Retention, and Reuse Intervention	0.332	Water Availability (Systems and Sources)	0.500	Water Resources	0.532
2	Trends of Terrace Farming for Water Retention (Change in agriculture cover)	0.495						
3	Draining of glacier lakes and monitoring plan	0.487	Disaster Prevention Measures	0.341				
4	Access to climate information	0.513						
5	Number of wetland conservation indicatives	0.331	Conservation/ Management Plans and Investments	0.327				
6	Environment/Climate Change Relevant Budget	0.340						
7	Number of management of conservation pond and reservoir	0.329						
8	Total Usable Water for Irrigation (Water-Use Potentials)	0.331	Water Conservation Practices	0.510	Water Services (Demand, Supply and Use)	0.500		
9	Total Usable Water for Drinking Water (Water-Use Potentials)	0.353						
10	Number of bioengineering practices (Bio-Engineering applications)	0.316						
11	Registration of Water Users Association (WUA) of Irrigation Systems	0.199	Water Service Systems Management	0.490				
12	Turnover of Water Users Association (WUA) of Irrigation Systems	0.191						
13	Gross Command Area Covered by Operational Irrigation Systems	0.208						
14	No. of Well-functional Drinking Water Supply Schemes	0.205						
15	Gender Development Index (GDI)	0.197						
16	Hydropower Potentials (Total Generation Capacity)	0.501	Operation Status of Hydro Plants		Hydropower	0.520	Energy	0.468
17	Electrification Coverage Status	0.499						
18	Biogas Plants Coverage by Households	0.485	Access to Technology of Alternative Energy	0.507	Alternative Energy (Traditional and Renewable)	0.480		
19	Solar Plants Coverage by Households	0.515						
20	Household Income/Per Capita Income			0.493				

Weightages in the Hazard Component based on Category

SN	Indicator			Weight	Element	Weight	Category	Weight
1	Annual Precipitation			0.197	Historical Trends of Climatic Variables	0.490	Climate and Climate Extreme Events	0.499
2	Monsoon Precipitation			0.210				
3	Winter Precipitation			0.192				
4	Maximum Temperature			0.204				
5	Minimum Temperature			0.197				
6	Extreme Wet Days			0.134	Historical Trends of Climate Extreme Events	0.510		
7	Very Wet Days			0.129				
8	Consecutive Wet Days			0.126				
9	Consecutive Dry Days			0.127				
10	Number of Rainy Days			0.123				
11	Warms Days			0.122				
12	Warm Nights			0.118				
13	Warm Spell Duration			0.121				
14	Annual Precipitation			0.508	Future Scenarios of Climatic Variables	0.486		
15	Average Temperature			0.492				
16	Extreme Wet Days			0.133	Future Scenarios of Climate Extreme Events	0.514		
17	Very Wet Days			0.131				
18	Consecutive Wet Days			0.127				
19	Consecutive Dry Days			0.129				
20	Number of Rainy Days			0.123				
21	Warms Days			0.121				
22	Warm Nights			0.115				
23	Warm Spell Duration			0.121				
24	Heavy Rainfall			0.180	Hazard Events	0.490	Climate-Induced Hazard	0.501
25	Occurrence	0.458	Snow Storm	0.155				
	Snowy Area	0.542						
26	Occurrence	0.437	Landslides	0.173				
	Prone Area	0.563						
27	Occurrence	0.458	Flood/Flash Floods	0.181				
	Prone Area	0.542						
28	Occurrence	0.292	Glacial Lake Outburst Floods (GLOFs)	0.159				
	Potentially Dangerous Glacier Lakes	0.375						
	Distance from Glacier Lakes	0.333						
29	Avalanche			0.152				
30	Number of People Death			0.261	Loss and Damage	0.510		
31	Number of Injured People			0.245				
32	Property Loss			0.245				
33	Number of Affected Family			0.249				

Weightages in the Hazard Component based on Sub-sectors

<table>
<tr><th>SN</th><th colspan="3">Indicator</th><th>Weight</th><th>Element</th><th>Weight</th><th>Category</th><th>Weight</th><th>Sub-sector</th><th>Weight</th></tr>
<tr><td colspan="11">Water Resources</td></tr>
<tr><td>1</td><td colspan="3">Annual Precipitation</td><td>0.508</td><td rowspan="2">Future Change Scenarios of Climatic Variables</td><td rowspan="2">0.486</td><td rowspan="10">Climatic Variables and Climate Extreme Events</td><td rowspan="10">0.499</td><td rowspan="25">Water Resources</td><td rowspan="25">0.532</td></tr>
<tr><td>2</td><td colspan="3">Average Temperature</td><td>0.492</td></tr>
<tr><td>3</td><td colspan="3">Extreme Wet Days</td><td>0.133</td><td rowspan="8">Future Change Scenarios of Climate Extreme Events</td><td rowspan="8">0.514</td></tr>
<tr><td>4</td><td colspan="3">Very Wet Days</td><td>0.131</td></tr>
<tr><td>5</td><td colspan="3">Consecutive Wet Days</td><td>0.127</td></tr>
<tr><td>6</td><td colspan="3">Consecutive Dry Days</td><td>0.129</td></tr>
<tr><td>7</td><td colspan="3">Number of Rainy Days</td><td>0.123</td></tr>
<tr><td>8</td><td colspan="3">Warms Days</td><td>0.121</td></tr>
<tr><td>9</td><td colspan="3">Warm Nights</td><td>0.115</td></tr>
<tr><td>10</td><td colspan="3">Warm Spell Duration</td><td>0.121</td></tr>
<tr><td>11</td><td colspan="3">Heavy Rainfall</td><td>0.180</td><td rowspan="11">Hazard Events</td><td rowspan="11">0.490</td><td rowspan="15">Climate-Induced Hazard</td><td rowspan="15">0.501</td></tr>
<tr><td rowspan="2">12</td><td>Occurrence</td><td>0.458</td><td rowspan="2">Snow Storm</td><td rowspan="2">0.155</td></tr>
<tr><td>Snowy Area</td><td>0.542</td></tr>
<tr><td rowspan="2">13</td><td>Occurrence</td><td>0.437</td><td rowspan="2">Landslides</td><td rowspan="2">0.173</td></tr>
<tr><td>Prone Area</td><td>0.563</td></tr>
<tr><td rowspan="2">14</td><td>Occurrence</td><td>0.458</td><td rowspan="2">Flood/Flash Floods</td><td rowspan="2">0.181</td></tr>
<tr><td>Prone Area</td><td>0.542</td></tr>
<tr><td rowspan="3">15</td><td>Occurrence</td><td>0.292</td><td rowspan="3">Glacial Lake Outburst Floods (GLOFs)</td><td rowspan="3">0.159</td></tr>
<tr><td>Potentially Dangerous Glacier Lakes</td><td>0.375</td></tr>
<tr><td>Distance from Glacier Lakes</td><td>0.333</td></tr>
<tr><td>16</td><td colspan="3">Avalanche</td><td>0.152</td></tr>
<tr><td>17</td><td colspan="3">Number of People Death</td><td>0.261</td><td rowspan="4">Loss and Damage</td><td rowspan="4">0.510</td></tr>
<tr><td>18</td><td colspan="3">Number of Injured People</td><td>0.245</td></tr>
<tr><td>19</td><td colspan="3">Property Loss</td><td>0.245</td></tr>
<tr><td>20</td><td colspan="3">Number of Affected Families</td><td>0.249</td></tr>
</table>

<table>
<tr><th>SN</th><th colspan="3">Indicator</th><th>Weight</th><th>Element</th><th>Weight</th><th>Category</th><th>Weight</th><th>Sub-sector</th><th>Weight</th></tr>
<tr><td colspan="11">Energy</td></tr>
<tr><td>1</td><td colspan="3">Annual Precipitation</td><td>0.508</td><td rowspan="2">Future Change Scenarios of Climatic Variables</td><td rowspan="2">0.486</td><td rowspan="4">Climatic Variables and Climate Extreme Events</td><td rowspan="4">0.499</td><td rowspan="19">Energy</td><td rowspan="19">0.468</td></tr>
<tr><td>2</td><td colspan="3">Average Temperature</td><td>0.492</td></tr>
<tr><td>3</td><td colspan="3">Extreme Wet Days</td><td>0.524</td><td rowspan="2">Future Change Scenarios of Climate Extreme Events</td><td rowspan="2">0.514</td></tr>
<tr><td>4</td><td colspan="3">Warm Spell Duration</td><td>0.476</td></tr>
<tr><td>5</td><td colspan="3">Heavy Rainfall</td><td>0.180</td><td rowspan="11">Hazard Events</td><td rowspan="11">0.490</td><td rowspan="15">Climate-Induced Hazard</td><td rowspan="15">0.501</td></tr>
<tr><td rowspan="2">6</td><td>Occurrence</td><td>0.458</td><td rowspan="2">Snow Storm</td><td rowspan="2">0.155</td></tr>
<tr><td>Snowy Area</td><td>0.542</td></tr>
<tr><td rowspan="2">7</td><td>Occurrence</td><td>0.437</td><td rowspan="2">Landslides</td><td rowspan="2">0.173</td></tr>
<tr><td>Prone Area</td><td>0.563</td></tr>
<tr><td rowspan="2">8</td><td>Occurrence</td><td>0.458</td><td rowspan="2">Flood/Flash Floods</td><td rowspan="2">0.181</td></tr>
<tr><td>Prone Area</td><td>0.542</td></tr>
<tr><td rowspan="3">9</td><td>Occurrence</td><td>0.292</td><td rowspan="3">Glacial Lake Outburst Floods (GLOFs)</td><td rowspan="3">0.159</td></tr>
<tr><td>Potentially Dangerous Glacier Lakes</td><td>0.375</td></tr>
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<tr><td>10</td><td colspan="3">Avalanche</td><td>0.152</td></tr>
<tr><td>11</td><td colspan="3">Number of People Death</td><td>0.261</td><td rowspan="4">Loss and Damage</td><td rowspan="4">0.510</td></tr>
<tr><td>12</td><td colspan="3">Number of Injured People</td><td>0.245</td></tr>
<tr><td>13</td><td colspan="3">Property Loss</td><td>0.245</td></tr>
<tr><td>14</td><td colspan="3">Number of Affected Families</td><td>0.249</td></tr>
</table>

Annex 4: WatRES District-wise Exposure, Sensitivity, Adaptive capacity, and Vulnerability indices

Province	District	Water resources: Exposure	Energy: Exposure	WatRES Exposure	Water resources: Sensitivity	Energy: Sensitivity	WatRES Sensitivity	Water resources: Adaptive capacity	Energy: Adaptive capacity	WatRES Adaptive capacity	Water resources: Vulnerability	Energy: Vulnerability	WatRES Vulnerability
Sudurpashchim	Achham	0.229	0.275	0.26	0.42	0.12	0.164	0.659	0.384	0.574	0.33	0.218	0.211
Lumbini	Arghakhanchi	0.245	0.195	0.22	0.599	0.974	1	0.239	0.539	0.492	0.683	0.785	0.812
Gandaki	Baglung	0.364	0.602	0.538	0.404	0.99	0.95	0.273	0.581	0.538	0.566	0.774	0.751
Sudurpashchim	Baitadi	0.231	0.402	0.34	0.186	0.938	0.832	0.439	0.098	0.27	0.354	1	0.836
Sudurpashchim	Bajhang	0.233	0.391	0.334	0.626	0.673	0.735	0.122	0.265	0.244	0.771	0.706	0.788
Sudurpashchim	Bajura	0.067	0.037	0.023	0.496	0.826	0.831	0	0	0	0.784	0.968	1
Lumbini	Banke	0.435	0.433	0.473	0.082	0.14	0.072	0.416	0.509	0.551	0.318	0.165	0.163
Province 2	Bara	0.341	0.421	0.413	0.151	0.276	0.218	0.547	0.605	0.679	0.269	0.216	0.182
Lumbini	Bardiya	0.218	0.401	0.332	0.002	0.224	0.122	0.6	0.545	0.661	0.162	0.209	0.13
Bagmati Province	Bhaktapur	0.031	0.168	0.084	0.15	0.274	0.216	0.456	0.614	0.644	0.326	0.209	0.202
Province 1	Bhojpur	0.358	0.225	0.302	0.234	0.872	0.788	0.321	0.515	0.512	0.452	0.721	0.66
Bagmati Province	Chitwan	0.319	0.656	0.546	0.149	0.923	0.807	0.559	0.624	0.698	0.26	0.7	0.559
Sudurpashchim	Dadeldhura	0.158	0.268	0.216	0.253	0	0	0.514	0.499	0.589	0.34	0.063	0.093
Karnali	Dailekh	0.245	0.207	0.227	0.396	0.86	0.83	0.184	0.198	0.225	0.619	0.885	0.862
Lumbini	Dang	0.788	0.602	0.774	0.19	0.193	0.155	0.568	0.495	0.61	0.275	0.213	0.183
Sudurpashchim	Darchula	0.099	0.365	0.243	0.417	0.787	0.771	0.199	0.244	0.264	0.62	0.805	0.8
Bagmati Province	Dhading	0.399	0.8	0.68	0.285	0.969	0.893	0.359	0.511	0.527	0.453	0.797	0.72
Province 1	Dhankuta	0.291	0.128	0.204	0.186	0.311	0.261	0.563	0.576	0.666	0.276	0.259	0.219
Province 2	Dhanusha	0.573	0.687	0.707	0.237	0.255	0.227	0.533	0.514	0.608	0.32	0.25	0.231
Bagmati Province	Dolakha	0.309	0.742	0.594	0.425	0.901	0.876	0.425	0.675	0.673	0.481	0.655	0.62
Karnali	Dolpa	0.396	0.08	0.233	0.562	0.691	0.73	0.023	0.38	0.28	0.802	0.657	0.763
Sudurpashchim	Doti	0.298	0.187	0.244	0.323	0.529	0.505	0.504	0.381	0.501	0.38	0.532	0.48
Lumbini	Eastern Rukum	0	0.06	0	0.442	0.698	0.697	0.158	0.253	0.252	0.658	0.732	0.758
Gandaki	Gorkha	0.476	0.787	0.715	0.592	0.846	0.881	0.323	0.734	0.669	0.627	0.58	0.625
Lumbini	Gulmi	0.354	0.263	0.322	0.333	1	0.937	0.269	0.5	0.478	0.534	0.827	0.779
Karnali	Humla	0.405	0.004	0.192	1	0.627	0.814	0.05	0.258	0.206	1	0.674	0.863
Province 1	Ilam	0.379	0.83	0.687	0.225	0.757	0.68	0.582	0.548	0.655	0.283	0.615	0.502
Karnali	Jajarkot	0.143	0.289	0.221	0.606	0.531	0.598	0.135	0.37	0.325	0.753	0.539	0.649
Province 1	Jhapa	0.945	0.826	1	0.095	0.311	0.232	0.436	0.577	0.609	0.312	0.258	0.234
Karnali	Jumla	0.224	0.111	0.156	0.568	0.833	0.861	0.019	0.169	0.129	0.808	0.881	0.941
Sudurpashchim	Kailali	0.427	0.724	0.648	0.121	0.989	0.858	0.428	0.469	0.528	0.33	0.835	0.696
Karnali	Kalikot	0.083	0.326	0.211	0.368	0.541	0.53	0.174	0.353	0.331	0.611	0.556	0.6
Sudurpashchim	Kanchanpur	0.249	0.49	0.405	0.107	0.285	0.212	0.441	0.468	0.533	0.315	0.298	0.267
Lumbini	Kapilbastu	0.75	0.459	0.665	0.387	0.219	0.243	0.443	0.519	0.57	0.45	0.22	0.265
Gandaki	Kaski	0.659	1	0.949	0.21	0.782	0.698	1	0.765	1	0.011	0.514	0.303
Bagmati Province	Kathmandu	0.612	0.824	0.814	0.114	0.211	0.147	0.562	0.907	0.901	0.241	0	0
Bagmati Province	Kavrepalanchok	0.244	0.624	0.485	0.118	0.929	0.802	0.437	0.509	0.561	0.322	0.767	0.639

Province	District	Water resources: Exposure	Energy: Exposure	WatRES Exposure	Water resources: Sensitivity	Energy: Sensitivity	WatRES Sensitivity	Water resources: Adaptive capacity	Energy: Adaptive capacity	WatRES Adaptive capacity	Water resources: Vulnerability	Energy: Vulnerability	WatRES Vulnerability
Province 1	Khotang	0.39	0.27	0.347	0.262	0.462	0.423	0.327	0.583	0.563	0.463	0.37	0.388
Bagmati Province	Lalitpur	0.157	0.27	0.217	0.175	0.773	0.678	0.326	0.712	0.655	0.421	0.536	0.501
Gandaki	Lamjung	0.147	0.72	0.49	0.352	0.774	0.737	0.372	0.781	0.724	0.478	0.5	0.497
Province 2	Mahottari	0.488	0.442	0.508	0.239	0.265	0.236	0.415	0.444	0.505	0.395	0.296	0.3
Bagmati Province	Makawanpur	0.272	0.794	0.605	0.13	0.54	0.451	0.536	0.567	0.647	0.265	0.438	0.355
Gandaki	Manang	0.344	0	0.154	0.25	0.717	0.652	0.105	0.541	0.433	0.597	0.588	0.618
Province 1	Morang	1	0.74	0.978	0.202	0.996	0.89	0.444	0.545	0.589	0.359	0.799	0.68
Karnali	Mugu	0.576	0.257	0.443	0.776	0.476	0.604	0.114	0.374	0.317	0.85	0.496	0.657
Gandaki	Mustang	0.368	0.057	0.203	0.407	0.632	0.626	0.389	0.59	0.597	0.494	0.496	0.501
Gandaki	Myagdi	0.173	0.425	0.322	0.622	0.866	0.909	0.258	0.677	0.599	0.683	0.627	0.687
Gandaki	Nawalpur	0.105	0.402	0.27	0.036	0.968	0.811	0.602	0.54	0.658	0.178	0.78	0.586
Bagmati Province	Nuwakot	0.263	0.646	0.509	0.031	0.798	0.655	0.449	0.561	0.603	0.272	0.639	0.516
Province 1	Okhaldhunga	0.236	0.278	0.266	0.338	0.927	0.871	0.09	0.311	0.262	0.65	0.874	0.867
Lumbini	Palpa	0.374	0.298	0.356	0.311	0.767	0.718	0.147	0.468	0.4	0.601	0.666	0.682
Province 1	Panchthar	0.332	0.427	0.412	0.326	0.669	0.633	0.286	0.626	0.576	0.52	0.504	0.519
Lumbini	Parasi	0.344	0.306	0.344	0.036	0.573	0.451	0.293	0.539	0.517	0.373	0.479	0.435
Gandaki	Parbat	0.125	0.314	0.227	0.184	0.929	0.824	0.422	0.543	0.579	0.364	0.749	0.643
Province 2	Parsa	0.369	0.312	0.362	0.045	0.242	0.153	0.421	0.559	0.589	0.297	0.215	0.194
Lumbini	Pyuthan	0.324	0.411	0.397	0.35	0.756	0.72	0.208	0.423	0.395	0.581	0.683	0.686
Bagmati Province	Ramechhap	0.275	0.711	0.556	0.37	0.809	0.775	0.141	0.75	0.597	0.634	0.543	0.599
Bagmati Province	Rasuwa	0.054	0.386	0.231	0.336	0.64	0.609	0.118	0.792	0.617	0.631	0.391	0.478
Province 2	Rautahat	0.408	0.455	0.471	0	0.221	0.119	0.739	0.459	0.663	0.073	0.254	0.126
Lumbini	Rolpa	0.248	0.319	0.299	0.405	0.499	0.504	0.255	0.399	0.4	0.578	0.499	0.54
Lumbini	Rupandehi	0.759	0.695	0.815	0.209	0.252	0.215	0.442	0.528	0.577	0.364	0.24	0.242
Karnali	Salyan	0.163	0.139	0.14	0.279	0.174	0.167	0.393	0.329	0.413	0.429	0.29	0.31
Province 1	Sankhuwasabha	0.46	0.774	0.698	0.635	0.586	0.658	0.333	1	0.863	0.641	0.235	0.361
Province 2	Saptari	0.651	0.462	0.612	0.17	0.183	0.14	0.738	0.47	0.67	0.157	0.219	0.136
Province 2	Sarlahi	0.525	0.573	0.61	0.106	0.248	0.178	0.937	0.474	0.764	0	0.267	0.104
Bagmati Province	Sindhuli	0.191	0.496	0.376	0.172	0.072	0.039	0.535	0.421	0.543	0.287	0.161	0.147
Bagmati Province	Sindhupalchok	0.268	0.899	0.668	0.404	0.936	0.901	0.478	0.585	0.634	0.437	0.731	0.661
Province 2	Siraha	0.624	0.447	0.587	0.126	0.237	0.175	0.496	0.445	0.543	0.289	0.274	0.237
Province 1	Solukhumbu	0.577	0.622	0.669	0.622	0.781	0.832	0.538	0.591	0.665	0.505	0.61	0.595
Province 1	Sunsari	0.653	0.498	0.635	0.328	0.256	0.258	0.834	0.513	0.745	0.174	0.251	0.168
Karnali	Surkhet	0.251	0.451	0.382	0.226	0.614	0.55	0.653	0.577	0.707	0.239	0.489	0.384
Gandaki	Syangja	0.352	0.266	0.324	0.208	0.612	0.543	0.415	0.656	0.655	0.381	0.444	0.411
Gandaki	Tanahu	0.307	0.538	0.466	0.124	0.771	0.66	0.567	0.607	0.69	0.243	0.593	0.467
Province 1	Taplejung	0.398	0.52	0.506	0.201	0.669	0.592	0.2	0.656	0.558	0.513	0.488	0.503
Province 1	Terhathum	0.219	0.214	0.217	0.327	0.699	0.661	0.213	0.59	0.516	0.566	0.548	0.574
Province 1	Udayapur	0.337	0.201	0.275	0.293	0.176	0.173	0.325	0.361	0.405	0.479	0.273	0.319
Karnali	Western Rukum	0.088	0.176	0.121	0.39	0.901	0.865	0.094	0.425	0.345	0.672	0.792	0.812

Annex 5: WatRES District-wise Hazard indices

Province	District	Water resources: Baseline context of hazards	Water resources: Hazards (RCP 4.5 2030)	Water resources: Hazards (RCP 4.5 2050)	Water resources: Hazards (RCP 8.5 2030)	Water resources: Hazards (RCP 8.5 2050)	Energy: Baseline context of hazards	Energy: Hazards (RCP 4.5 2030)	Energy: Hazards (RCP 4.5 2050)	Energy: Hazards (RCP 8.5 2030)	Energy: Hazards (RCP 8.5 2050)	WatRES: Baseline context of hazards	WatRES: Hazards (RCP 4.5 2030)	WatRES: Hazards (RCP 4.5 2050)	WatRES: Hazards (RCP 8.5 2030)	WatRES: Hazards (RCP 8.5 2050)
Sudurpashchim	Achham	0.695	0.539	0.681	0.68	0.695	0.695	0.464	0.705	0.54	0.492	0.695	0.503	0.691	0.616	0.643
Lumbini	Arghakhanchi	0.029	0.228	0.333	0.444	0.357	0.029	0.15	0.34	0.328	0.195	0.029	0.191	0.333	0.379	0.302
Gandaki	Baglung	0.351	0.542	0.656	0.595	0.567	0.351	0.477	0.648	0.582	0.587	0.351	0.511	0.651	0.589	0.616
Sudurpashchim	Baitadi	0.256	0.185	0.358	0.36	0.383	0.256	0.147	0.4	0.196	0.239	0.256	0.167	0.375	0.267	0.338
Sudurpashchim	Bajhang	0.198	0.153	0.293	0.258	0.242	0.198	0.121	0.34	0.135	0.137	0.198	0.137	0.313	0.179	0.207
Sudurpashchim	Bajura	0.34	0.246	0.359	0.353	0.335	0.34	0.175	0.372	0.248	0.206	0.34	0.212	0.362	0.288	0.294
Lumbini	Banke	0.649	0.695	0.804	0.827	0.832	0.649	0.613	0.848	0.603	0.591	0.649	0.655	0.825	0.73	0.77
Province 2	Bara	0.489	0.485	0.561	0.61	0.424	0.489	0.503	0.482	0.543	0.358	0.489	0.494	0.52	0.578	0.42
Lumbini	Bardiya	0.461	0.437	0.668	0.721	0.752	0.461	0.36	0.645	0.445	0.427	0.461	0.4	0.655	0.592	0.643
Bagmati Province	Bhaktapur	0	0.174	0.108	0.123	0.029	0	0.116	0.112	0.205	0.071	0	0.146	0.106	0.138	0.052
Province 1	Bhojpur	0.235	0.302	0.024	0.083	0.05	0.235	0.373	0.051	0	0.086	0.235	0.336	0.033	0.014	0.071
Bagmati Province	Chitwan	0.95	0.779	0.813	0.89	0.676	0.95	0.725	0.729	0.923	0.613	0.95	0.753	0.771	0.923	0.691
Sudurpashchim	Dadeldhura	0.048	0	0.217	0.255	0.317	0.048	0	0.28	0.059	0.14	0.048	0	0.244	0.14	0.251
Karnali	Dailekh	0.353	0.256	0.41	0.407	0.412	0.353	0.146	0.41	0.246	0.183	0.353	0.203	0.407	0.318	0.327
Lumbini	Dang	0.583	0.632	0.68	0.795	0.729	0.583	0.48	0.681	0.6	0.518	0.583	0.559	0.679	0.71	0.675
Sudurpashchim	Darchula	0.134	0.086	0.26	0.233	0.214	0.134	0.057	0.306	0.124	0.125	0.134	0.072	0.279	0.16	0.185
Bagmati Province	Dhading	0.552	0.673	0.693	0.66	0.539	0.552	0.598	0.662	0.657	0.593	0.552	0.637	0.677	0.662	0.602
Province 1	Dhankuta	0.143	0.286	0	0	0.035	0.143	0.383	0.058	0.066	0.1	0.143	0.333	0.024	0	0.07
Province 2	Dhanusha	0.715	0.797	0.524	0.708	0.647	0.715	0.853	0.52	0.686	0.636	0.715	0.824	0.52	0.703	0.686
Bagmati Province	Dolakha	0.424	0.524	0.304	0.332	0.339	0.424	0.505	0.347	0.38	0.451	0.424	0.515	0.322	0.341	0.417
Karnali	Dolpa	0.495	0.561	0.726	0.664	0.672	0.495	0.558	0.775	0.662	0.63	0.495	0.56	0.749	0.667	0.698
Sudurpashchim	Doti	0.638	0.511	0.668	0.673	0.687	0.638	0.462	0.705	0.489	0.494	0.638	0.487	0.685	0.587	0.639
Lumbini	Eastern Rukum	0.018	0.1	0.227	0.253	0.269	0.018	0.029	0.283	0.19	0.139	0.018	0.066	0.251	0.203	0.224
Gandaki	Gorkha	0.633	0.7	0.768	0.71	0.618	0.633	0.674	0.78	0.688	0.672	0.633	0.687	0.773	0.706	0.687
Lumbini	Gulmi	0.169	0.406	0.495	0.493	0.409	0.169	0.318	0.483	0.431	0.368	0.169	0.364	0.487	0.457	0.417
Karnali	Humla	0.535	0.398	0.555	0.585	0.543	0.535	0.355	0.553	0.434	0.387	0.535	0.377	0.552	0.51	0.503
Province 1	Ilam	0.18	0.377	0.085	0.101	0.073	0.18	0.493	0.143	0.22	0.221	0.18	0.433	0.109	0.133	0.151
Karnali	Jajarkot	0.407	0.312	0.409	0.396	0.365	0.407	0.198	0.413	0.269	0.184	0.407	0.257	0.408	0.322	0.301
Province 1	Jhapa	0.686	0.802	0.487	0.495	0.409	0.686	0.865	0.48	0.547	0.499	0.686	0.832	0.481	0.515	0.481
Karnali	Jumla	0.286	0.167	0.24	0.241	0.194	0.286	0.065	0.264	0.167	0.073	0.286	0.118	0.248	0.186	0.148
Sudurpashchim	Kailali	0.886	0.721	0.911	1	1	0.886	0.635	0.886	0.739	0.709	0.886	0.68	0.898	0.894	0.925
Karnali	Kalikot	0.4	0.277	0.368	0.347	0.318	0.4	0.144	0.347	0.241	0.149	0.4	0.213	0.355	0.281	0.257
Sudurpashchim	Kanchanpur	0.624	0.472	0.698	0.767	0.846	0.624	0.445	0.661	0.478	0.596	0.624	0.459	0.678	0.634	0.781
Lumbini	Kapilbastu	0.201	0.153	0.296	0.459	0.324	0.201	0.081	0.247	0.384	0.05	0.201	0.118	0.269	0.415	0.211
Gandaki	Kaski	0.841	0.89	1	0.96	0.881	0.841	0.859	1	1	1	0.841	0.875	1	1	1
Bagmati Province	Kathmandu	0.252	0.418	0.353	0.331	0.23	0.252	0.352	0.348	0.404	0.277	0.252	0.387	0.348	0.352	0.269
Bagmati Province	Kavrepalanchok	0.359	0.456	0.335	0.381	0.333	0.359	0.438	0.323	0.468	0.394	0.359	0.447	0.326	0.412	0.385
Province 1	Khotang	0.278	0.361	0.074	0.148	0.092	0.278	0.416	0.084	0.079	0.126	0.278	0.387	0.075	0.09	0.115
Bagmati Province	Lalitpur	0.031	0.085	0.063	0.113	0	0.031	0.068	0.035	0.148	0	0.031	0.077	0.045	0.104	0

Province	District	Water resources: Baseline context of hazards	Water resources: Hazards (RCP 4.5 2030)	Water resources: Hazards (RCP 4.5 2050)	Water resources: Hazards (RCP 8.5 2030)	Water resources: Hazards (RCP 8.5 2050)	Energy: Baseline context of hazards	Energy: Hazards (RCP 4.5 2030)	Energy: Hazards (RCP 4.5 2050)	Energy: Hazards (RCP 8.5 2030)	Energy: Hazards (RCP 8.5 2050)	WatRES: Baseline context of hazards	WatRES: Hazards (RCP 4.5 2030)	WatRES: Hazards (RCP 4.5 2050)	WatRES: Hazards (RCP 8.5 2030)	WatRES: Hazards (RCP 8.5 2050)
Gandaki	Lamjung	0.199	0.344	0.467	0.414	0.344	0.199	0.344	0.503	0.445	0.457	0.199	0.344	0.482	0.42	0.423
Province 2	Mahottari	0.867	0.945	0.746	0.899	0.844	0.867	0.97	0.702	0.848	0.773	0.867	0.957	0.723	0.89	0.867
Bagmati Province	Makawanpur	0.747	0.661	0.692	0.721	0.55	0.747	0.64	0.608	0.659	0.476	0.747	0.651	0.649	0.697	0.552
Gandaki	Manang	0.355	0.434	0.582	0.544	0.507	0.355	0.444	0.631	0.473	0.475	0.355	0.439	0.604	0.506	0.526
Province 1	Morang	0.865	0.928	0.603	0.628	0.523	0.865	0.933	0.571	0.655	0.612	0.865	0.93	0.585	0.643	0.603
Karnali	Mugu	0.233	0.149	0.274	0.286	0.238	0.233	0.099	0.312	0.189	0.078	0.233	0.125	0.29	0.221	0.176
Gandaki	Mustang	0.229	0.347	0.596	0.543	0.549	0.229	0.396	0.652	0.452	0.47	0.229	0.37	0.622	0.495	0.547
Gandaki	Myagdi	0.339	0.456	0.611	0.583	0.573	0.339	0.428	0.624	0.545	0.586	0.339	0.442	0.616	0.564	0.619
Gandaki	Nawalpur	0.167	0.152	0.229	0.36	0.196	0.167	0.108	0.197	0.424	0.13	0.167	0.131	0.21	0.379	0.177
Bagmati Province	Nuwakot	0.348	0.578	0.542	0.475	0.388	0.348	0.525	0.593	0.541	0.502	0.348	0.553	0.565	0.501	0.47
Province 1	Okhaldhunga	0.162	0.297	0.009	0.084	0.044	0.162	0.314	0	0.085	0.106	0.162	0.306	0	0.057	0.078
Lumbini	Palpa	0.271	0.416	0.483	0.53	0.394	0.271	0.33	0.447	0.544	0.339	0.271	0.375	0.463	0.533	0.394
Province 1	Panchthar	0.153	0.356	0.063	0.088	0.071	0.153	0.461	0.124	0.167	0.241	0.153	0.406	0.089	0.099	0.16
Lumbini	Parasi	0.112	0.106	0.186	0.317	0.155	0.112	0.064	0.157	0.381	0.089	0.112	0.086	0.168	0.333	0.133
Gandaki	Parbat	0.152	0.378	0.468	0.447	0.354	0.152	0.334	0.511	0.472	0.44	0.152	0.357	0.487	0.452	0.421
Province 2	Parsa	0.657	0.54	0.64	0.732	0.504	0.657	0.552	0.552	0.788	0.503	0.657	0.545	0.595	0.767	0.538
Lumbini	Pyuthan	0.192	0.417	0.5	0.547	0.501	0.192	0.301	0.488	0.433	0.389	0.192	0.361	0.492	0.489	0.48
Bagmati Province	Ramechhap	0.268	0.391	0.127	0.194	0.186	0.268	0.395	0.146	0.233	0.276	0.268	0.393	0.132	0.191	0.243
Bagmati Province	Rasuwa	0.426	0.643	0.651	0.534	0.486	0.426	0.61	0.718	0.523	0.642	0.426	0.627	0.682	0.525	0.596
Province 2	Rautahat	0.775	0.758	0.787	0.791	0.624	0.775	0.77	0.712	0.727	0.541	0.775	0.764	0.749	0.77	0.625
Lumbini	Rolpa	0.149	0.3	0.398	0.417	0.428	0.149	0.207	0.44	0.294	0.273	0.149	0.255	0.416	0.347	0.381
Lumbini	Rupandehi	0.477	0.356	0.453	0.605	0.443	0.477	0.303	0.368	0.558	0.226	0.477	0.33	0.409	0.583	0.367
Karnali	Salyan	0.103	0.158	0.292	0.291	0.306	0.103	0.063	0.323	0.09	0.083	0.103	0.113	0.304	0.176	0.217
Province 1	Sankhuwasabha	0.592	0.659	0.411	0.411	0.393	0.592	0.666	0.39	0.333	0.488	0.592	0.662	0.398	0.363	0.466
Province 2	Saptari	0.896	0.89	0.575	0.728	0.565	0.896	0.921	0.557	0.732	0.647	0.896	0.905	0.564	0.738	0.644
Province 2	Sarlahi	1	1	0.908	0.978	0.871	1	1	0.856	0.954	0.825	1	1	0.882	0.987	0.908
Bagmati Province	Sindhuli	0.494	0.617	0.401	0.505	0.456	0.494	0.627	0.374	0.502	0.494	0.494	0.622	0.385	0.499	0.506
Bagmati Province	Sindhupalchok	0.683	0.831	0.75	0.689	0.677	0.683	0.792	0.799	0.784	0.834	0.683	0.812	0.773	0.741	0.801
Province 2	Siraha	0.71	0.761	0.448	0.646	0.507	0.71	0.815	0.457	0.62	0.554	0.71	0.787	0.45	0.636	0.565
Province 1	Solukhumbu	0.86	0.855	0.607	0.614	0.564	0.86	0.849	0.617	0.589	0.626	0.86	0.852	0.61	0.603	0.633
Province 1	Sunsari	0.693	0.728	0.422	0.525	0.385	0.693	0.75	0.413	0.512	0.44	0.693	0.739	0.415	0.515	0.438
Karnali	Surkhet	0.393	0.304	0.475	0.524	0.541	0.393	0.23	0.496	0.338	0.294	0.393	0.268	0.483	0.429	0.456
Gandaki	Syangja	0.266	0.485	0.55	0.53	0.397	0.266	0.405	0.565	0.554	0.448	0.266	0.447	0.555	0.538	0.449
Gandaki	Tanahu	0.316	0.495	0.557	0.533	0.376	0.316	0.403	0.54	0.568	0.405	0.316	0.451	0.547	0.547	0.416
Province 1	Taplejung	0.691	0.834	0.563	0.53	0.529	0.691	0.854	0.544	0.53	0.676	0.691	0.844	0.552	0.527	0.638
Province 1	Terhathum	0.126	0.316	0.02	0.059	0.047	0.126	0.413	0.091	0.113	0.194	0.126	0.362	0.051	0.056	0.123
Province 1	Udayapur	0.382	0.475	0.184	0.31	0.189	0.382	0.515	0.185	0.29	0.257	0.382	0.494	0.181	0.285	0.236
Karnali	Western Rukum	0.192	0.245	0.364	0.388	0.398	0.192	0.167	0.409	0.326	0.27	0.192	0.207	0.383	0.346	0.362

Annex 6: WatRES District-wise Risk indices

Province	District	Water resources: Baseline context of risks	Water resources: Risks (RCP 4.5 2030)	Water resources: Risks (RCP 4.5 2050)	Water resources: Risks (RCP 8.5 2030)	Water resources: Risks (RCP 8.5 2050)	Energy: Baseline context of risks	Energy: Risks (RCP 4.5 2030)	Energy: Risks (RCP 4.5 2050)	Energy: Risks (RCP 8.5 2030)	Energy: Risks (RCP 8.5 2050)	WatRES: Baseline context of risks	WatRES: Risks (RCP 4.5 2030)	WatRES: Risks (RCP 4.5 2050)	WatRES: Risks (RCP 8.5 2030)	WatRES: Risks (RCP 8.5 2050)
Sudurpashchim	Achham	0.336	0.311	0.293	0.291	0.292	0.103	0.085	0.113	0.101	0.104	0.166	0.11	0.127	0.122	0.117
Lumbini	Arghakhanchi	0.157	0.483	0.505	0.522	0.53	0.066	0.161	0.256	0.247	0.267	0.077	0.229	0.366	0.374	0.381
Gandaki	Baglung	0.4	0.619	0.574	0.547	0.549	0.389	0.546	0.691	0.659	0.688	0.412	0.57	0.798	0.763	0.781
Sudurpashchim	Baitadi	0.176	0.234	0.262	0.25	0.274	0.299	0.33	0.551	0.447	0.559	0.267	0.269	0.509	0.416	0.53
Sudurpashchim	Bajhang	0.331	0.491	0.547	0.499	0.557	0.178	0.218	0.364	0.29	0.368	0.223	0.275	0.486	0.402	0.488
Sudurpashchim	Bajura	0.38	0.451	0.47	0.445	0.48	0.114	0.11	0.171	0.149	0.175	0.189	0.179	0.271	0.246	0.272
Lumbini	Banke	0.381	0.421	0.373	0.381	0.369	0.101	0.103	0.128	0.11	0.113	0.179	0.163	0.182	0.177	0.162
Province 2	Bara	0.236	0.273	0.253	0.256	0.239	0.104	0.119	0.131	0.135	0.132	0.133	0.122	0.122	0.135	0.117
Lumbini	Bardiya	0.119	0.138	0.141	0.145	0.145	0.093	0.094	0.136	0.117	0.127	0.086	0.055	0.069	0.061	0.068
Bagmati Province	Bhaktapur	0.048	0.164	0.156	0.143	0.161	0.014	0.037	0.052	0.054	0.061	0	0.021	0	0.002	0.015
Province 1	Bhojpur	0.246	0.392	0.302	0.284	0.338	0.138	0.222	0.198	0.174	0.252	0.163	0.243	0.209	0.185	0.276
Bagmati Province	Chitwan	0.381	0.326	0.274	0.288	0.253	0.82	0.672	0.705	0.799	0.674	0.743	0.562	0.655	0.756	0.627
Sudurpashchim	Dadeldhura	0.077	0.16	0.209	0.201	0.233	0.007	0.012	0.024	0.018	0.025	0.005	0	0.002	0	0.016
Karnali	Dailekh	0.386	0.451	0.48	0.46	0.493	0.209	0.187	0.315	0.267	0.309	0.266	0.237	0.407	0.36	0.403
Lumbini	Dang	0.402	0.461	0.403	0.43	0.407	0.156	0.151	0.194	0.184	0.184	0.229	0.213	0.257	0.27	0.246
Sudurpashchim	Darchula	0.185	0.305	0.363	0.332	0.373	0.159	0.209	0.384	0.311	0.397	0.159	0.202	0.41	0.334	0.427
Bagmati Province	Dhading	0.461	0.57	0.486	0.474	0.45	0.707	0.806	0.909	0.907	0.9	0.682	0.751	0.951	0.951	0.93
Province 1	Dhankuta	0.107	0.219	0.168	0.147	0.19	0.028	0.059	0.053	0.05	0.067	0.031	0.057	0.007	0.001	0.034
Province 2	Dhanusha	0.468	0.515	0.365	0.403	0.389	0.24	0.277	0.229	0.255	0.252	0.317	0.328	0.269	0.32	0.301
Bagmati Province	Dolakha	0.367	0.49	0.374	0.361	0.397	0.447	0.565	0.563	0.565	0.654	0.446	0.539	0.579	0.581	0.678
Karnali	Dolpa	0.749	0.92	0.872	0.838	0.841	0.126	0.15	0.188	0.176	0.177	0.321	0.376	0.493	0.473	0.445
Sudurpashchim	Doti	0.392	0.378	0.363	0.362	0.363	0.185	0.163	0.217	0.187	0.201	0.248	0.193	0.258	0.236	0.241
Lumbini	Eastern Rukum	0.103	0.285	0.326	0.31	0.352	0.035	0.071	0.136	0.121	0.145	0.035	0.09	0.165	0.15	0.183
Gandaki	Gorkha	0.764	0.864	0.75	0.727	0.692	0.565	0.62	0.701	0.665	0.666	0.671	0.715	0.897	0.861	0.829
Lumbini	Gulmi	0.24	0.511	0.49	0.476	0.477	0.145	0.262	0.359	0.34	0.364	0.167	0.316	0.452	0.436	0.447
Karnali	Humla	1	1	1	1	1	0.09	0.081	0.111	0.1	0.108	0.376	0.352	0.488	0.488	0.458
Province 1	Ilam	0.135	0.27	0.202	0.185	0.218	0.269	0.577	0.49	0.504	0.61	0.229	0.47	0.423	0.434	0.551
Karnali	Jajarkot	0.459	0.516	0.516	0.49	0.518	0.174	0.153	0.238	0.205	0.233	0.262	0.235	0.355	0.32	0.344
Province 1	Jhapa	0.577	0.659	0.456	0.445	0.446	0.28	0.337	0.268	0.279	0.288	0.384	0.426	0.352	0.364	0.361
Karnali	Jumla	0.427	0.518	0.547	0.51	0.564	0.131	0.116	0.202	0.177	0.211	0.218	0.207	0.339	0.305	0.345
Sudurpashchim	Kailali	0.506	0.441	0.404	0.432	0.404	1	0.803	0.998	0.923	0.906	0.926	0.703	0.989	0.943	0.915
Karnali	Kalikot	0.34	0.372	0.377	0.353	0.38	0.193	0.157	0.253	0.223	0.256	0.237	0.186	0.297	0.266	0.3
Sudurpashchim	Kanchanpur	0.301	0.286	0.289	0.3	0.303	0.195	0.172	0.228	0.199	0.226	0.227	0.167	0.229	0.216	0.235
Lumbini	Kapilbastu	0.311	0.458	0.512	0.549	0.542	0.063	0.071	0.119	0.129	0.124	0.126	0.152	0.244	0.281	0.254

Province	District	Water resources: Baseline context of risks	Water resources: Risks (RCP 4.5 2030)	Water resources: Risks (RCP 4.5 2050)	Water resources: Risks (RCP 8.5 2030)	Water resources: Risks (RCP 8.5 2050)	Energy: Baseline context of risks	Energy: Risks (RCP 4.5 2030)	Energy: Risks (RCP 4.5 2050)	Energy: Risks (RCP 8.5 2030)	Energy: Risks (RCP 8.5 2050)	WatRES: Baseline context of risks	WatRES: Risks (RCP 4.5 2030)	WatRES: Risks (RCP 4.5 2050)	WatRES: Risks (RCP 8.5 2030)	WatRES: Risks (RCP 8.5 2050)
Gandaki	Kaski	0.02	0.02	0.017	0.017	0.016	0.777	0.788	0.861	0.877	0.818	0.59	0.541	0.665	0.687	0.648
Bagmati Province	Kathmandu	0.171	0.295	0.256	0.239	0.249	0	0	0	0	0	0.03	0.039	0.005	0.003	0
Bagmati Province	Kavrepalanchok	0.203	0.287	0.238	0.234	0.247	0.404	0.534	0.562	0.618	0.649	0.357	0.443	0.507	0.563	0.6
Province 1	Khotang	0.288	0.44	0.332	0.32	0.365	0.088	0.135	0.118	0.11	0.148	0.138	0.193	0.151	0.146	0.193
Bagmati Province	Lalitpur	0.088	0.223	0.231	0.217	0.243	0.056	0.116	0.163	0.173	0.202	0.046	0.102	0.14	0.149	0.184
Gandaki	Lamjung	0.185	0.34	0.341	0.317	0.327	0.204	0.349	0.47	0.444	0.488	0.195	0.321	0.476	0.448	0.49
Province 2	Mahottari	0.631	0.652	0.473	0.518	0.483	0.235	0.252	0.214	0.236	0.222	0.367	0.358	0.311	0.362	0.317
Bagmati Province	Makawanpur	0.302	0.29	0.249	0.253	0.232	0.492	0.458	0.48	0.496	0.468	0.46	0.386	0.438	0.462	0.426
Gandaki	Manang	0.416	0.581	0.57	0.546	0.553	0.056	0.076	0.098	0.087	0.095	0.156	0.199	0.256	0.242	0.232
Province 1	Morang	0.834	0.854	0.581	0.582	0.56	0.955	1	0.805	0.85	0.851	1	1	0.905	0.955	0.937
Karnali	Mugu	0.56	0.752	0.832	0.788	0.856	0.103	0.11	0.187	0.161	0.188	0.24	0.286	0.471	0.434	0.463
Gandaki	Mustang	0.267	0.453	0.488	0.463	0.478	0.051	0.085	0.118	0.102	0.112	0.102	0.16	0.232	0.212	0.213
Gandaki	Myagdi	0.381	0.56	0.547	0.53	0.537	0.234	0.319	0.42	0.396	0.425	0.284	0.376	0.537	0.514	0.531
Gandaki	Nawalpur	0.059	0.096	0.103	0.107	0.107	0.184	0.24	0.365	0.43	0.415	0.137	0.151	0.258	0.326	0.317
Bagmati Province	Nuwakot	0.172	0.276	0.233	0.217	0.219	0.339	0.503	0.584	0.559	0.582	0.296	0.415	0.524	0.501	0.525
Province 1	Okhaldhunga	0.252	0.491	0.375	0.358	0.424	0.156	0.286	0.261	0.267	0.353	0.179	0.327	0.303	0.308	0.411
Lumbini	Palpa	0.362	0.593	0.559	0.561	0.545	0.167	0.233	0.307	0.326	0.315	0.224	0.323	0.44	0.467	0.433
Province 1	Panchthar	0.217	0.463	0.348	0.32	0.382	0.119	0.267	0.231	0.229	0.295	0.139	0.303	0.262	0.253	0.337
Lumbini	Parasi	0.137	0.252	0.277	0.287	0.291	0.077	0.112	0.178	0.21	0.205	0.08	0.109	0.178	0.219	0.21
Gandaki	Parbat	0.119	0.26	0.252	0.241	0.243	0.141	0.273	0.374	0.36	0.384	0.123	0.235	0.344	0.331	0.353
Province 2	Parsa	0.337	0.326	0.3	0.316	0.282	0.106	0.1	0.11	0.129	0.113	0.168	0.127	0.128	0.16	0.12
Lumbini	Pyuthan	0.271	0.545	0.519	0.522	0.526	0.175	0.289	0.407	0.385	0.415	0.201	0.349	0.511	0.5	0.517
Bagmati Province	Ramechhap	0.342	0.55	0.419	0.407	0.467	0.263	0.4	0.381	0.395	0.485	0.293	0.435	0.436	0.45	0.553
Bagmati Province	Rasuwa	0.352	0.516	0.44	0.403	0.407	0.16	0.224	0.258	0.226	0.252	0.216	0.288	0.335	0.294	0.309
Province 2	Rautahat	0.099	0.099	0.083	0.084	0.076	0.188	0.19	0.19	0.192	0.178	0.153	0.114	0.088	0.098	0.083
Lumbini	Rolpa	0.218	0.444	0.447	0.435	0.466	0.094	0.154	0.24	0.208	0.24	0.12	0.21	0.321	0.294	0.326
Lumbini	Rupandehi	0.447	0.468	0.459	0.494	0.466	0.169	0.154	0.198	0.226	0.205	0.254	0.218	0.29	0.341	0.293
Karnali	Salyan	0.124	0.253	0.28	0.263	0.295	0.028	0.042	0.078	0.06	0.078	0.037	0.056	0.088	0.07	0.094
Province 1	Sankhuwasabha	0.73	0.845	0.62	0.595	0.63	0.214	0.247	0.217	0.202	0.248	0.384	0.423	0.39	0.371	0.411
Province 2	Saptari	0.296	0.287	0.197	0.214	0.196	0.185	0.186	0.15	0.168	0.162	0.217	0.178	0.111	0.143	0.125
Province 2	Sarlahi	0	0	0	0	0	0.293	0.284	0.259	0.278	0.25	0.203	0.15	0.109	0.132	0.113
Bagmati Province	Sindhuli	0.214	0.276	0.208	0.215	0.219	0.089	0.113	0.102	0.111	0.118	0.114	0.119	0.073	0.092	0.095

Province	District	Water resources: Baseline context of risks	Water resources: Risks (RCP 4.5 2030)	Water resources: Risks (RCP 4.5 2050)	Water resources: Risks (RCP 8.5 2030)	Water resources: Risks (RCP 8.5 2050)	Energy: Baseline context of risks	Energy: Risks (RCP 4.5 2030)	Energy: Risks (RCP 4.5 2050)	Energy: Risks (RCP 8.5 2030)	Energy: Risks (RCP 8.5 2050)	WatRES: Baseline context of risks	WatRES: Risks (RCP 4.5 2030)	WatRES: Risks (RCP 4.5 2050)	WatRES: Risks (RCP 8.5 2030)	WatRES: Risks (RCP 8.5 2050)
Bagmati Province	Sindhupalchok	0.459	0.537	0.42	0.406	0.401	0.849	0.969	1	1	1	0.792	0.864	1	1	1
Province 2	Siraha	0.438	0.472	0.328	0.364	0.344	0.186	0.209	0.171	0.19	0.19	0.264	0.262	0.197	0.241	0.222
Province 1	Solukhumbu	0.864	0.849	0.607	0.601	0.595	0.628	0.621	0.548	0.536	0.565	0.753	0.709	0.684	0.678	0.689
Province 1	Sunsari	0.264	0.284	0.199	0.207	0.2	0.181	0.198	0.164	0.174	0.181	0.203	0.186	0.125	0.145	0.144
Karnali	Surkhet	0.161	0.185	0.194	0.195	0.203	0.212	0.201	0.315	0.273	0.306	0.193	0.153	0.259	0.229	0.262
Gandaki	Syangja	0.221	0.392	0.36	0.348	0.338	0.102	0.158	0.206	0.203	0.204	0.127	0.194	0.246	0.244	0.232
Gandaki	Tanahu	0.151	0.241	0.22	0.212	0.204	0.253	0.351	0.451	0.457	0.446	0.222	0.287	0.397	0.405	0.393
Province 1	Taplejung	0.623	0.723	0.511	0.49	0.506	0.363	0.432	0.363	0.356	0.4	0.465	0.521	0.466	0.457	0.493
Province 1	Terhathum	0.191	0.428	0.323	0.298	0.363	0.074	0.171	0.152	0.146	0.196	0.095	0.217	0.178	0.167	0.236
Province 1	Udayapur	0.349	0.481	0.353	0.364	0.378	0.067	0.092	0.08	0.084	0.097	0.142	0.176	0.127	0.144	0.151
Karnali	Western Rukum	0.236	0.398	0.416	0.404	0.437	0.117	0.158	0.257	0.234	0.263	0.144	0.196	0.321	0.302	0.333

Annex 7: WatRES subbasin exposure, sensitivity, adaptive capacity, and vulnerability indices

Basin	Subbasin	Water resources: Exposure	Energy: Exposure	WatRES: Exposure	Water resources: Sensitivity	Energy: Sensitivity	WatRES: Sensitivity	Water resources: Adaptive capacity	Energy: Adaptive capacity	WatRES: Adaptive capacity	Water resources: Vulnerability	Energy: Vulnerability	WatRES: Vulnerability
Karnali Mohana	Humla Karnali	0.455	0	0.095	1	0.607	0.903	0.007	0.066	0	1	0.838	1
Karnali Mohana	Mugu Karnali	0.565	0.197	0.275	0.646	0.55	0.703	0.033	0.251	0.141	0.798	0.651	0.78
Karnali Mohana	West Seti	0.192	0.341	0.178	0.451	0.528	0.602	0.329	0.084	0.177	0.535	0.739	0.69
Karnali Mohana	Mohana	0.422	0.804	0.586	0.042	0.876	0.757	0.537	0.399	0.501	0.206	0.909	0.612
Karnali Mohana	Karnali	0.314	0.515	0.349	0.093	0.556	0.48	0.67	0.409	0.575	0.161	0.552	0.376
Karnali Mohana	Tila	0.166	0.208	0.081	0.455	0.715	0.778	0.126	0	0.015	0.646	1	0.905
Narayani/Gandaki	Narayani	0.194	0.584	0.332	0.02	1	0.864	0.681	0.555	0.682	0.116	0.94	0.582
Narayani/Gandaki	Trishuli	0.202	0.715	0.419	0.168	0.815	0.752	0.352	0.679	0.6	0.372	0.655	0.551
Narayani/Gandaki	Marshyangdi	0.32	0.446	0.309	0.275	0.79	0.773	0.281	0.683	0.567	0.467	0.625	0.585
Narayani/Gandaki	Budhi Gandaki	0.518	0.952	0.727	0.466	0.948	1	0.402	0.729	0.66	0.504	0.767	0.689
Narayani/Gandaki	East Seti	0.545	0.956	0.744	0.125	0.818	0.737	1	0.78	1	0	0.591	0.312
Koshi Bagmati Province	Saptakoshi	0.722	0.519	0.557	0.183	0.047	0.042	0.925	0.401	0.7	0.071	0	0
Koshi Bagmati Province	Bagmati Province	0.308	0.682	0.451	0.054	0.27	0.196	0.722	0.538	0.691	0.112	0.153	0.113
Koshi Bagmati Province	Tamakoshi	0.308	0.889	0.582	0.364	0.955	0.965	0.442	0.753	0.697	0.428	0.759	0.643
Koshi Bagmati Province	Kamala	0.557	0.592	0.52	0.12	0.048	0.015	0.71	0.37	0.569	0.154	0.021	0.057
Koshi Bagmati Province	Dudhkoshi	0.626	0.666	0.601	0.52	0.773	0.859	0.609	0.566	0.653	0.421	0.684	0.595
Koshi Bagmati Province	Arun	0.474	0.708	0.552	0.459	0.63	0.7	0.418	1	0.856	0.491	0.238	0.369
Koshi Bagmati Province	Tamor	0.382	0.52	0.387	0.173	0.632	0.584	0.285	0.666	0.556	0.411	0.464	0.459
Koshi Bagmati Province	Indrawati	0.251	0.96	0.598	0.256	0.954	0.919	0.559	0.564	0.626	0.307	0.885	0.652
Koshi Bagmati Province	Likhu	0.256	0.595	0.37	0.282	0.737	0.727	0.242	0.46	0.392	0.492	0.717	0.653
Koshi Bagmati Province	Sun Koshi	0.391	0.288	0.245	0.208	0.33	0.316	0.382	0.436	0.447	0.378	0.287	0.336
East Churiya	Bakaiya	0.384	0.507	0.38	0	0.141	0.053	0.682	0.538	0.671	0.105	0.011	0.025
West Rapti and West Churiya	West Rapati	0.482	0.501	0.425	0.201	0.318	0.302	0.456	0.399	0.46	0.333	0.298	0.319
Mahakali	Mahakali	0.111	0.443	0.201	0.232	0.561	0.542	0.416	0.125	0.249	0.372	0.748	0.606
West Churiya	Tinau	0.742	0.565	0.596	0.225	0.3	0.295	0.45	0.477	0.51	0.35	0.226	0.285
Kankai	Kankaimai	0.935	0.909	0.91	0.137	0.754	0.683	0.671	0.524	0.655	0.184	0.692	0.471
Kankai	Mechi	1	1	1	0.051	0.336	0.257	0.594	0.559	0.64	0.18	0.211	0.184
Babai	Babai	0.456	0.457	0.384	0.105	0.037	0	0.643	0.366	0.532	0.182	0.013	0.067
Koshi Bagmati Province	Trijuga	0.36	0.237	0.197	0.231	0	0.017	0.394	0.228	0.309	0.383	0.064	0.207
Karnali Mohana	Thuli Bheri	0.35	0.132	0.126	0.517	0.692	0.782	0	0.26	0.131	0.747	0.801	0.841
Karnali Mohana	Sani Bheri	0	0.212	0	0.395	0.82	0.851	0.174	0.229	0.198	0.589	0.962	0.851
Karnali Mohana	Bheri	0.165	0.407	0.206	0.302	0.472	0.488	0.54	0.397	0.5	0.342	0.469	0.425
Narayani/Gandaki	East Rapati	0.297	0.881	0.572	0.063	0.734	0.633	0.697	0.597	0.719	0.131	0.621	0.4
Narayani/Gandaki	Upper Kali Gandaki	0.326	0.312	0.227	0.403	0.764	0.802	0.478	0.651	0.645	0.429	0.617	0.56
Narayani/Gandaki	Lower Kali Gandaki	0.338	0.449	0.32	0.25	0.949	0.912	0.384	0.541	0.521	0.399	0.895	0.708

Annex 8: WatRES sub-basin hazard indices

Basin	Subbasin	Water resources: Baseline context of hazards	Water resources: Hazards (RCP 4.5 2030)	Water resources: Hazards (RCP 4.5 2050)	Water resources: Hazards (RCP 8.5 2030)	Water resources: Hazards (RCP 8.5 2050)	Energy: Baseline context of hazards	Energy: Hazards (RCP 4.5 2030)	Energy: Hazards (RCP 4.5 2050)	Energy: Hazards (RCP 8.5 2030)	Energy: Hazards (RCP 8.5 2050)	WatRES: Baseline context of hazards	WatRES: Hazards (RCP 4.5 2030)	WatRES: Hazards (RCP 4.5 2050)	WatRES: Hazards (RCP 8.5 2030)	WatRES: Hazards (RCP 8.5 2050)
Karnali Mohana	Humla Karnali	0.567	0.384	0.591	0.514	0.496	0.567	0.326	0.607	0.439	0.394	0.567	0.355	0.599	0.523	0.469
Karnali Mohana	Mugu Karnali	0.335	0.318	0.519	0.369	0.393	0.335	0.288	0.594	0.425	0.337	0.335	0.303	0.555	0.427	0.38
Karnali Mohana	West Seti	0.336	0.205	0.423	0.285	0.341	0.336	0.159	0.485	0.193	0.189	0.336	0.182	0.453	0.266	0.289
Karnali Mohana	Mohana	0.969	0.798	1	1	1	0.969	0.665	1	0.816	0.915	0.969	0.731	1	1	1
Karnali Mohana	Karnali	0.707	0.589	0.809	0.758	0.781	0.707	0.476	0.839	0.593	0.624	0.707	0.532	0.823	0.746	0.745
Karnali Mohana	Tila	0.338	0.162	0.339	0.217	0.253	0.338	0.044	0.357	0.157	0.026	0.338	0.103	0.347	0.208	0.169
Narayani/Gandaki	Narayani	0.486	0.407	0.482	0.505	0.322	0.486	0.336	0.422	0.735	0.299	0.486	0.371	0.453	0.657	0.319
Narayani/Gandaki	Trishuli	0.466	0.763	0.706	0.493	0.426	0.466	0.665	0.772	0.666	0.752	0.466	0.714	0.737	0.616	0.56
Narayani/Gandaki	Marshyangdi	0.332	0.489	0.635	0.459	0.422	0.332	0.478	0.704	0.564	0.608	0.332	0.484	0.668	0.547	0.503
Narayani/Gandaki	Budhi Gandaki	0.678	0.85	0.853	0.669	0.565	0.678	0.761	0.886	0.823	0.867	0.678	0.805	0.869	0.799	0.696
Narayani/Gandaki	East Seti	0.665	0.855	0.906	0.751	0.626	0.665	0.75	0.933	1	1	0.665	0.802	0.919	0.933	0.786
Koshi Bagmati Province	Saptakoshi	0.854	0.959	0.462	0.518	0.375	0.854	0.959	0.459	0.667	0.613	0.854	0.959	0.461	0.632	0.473
Koshi Bagmati Province	Bagmati Province	0.546	0.658	0.505	0.455	0.371	0.546	0.622	0.464	0.606	0.478	0.546	0.64	0.485	0.565	0.42
Koshi Bagmati Province	Tamakoshi	0.377	0.546	0.215	0.144	0.222	0.377	0.516	0.267	0.316	0.453	0.377	0.531	0.24	0.237	0.312
Koshi Bagmati Province	Kamala	0.834	1	0.589	0.668	0.574	0.834	1	0.581	0.812	0.794	0.834	1	0.585	0.793	0.674
Koshi Bagmati Province	Dudhkoshi	0.859	0.949	0.524	0.434	0.415	0.859	0.913	0.551	0.533	0.651	0.859	0.931	0.537	0.518	0.514
Koshi Bagmati Province	Arun	0.484	0.616	0.236	0.137	0.189	0.484	0.644	0.232	0.13	0.353	0.484	0.63	0.234	0.145	0.252
Koshi Bagmati Province	Tamor	0.488	0.758	0.328	0.196	0.261	0.488	0.807	0.353	0.348	0.577	0.488	0.783	0.34	0.284	0.385
Koshi Bagmati Province	Indrawati	0.605	0.845	0.627	0.49	0.496	0.605	0.77	0.685	0.772	0.882	0.605	0.807	0.654	0.664	0.656
Koshi Bagmati Province	Likhu	0.26	0.436	0.074	0.052	0.099	0.26	0.45	0.066	0.158	0.202	0.26	0.443	0.071	0.106	0.135
Koshi Bagmati Province	Sun Koshi	0.259	0.383	0	0	0	0.259	0.46	0	0	0.019	0.259	0.422	0	0	0
East Churiya	Bakaiya	0.711	0.668	0.72	0.679	0.458	0.711	0.665	0.63	0.829	0.53	0.711	0.667	0.677	0.807	0.496
West Rapti and West Churiya	West Rapati	0.36	0.532	0.635	0.595	0.587	0.36	0.373	0.679	0.502	0.467	0.36	0.452	0.656	0.603	0.557
Mahakali	Mahakali	0.133	0	0.308	0.197	0.288	0.133	0	0.363	0.053	0.113	0.133	0	0.334	0.146	0.225
West Churiya	Tinau	0.211	0.158	0.334	0.398	0.271	0.211	0.088	0.266	0.48	0	0.211	0.123	0.302	0.471	0.171
Kankai	Kankaimai	0.665	0.88	0.391	0.31	0.269	0.665	0.917	0.403	0.522	0.516	0.665	0.899	0.396	0.436	0.366
Kankai	Mechi	0.608	0.856	0.373	0.268	0.242	0.608	0.932	0.392	0.494	0.478	0.608	0.894	0.382	0.397	0.335

Basin	Subbasin	Water resources: Baseline context of hazards	Water resources: Hazards (RCP 4.5 2030)	Water resources: Hazards (RCP 4.5 2050)	Water resources: Hazards (RCP 8.5 2030)	Water resources: Hazards (RCP 8.5 2050)	Energy: Baseline context of hazards	Energy: Hazards (RCP 4.5 2030)	Energy: Hazards (RCP 4.5 2050)	Energy: Hazards (RCP 8.5 2030)	Energy: Hazards (RCP 8.5 2050)	WatRES: Baseline context of hazards	WatRES: Hazards (RCP 4.5 2030)	WatRES: Hazards (RCP 4.5 2050)	WatRES: Hazards (RCP 8.5 2030)	WatRES: Hazards (RCP 8.5 2050)
Babai	Babai	0.353	0.409	0.573	0.533	0.55	0.353	0.252	0.599	0.357	0.319	0.353	0.33	0.585	0.496	0.476
Koshi Bagmati Province	Trijuga	0.37	0.517	0.108	0.157	0.085	0.37	0.569	0.104	0.23	0.182	0.37	0.543	0.106	0.205	0.118
Karnali Mohana	Thuli Bheri	0.464	0.546	0.723	0.543	0.577	0.464	0.502	0.807	0.666	0.665	0.464	0.524	0.763	0.648	0.626
Karnali Mohana	Sani Bheri	0	0.103	0.311	0.206	0.282	0	0.032	0.375	0.231	0.176	0	0.068	0.341	0.235	0.245
Karnali Mohana	Bheri	0.311	0.208	0.42	0.33	0.385	0.311	0.098	0.455	0.202	0.118	0.311	0.153	0.436	0.299	0.291
Narayani/Gandaki	East Rapati	1	0.888	0.855	0.811	0.582	1	0.8	0.769	0.983	0.673	1	0.844	0.814	0.962	0.633
Narayani/Gandaki	Upper Kali Gandaki	0.258	0.434	0.691	0.517	0.536	0.258	0.452	0.765	0.586	0.682	0.258	0.443	0.726	0.594	0.606
Narayani/Gandaki	Lower Kali Gandaki	0.172	0.446	0.552	0.435	0.363	0.172	0.337	0.558	0.561	0.451	0.172	0.391	0.555	0.531	0.404

Annex 9: WatRES sub-basin risk indices

Basin	Subbasin	Water resources: Baseline context of risks	Water resources: Risks (RCP 4.5 2030)	Water resources: Risks (RCP 4.5 2050)	Water resources: Risks (RCP 8.5 2030)	Water resources: Risks (RCP 8.5 2050)	Energy: Baseline context of risks	Energy: Risks (RCP 4.5 2030)	Energy: Risks (RCP 4.5 2050)	Energy: Risks (RCP 8.5 2030)	Energy: Risks (RCP 8.5 2050)	WatRES: Baseline context of risks	WatRES: Risks (RCP 4.5 2030)	WatRES: Risks (RCP 4.5 2050)	WatRES: Risks (RCP 8.5 2030)	WatRES: Risks (RCP 8.5 2050)
Karnali Mohana	Humla Karnali	1	1	1	1	1	0.03	0	0.044	0.023	0.017	0.392	0.388	0.471	0.469	0.452
Karnali Mohana	Mugu Karnali	0.62	0.811	0.831	0.788	0.829	0.062	0.07	0.146	0.116	0.117	0.245	0.353	0.463	0.423	0.447
Karnali Mohana	West Seti	0.26	0.317	0.356	0.329	0.371	0.119	0.129	0.256	0.187	0.235	0.131	0.155	0.289	0.206	0.291
Karnali Mohana	Mohana	0.4	0.304	0.28	0.312	0.291	1	0.837	1	0.925	0.895	1	0.764	0.88	0.856	0.868
Karnali Mohana	Karnali	0.248	0.189	0.184	0.198	0.194	0.439	0.363	0.472	0.418	0.408	0.417	0.294	0.376	0.333	0.352
Karnali Mohana	Tila	0.35	0.388	0.419	0.394	0.437	0.112	0.076	0.189	0.147	0.171	0.166	0.146	0.268	0.21	0.27
Narayani/Gandaki	Narayani	0.122	0.097	0.088	0.103	0.09	0.473	0.461	0.543	0.645	0.548	0.39	0.334	0.382	0.479	0.424
Narayani/Gandaki	Trishuli	0.268	0.372	0.3	0.278	0.274	0.421	0.577	0.629	0.608	0.605	0.41	0.572	0.575	0.553	0.585
Narayani/Gandaki	Marshyangdi	0.333	0.467	0.443	0.419	0.421	0.179	0.27	0.341	0.315	0.318	0.22	0.354	0.41	0.377	0.399
Narayani/Gandaki	Budhi Gandaki	0.65	0.749	0.628	0.607	0.572	0.712	0.85	0.91	0.884	0.863	0.853	1	1	1	1
Narayani/Gandaki	East Seti	0	0	0	0	0	0.633	0.734	0.798	0.824	0.756	0.479	0.521	0.55	0.576	0.567
Koshi Bagmati Province	Saptakoshi	0.214	0.198	0.1	0.119	0.114	0.13	0.137	0.086	0.1	0.084	0.119	0.103	0	0	0
Koshi Bagmati Province	Bagmati Province	0.081	0.094	0.064	0.068	0.075	0.191	0.217	0.212	0.23	0.21	0.113	0.12	0.087	0.086	0.097
Koshi Bagmati Province	Tamakoshi	0.295	0.421	0.29	0.279	0.329	0.459	0.656	0.605	0.617	0.72	0.457	0.666	0.549	0.561	0.724
Koshi Bagmati Province	Kamala	0.292	0.301	0.177	0.21	0.201	0.166	0.189	0.135	0.156	0.132	0.188	0.199	0.085	0.106	0.096
Koshi Bagmati Province	Dudhkoshi	0.729	0.738	0.488	0.483	0.491	0.617	0.661	0.533	0.522	0.549	0.803	0.829	0.599	0.601	0.658
Koshi Bagmati Province	Arun	0.519	0.635	0.432	0.409	0.458	0.154	0.214	0.164	0.138	0.192	0.283	0.389	0.253	0.212	0.302
Koshi Bagmati Province	Tamor	0.392	0.529	0.34	0.318	0.358	0.249	0.375	0.28	0.272	0.318	0.31	0.476	0.3	0.275	0.363
Koshi Bagmati Province	Indrawati	0.304	0.368	0.263	0.255	0.264	0.781	1	0.966	1	1	0.755	0.938	0.841	0.889	0.951
Koshi Bagmati Province	Likhu	0.246	0.414	0.28	0.272	0.33	0.196	0.345	0.291	0.302	0.379	0.194	0.392	0.276	0.275	0.404
Koshi Bagmati Province	Sun Koshi	0.227	0.356	0.233	0.232	0.277	0.027	0.077	0.051	0.039	0.07	0.032	0.13	0.045	0.015	0.081
East Churiya	Bakaiya	0.173	0.135	0.119	0.132	0.111	0.123	0.114	0.121	0.131	0.096	0.094	0.051	0.04	0.037	0.01
West Rapti and West Churiya	West Rapati	0.222	0.353	0.331	0.343	0.346	0.071	0.115	0.198	0.168	0.171	0.069	0.162	0.225	0.198	0.217
Mahakali	Mahakali	0.091	0.135	0.194	0.179	0.218	0.128	0.158	0.332	0.249	0.323	0.06	0.089	0.262	0.171	0.286
West Churiya	Tinau	0.255	0.362	0.389	0.424	0.412	0.059	0.07	0.143	0.165	0.134	0.073	0.127	0.211	0.244	0.22
Kankai	Kankaimai	0.46	0.506	0.307	0.304	0.308	0.645	0.864	0.638	0.681	0.71	0.703	0.889	0.587	0.633	0.703
Kankai	Mechi	0.41	0.489	0.298	0.288	0.301	0.281	0.462	0.331	0.347	0.375	0.349	0.531	0.321	0.325	0.383

Basin	Subbasin	Water resources: Baseline context of risks	Water resources: Risks (RCP 4.5 2030)	Water resources: Risks (RCP 4.5 2050)	Water resources: Risks (RCP 8.5 2030)	Water resources: Risks (RCP 8.5 2050)	Energy: Baseline context of risks	Energy: Risks (RCP 4.5 2030)	Energy: Risks (RCP 4.5 2050)	Energy: Risks (RCP 8.5 2030)	Energy: Risks (RCP 8.5 2050)	WatRES: Baseline context of risks	WatRES: Risks (RCP 4.5 2030)	WatRES: Risks (RCP 4.5 2050)	WatRES: Risks (RCP 8.5 2030)	WatRES: Risks (RCP 8.5 2050)
Babai	Babai	0.144	0.187	0.184	0.194	0.201	0.035	0.026	0.082	0.055	0.051	0	0	0.043	0.006	0.019
Koshi Bagmati Province	Trijuga	0.28	0.392	0.252	0.268	0.287	0	0.017	0	0	0	0.031	0.096	0.012	0.002	0.021
Karnali Mohana	Thuli Bheri	0.631	0.789	0.75	0.716	0.727	0.085	0.101	0.164	0.139	0.13	0.272	0.37	0.432	0.399	0.4
Karnali Mohana	Sani Bheri	0.101	0.267	0.3	0.285	0.326	0.057	0.125	0.232	0.202	0.22	0	0.127	0.237	0.194	0.251
Karnali Mohana	Bheri	0.169	0.187	0.208	0.2	0.226	0.134	0.113	0.231	0.182	0.203	0.102	0.076	0.185	0.123	0.177
Narayani/Gandaki	East Rapati	0.268	0.19	0.146	0.161	0.133	0.775	0.694	0.684	0.764	0.644	0.734	0.583	0.535	0.62	0.538
Narayani/Gandaki	Upper Kali Gandaki	0.204	0.359	0.382	0.362	0.377	0.14	0.214	0.287	0.263	0.261	0.124	0.251	0.33	0.295	0.32
Narayani/Gandaki	Lower Kali Gandaki	0.187	0.388	0.366	0.356	0.356	0.185	0.332	0.446	0.438	0.436	0.157	0.368	0.456	0.448	0.472