GREEN CLIMATE FUND

Protecting livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal

Annex 2: Feasibility Study

June 2023

List of acronyms

AE	Accredited Entity
AF	Adaptation Fund
AMIS	Agriculture Management Information System
ARI	Acute Respiratory Infection
AWS	Automatic Weather Station
BMUB	Government of Germany's Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Building
BOB	Bay of Bengal
BRCH	Building Resilience to Climate Related Hazards
BRCRN	Building a Resilient Churia Region in Nepal
CAPA	Community Adaptation Plans of Action
CBA	Community-Based Adaption
CBDRR	Community-Based Disaster Risk Reduction
CBEWS	Community-Based Early Warning System
CCRD	Climate Change Resilience Development
CCUDRR	Child Centre Urban Disaster Risk Reduction
CDMC	Community Disaster Management Committee
CFGORRP	Community based Flood and Glacial Lake Outburst Risk Reduction Project
CIF	Climate Investment Fund
CLIVAR	Climate Variability and Predictability Programme of the World Climate Research Programme
CNDRC	Central Natural Disaster Relief Committee
CoP	Community of Practice
CP	Country Programme Document
CRDP	Climate Resilient Development Projects
CRI	Climate Risk Index
CV	Coefficient of Spatial Variation
DDC	District Development Committee
DHM	Department of Hydrology and Meteorology
DPNet-Nepal	Disaster Preparedness Network-Nepal
DPP	Disaster Preparedness Plans
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DRRM	Disaster Risk Reduction and Management
EbA	Ecosystem-based Adaptation
Eco-DRR	Eco-Disaster Risk Reduction
ECO-Nepal	Environment and Child Concern Organisation
EE	Executing Entity
EIA	Environmental Impact Assessment
ENSO	El Niño-Southern Oscillation
ERT	Electrical Resistivity Tomography
ESAP	Environmental and Social Action Plan
ETCCDI	Expert Team on Climate Change Detection and Indices
EWS	Early Warning System
E2E	End to End
FAO	Food and Agriculture Organization
FFGS	Flash Flood Guidance System
GAAP	Gender Assessment and Action Plan
GBON	Global Basic Observing Network

GCCA	Global Climate Change Alliance +
GCF	Green Climate Fund
GDP	Gross domestic product
GEF	Global Environment Facility
GHGs	Greenhouse gases
GLOF	Glacial Lake Outburst Flood
GLoFAS	Global Flood Awareness System
GNA	Global Needs Assessment
GNI	Gross National Income
GoN	Government of Nepal
GPR	Ground Penetrating Radar
GSM	Global System for Mobile Communications
HDI	Human Development Index
HMA	High Mountain Asia
HMGWP	High Mountain Glacial Watershed Partnership
HRI	Himalayan Risk Research Institute
HRVA	Hazard, Risk and Vulnerability Analysis
ICIMOD	International Centre for Integrated Mountain Development
ICAO	International Civil Aviation Organization
IDS-Nepal	Integrated Development Society Nepal
IEC	Information, Education and Communication
IFRC	International Federation of Red Cross and Red Crescent Societies
IIASA	International Institute for Applied Systems Analysis
IP	Impact Pathway
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
IT	Information Technology
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resource Management
JCOMM	Joint World Meteorological Organization-Intergovernmental Oceanographic Commission Technical Commission for Oceanography and Marine Meteorology
KAP	Knowledge, Attitude and Practice
LAPA	Local Adaptation Programmes of Action
LDC	Least Developed Country
LDCF	Least Developed Countries Fund
M&E	Monitoring and Evaluation
MDGs	Millennium Development Goals
METAR	Meteorological Aviation Report
MoAD	Ministry of Agriculture Development
MoE	Ministry of Environment
MoEWRI	Ministry of Energy, Water Resources and Irrigation
MoFE	Ministry of Forests and Environment
MoHA	Ministry of Home Affairs
MoPE	Ministry of Population and Environment
MoSTE	Ministry of Science, Technology and Environment
NAP	National Adaptation Plan
NAPA	National Adaptation Programme of Action
NBSAP	National Biodiversity Strategy and Action Plan
NCCSP	Nepal Climate Change Support Programme
NCCSP I-TE	Nepal Climate Change Support Programme I - Transition Extension
NDC	Nationally Determined Contribution

NEA	Nepal Electricity Authority
NEOC	National Emergency Operations Centre
NGOs	Non-governmental organisations
NPC	National Planning Commission
NRRC	Nepal Risk Reduction Consortium
NbS	Nature-based Solutions
NSDRM	National Strategy for Disaster Risk Management
O&M	Operations and Maintenance
ODF	Open Defecation Free
OFDA	Office of U.S. Foreign Disaster Assistance
PDGL	Potentially Dangerous Glacial Lakes
PERC	Post Event Review Capability
PPCR	Pilot Program for Climate Resilience
PPE	Personal Protective Equipment
PPP	Purchasing Power Parity
PTSD	Post-Traumatic Stress Disorder
QDO	Quasi-Decadal Oscillation
RAI	Rural Access Index
RCC	Reinforced Cement Concrete
RCP	Representative Concentration Pathway
SC	Safe School
SCCF	Special Climate Change Fund
SCDRR-Nepal	Strategic Centre for Disaster Risk Reduction Nepal
SDGs	Sustainable Development Goals
SFDRR	Sendai Framework for Disaster Risk Reduction
SNRM	Sustainable Natural Resource Management
SOI	Southern Oscillation Index
SOP	Standard Operating Procedure
SPCR	SPCR
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
USAID	United States Agency for International Development
UNFCCC	United Nations Framework Convention on Climate Change
VDC	Vulnerable Districts and Villages
VDRMP	Village-level Disaster Risk Management Plan
WHO	World Health Organisation
WIGOS	WMO Integrated Global Observing System

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1. Executive summary

This Feasibility Study supports the proposed GCF project, entitled "*Protecting livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal"* which has the objective of reducing the risk of Glacial Lake Outburst Flood (GLOF) occurrence and impacts under climate change at the Hongu 2, Lower Barun, Lumding Tsho and Thulagi Glacial Lakes in Nepal. The project's approach is to: i) reduce the impacts of a GLOF and its residual impacts on vulnerable communities; ii) promote the adoption of GLOF EWS measures among national- and local-level decision-makers to enhance rapid response to an impending GLOF; and iii) strengthen the technical and institutional capacity of the GoN and local communities to implement GLOF risk reduction measures through targeted training and awareness raising. The Feasibility Study describes the baseline situation of the country context and provides technical analyses and support of the proposed project interventions presented in the GCF Funding Proposal.

1.1. Geography, demographics and socio-economic context

1.1.1. Geography

Nepal is a landlocked country located north of India and south of China, with the Himalaya Mountain Range forming this northern border. Spanning southwards from the Himalaya Mountains, the country extends for 200 km into low-lying plains and has a total land area of 147,000 km^2. Nepal's unique geography results in a highly variable climate across the country with a sharp climatic gradient, spanning from polar frosts in the northern mountains to subtropical conditions in the southern plains. The annual seasons in Nepal are divided into a wet season — consisting of the pre-monsoon period from March–May and monsoon season from June–September — as well as a dry season, which consists of a post-monsoon season from October–November and winter from December–February.

1.1.2. Population

In 2019, the total number of the country's inhabitants was 28.6 million people and the population density was 196 people/km^2. Nepal is a Least Developed Country (LDC), ranked the 17th poorest nation globally and over 80% of the population live in rural areas with poverty particularly prevalent among communities in the mountains, at 42%. The Human Development Index (HDI) for the country has increased over the last decade, reaching 0.579 in 2018, placing Nepal within the 'medium human development' ranking. This ranking remains below the global average as well as the average for South Asia.

The population of Nepal has been and remains vulnerable to numerous natural disasters such as floods, droughts, landslides and earthquakes, with climate-induced disasters resulting in more than 4,000 deaths in Nepal and accumulated economic losses of US$5.34 billion between 2005 and 2015. These impacts are amplified for vulnerable communities that have inadequate resources and skills to recover from the impacts or are isolated and cut-off from post-disaster relief efforts. Women and marginalised groups in Nepal also face disproportionately high impacts from these disasters.

1.1.3. Economy

The country's economy is currently based on the agricultural sector, with 66% of the national population engaged in agricultural activities. Despite its importance, the agricultural sector remains underdeveloped, with only 28% of cultivated land under irrigation, and as a result agriculture — and subsequently community livelihoods — are heavily dependent on rainfall. The limited development of the agricultural sector has resulted in poor climate resilience of the sector and, as a result, events such as floods and droughts, as well as changing rainfall patterns, have a strong negative impact on agriculture. With such limited development and the negative impacts of extreme climate events, the contribution of agriculture to the national GDP is only 33%. In addition to agriculture, tourism is a prominent economic sector, employing 20% of the population and contributing 6.7% of total GDP in 2019.

The energy supply sector in Nepal faces significant challenges, with no significant deposits of fossil fuels in the country, imports of fuel to meet growing energy demands have resulted in a trade deficit. Hydropower has been a prominent focus for meeting the growing energy needs. However, despite extensive potentially exploitable hydropower resources, less than 2% of the country's total commercial generation potential has been achieved. Limited energy supply results in prominent reliance on fuel wood, which has been linked to deforestation across much of the country.

1.2. Climate profile

Nepal is dominated by a temperate climate but features polar regions in the northern mountains and subtropical regions along the southern plains. Mean annual temperature is 12°C and average annual rainfall is 1,360 mm. Temperature trends for Nepal show an increasing trend for temperature of 0.55°C per decade, while precipitation trends show a general positive trend in the majority of the country, with a maximum increase of 15% per decade in a few isolated pockets. The climate regime is characterised by a wet monsoon season and a dry winter season, with 80% of annual precipitation falling during the summer monsoon. The monsoon season is strongly influenced by global climatic variations such as the El Niño-Southern Oscillation (ENSO) and Southern Oscillation Index (SOI), which result in variability and increased intensity of the monsoon rainfall patterns.

1.3. Climate rationale

Nepal is vulnerable to many climate-induced disasters, including Glacial Lake Outburst Floods (GLOFs) that originate from glacial lakes in the Himalaya Mountains in the north of the country. As temperatures rise and glaciers retreat, they erode land, forming a depression that fills with water from the melting glacier and surrounding snowmelt, forming a glacial lake. This unique origin results in glacial lakes being dammed by moraines which consist of unconsolidated rock and often contain large masses of ice. These moraines are structurally insecure, which presents a great risk of breaching and failure through damage or an overtopping wave, resulting in a high-intensity GLOF. The predominant trigger of GLOFs in Nepal is avalanches, but other triggers include: i) rockfalls; ii) seismic activity; iii) intense rainfall; and iv) melting of ice-cored moraines. GLOFs are unpredictable and highly destructive events, with large volumes of water expelled from the glacial lakes at high velocities within a very short time after the trigger event. Nepal has suffered catastrophic consequences from past GLOFs, with loss of life and extensive damage to infrastructure and the environment, as well as secondary impacts such as landslides. There are 26 GLOFs recorded in Nepal's history since the 1970s, and the country has been ranked alongside Bhutan as experiencing the overall greatest global national-level economic consequences of GLOF impacts. The risk posed by GLOFs in Nepal is considerable and is expected to increase under climate change. Climate change projections show that temperatures will rise in Nepal, with amplified effect within the high-altitude Himalayan Mountains, and rainfall is expected to become more variable within the monsoon season, with more frequent high-intensity monsoon rains. Rising temperatures and intense rainfall events increase the likelihood and intensity of GLOFs in Nepal. Glacial lakes are expanding in size and volume as temperatures rise, which increases the risk of GLOF occurrence as well as the potential severity of the GLOFs (see Section 4.1). The trigger mechanisms of GLOFs are also influenced by climate change (see Section 4.4), increasing the risk of GLOFs becoming more frequent in Nepal.

An assessment for updating the inventory of the glacial lakes in the Himalayas was carried out by UNDP and the International Centre for Integrated Mountain Development (ICIMOD) United Nations Development Programme (UNDP) to identify and rank Potentially Dangerous Glacial Lakes

(PDGLs)[1]. Several Rank 1 glacial lakes were identified within Nepal, and while all pose a serious risk, four of the lakes at the highest risk were selected for interventions under the proposed project to reduce the risk they pose to the population of Nepal (see section 3 for the selection criteria of these four lakes). The glacial lakes that were selected are: i) Hongu 2; ii) Lower Barun; iii) Lumding Tsho; and iv) Thulagi. To determine the most appropriate project interventions and ensure that maximum benefits are realised as a result of these interventions, breach modelling assessments were commissioned by UNDP. These models aimed to assess the potential intensity of a GLOF at these four lakes. In order to inform the selection of appropriate interventions within the Arun and Dudhkosi River Basins, residual risk modelling and environment and climate change vulnerability assessments (Annex 23) were commissioned by UNDP at the watershed and sub-watershed level for the three lakes within these basins — Hongu 2, Lower Barun and Lumding Tsho. These assessments were also used to inform the Financial and Economic Appraisal (Annex 3) for the proposed project. The assessments were carried out using scenarios that modelled for the impact of GLOFs without interventions in comparison to the impacts after glacial lake lowering at the four glacial lakes. Glacial lake lowering is a method of reducing the likelihood of GLOF occurrence and the potential impact of a GLOF should it occur by reducing the total volume of water available to be discharged. There are numerous previous cases of successful glacial lake lowering within Nepal and the rest of the world. In addition to the post-lake lowering impacts, models were run to determine the benefits of downstream interventions aimed at reducing the impacts of GLOFs within the Arun and Dudhkosi River Basins. These downstream interventions included grey infrastructure such as flood walls, gabions and revetments, as well as Nature-based Solutions (NbS) such as brush layering and reforestation. Furthermore, the proposed downstream interventions would serve to aid risk reduction for monsoon rainfall-induced flooding in the Arun and Dudhkosi River Basins. Floods resulting from intense monsoon season rainfall in Nepal are frequent — occurring annually since 2016 — and have resulted in over 1,000 deaths and impacting more than 2 million people over the last decade. Average annual losses resulting from flooding exceed US$ 143 million, while secondary impacts such as water- and vector-borne disease outbreaks significantly impact the wellbeing of the population in Nepal. These floods are expected to increase in intensity under projected climate change impacts as rainfall intensity is projected to increase (see Section 4.3). As with GLOFS, these floods are also associated with secondary impacts such as landslides, which result in loss of life and severely impact infrastructure and the environment (see Section 5.1).

Given that the likelihood and intensity of GLOFs will increase under future climate conditions, the impacts of these events will become increasingly severe in the absence of urgent interventions. This will have intensive impacts on the lives and livelihoods of local communities as well as the economy as a whole. Following a GLOF, power supply can be disrupted, while damage to communication and transport infrastructure impedes relief and recovery efforts and disrupts associated services. Additionally, the capacity of the country to respond to such events is constrained by the vulnerability of critical public services, including healthcare, police, fire and rescue services as well as government coordination and response agencies. Disruption to these services, caused by GLOF-linked damages to critical infrastructure, reduces the efficiency and effectiveness of emergency response and delays recovery. This vulnerability is further exacerbated by limited capacity within Nepal's Department of Hydrology and Meteorology (DHM) and National Disaster Risk Reduction and Management Authority (NDRRMA) for early warning and preparatory action tailored to GLOFs. The Government of Nepal (GoN) is already investing in climate change adaptation, however, given the existing challenges to

[1] ICIMOD and UNDP. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905

the country's socio-economic development, further external support is required to address the adaptation needs related to the four target glacial lakes.

1.4. Policies and governance

The Government of Nepal (GoN) has established several policy frameworks, strategies and initiatives to increase the resilience of the country's population to the impacts of extreme climate events. These include *inter alia* the: i) Nepal Disaster Risk Reduction National Strategic Plan of Action (2018-2030) — serving as the policy framework for Disaster Risk Reduction (DRR) planning, guidance and management; ii) Natural Calamity (Relief) Act (1982) — to enable the GoN to effectively provide for relief resources and services relating to a natural disaster; and iii) District-level disaster preparedness plans — to reduce risk in Vulnerable Districts and Villages (DDCs/VDCs).

The proposed project aligns with *inter alia*: i) Nepal's Third National Communication (TNC) to the UNFCCC (2021) — which outlines the country's adaptation and mitigation targets; ii) Nepal National Adaptation Programme of Action (NAPA) (2010) — which provides a pathway for Nepal as a Least Developed Country (LDC) to identify priority activities that respond to the country's immediate climate change adaptation needs as well as guides implementation of projects with the objective of reducing the economic and social costs of climate change; and iii) National Climate Change Policy (2019) — which aims to minimise the existing effects and likely future impacts of climate change across different ecological regions and sectors within the country. Project interventions relating to the natural environment — particularly those with the objective of improving riverbank stability and the restoration of deforested mountain slopes and riparian regions — will closely follow the standards and guidelines set out in the Environmental Protection Act (2019) as well as the Soil and Watershed Conservation Act (1982).

Best practices from the lowering of the Tsho Rolpa and Imja Glacial Lakes in Nepal, as well as lowering of other glacial lakes in Pakistan, were used to inform the design of interventions to be implemented under the project. Lessons learned from numerous baseline investments into climate change adaptation in Nepal were also used to guide the design of all project interventions. Such lessons include appropriate mechanisms for ensuring that project activities are implemented in a participatory, gender-inclusive and sustainable way. Specific details on all best practices and lessons learned relevant to the project are presented in Section 7 of this Feasibility Study.

1.5. Preferred adaptation solution

There is an urgent need in Nepal to shift away from a reactive, project-based response to GLOFs towards building sustainable national capacity to respond to an impending GLOF event and implement tangible and cost-effective GLOF risk reduction measures both up- and downstream. This integrated approach to the reduction of GLOF risk and the associated impacts on downstream communities should comprise: i) physical risk reduction measures at the four glacial lakes in Nepal most at risk of breaching, namely the Thulagi, Lower Barun, Lumding Tsho and Hongu 2 Lakes; ii) downstream, watershed-level interventions to complement the physical risk reduction interventions and reduce the residual impacts of a GLOF event on vulnerable downstream communities; iii) interventions to strengthen technical and institutional capacity at the national level to integrate climate risk and hazard information into planning, policy and response strategies; iv) a GLOF early warning system (GLOF EWS) to generate and disseminate improved GLOF- and climate change-related information to national and local decision-makers; and v) community-level GLOF awareness and early warnings to promote appropriate response strategies and develop long-term adaptive capacity. Further details of how this integrated approach was formulated can be found in Section 5.

1.6. Barriers to achieving the preferred adaptation solution

Several technical, institutional and financial barriers to the preferred adaptation solution in Nepal have been identified. These are summarised below and explained in detail in Section 10 of this Feasibility Study.

Barrier 1 — *Limited technical knowledge and institutional capacity, including watershed-level approaches to GLOF risk reduction:* The GoN has: i) a lack of sufficient data and expertise related to GLOF risk reduction and management; ii) limited guidelines for mainstreaming disaster risk reduction (DRR) into policy and planning, as well as for training national- and local-level decision-makers effective GLOF risk reduction planning and response; and iii) inadequate mechanisms to ensure the coordination of efforts between national and sub-national governments, including the local level governments and key stakeholders. These capacity constraints hinder the establishment of a sufficient knowledge base for GLOF risk reduction in Nepal. Adequate DRR in Nepal is further inhibited by the combination of knowledge gaps and limited capacity to develop and effectively implement watershed-level management plans for GLOF DRR. At present, the legal and policy frameworks on climate change adaptation in Nepal focus on across-the-board approaches to GLOF risk reduction. This gap for watershed-level approaches to GLOF management has been further hindered by limited collaboration and coordination between different GoN agencies. Moreover, there is limited GLOF monitoring, glacial lake mapping, DRR and EWS in Nepal, and to date, most studies on high mountain regions and GLOF risk in Nepal have been project-based, resulting in insufficient data to effectively support watershed-level approaches for DRR.

Barrier 2 — *Limited access to current, reliable and timely climate risk information and early warnings technology*: There are gaps in Nepal's hydrometeorological monitoring network, which constrain the implementation of integrated watershed-level approaches for catchment management, DRR and the dissemination of early warnings to communities. This is particularly evident in the lack of vulnerability maps, technical field surveys, hazard and risk information and comprehensive climate information in Nepal. Additionally, research and monitoring in remote areas of the Himalayan region are constrained, resulting in gaps in coverage of the existing hydrometeorological system.

Barrier 3 — Limited investment in, and investment planning for, long-term climate risk reduction to address GLOF and flood risk: There is a general lack of investment in long-term climate risk reduction in Nepal. Given the high cost of GLOF risk reduction interventions, the country has limited financial mechanisms to sustain risk reduction approaches or to support the mainstreaming of public investment initiatives or public-private partnerships (PPPs) for downstream flood management. Moreover, investment in risk reduction measures is hindered by limited opportunities to generate income or recoup the high costs associated with implementing these measures, which constrains the GoN's ability to attract and secure the necessary investments for GLOF risk reduction, particularly from the private sector. This challenge is compounded by the GoN's limited capacity to systematically identify, plan for and program financial requirements for risk reduction measures.

Barrier 4 — *Limited community awareness and skills for GLOF disaster reduction actions*: Knowledge of climate change and its impacts — including GLOFs and rain-induced flooding — is limited among the different groups living in areas exposed to GLOFs and other extreme climate events throughout Nepal. Linked to this is the limited adaptive capacity of these groups to manage the impacts of extreme flooding events. This limited adaptive capacity is further exacerbated by inadequate investment in DRR interventions in the exposed areas, which increases the risk of damage to infrastructure, disruption of livelihoods — including agriculture and tourism — as well as potential injury and loss of life in these areas. The youth, women and marginalised Indigenous groups are the most vulnerable to these impacts.

1.7. Proposed project interventions to overcome existing barriers

Direct investments for the proposed project will be used to reduce the risk of a GLOF occurring by lowering four glacial lakes in Nepal that have been identified as the most at-risk of breaching, namely the Thulagi, Lower Barun, Lumding Tsho and Hongu 2 Glacial Lakes. The lowering of these lakes will be complemented by implementing a set of adaptation interventions downstream of these lakes to protect vulnerable communities and infrastructure from the residual impacts of GLOF events. This proactive approach will include improvements to the existing Early Warning System (EWS) specific to GLOF risks, with improved capacity for disaster prediction, warning and response in communities in the Arun and Dudhkosi River Basins. The combined transformative effect of project interventions will result in reduced vulnerability of the communities to the impacts of GLOFs while safeguarding lives, infrastructure and the environment against the impacts of these disastrous events.

2. Context and baseline

2.1. Physical and geographical situation

Nepal is a landlocked country located in southern Asia, between China to the northeast and India to the southwest. Five physiographic zones broadly divide the country into east-west belts (Figure 1)[2] across an area of 147,000 km^2. From north to south, these zones comprise the: i) Tibetan Plateau; ii) Greater Himalaya, a mostly uninhabited mountain range with elevations up to 9,000 m; iii) Lesser Himalaya, a mid-mountain region between the Mahābhārat Range and the Greater Himalayas, which encloses the Kathmandu and Pokhara valleys, including the capital city of Kathmandu; iv) forested Churia foothills; and v) Terai, a low, flat fertile land adjacent to India which forms the northern extension of the Gangetic Plain[3]. While the southern regions of the country are relatively flat, high mountain ranges are the dominant landscape across the rest of Nepal — covering approximately 75% of the country[4]. Of the world's 10 highest peaks, eight of them are located in the Greater Himalaya zone, including Everest as the highest and Kanchenjuna as the third-highest[5].

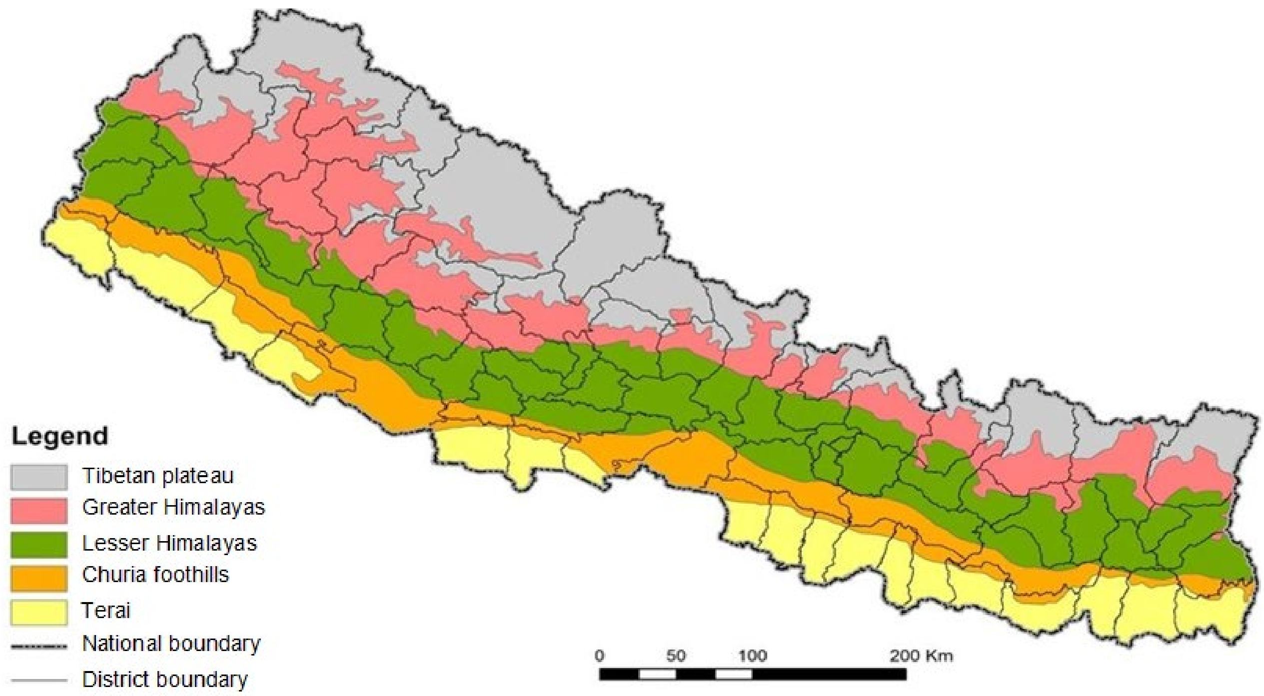

Figure 1. Map of Nepal's physiographic regions[6]**.**

Nepal's unique physiographical and topographical characteristics result in a highly variable climate across the country. Conditions range from subtropical or temperate in the southern Terai to polar frost and temperatures consistently below freezing in the northern Himalayas, despite the two regions only being 200 km apart. Annual seasons in Nepal can be divided into a wet season, which consists of pre-monsoon season (March–May) and monsoon season (June–September), and a dry season, which consists of a post-monsoon season (October–November) and winter (December–February). In addition to the temporal variation of wet and dry seasons in Nepal, precipitation also varies spatially

[2] More information available at: https://www.britannica.com/place/Nepal/The-economy
[3] The Gangetic Plain is the world's largest alluvial plan and covers ~2.5 million km2, encompassing northern regions of the Indian subcontinent — including northern and eastern India, eastern parts of Pakistan, most of Bangladesh and the southern plains of Nepal.
[4] More information available at: https://www.britannica.com/place/Nepal#ref23636
[5] https://www.cia.gov/library/publications/the-world-factbook/geos/np.html
[6] Gurung, T.B., 2017. Chapter III. Aquatic biodiversity for food and agriculture in Nepal. The State of Nepal's Biodiversity for Food and Agriculture, p.37.

from southeast to northwest regions as a result of two major weather systems. The southwest monsoon winds cause high levels of rainfall in the south-eastern parts of the country during monsoon season, while in the north-western areas the Himalayas serve as a barrier to north-eastern winds blowing from Central Asia during winter, subsequently resulting in predominantly winter rainfall.

2.1.1. Water resources

Nepal has abundant water resource availability, with natural water sources available in the form of rivers, springs, lakes and groundwater. As a result, water is one of the most important natural resources in the country. Forming part of the larger Ganga River Basin, Nepal has an estimated 6,000 rivers and streams, which have a cumulative length of 45,000 km[7]. Rivers in Nepal can be classified into three groups based on their origin. The first is snow-fed rivers, which originate from snow and glaciated regions in the Himalayas. As a result of being fed by melting snow and glaciers, the flow of these rivers is perennial, and their flow is sustained during the dry season. This reliable flow, combined with the surrounding steep topography, provides opportunities for hydropower generation and irrigation downstream. The second group of rivers originate in Nepal's middle mountains and hilly regions and while they are affected by monsoon and precipitation patterns in the country, groundwater sources sustain flow at a low level during dry seasons. The third group of rivers originate in the Churia foothills, with their flow depending on monsoon precipitation and accordingly, they can be fully depleted during non-monsoon seasons.

All these factors contribute to Nepal being one of the most water-rich countries in the world, accounting for 2.27% of the world's water resources[8]. These abundant water resources — in the form of snow cover, rivers, springs, lakes, and groundwater — amounted to a per capita water availability of 7,000 m^3/yr in 2016[9]. The country's total renewable water resources are estimated to be 237 km^3/yr, of which 225 km^3/yr represents surface sources and 12 km^3/yr represents groundwater sources[10]. Nepal also has abundant groundwater resources[11], with the renewable groundwater potential of the country estimated to be 12 km^3. Groundwater is the primary water source for domestic use as well as for agricultural irrigation in the Terai region and cities such as the capital, Kathmandu. Another natural source of freshwater in Nepal is snow cover. Snowmelt from the Himalayas maintains the water levels in downstream rivers and wetlands, thereby providing important ecosystem services and supporting dependent livelihoods. Snow cover in the Himalayas also provides substantial natural freshwater storage in the form of glaciers, permafrost, and glacial lakes. Subsequent snow-melt discharges maintain the water levels in downstream rivers and wetlands, providing critical ecosystem services and supporting their dependent livelihoods. To this end, there are 3,250 glaciers with a total coverage of 5,300 km^2 in Nepal[12]. In addition, there are numerous enclosed water bodies across the country, including up to 5,358 lakes (of which 2,070 are glacial lakes), as reported by the National Lakes Conservation Development Committee[13]. Of these, noteworthy lakes include Phewa, Rupa, and Begnas in Pokhara because they serve as water sources for irrigation, recreation, subsistence fishing and other domestic uses. Glacial lakes are formed as glaciers retreat, leaving behind an embankment

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[7] Water Environment Partnership in Asia (WEPA) 2019. More information available at: http://www.wepa-db.net/policies/state/nepal/state.htm

[8] HEMS (2015). LUPWY Documentation. Developer Manual. Health and Environmental Management Society (HEMS), Chundevi, Kathmandu, Nepal.

[9] Nepal, S., Neupane, N., Belbase, D., Pandey, V.P. and Mukherji, A., 2019. Achieving water security in Nepal through unravelling the water-energy-agriculture nexus. International Journal of Water Resources Development, pp.1-27.

[10] Water Environment Partnership in Asia. http://www.wepa-db.net/policies/state/nepal/state.htm#:~:text=STATE%20OF%20WATER%20RESOURCES,springs%2C%20lakes%2C%20and%20groundwater. Accessed: 24 July 2020.

[11] http://www.wepa-db.net/policies/state/nepal/state.htm

[12] Armstrong, R., Alford, D. and Racoviteanu, A., 2009, April. A preliminary assessment of the role of glaciers in the hydrologic regime of the Nepal Himalaya. In EGU General Assembly Conference Abstracts (p. 10794).

[13] http://www.wepa-db.net/policies/state/nepal/state.htm

of rock debris — known as a moraine — which forms a weak ridge. Glacial melt subsequently fills the space between the retreating glacier and the moraines, creating the glacial lake. As a result of the unstable structure of their banks, these glacial lakes are at risk of producing a glacial lake outburst flood (GLOF), when their moraines are breached. By discharging up to tens of millions of cubic metres of water and debris in a short amount of time — within minutes to hours — GLOFs can cause catastrophic flooding downstream, loss of life and destroying homes and infrastructure[14].

Water scarcity is an emerging national concern in Nepal, primarily because of its impact on food and energy security, which impedes the growth of the country's gross domestic product (GDP)[15]. Despite being this water-rich, Nepal is ranked by the World Health Organization (WHO) as one of the world's top five countries with poorly developed drinking water systems[16]. Although water scarcity and limited sanitation services affect most of the population, these impacts are worse in inaccessible remote areas of the country as the provision of services and infrastructural development is more challenging. Those belonging to poor and marginalised communities in rural areas have limited to no access to safe water and rely on small brooks running from the mountains, spending hours travelling to access these water sources. The challenges of water scarcity are exacerbated by the growing impacts of water pollution, which is of growing concern in the country.

Nepal faces numerous challenges with regard to water pollution and even though an estimated 87% of the total population has access to drinking water, it is often not safe[17,18,19]. Supplied water (the provision of water by public utilities) is often polluted, primarily as a result of the contamination of surface and groundwater in the Kathmandu Valley by natural and anthropogenic sources[20,21]. In low-altitude lakes, pollutants are deposited by anthropogenic activity and can drain down into groundwater reserves, and high-altitude lakes can be contaminated by atmospheric long-range transportation of airborne pollutants from industrial areas[22]. The contamination of groundwater by industrial activities results in water from dug wells, hand pumps and spouts being found to have elevated nitrate and mercury levels[23]. Deep wells located within the central aquifer are severely threatened by ammonia pollution, in addition to iron, manganese and mercury concentrations exceeding the guideline values for adequate water quality set by the WHO. In the Terai Region, groundwater is vulnerable to arsenic contamination as the geological and geochemical conditions in the region promote the release of the highly poisonous contaminant from the sediments hosting the groundwater in the region[24].

Surface water is polluted by industrial and domestic waste along with the discharge of untreated sewage from densely populated residential neighbourhoods. The inadequate domestic sewage system is one of the main sources of water pollution for rivers and lakes, which are often primary

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[14] ICIMOD (2011) Glacial lakes and glacial lake outburst floods in Nepal
[15] Panthi, J., Khatiwada, K.R., Shrestha, M.L. and Dahal, P., 2019. Water poverty in the context of climate change: a case study from Karnali river basin in Nepal Himalaya. International Journal of River Basin Management, 17(2), pp.243-250.
[16]World Heealth Organization. 2017. Progress on drinking water, sanitation and hygiene: 2017 Update and SDG baselines.
[17] Budhathoki, C.B., 2019. Water Supply, Sanitation and Hygiene Situation in Nepal: A Review. Journal of Health Promotion, 7, pp.65-76.
[18] https://thewaterproject.org/water-crisis/water-in-crisis-nepal
[19] Maharjan, S., Joshi, T.P. and Shrestha, S.M., 2018. Poor quality of treated water in Kathmandu: Comparison with Nepal drinking water quality standards. Tribhuvan University Journal of Microbiology, 5, pp.83-88.
[20] Khatiwada, N.R., Takizawa, S., Tran, T.V.N. and Inoue, M., 2002. Groundwater contamination assessment for sustainable water supply in Kathmandu Valley, Nepal. Water Science and Technology, 46(9), pp.147-154.
[21] Shrestha, S., Semkuyu, D.J. and Pandey, V.P., 2016. Assessment of groundwater vulnerability and risk to pollution in Kathmandu Valley, Nepal. Science of the Total Environment, 556, pp.23-35.
[22] Sharma, C.M., Kang, S., Sillanpää, M., Li, Q., Zhang, Q., Huang, J., Tripathee, L., Sharma, S. and Paudyal, R., 2015. Mercury and selected trace elements from a remote (Gosainkunda) and an urban (Phewa) lake waters of Nepal. Water, Air, & Soil Pollution, 226(2), pp.1-10.
[23] Sharma, C.M., Kang, S., Sillanpää, M., Li, Q., Zhang, Q., Huang, J., Tripathee, L., Sharma, S. and Paudyal, R., 2015. Mercury and selected trace elements from a remote (Gosainkunda) and an urban (Phewa) lake waters of Nepal. Water, Air, & Soil Pollution, 226(2), pp.1-10.
[24] Mueller, B., 2018. Preliminary trace element analysis of arsenic in Nepalese groundwater may pinpoint its origin. Environmental earth sciences, 77(2), p.35.

sources of drinking water[25]. Nepal's 2011 Sanitation and Hygiene Master Plan has led to considerable progress in eliminating open defecation in the country, with the Open Defecation Free (ODF) initiative working toward this goal on a national scale[26]. Despite this progress, the capital city of Kathmandu is estimated to produce 150 tonnes of wastewater daily, of which almost half is dumped into rivers, contributing to the spread of diseases and degradation of essential aquatic ecosystems[27].

As water resources are deteriorating, the demand for clean water is increasing significantly in Nepal, ensuring access to safe and adequate drinking water is becoming a crucial development challenge. The Nepali public's awareness and education on adequate sanitation use and services is limited. In addition, domestic and industrial wastewater treatment plants need to be increased and improved. Nepal is presented with several barriers to overcoming this obstacle, such as intermittent energy supply, frequent natural disasters, and limited socio-economic growth, which is necessary for the development and wellbeing of the country's population.

2.1.2. Energy resources

Nepal relies heavily on traditional energy resources such as wood and cow dung, as no significant deposits of fossil fuels are available within the country[28]. While fossil fuel imports and hydropower developments have facilitated electricity generation, 3 million people (10%) in Nepal are still without access to electricity and those with access experience load-shedding, particularly during dry winter seasons[29,30]. There is significant disparity in electricity access between the provinces of Nepal (Table 1), with 95.83% of the population in Bagmati Province with electricity access in contrast to only 27.74% in Karnali province.

Table 1. Percentage of the population in each province with access to electricity in Nepal for the 2019/20 fiscal year[31].

Province	Percentage (%) of the population with access to electricity
Province No. 1	86.3
Province No. 2	87.25
Bagmati	95.83
Gandaki	87.48
Province No. 5	89.07
Karnali	27.74
Sudurpaschim	67.33

Nepal's per capita per year electricity consumption is low at 146 kWh compared with the global average of 3133 kWh per capita annually[32]. This low level of consumption results from the Nepali population's primary reliance on traditional energy sources such as wood for energy Table 2.

[25] Mishra, B.K., Regmi, R.K., Masago, Y., Fukushi, K., Kumar, P. and Saraswat, C., 2017. Assessment of Bagmati river pollution in Kathmandu Valley: Scenario-based Modeling and analysis for sustainable urban development. Sustainability of Water Quality and Ecology, 9, pp.67-77.
[26] https://sites.google.com/view/odfnepal2019/home?authuser=0
[27] Shrestha, N., Lamsal, A., Regmi, R.K. and Mishra, B.K., 2015. Current status of water environment in Kathmandu Valley, Nepal. UNU-IAS. Water and Urban Initiative Working Paper Series, 03.
[28] https://nepal.gov.np:8443/NationalPortal/view-page?id=92 Accessed 24 July 2020.
[29] Central Intelligence Agency. The world fact book. https://www.cia.gov/library/publications/the-world-factbook/geos/np.html Accessed: 29 August 2020.
[30] Government of Nepal. Ministry of Finance. Nepal: Economic Survey 2018/19. Kathmandu; 2019.
[31] Government of Nepal. Ministry of Finance. Nepal: Economic Survey 2019/20. Kathmandu; 2020.
[32] World Bank. 2014. https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?end=2014&locations=NP-1W&name_desc=false&start=1971&view=chart Accessed: 24 July 2020.

Accordingly, traditional fuels represent 69% of total energy consumption, followed by 18% for petroleum products and on-grid electricity use, while modern renewable energies are small contributors at 4% and 3%, respectively. Nepal depends on imported electricity and fossil fuels, with 2500 GW hours of electricity imported from India in the 2017–2018 fiscal year to reduce loadshedding. Diesel imports have been increasing to support growth in the industrial and manufacturing sectors, and since Nepal has no local source of petroleum products, their imports have become a major cause of the country's trade deficit, as consumption has been increasing to meet the demand of the growing population[33].

Table 2. Energy consumption sources and measures in Nepal for the 2018–2019 fiscal year[34].

Source	Proportion (%) of total national energy consumption
Traditional:	68.56
Firewood	62.27
Agricultural residue	3.08
Cow dung cake	3.21
Commercial:	28.22
Coal	6.31
Petroleum products	17.57
Electricity	4.34
Renewable	3.23

The prominent reliance on traditional energy sources in Nepal presents challenges to its natural resources as forests are under increasing threat from growing human and livestock populations and their annual requirements for fuelwood, fodder, timber, and other minor forest products. About 44,000 ha of forest area is believed to be degraded and deforested annually, while only about 4,000 ha are reforested[35]. Deforestation is recognised as a serious environmental concern across Nepal but is most intensely experienced in many parts of Tarai and Churia. Numerous factors are driving this deforestation, including socioeconomic and governance challenges[36]. Previous efforts to control deforestation and degradation have largely failed because many of these drivers of deforestation operate outside the forest sector, such as i) the transboundary economy across Nepal's open borders, ii) political unrest in the region, and iii) limited incentives for marginalised poor communities to conserve forest resources as they depend on local resources for their livelihoods. Although many of these causes still persist, several successful efforts have been undertaken in recent years to reverse Nepal's deforestation, proving most successful under a community-based forest management approach.

With Nepal's extensive natural water resources, hydropower is considered the primary option to meet the growing energy demand. The hydropower potential of Nepal's river systems is 83,000 MW, but utilisation of this power is currently only at 2% of its potential[37,38]. There are 91 hydropower plants in

[33] Renewable Energy and Energy Efficiency Partnership (REEEP) Clean Energy Information Portal, Energy Profile Nepal (Vienna: REEEP Secretariat, 2012)
[34] Government of Nepal. Ministry of Finance. Nepal: Economic Survey 2018/19. Kathmandu; 2019.
[35] https://nepal.gov.np:8443/NationalPortal/view-page?id=92 Accessed: 24 July 2020.
[36] Chaudhary, R.P., Uprety, Y. and Rimal, S.K., 2016. Deforestation in Nepal: Causes, consequences and responses. Biological and Environmental hazards, risks, and disasters, pp.335-372.
[37] https://nepal.gov.np:8443/NationalPortal/view-page?id=92 Accessed: 24 July 2020.
[38] Poudyal, R., Loskot, P., Nepal, R., Parajuli, R. and Khadka, S.K., 2019. Mitigating the current energy crisis in Nepal with renewable energy sources. Renewable and Sustainable Energy Reviews, 116, p.109388.

operation in Nepal with the total generating capacity of 1038.07 MW[39]. Another 203 hydropower plants are in the construction phase with a combined generating capacity of 7780.563 MW. Most of the existing hydropower stations are a run-of-river type, which means any reduction in water flow during the dry months will immediately result in reduced energy generation. In addition, most hydropower plants do not have reservoirs, and because 80% of rainfall occurs between June and September, overall production is reduced by as much as 35% during dry seasons.

Small-scale hydropower generation is increasingly favoured for the off-grid power supply in Nepal's remote areas[40]. Over 400 micro-hydropower plants were constructed between 2007 and 2014 across Nepal, providing 150,000 rural households with access to reliable and clean power. Nepal generated 1249 kW of electricity from the micro- and small-scale hydroelectricity plants in 2017–2018[41].

2.2. Socio-economic context

2.2.1. Socio-economic development overview

Nepal is a Least Developed Country (LDC), ranking as the 17th poorest nation globally and among the poorest in southern Asia[42]. The country has a population of 29 million[43], of which over 80% live in rural areas — mainly in the southern Terai and the central hilly region between the Mahābhārat Range and the Himalayas. Poverty among communities in the mountains, where population density is lowest, is most prevalent at 42%, in contrast to an average of 9% in urban areas[44]. Baseline information on population, socio-economic and vulnerability indicators is listed in Table 3 to contextualise Nepal's global ranking.

The Human Development Index (HDI) for Nepal has increased over the last decade, from 0.380 in 1990 to 0.579 in 2018, indicating an improvement in overall human development. The country currently ranks at 147 out of 189 countries, placing it within the 'medium human development' category. In addition to an increased HDI, Nepal has also seen an increase in its Gross National Income (GNI) per capita by 151% from 1990 to 2019. While there is improvement, Nepal's 2018 HDI value is still below the average 0.634 for other countries in the medium human development category and below the average of 0.642 for countries in South Asia.[45] Recent surveys of national living standards indicate that 30% of the population live below the national income poverty line of US$1.90/day[46].

Table 3. Baseline information on population, socio-economic and vulnerability indicators[47].

Indicator		Value	Year
Population	Total population	28,608,710	2019
	Population growth (annual %)	1.8%	2019
	Age dependency ratio- elderly	8.9%	2019
	Age dependency ratio- youth and children	45.7%	2019

[39] 60 of the hydropower plants belong to the Independent Power Producers (IPP) while the rest are owned by the Nepal Electricity Authority.
[40] Mainali, B. and Silveira, S., 2013. Alternative pathways for providing access to electricity in developing countries. Renewable energy, 57, pp.299-310.
[41] Government of Nepal. Ministry of Finance. Nepal: Economic Survey 2018/19. Kathmandu; 2019.
[42] https://www.usaid.gov/nepal/economic-growth-and-trade
[43] World Bank, 2019. More information available at: https://data.worldbank.org/country/NP
[44] Country Poverty Analysis – Nepal, Asian Development Bank 2017. More information available at: https://www.adb.org/sites/default/files/linked-documents/cps-nep-2013-2017-pa-detailed.pdf
[45] Human Development Report 202, UNDP. More information available at: http://hdr.undp.org/sites/all/themes/hdr_theme/country-notes/NPL.pdf
[46] World Bank, 2019. More information available at: https://data.worldbank.org/country/NP
[47] https://databank.worldbank.org/source/world-development-indicators

	Percentage of population with access to electricity	93.9%	2018
	Total net enrolment in primary education (men and women) [48]	96.3%	2019
	Mean years of school (of adults)	4.9 years	2017
Five-year Indicators	Life expectancy at birth	70.5 years	2018
	Crude death rate	6.4 people	2018
	Infant mortality range (per 1,000 live births)	32.2	2018
	Under-five mortality	26.7	2018
Economy	Gross Domestic Product (GDP) per capita; PPP	US$ 3,558	2019
	Gross National Income (GNI) per capita; PPP	US$ 3,600	2019
	Inflation; consumer prices	5.6%	2019
Vulnerability	Proportion of population using improved drinking water resources[49]	91.6%	2015
	Global Needs Assessment (GNA) Crisis Index[50]	0	2014
	GNA Vulnerability Index[51]	2	2014

Until signing a Comprehensive Peace Agreement in 2006, the country experienced a decade-long armed violent conflict between the Government of Nepal (GoN) and the Maoist Communist Party of Nepal[52]. Following the 2006 peace agreement, Nepal has been focused on peace building, social reconciliation and economic revival. In 2015, Nepal became a democracy and transitioned its constitution to establish a federal structure. The newly restructured constitution and an ongoing shift to federalism aim to address the poverty and inequalities that existed under — and were perpetuated by — decades of civil conflict. In 2017, elections were successfully held at the federal, state and local tiers, indicating a complete shift to federalism. However, while the federalist structure presents opportunities for Nepal to reset as a country, it also brings about new challenges and a source of fragility in the country. Accordingly, potential governance challenges include: i) clarification of the functions and accountability of the federal, state and local governments; ii) creating a conducive environment for private sector investment; and iii) addressing limitations in governance that may worsen in the early years of a new federal system[53].

In recent years, while undergoing the constitutional development process, Nepal has experienced major economic and development challenges. The first was a series of earthquakes in 2015, which led to extensive loss of lives and damage or destruction of homes and important infrastructure. To prioritise rehabilitation and reconstruction in the wake of these earthquakes, the GoN introduced a five-year Reconstruction Strategy[54]. Under this strategy, interventions that promote sustainable livelihoods and accelerate the reconstruction of infrastructure lost during the earthquakes will be prioritised by GoN for several years into the future. In 2015, Nepal was also confronted with its second major challenge — a trade blockade on the border of Nepal and India, precipitated by the country's constitutional changes. As previously mentioned, Nepal is landlocked by India and China, and this geographic disadvantage makes it difficult for the Nepalese economy to interact with countries other than its much larger neighbours. The four-month long trade blockade crippled the national economy

[48] https://ourworldindata.org/grapher/mean-years-of-schooling-long-run?tab=chart&country=~NPL
[49] https://ourworldindata.org/grapher/share-of-the-population-with-access-to-improved-drinking-water?tab=chart&country=~NPL
[50] Global Needs Assessment (GNA) 2014: Global Vulnerability Index. More information available at: https://reliefweb.int/sites/reliefweb.int/files/resources/gna_2013_2014%20%281%29.pdf
[51] Global Needs Assessment (GNA) 2014: Global Vulnerability Index. More information available at: https://reliefweb.int/sites/reliefweb.int/files/resources/gna_2013_2014%20%281%29.pdf
[52] https://peacemaker.un.org/nepal-comprehensiveagreement2006
[53] World Bank country overview 2020. More information available at: https://www.worldbank.org/en/country/nepal/overview#1
[54] Government of Nepal's Post Disaster Recover Framework can be found at: https://www.recoveryplatform.org/assets/publication/PDNA/RecoveryFrameworks/Nepal_Earthquake_2016_PDRF.pdf

and highlighted the country's overdependence on imports from India. As a result, Nepal's priorities now include developing self-sufficiency in basic goods such as food, medicine and energy.

Despite these economic and developmental challenges, Nepal has still experienced a substantial decline in incidence of poverty[55], which has fallen from 68% of the population in 1996 to 25% in 2011[56]. However, since 2014 the proportion of the population living in poverty slowly increased over five years, to 30% in 2019. This is likely to be exacerbated by 2020's low economic growth, resulting from a national lockdown in response to the Covid-19 pandemic.

2.2.2. Major economic sectors in Nepal

Most of Nepal's population are dependent on the country's agricultural sector for their livelihoods. In particular, the fertile floodplains of the Terai region is the country's most productive region, accounting for 56% of the national grain production despite only covering 23% of Nepal's total land area[57]. Despite the importance of agriculture, limited access to improved technologies — such as fertilizers and improved seeds — and the use of inefficient techniques result in low yields. Moreover, only 28% of Nepal's cultivated land is under irrigation, which means agricultural outputs depend on water availability[58]. As a result, agriculture — and ultimately community livelihoods — are heavily dependent on rainfall. Increased flood events, droughts and changing rainfall patterns that are occurring as a result of climate change leads to the destruction of crop yields or disruption in cultivation and planting[59].

In recent years, with the improved use of science and technology, Nepal's economy has gradually shifted away from largely subsistence agriculture to industry and services. As a result, the contribution of the agricultural sector to the economy is declining, while contributions from the industrial sector are growing. Consequently, although 66% of the national population engages in agriculture, the agricultural sector only accounts for 33% of the national GDP[60].

Tourism — particularly in Nepal's middle and upper mountainous regions — is another important economic sector in Nepal that has experienced growth in recent years, providing one of the country's most substantial sources of foreign currency. Mount Everest alone generates US$13 million a year, and the annual number of visitors to Nepal's national parks averages over 500,000 people[61]. In 2019, visitor spending in the country comprised 31% of the total national exports[62]. The tourism-linked service sector, which includes restaurants and hotels, employs 20% of the population. Overall, the travel and tourism industry contributed 6.7% of the total GDP in 2019[63].

In terms of Nepal's energy sector, the country has no known significant deposits of oil, gas or coal and does not have any refineries for producing oil products[64]. As a result, the country relies on imports from India for its oil use. Most energy consumption in the country is generated by traditional sources

[55] Based on the international poverty line of $1.25 per day.
[56] Country Poverty Analysis – Nepal, Asian Development Bank 2017. More information available at: https://www.adb.org/sites/default/files/linked-documents/cps-nep-2013-2017-pa-detailed.pdf
[57] Ministry of Agriculture and Co-operatives (MOAC). 2010. Singhadarbar, Kathmandu Nepal, Statistical Information on Nepalese Agriculture
[58] https://www.worldbank.org/en/results/2014/04/11/nepal-irrigation-and-water-resource-management
[59] Participatory assessment of multiple socio-economic drivers and climate stresses leading to differentiated vulnerabilities in the Hindu Kush Himalaya (2019) HI-AWARE Working Paper. Report available at: https://lib.icimod.org/record/34486
[60] Country Poverty Analysis – Nepal, Asian Development Bank 2017. More information available at: https://www.adb.org/sites/default/files/linked-documents/cps-nep-2013-2017-pa-detailed.pdf
[61] Nepal Department of Tourism. 2017.
[62] Travel & Tourism Economic Impact 2020. Nepal. 2020. World Travel and Tourism Council (WTTC)
[63] Travel & Tourism Economic Impact 2020. Nepal. 2020. World Travel and Tourism Council (WTTC)
[64] Ministry of Population and Environment. 2016. Intended Nationally Determined Contributions (INDC). Communicated to the United Nations Framework Convention on Climate Change (UNFCCC)

of energy — such as firewood, agricultural waste and animal dung[65]. This is attributed to limited alternative sources, particularly in rural areas. These practices further contribute to deforestation and subsequent soil erosion and depletion, which lead to increased flooding and landslide risks.

As mentioned in Section 2.1.2, Nepal has a considerable amount of hydropower potential provided by the perennial nature of the expansive Nepali river system and the steep gradient of the country's topography. The development potential of Nepal's hydro resources is 83,000 megawatts (MW) of which 42,000 MW are technically and economically viable for exploitation[66]. Despite this potential capacity, existing hydropower stations have only been able to develop 680 MW of power in recent years, or less than 2% of the total commercial generation potential. With these hydroelectricity sources left unutilised, total energy consumption in the country is low and only 1% of the country's energy requirements are fulfilled by electricity. The slow progress of hydropower development results from: i) inadequate planning and investment in generation, transmission, and distribution capacity; ii) concerns about the ability of the Nepal Electricity Authority (NEA) to honour take-or-pay contract obligations; and iii) delays in project development, caused partly by legal and regulatory limitations[67]. If Nepal is able to overcome these barriers, the hydropower produced could not only be applied within the country but also exported to neighbouring countries and become a mainstay of Nepal's economy.

2.2.3. Vulnerability of the population

Overall, Nepal is confronted with high incidences of natural disasters including, *inter alia:* floods, droughts, landslides, earthquakes, forest fires, GLOFs and avalanches. Reports from Nepal's Ministry of Home Affairs (MoHA) indicate that over the past 10 years, more than 4,000 people have died from climate-induced disasters. Moreover, these disasters have resulted in accumulated economic losses of US$5.34 billion as of 2015[68]. Nepal's risks and vulnerabilities to natural disasters are exacerbated by: i) a strong dependence on monsoon-fed agriculture; ii) farming and human settlements in fragile terrain; iii) poor infrastructure; iv) environmental degradation; and v) climate change impacts.

Despite Nepal's numerous economic and governance challenges in recent years (Section 2.2.1), poverty in the country has reduced in recent years. On average, poverty has reduced by at least one percentage point every year during the last two decades[69]. However, this progress is not equally spread across the country. Some social groups and geographical areas remain far below the national average. In particular, economic and human development have been greatly constrained in the country's mountainous terrain, primarily because of its associated problems with inaccessibility and its high susceptibility to natural and climate-induced disasters[70].

Without access to the country's hydroelectricity potential, only 40% of Nepal's population has access to electricity. At present, the bulk of energy needs are met by fuelwood — exacerbating the country's deforestation problem, which subsequently contributes to landslides and flooding. Demand for electricity has grown over recent years by an average of 7.9% annually, resulting in a widening supply-demand gap. As a result, Nepal now suffers from a considerable power shortage. Imports from India have, to some extent, bridged this gap, as well as the application of administrative load shedding in

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[65] Nepal Energy Sector Assessments, Strategy and Road Map. Asian Development Bank. 2017. More information available at: https://www.adb.org/sites/default/files/publication/356466/nepal-energy-assessment-road-map.pdf
[66] Nepal Energy Sector Assessments, Strategy and Road Map. Asian Development Bank. 2017. More information available at: https://www.adb.org/sites/default/files/publication/356466/nepal-energy-assessment-road-map.pdf
[67] Nepal Energy Sector Assessments, Strategy and Road Map. Asian Development Bank. 2017. More information available at: https://www.adb.org/sites/default/files/publication/356466/nepal-energy-assessment-road-map.pdf
[68] Nepal Ministry of Home Affairs (MoHA). Disaster Preparedness Network, 2018.
[69] Country Poverty Analysis – Nepal, Asian Development Bank 2017. More information available at: https://www.adb.org/sites/default/files/linked-documents/cps-nep-2013-2017-pa-detailed.pdf
[70] Ministry of Forests and Environment. 2021. Third National Communication to United Nations Framework Convention on Climate Change

most parts of the country. Load shedding is frequent, with occurrences of up to 11 hours daily. Consequently, Nepal ranks 137th out of 147 countries on a scale of quality of electricity supply[71].

Nepal's current hydropower plants are predominantly run-of-the-river plants[72], which leads to power shortages during the dry season when demand rises but water flow decreases. This shortcoming will be exacerbated as climate change results in more variable rainfall patterns, which lead to longer dry seasons (see Section 4.3). Moreover, the development of more hydropower infrastructure is vulnerable to the effects of climate change because plants need to be installed high up in watersheds to maximise their energy generating potential. This exposes key infrastructure to GLOF risk, which is intensified by increasing temperatures resulting from climate change.

Another barrier to installing hydropower infrastructure is caused by inaccessibility to the mountainous regions where plants need to be installed. Generally, transport facilities in Nepal are limited. By regional standards, road density is relatively low across the country at 9.3km/100 km^2 of land[73] and road accessibility differs spatially throughout the different regions of Nepal. Road connectivity is the highest along the southern lowlands, particularly along Nepal's southern border with India, where road density and population size are the highest. In the north of the country, mountainous terrain, paired with low road density and inadequate road quality, leaves large portions of the population disconnected. Nationally, the Rural Access Index (RAI)[74] is 54%, resulting in approximately 10.3 million rural residents unconnected to roads that are in good or fair condition. Two districts — Humla and Dolpa — have no connectivity at all. Limited road infrastructure and poor quality of roads obstruct the delivery of goods and services to communities in these areas. Low access and mobility in these regions also impact the delivery of aid to communities in the event of a disaster such as a GLOF or an avalanche.

Even in regions such as the lowland Terai, where road density and quality are high, the roads are often at high risk of flooding. In the Himalayan region, the density of paved roads is low compared to the Terai and Churia Hills regions, but there are numerous trekking trails that provide connectivity throughout Nepal's national parks. These trails are important for tourism in these areas and also provide access to mountain communities. In these regions, roads — both paved or unpaved — are at risk of destruction from GLOFs and landslides. This can substantially impact daily life, economic productivity and industry, most acutely in mountainous areas where access is already limited.

This inadequate transport infrastructure constrains the connectivity for food supply across the country, particularly for mountain communities. As a result, food security is a concern in some areas of Nepal, although not necessarily because of food shortages. Overall, Nepal has a small surplus of food grains. However, there are major dislocations in supply and demand. Periods of shortage between harvests often occur in the mountains, while substantial amounts of food grain are moved to India from the Terai, where most of the grain is grown. As a result of limited adequate transportation and infrastructure, surplus food grain from the Terai does not move north into the food deficit areas of the mid-mountain region. Opportunities to increase agricultural production in these mountain regions are limited, as almost all land capable of cultivation is already tilled[75]. Attempts to increase the cultivated land area by cutting into standing forests exacerbate deforestation and subsequently aggravates erosion, resulting in reduced yields and land losses from landslides.

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[71] ADB. 2015. Asian Development Outlook 2015: Financing Asia's Future Growth. Manila.

[72] Run-of-river power plants are built on rivers and use the kinetic energy of water flowing down a gradient to generate electricity.

[73] Transport & ICT. 2016. Measuring Rural Access: Using New Technologies. Washington DC: World Bank. More information available at: http://documents1.worldbank.org/curated/en/367391472117815229/pdf/107996-REVISED-PUBLIC-MeasuringRuralAccessweb.pdf

[74] An indicator developed by the World Bank which measures the proportion of people who have access to an all-season road within an approximate walking distance of 2 km.

[75] Tilling is the agricultural preparation of soil for crop cultivation by mechanical agitation or stirring.

2.3. Indigenous Peoples in Nepal

The information presented in this subsection was obtained mostly through consultations with Indigenous Peoples groups in the project area during the development of the proposed project. Details on these consultations are presented in Section D.5 of the Funding Proposal and Annex 7: Stakeholder consultations and engagement plan.

Nepal is an ethnically complex and diverse country, with the national census[76] in 2011 recognising 126 Indigenous castes[77] and ethnic groups, 123 Indigenous languages and nine religions among these groups. Within the proposed project area, there are Rai, Limbu and Gurung Indigenous communities, who speak Tibeto-Burman languages[78]. These Indigenous Peoples rely on agriculture for their livelihoods, with most of the communities practising subsistence farming, which is vulnerable to climate change impacts, particularly flooding. The vulnerability of these communities to climate change impacts is compounded by their reliance on climate-sensitive resources, such as local water supplies, agricultural land, fuelwood and medicinal herbs — as well as climate-sensitive activities such as farming and livestock rearing. With ongoing changes in climatic conditions occurring in Nepal, these communities are facing challenges in continuing their traditional livelihoods and practices. For example, climate change is causing a shift in monsoon patterns, with the monsoon season having been observed by communities in the project area to begin at unexpected or untimely times of the year. These changes, combined with prolonged dry spells, have severe impacts on crop production and livelihoods as communities may be forced to leave agricultural land barren because of the uncertainties in rainfall or diseases becoming more prevalent under climate change conditions. In addition to the negative impacts on livelihoods, climate change has influenced the spatial distributions of indigenous plant species, many of which Indigenous communities rely on for producing traditional clothing items, as well as for medicinal purposes.

A relationship with nature is central to Nepalese Indigenous Peoples' culture, which extends beyond sustenance of lives and livelihoods and into emotional and cultural dimensions of value. Changes in the environment caused by climate change and human development fragment this relationship, putting knowledge systems and skills that are embedded in nature at risk. Water is particularly important to Indigenous Peoples in the proposed project area. Beyond consumptive value, the communities' relationship with water is culturally crucial as they believe that calamities related to water — such as floods or Glacial Lake Outburst Floods (GLOFs) — are related to Gods or ancestors. These communities traditionally preserve water resources, holding them as sacred elements. Consequently, any infrastructure or dilution of the structure of natural resources — including lake lowering — may negatively impact Indigenous Peoples' cultural practices and wellbeing. The knowledge among these communities regarding water resource management has not yet been documented effectively and is therefore not incorporated into plans or policies created by the government of Nepal. Further to climate change and natural disasters, when asked to identify threats to their communities, Indigenous Peoples indicated the impacts of inappropriate policies, laws and interventions. For example, restrictions on land use prevent Indigenous Peoples from accessing resources that are necessary for their cultural and livelihood needs.

Governance structures within Indigenous Peoples' communities include village chiefs and head priests in each village. As authority figures in the community, chiefs are often consulted on matters

[76] CBS (2011). National population and housing census. Kathmandu: Government of Nepal, National Planning Commission Secretariat, Central Bureau of Statistics.
[77] The Nepalese caste system broadly borrows the classical Hindu Chaturvarnashram model, consisting of four broad social classes or varna: Brahmin, Kshatriya, Vaishya, Sudra.
[78] Tibeo-Burman languages comprise a group of approximately 250-300 languages spoken throughout countries in Southeast Asia, mostly in remote mountain areas.

concerning the village. Community priests also play an important role in climate change response, as Indigenous beliefs about the causes of climate change are related to Gods or ancestors. Indigenous Peoples often rely on traditional Lama gurus or shamans for forecasting natural disasters in the community. Combining these systems of Indigenous Peoples into project interventions will help ensure the effectiveness and sustainability of the project as it will relate to a fundamental element of community life in the context and will foster community ownership. Similarly, Indigenous Peoples in the proposed project area have traditional systems of communities — called a *Katuwal* system — used for relaying messages and information. These systems can co-create and play active roles in disseminating information about the need for early warning systems (EWS).

The design of the proposed project encourages ownership and benefits by acknowledging and appropriately incorporating traditional practices, knowledge and skills of Indigenous Peoples in the project area. These communities have practised and adapted different measures over centuries in response to changing climate conditions. Particular focus has, therefore, been placed on considering the Indigenous and local techniques that are effective in building resilience among vulnerable communities in Nepal.

2.4. Gender considerations in Nepal

In Nepal, traditional family structures are grounded in beliefs that men have predominance over women. Gender roles may vary with context, caste[79], ethnic group, religion and socio-economic class. Generally, however, women and girls are frequently disadvantaged by many traditional practices, including, *inter alia*: the dowry system, early marriage, stigmatization of widows, family violence, polygamy, son-preference and *chhaupadi*[80,81]. Within families, Nepalese girls have the responsibility of helping their mothers with housework, while men and boys generally do not participate in domestic work[82]. Women also play a large role in the management and care of family farm animals and livestock, contributing to 70% of the work[83]. Their roles can include: i) day-to-day decisions about animal grazing; ii) collection of water and fodder; iii) watering and feeding livestock; iv) application of composts; and v) home-based processing of livestock products. Although women contribute significantly to the livestock and agricultural sectors, surveys show that women make little contribution to decision-making in livestock rearing and management. Even in the cases where women do have ownership over livestock or property, they are marginalised from access to credit and newer technologies. This marginalisation limits them to traditional practices instead of investing in more value-added and higher income generation activities, such as dairy or meat processing and improved dairy animal farming practices[84]. Limited access to new technologies also puts women at a disadvantage for responding to new and emerging pests and diseases that are outside of the realms of traditional knowledge and local management methods. While women's economic contributions are substantial, their labour is often not credited because the nature of the work is informal and the traditional role of women as caretakers is not accounted for.

Household division of labour is gendered in Nepal. The primary responsibility of women is water, fuelwood and fodder collection, while men are responsible for income-generating activities such as farm work. Trends of decreasing or irregular availability of water, and long periods of drought, has a

[79] Castes are hereditary classes of Hindu society, distinguished by relative degrees of ritual purity or pollution and of social status. The Nepalese caste system broadly borrows the classical Hindu model consisting of four broad social classes: Brahmin, Kshatriya, Vaishya, Sudra.
[80] *Chhaupadi* is a traditional practice where women are girls are confined to a kind of cow-shed outside of the house during their menstruation period, mostly practiced in East Western Nepal.
[81] Nepal Gender and Protection in Brief. CARE. 2015. More information available at: https://reliefweb.int/sites/reliefweb.int/files/resources/gender_and_protection_gorkha_lamjung_dharding_khatmandu_ds_final.pdf
[82] https://www.adb.org/sites/default/files/publication/28745/gender-case-study-nep.pdf
[83] https://www.adb.org/sites/default/files/publication/28745/gender-case-study-nep.pdf
[84] https://www.adb.org/sites/default/files/publication/28745/gender-case-study-nep.pdf

direct impact on women's water fetching time. When women need to travel further and spend more time collecting water, it limits their available time for social, educational and livelihood opportunities[85]. In addition to constraining time, further water collection travel creates safety and security concerns, especially where the terrain is rugged, and areas are remote or isolated.

Because of an increased workload as a result of climate change impacts, women's mobility and participation in community initiatives, committees and decision-making processes is limited. Even when opportunities are presented, women experiencing time poverty are unable to take advantage of them. As mentioned above, caring and household work is traditionally a woman's responsibility. In the communities of the proposed target areas, even women in positions such as elected ward members, Community Forestry Executive members and Female Community Health Volunteers are required to finish their household duties before participating.

As compared to men, women across all social and economic groups are more often excluded from accessing climate change and development resources. However, the degree of exclusion and vulnerability is highest among poor single women, particularly those living in the remote and disaster-prone areas targeted by the proposed project. With regards to the frequent climate hazards faced by these communities, women have less access to early warning and climate information and generally lack the skills to survive extreme events. Women and marginalized groups are poorly represented in structures for planning disaster related policies and programmes. As a result, the valuable knowledge, skills, experience and coping capacities that women can offer — which differ from those of men — are ignored. Further to this, policy makers and planners give little attention to the social barriers and constraints that hinder women's participation in capacity building around disaster responses and their access to information that could help achieve better preparedness.

During natural disasters, records show that more women than men die or get injured from climate change related hazards[86]. This is the result of, *inter alia*: i) women's lack of access to information; ii) cultural and social restrictions which limit the mobility of women and their ability to avoid disasters; iii) lack of decision-making power and access to resources and training related to climate information. In cases where the mortality rate for women was three times higher than for men, studies indicated that the main reason for this high mortality rate was early warning signals not reaching women[87]. In times of displacement, women face the risk of increased sexual violence in temporary shelters. Women are also met with the burden of providing increased care of vulnerable children, sick, disabled or old age people during climate disasters.

In recent years, there have been changes to improve the challenges faced by women and girls in Nepal. The government has been legislating for more gender equality. Nepal was the first country in Asia to develop a National Action Place on Women's Peace and Security in 2011[88]; and women's and girls' rights are protected in the Comprehensive Peace Agreement, signed in 2006 between the Government of Nepal and the Communist Party of Nepal (Maoist)[89]. However, progress in traditional systems has been slow.

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[85] https://journals.sagepub.com/doi/full/10.1177/2158244018823078#_i18
[86] ICIMOD. (2014). Flood Early Warning Systems in Nepal. A Gendered Perspective Working Paper 2014/4, International Center for Integrated Mountain Development, Nepal.
[87] UNEP (1997) 'Asian disaster management news: Gender and disaster.' A Newsletter of the Disaster Management Community in Asia and the Pacific 3(3). Nairobi, Kenya: UNEP
[88] http://peacewomen.org/sites/default/files/nepal_2011.pdf
[89] https://peacemaker.un.org/nepal-comprehensiveagreement2006

3. Selection process for target river basins and glacial lakes

A report published in 2020 by ICIMOD and UNDP[90], in collaboration with the government of Nepal (GoN), updated the status and changes in the number and size of glacial lakes in the Koshi, Gandaki and Karnali basins in the Hindu Kush Himalayan region[91]. Glacial lakes with an area equal to or larger than 0.003 km^2 were mapped using Landsat images and remote sensing as part of a survey of the area. The study found 3,624 lakes located in the three basins, of which 2,070 are in Nepal. Of the total number of lakes, 1,410 are larger or equal to 0.02 km^2, which are considered large enough to cause a glacial lake outburst flood (GLOF). The following criteria were used to identify potentially dangerous lakes: i) characteristics of the lakes and their dams, such as the area of the lake and the condition of the dam; ii) the characteristics of the source glacier (such as the condition of hanging glaciers, the distance to lakes, the steepness of glacier tongues etc.); and iii) the physical condition of the surroundings (such as the presence of large snow avalanche sites immediately above the lake and potential rockfall or rock slide sites around the lake). As a result of this analysis, 47 glacial lakes were identified as potentially dangerous glacial lakes (PDGLs). Of these 47 PDGLs, 21 are in Nepal — 13 of which were previously identified in a previous PGDL identification study in 2011.

The identified PGDLs were then categorised into three ranks of hazard level based on their physical parameters. Most critical lakes are classified as Rank I[92]. These have a greater possibility of expansion, are dammed by loose moraine material, and are at risk of snow or ice avalanches and landslides in their surrounding that may impact the lake. In Rank I lakes, a slight rise in the water levels of the lakes or reduction in strength of their dams could cause a breach, necessitating the implementation of potential measures for GLOF mitigation. However, the lakes classified under Ranks II[93] and III[94] also have the potential to expand and therefore require close and regular monitoring to determine whether their ranking needs to be recategorized.

Of the 21 PDGLs identified in Nepal, four Rank I glacial lakes have been prioritized for intervention under the proposed project, namely the Thulagi, Lower Barun, Lumding Tsho and Hongu 2 Lakes (Table 4). The proposed lakes are all located in the northern Himalayan region of Nepal and are the only Rank I PDGLs identified in both the 2011 and 2020 studies, for Nepal, which are yet to be mitigated. Thulagi is located in the Solukhumbu district, Lower Barun in the Sankhuwasabha district and Lumding Tsho and Hongu are in the Solukhumbu district (Figure 2.). Each of the target glacial lakes is located on unstable surroundings, with a high risk of GLOF events that threaten communities and infrastructure downstream, causing substantial socio-economic consequences.

Table 4. Details of each of the target glacial lakes.

Target glacial lake	District	Basin	Coordinates (Latitude, Longitude)	Elevation (masl)	Area (km^2)	Length (km)	Average depth (m)	Water volume (millions, m^3)

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[90] https://lib.icimod.org/record/34905
[91] These three transboundary basins comprise the majority of Nepal, with the Hindu Kush Himalayan region covers the entire country
[92] **Rank I** – Large lake and possibility of expansion due to the calving of glaciers; lake close to the loose moraine end; no overflow through the moraine; steep outlet slope; hanging source glacier; chances of snow and/or ice avalanches and landslides in the surroundings impacting the lake and dam.
[93] **Rank II** – Confined lake outlet; lake outlet close to compact and old end-moraine; hanging lake; distinct seepage at the bottom of end-moraine dam; gentle outward slope of moraine.
[94] **Rank III** – Confined lake outlet; gentle outward slope of the dam; large lake but shallow depth; moraine more than 200 m wide; old and compact moraine.

Thulagi	Manang	Marsyandg, sub-basin of Gandaki Basin	28.314767, 84.198400	4,050	0.9	2.5	54.2	36.1
Lower Barun	Sankhuwasabha	Arun, sub-basin of Koshi Basin	27.797007, 87.096101	4,050	1.99	2.5	653.2	112.3
Lumding Tsho	Solukhumbu	Dudhkosi, sub-basin of Koshi basin	27.779504, 86.613978	5,141	1.37	2.92	59.5	57.7
Hongu 2	Solukhumbu	Dudhkosi, sub-basin of Koshi basin	27.783756, 86.956724	5,205	0.89	2.29	53.42	29.1

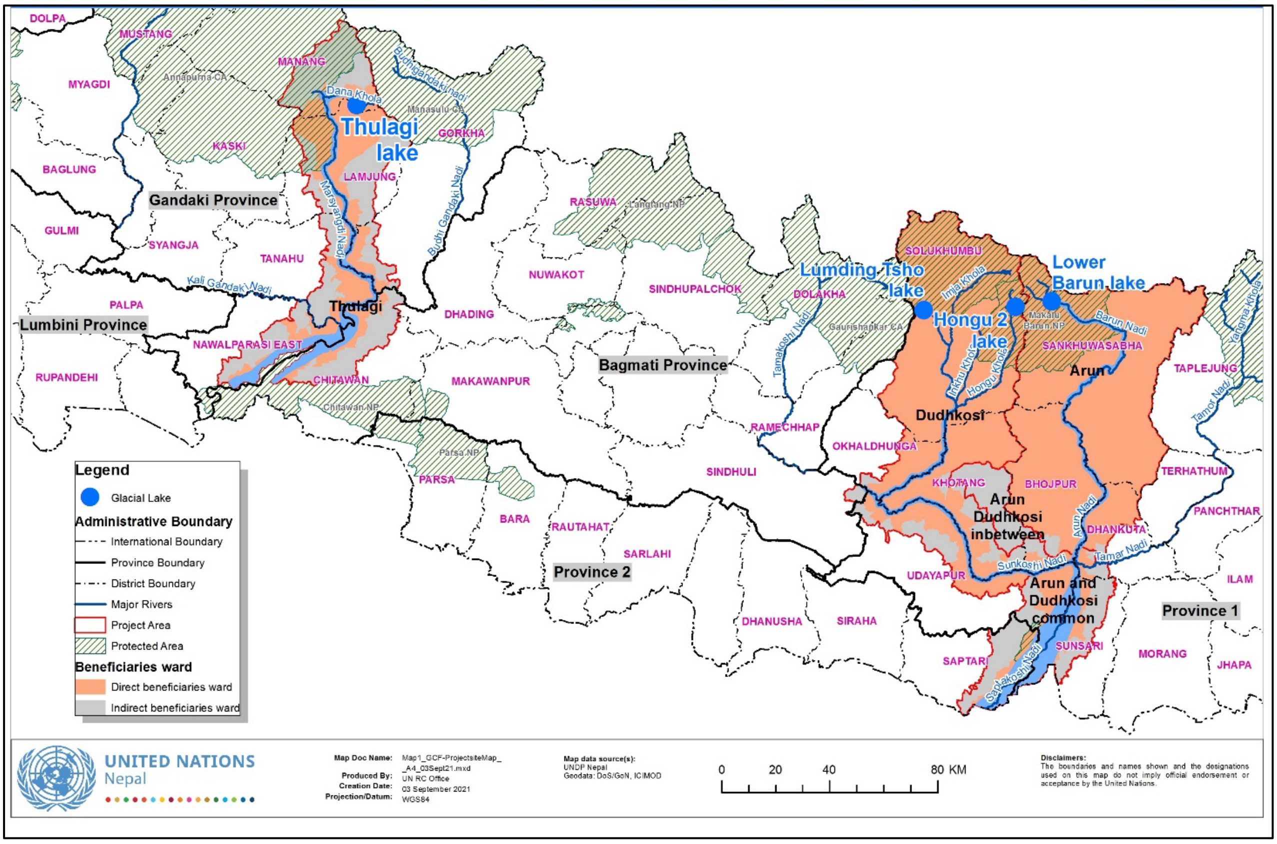

Figure 2. Locations of each of the glacial lakes, relative to one another and their respective districts.

3.1. Thulagi Glacial Lake

Thulagi Glacial Lake, locally known as Dona Tal, is located in the Marsyangdi basin, a sub-basin of the Gandaki basin. It is a moraine-dammed lake[95] of the heavily-debris covered Thulagi Glacier. The

95 A moraine is a mass of rocks and sediment carried down and deposited by a glacier, typically as ridges at its edges or extremity. A moraine-dammed lake occurs when the terminal moraine has prevented some meltwater from leaving the valley. These lakes typically exist in a long ribbon shape.

lake forms the headwaters of Dona Khola, a tributary of the Marsyangdi River. Thulagi Glacial Lake has been categorised as one of the most dangerous PDGLs identified, falling under Rank I.

3.2. Lower Barun Glacial Lake

The Lower Barun Glacial Lake is located in the Arun sub-basin of the Koshi basin, south-east of Imja Glacial Lake in the upper reaches of the Barun River. It is a proglacial[96] lake dammed by an ice-cored[97] end moraine bounded by the calving front of Lower Barun Glacier. Lower Barun Glacial Lake was formed by the coalescence of small supraglacial ponds[98] from the early to mid-1960s. The area of the lake increased by 34% from 2000 to 2017, at an average growth rate of 0.04 km^2. Over the past three years, the lake has grown by 0.19 km^2 — which is a 50% faster growth rate than the previous long-term average growth rate. These changes in size indicate the glacial lake's high risk of bursting.

3.3. Lumding Tsho Glacial Lake

Lumding Tsho is a pro-glacial lake formed at the calving of the heavy debris-covered Lumding Glacier. This lake poses a threat for a GLOF in the Dudhkosi Valley in the Mount Everest Region of the Himalayas. Similar to Lower Barun Glacial Lake, Lumding Tsho has been expanding as a result of the retreat of its corresponding glacier. Remote sensing data of the lake's area, length and depth indicate that Lumding Tsho Glacial Lake is growing at an average of 0.023 km^2 per year. While the Lumding Tsho Lake is at a high risk of bursting, no seepage, ponds or karst-like features have been observed at the terminal moraine, indicating that the moraine is relatively stable.

3.4. Hongu 2 Glacial Lake

Hongu 2 Glacial Lake, located in the same sub-basin as Lumding Tsho, is a moraine-dammed kettle lake[99] that is located just below Chamlang Peak (7,319 m). This lake was not listed as a high risk for GLOFs when examined in 2007 but was updated to Rank II by ICIMOD in 2010. Hongu 2 is determined to be at high risk of GLOFs as a result of its highly unstable terminal moraine. Ice overhangs have been observed on Chamlang peak, which could be displaced into the glacial lake and easily break the unstable terminal moraine. Further details on the selection of project sites and intervention options are presented in Section 5 below.

4. Climate change context

4.1. Climate baseline

While Nepal is dominated by a temperate climate with dry winters and hot summers, polar conditions feature at higher altitudes along the northern border of the country, with intermediate cold climates south of the higher peaks, transitioning into tropical conditions along the southern border[100]. The country's mean annual temperature is 12°C and average annual rainfall is 1,360 mm[101]. Nepal's climate varies noticeably both seasonally (Figure 3) and according to altitude. Winters are generally

[96] A proglacial lake is a lake formed either by the damming action of a moraine during the retreat of a melting glacier, a glacial ice dam, or by meltwater trapped against an ice sheet as a result of isostatic depression of the crust around the ice.
[97] Ice-cored moraines are ice-marginal landforms that comprise a discrete body of glacier ice buried underneath sediment.
[98] A supraglacial pond is a pond of liquid water on the top of a glacier. They may reach kilometres in diameter and be several meters deep. They may last for months or even decades at a time but can empty in the course of hours.
[99] Kettles form when a block of stagnant ice (a serac) detaches from the glacier. Eventually, it becomes wholly or partially buried in sediment and slowly melts, leaving behind a pit. In many cases, water begins fills the depression and forms a pond or lake—a kettle.
[100] Karki, R., Talchabhadel, R., Aalto, J. and Baidya, S.K., 2016. New climatic classification of Nepal. *Theoretical and applied climatology*, *125*(3-4), pp.799-808.
[101] https://climateknowledgeportal.worldbank.org/country/nepal/climate-data-historical. Accessed 23 July 2020

dry while, in the summer months (June–September), the monsoons drive the rainfall in Nepal as they migrate through the country. These monsoons bring 250–450 mm of rainfall each month to most of the country — except for the north-western mountains that receive 100–150 mm/month.

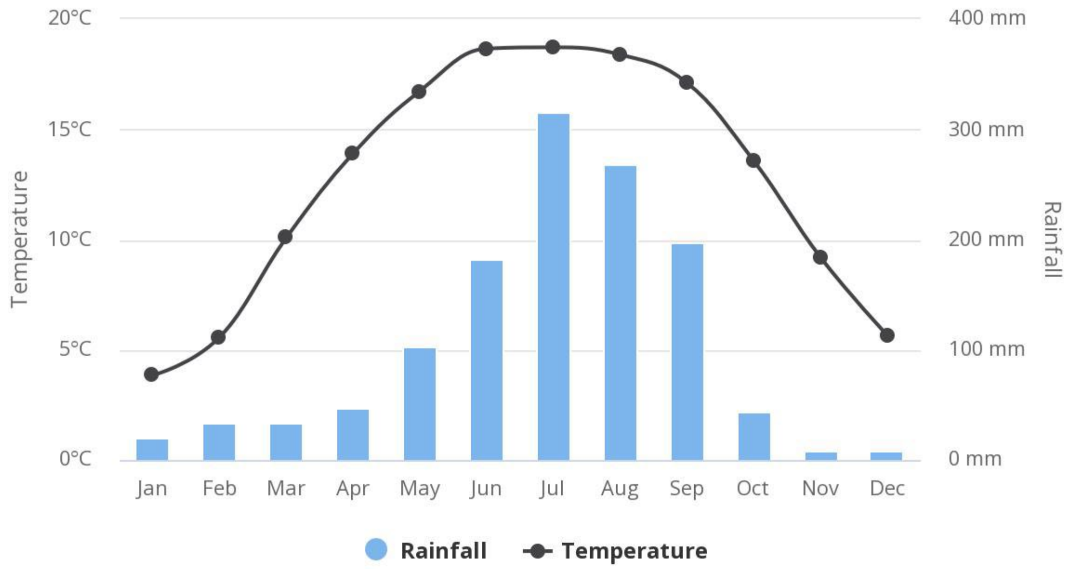

Figure 3. Average monthly temperature and rainfall of Nepal for 1991–2016[102].

Nepal's climate variability is impacted by the extensive elevation span from 67m to 8,848 m above sea level (masl), across a north–south trajectory of only 80 km. The country can be divided into five regions (Figure 4,Table 5) with distinct climates; these are: i) the Terai plains; ii) the Siwalik hills; iii) the Middle Mountains; iv) the High Mountains; and v) the High Himalayas[103]. The Terai plains lie below 500 masl with humid tropical climates and average temperatures of 30°C in the summer and 10–15°C in the winter. The more elevated areas, such as the Siwalik hills at 500–1,000 masl, have a moist tropical climate and average annual temperatures of 25°C. A temperate zone features across the Middle Mountains at elevations of 1,000–3,000 masl, with average annual temperatures of 20°C. The High Mountains, located 3,000–5,000 masl, have a cool, sub-alpine climate with average summer temperatures of 5–15°C and winter temperatures below 0°C. Extreme conditions dominate the High Himalayas, which comprise an alpine to arctic zone higher than 5,000 masl with average annual temperatures of <0 to 5°C[104].

[102] https://climateknowledgeportal.worldbank.org/country/nepal/climate-data-historical. Accessed 23 July 2020
[103] Karki, R., Schickhoff, U., Scholten, T. and Böhner, J., 2017. Rising precipitation extremes across Nepal. Climate, 5(1), p.4.
[104] Pokharel, B., Wang, S.Y.S., Meyer, J., Marahatta, S., Nepal, B., Chikamoto, Y. and Gillies, R., 2020. The east–west division of changing precipitation in Nepal. International Journal of Climatology, 40(7), pp.3348-3359.

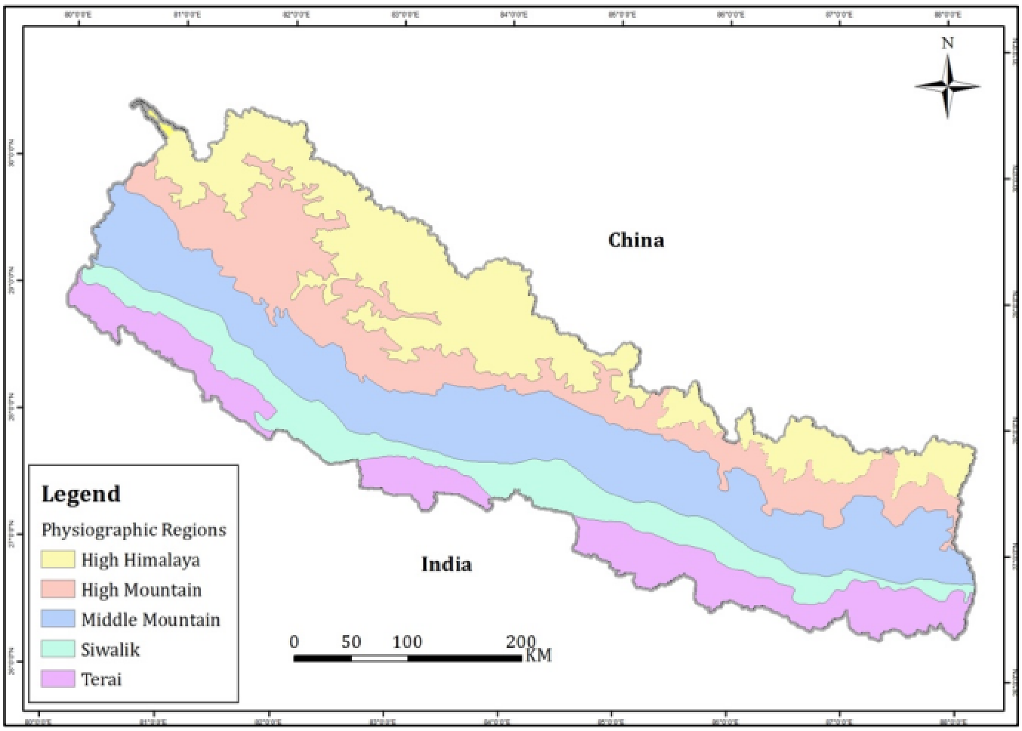

Figure 4. Physiographic zones of Nepal[105].

Table 5. Climatic division of Nepal[106].

Physiographic zone	Elevation (m)	Climate
High Himalaya	above 5,000	Tundra-type & Arctic
High Mountains	4,000-5,000	Alpine
	3,000-4,000	Sub-alpine
Middle Mountain	2,000-3,000	Cool temperate monsoon
	1,000-2,000	Warm temperate monsoon
Siwalik Hills	500-1,000	Hot monsoon & Subtropical
Terai	below 500	Hot monsoon & Tropical

As mentioned above, precipitation patterns in Nepal are dominated by the monsoon circulation system. Accordingly, precipitation occurs in intense events over a short period of time, with 80% of annual precipitation falling during the summer monsoon, which occurs in early June. This monsoon period is characterised by intense lightning and thunderstorms that last until September. Given that circulation patterns are unequally distributed over the Nepal Himalaya, precipitation that falls during the monsoon period is not uniform across the country, which results in more rainfall falling in the central-eastern region than in the north-western region. The volatility of the monsoon is also attributable to the long-term climatic variability driven by the El Niño-Southern Oscillation[107] (ENSO)

[105] Government of Nepal. Ministry of Forests and Environment. 2021. Third National Communication to United Nations Framework Convention on Climate Change.
[106] https://unfccc.int/sites/default/files/resource/nplnc2.pdf
[107] El Niño and La Niña are opposite phases of a natural climate pattern across the tropical Pacific Ocean that swings back and forth every 3-7 years on average. Together, they form the El Niño-Southern Oscillation (ENSO). The ENSO pattern in the tropical Pacific can be in one of three states: El Niño, Neutral, or La Niña. El Niño (the warm phase) and La Niña (the cool phase) lead to significant differences from the average ocean temperatures, winds, surface pressure, and rainfall across parts of the tropical Pacific. Neutral indicates that conditions are near their long-term average.

and Southern Oscillation Index[108] (SOI). During La Niña events of the ENSO, a blockage of the eastward moisture cycle over BOB develops[109] and the monsoon precipitation in Nepal becomes more intense as moisture cycles divert towards the north and subsequently interact with the southern Himalayan foothills. This redirection of moisture is controlled through the Pacific Quasi-Decadal Oscillation[110] (QDO), which operates on a longer timescale, which means there is a lagged effect of two years between the precipitation anomalies in Nepal and the extreme phases of the Pacific QDO[111]. This lagged relationship between the monsoon precipitation and the Pacific QDO is unique to Nepal and results in added variability to annual precipitation patterns, which increase the unpredictability of disaster events.

These monsoons present severe threats to Nepal, such as the associated floods and landslides which result in loss of life and extensive damage to infrastructure. Recently in 2019, 50 people were killed during floods and landslides that resulted from the monsoon rains across Nepal[112,113]. In 2020, intense rainfall events resulted in 132 deaths during the monsoon season from flooding and landslides that were caused by cloudbursts[114], with some areas receiving 140 mm of rain in just one hour[115]. These events are part of a period of high fatalities form extreme climate events, with monsoon flooding and landslides killing 80 people in Nepal in 2017[116], 53 people in 2014[117], 72 people in 2007[118], 240 people in 2003[119], and 290 people in 2002[120]. Records reveal that death as a result of disasters have increased during the period from 1971 to 2011 (Figure 5)[121]. This figure shows a period of the increasing number of fatalities. Between 1990 and 2012 around 78 major events have occurred including floods and landslides, and have resulted in fatalities of 11,112 people and causing economic damage equivalent to USD 43 million[122].

[108] The Southern Oscillation Index (SOI) is a standardized index based on the observed sea level pressure differences between Tahiti and Darwin, Australia. The SOI is one measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific during El Niño and La Niña episodes.
[109] Sigdel, M. and Ikeda, M., 2012. Summer monsoon rainfall over Nepal related with large-scale atmospheric circulations. *J Earth Sci Climate Change*, *3*(112), p.2.
[110] The Pacific Decadal Oscillation (PDO) is a robust, recurring pattern of ocean-atmosphere climate variability centred over the mid-latitude Pacific basin. The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20°N.
[111] Wang, S.Y. and Gillies, R.R., 2013. Influence of the Pacific quasi-decadal oscillation on the monsoon precipitation in Nepal. *Climate dynamics*, *40*(1-2), pp.95-107.
[112] https://www.dw.com/en/scores-dead-as-monsoons-hit-india-nepal-bangladesh/a-49577881
[113] https://www.aljazeera.com/news/2020/07/south-asia-monsoon-130-people-killed-nepal-floods-200725112334617.html
[114] A sudden, very heavy rainfall, usually local in nature and of brief duration.
[115] https://www.nepalitimes.com/latest/heavier-than-usual-monsoon-in-nepal/
[116] https://www.aljazeera.com/news/2017/08/floods-landslides-kill-dozens-nepal-india-170813132206327.html
[117] https://www.scientificamerican.com/article/at-least-53-killed-in-nepal-floods-and-mudslides/
[118] World Health Organization. 2007. Flood Fury: A recurring hazard. Available at: http://origin.searo.who.int/entity/emergencies/topics/focus_vol1.pdf
[119] https://reliefweb.int/report/nepal/nepal-floods-and-landslides-heavily-disrupted-lives-nationwide
[120] https://www.ifrc.org/fr/nouvelles/nouvelles/common/south-asia-struck-by-floods-and-drought/
[121] Ministry of Forests and Environment. 2021. Third National Communication to UNFCCC
[122] Ministry of Forests and Environment. 2021. Third National Communication to UNFCCC

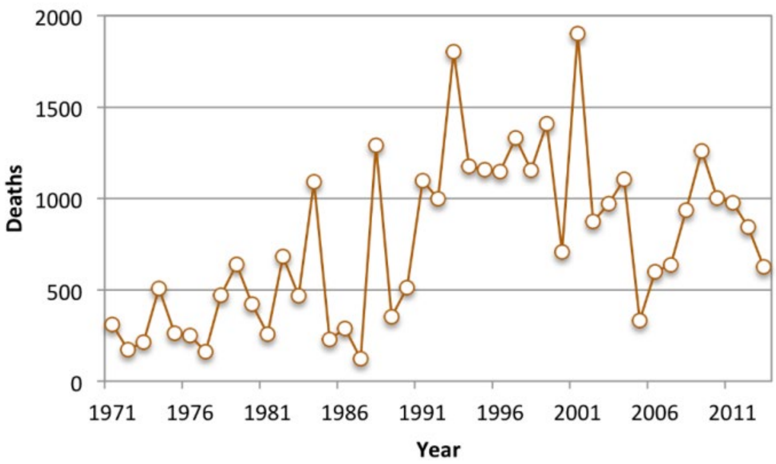

Figure 5. Number of fatalities as a result of various disasters from 1971 to 2011 in Nepal[123].

4.1.1. Extreme climate events in Nepal

Glacial Lake Outburst Floods

Glacial lakes are formed as glaciers erode land and subsequently begin to retreat[124]. In Nepal, 3,808 glaciers have been identified with 2,070 glacial lakes[125] , which are spatially and temporally heterogeneous[126] and have been increasing in quantity, volume and surface area over the last 40 years[127,128]. For example, studies reveal that the glacial lakes exhibited 25% expansion of surface areas from 1987 to 2017[129]. Glacial lakes often have structurally insecure moraines (Section 2.1) as they are usually formed of unconsolidated debris and may include — or predominantly consist of — ice that is vulnerable to melting with warming temperatures. When a glacial lake moraine fails, the result is a Glacial Lake Outburst Flood (GLOF).[130] In the Himalayas, the main trigger of GLOFs is an avalanche entering a lake, which can cause a tsunami-like wave that can overtop and erode the terminal moraine, and generate the flood[131,132,133]. Secondary trigger mechanisms include: i) displacement waves from rockfalls; ii) moraine failure as a result of dam settlement and/or piping; iii) the degradation of an ice-cored moraine, iv) seismic activity; and v) the rapid input of water during extreme events such as intense rainfall or from outburst flooding of a glacial lake upstream. Often,

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[123] https://unfccc.int/sites/default/files/resource/TNC%20Nepal_Final_v2.pdf

[124] A glacier retreats when the lower end of the glacier does not extend as far as it previously did. This occurs when the rate at which the exiting glacial ice melts is more rapid than the rate at which snowfall can accumulate and form new glacial ice. Rising temperatures and decreasing snowfall have led to increasing glacial retreat globally.

[125] ICIMOD and UNDP. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://www.np.undp.org/content/nepal/en/home/library/crisis_prevention_and_recovery/glacial_lake_inventory_2020.html?fbclid=IwAR3JuBoUUnY4OmLbtqM3eEa6TpbedW9Uiai0lUAn-K2L60tsR7ultASRzq8

[126] Khadka, N., Zhang, G. and Thakuri, S., 2018. Glacial lakes in the Nepal Himalaya: Inventory and decadal dynamics (1977–2017). Remote Sensing, 10(12), p.1913.

[127] Nie, Y., Sheng, Y., Liu, Q., Liu, L., Liu, S., Zhang, Y. and Song, C., 2017. A regional-scale assessment of Himalayan glacial lake changes using satellite observations from 1990 to 2015. Remote Sensing of Environment, 189, pp.1-13.

[128] Khadka, N., Zhang, G. and Thakuri, S., 2018. Glacial lakes in the Nepal Himalaya: Inventory and decadal dynamics (1977–2017). Remote Sensing, 10(12), p.1913.

[129] Khadka, N., Zhang, G. and Thakuri, S., 2018. Glacial lakes in the Nepal Himalaya: Inventory and decadal dynamics (1977–2017). Remote Sensing, 10(12), p.1913.

[130] A video showing the triggers and mechanisms of a GLOF is available on the International Centre for Integrated Mountain Development (ICIMOD) website at the following link: https://www.icimod.org/mountain/glacial-lake-outburst-flood/.

[131] Emmer, A. and Cochachin, A., 2013. The causes and mechanisms of moraine-dammed lake failures in the Cordillera Blanca, North American Cordillera, and Himalayas. AUC Geographica, 48(2), pp.5-15.

[132] Falátková, K., 2016. Temporal analysis of GLOFs in high-mountain regions of Asia and assessment of their causes. AUC Geographica, 51(2), pp.145-154.

[133] Westoby, M.J., Glasser, N.F., Brasington, J., Hambrey, M.J., Quincey, D.J. and Reynolds, J.M., 2014. Modelling outburst floods from moraine-dammed glacial lakes. Earth-Science Reviews, 134, pp.137-159.

the unpredictable nature of these GLOFs and the remote locations of glacial lakes make it difficult to determine the exact trigger and cause of failure, particularly as these triggering mechanisms are interconnected. Figure 6 below is a screengrab from a video showing the severe damage to infrastructure from a GLOF experienced among downstream communities. The full video is available at the following link: https://www.youtube.com/watch?v=BDPbtP-0AW8.

Figure 6. Damage to infrastructure from a GLOF experienced by downstream communities in Langmale Kharka, Upper Barun region, Sankhuwashabha, Nepal[134].

There have been twenty-six GLOF events in recorded history in Nepal, with the southern region of the Himalayas being identified as a GLOF hotspot based on records of past GLOFs[135]. While there has been an increase in the reporting of GLOFs, no statistically significant increase in the rate of GLOF occurrence has been observed, with the current rate of 1 GLOF per year in the Himalayas remaining consistent since the 1980s[136]. Although there has been no significant increase in the rate of GLOF occurrences, it is important to note that coupled with a delayed response following climate warming and an increase in quantity, volume and surface area of glacial lakes, we can expect a considerable increase in GLOF incidence throughout the 21st century as glaciers and lakes react more dynamically to anthropogenic climate warming[137]. The remote nature of many glacial lakes and lack of effective monitoring in the Himalayas result in the potential for many GLOFs to go unrecorded[138]. A recent Landsat analysis identified 22 previously unrecorded GLOFs that occurred in the Himalayas

[134] Scientific American. Full video available at: https://www.youtube.com/watch?v=BDPbtP-0AW8.
[135] Veh, G., Korup, O., von Specht, S., Roessner, S. and Walz, A., 2019. Unchanged frequency of moraine-dammed glacial lake outburst floods in the Himalaya. Nature Climate Change, 9(5), pp.379-383.
[136] Veh, G., Korup, O., von Specht, S., Roessner, S. and Walz, A., 2019. Unchanged frequency of moraine-dammed glacial lake outburst floods in the Himalaya. *Nature Climate Change*, *9*(5), pp.379-383.
[137] Bajracharya, S.R., Maharjan, S.B., Shrestha, F., Bajracharya, O.R. and Baidya, S., 2014. Glacier status in Nepal and decadal change from 1980 to 2010 based on Landsat data. International Centre for Integrated Mountain Development.
[138] Ives, J.D., Shrestha, R.B. and Mool, P.K., 2010. Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment (pp. 10-11). Kathmandu: ICIMOD.

between 1988 and 2017, more than doubling the previous tally of 17 events[139]. This analysis was based upon changes in observed glacial lake size and did not account for the seismic, geomorphic and glaciological setting of the glacial lakes, which may further contribute to unrecorded GLOFs. These results are also conflated by the increased occurrence of GLOFs during the monsoon season, where the heavy rainfalls have been shown to be a trigger of GLOF events[140]; however, because the impacts sometimes cannot be discerned from direct flooding caused by the monsoon rains, minor GLOF events occasionally go unrecorded. With the difficulty of accurately recording the occurrence of GLOFs, it becomes increasingly challenging to identify trends in GLOF frequency. As more unrecorded GLOFs are identified through improved methods of analysis, the general understanding of their associated risks and impacts increases[141].

Historically, GLOFs have had catastrophic consequences in Nepal, leading to a loss of lives and livestock, as well as damages to infrastructure and transportation routes[142]. These damages were caused by the direct impacts of flooding from GLOFs and secondary impacts such as landslides, erosion, and sedimentation in river valleys. Damages caused by GLOFs require repair efforts for years or even decades, with high economic costs and severe impacts on downstream populations. Globally, Nepal has been ranked alongside Bhutan as experiencing the overall greatest national-level economic consequences of GLOF impacts, with Nepal accounting for 22% of the global total of all societal impact-related damage, excluding deaths[143]. The Dig Tsho GLOF of 1985 and the Tampokhari GLOF of 1998 both caused considerable loss of life, property and infrastructure and had severe impacts on the livelihoods of those living downstream of the glacial lakes. Recent GLOFs in Nepal include the Seti Kosi flood of 2012[144], which affected the Seti valley with flood waters as high as 30 m and resulting in 72 deaths and destruction of dozens of structures. Nepal was also subject to the Langmoche lake flood of 2015[145] and the Lhotse glacier outburst floods of 2015 and 2016[146]. In 2017, rockfalls triggered a GLOF from the Langmale glacial lake which flooded along the channel of the Barun River. The flood waters uprooted all vegetation in the riparian zone, deposited sediment, debris, and boulders throughout much of the river channel from the settlement of Langmale to the settlement of Yangle Kharka 6.5 km downstream. Peak discharge was estimated at 4,400 ± 1,800 $m^3 s^{-1}$, and total flood volume was estimated at 1.3×10^6 m^3 of water[147]. Valuable grazing land was covered in debris and sediment, six bridges were washed away and the travel routes for tourists and pilgrims were negatively impacted.

Furthermore, notable cases of glacier retreat and glacial lake expansion have been reported in recent decades in Nepal, attributed to increasing temperatures, which can severely impact downstream

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[139] Veh, G., Korup, O., von Specht, S., Roessner, S. and Walz, A., 2019. Unchanged frequency of moraine-dammed glacial lake outburst floods in the Himalaya. *Nature Climate Change*, *9*(5), pp.379-383.
[140] UNDP and ICIMOD. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905
[141] Ibid
[142] Richardson, S.D. and Reynolds, J.M., 2000. An overview of glacial hazards in the Himalayas. Quaternary International, 65, pp.31-47.
[143] Carrivick, J.L. and Tweed, F.S., 2016. A global assessment of the societal impacts of glacier outburst floods. Global and Planetary Change, 144, pp.1-16.
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[145] Byers III, A.C., Byers, E.A., McKinney, D.C. and Rounce, D.R., 2017. A field-based study of impacts of the 2015 earthquake on potentially dangerous glacial lakes in Nepal. HIMALAYA, the Journal of the Association for Nepal and Himalayan Studies, 37(2), p.7.
[146] Rounce, D.R., Byers, A.C., Byers, E.A. and McKinney, D.C., 2017. Brief communication: Observations of a glacier outburst flood from Lhotse Glacier, Everest area, Nepal. The Cryosphere, 11(1), pp.443-449.
[147] Byers, A.C., Rounce, D.R., Shugar, D.H., Lala, J.M., Byers, E.A. and Regmi, D., 2019. A rockfall-induced glacial lake outburst flood, Upper Barun Valley, Nepal. Landslides, 16(3), pp.533-549.

communities [148,149]. An estimated 1ºC rise in temperature will cause alpine glaciers worldwide to shrink by as much as 40% in area and more than 50% in volume as compared to estimates for 1850[150,151]. In addition, Himalayan glaciers have been retreating at an increased rate since 1970[152], with a 23% and 24% decrease in glacier areas in Nepal and Bhutan, respectively, in the 33 years between 1977 and 2010[153,154]. Glacier retreat, in the range of 11–14 m/yr, has been reported in two of the western glaciers in the Manaslu conservation area in Nepal from 1962–2008[155]. The Trakarding glacier on the southwestern slope of Manaslu Himal retreated at 66 m/yr between 1957–2000, while Imja glacier showed the highest rate of retreat among Nepal's glaciers, of 74 m/yr over 2001–2006[156].

Monsoon rain-induced floods

Nepal experiences frequent flooding as a result of monsoon rainfall that occurs during the period June–September. Figure 7 shows that flooding is observed to be the most frequent natural disaster between 1985 and 2018 and has therefore negatively affected the greatest number of people during this period. Furthermore, flooding has historically caused the most widespread and significant economic damages in the country with average annual losses of US$ 143.34 million[157], and the increased severity of their impacts have been attributed to unsuitable land-use planning, unplanned settlement distribution, and deforestation upstream of watersheds[158,159]. Because of the topography, the low-lying Terai Plains are most commonly affected by these floods, and with more than half of the total population of Nepal living in these plains, the impacts are particularly severe. Furthermore, the Terai Plains are the hub for agricultural production in Nepal, so flooding in this region has significant negative impacts on the agricultural industry and, subsequently, the national economy[160].

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[148] Agrawala, S., Raksakulthai, V., van Aalst, M., Larsen, P., Smith, J. and Reynolds, J., 2003. Development and climate change in Nepal: Focus on water resources and hydropower (pp. 14-28). Paris: Oecd.
[149] Bajracharya, S.R., Maharjan, S.B., Shrestha, F., Bajracharya, O.R. and Baidya, S., 2014. Glacier status in Nepal and decadal change from 1980 to 2010 based on Landsat data. International Centre for Integrated Mountain Development.
[150] Bajracharya, S.R., Mool, P.K. and Shrestha, B.R., 2008. Global climate change and melting of Himalayan glaciers. Melting glaciers and rising sea levels: Impacts and implications, pp.28-46.
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[153] Bajracharya, S.R., Maharjan, S.B. and Shrestha, F., 2014. Understanding dynamics of Himalayan glaciers: scope and challenges of remote sensing. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(8), p.1283.
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[156] Bajracharya, S.R., Mool, P.K. and Shrestha, B.R., 2007. Impact of climate change on Himalayan glaciers and glacial lakes: case studies on GLOF and associated hazards in Nepal and Bhutan. International Centre for Integrated Mountain Development (ICIMOD).
[157] https://www.preventionweb.net/countries/npl/data/
[158] Rimal, B., Zhang, L., Keshtkar, H., Sun, X. and Rijal, S., 2018. Quantifying the spatiotemporal pattern of urban expansion and hazard and risk area identification in the Kaski District of Nepal. Land, 7(1), p.37.
[159] Chaudhary, R.P., Uprety, Y. and Rimal, S.K., 2016. Deforestation in Nepal: Causes, consequences and responses. Biological and Environmental hazards, risks, and disasters, pp.335-372.
[160] Karki, Y.K., Nepal Portfolio Performance Review. Ministry of Agricultural Development, Kathmandu, 2015.

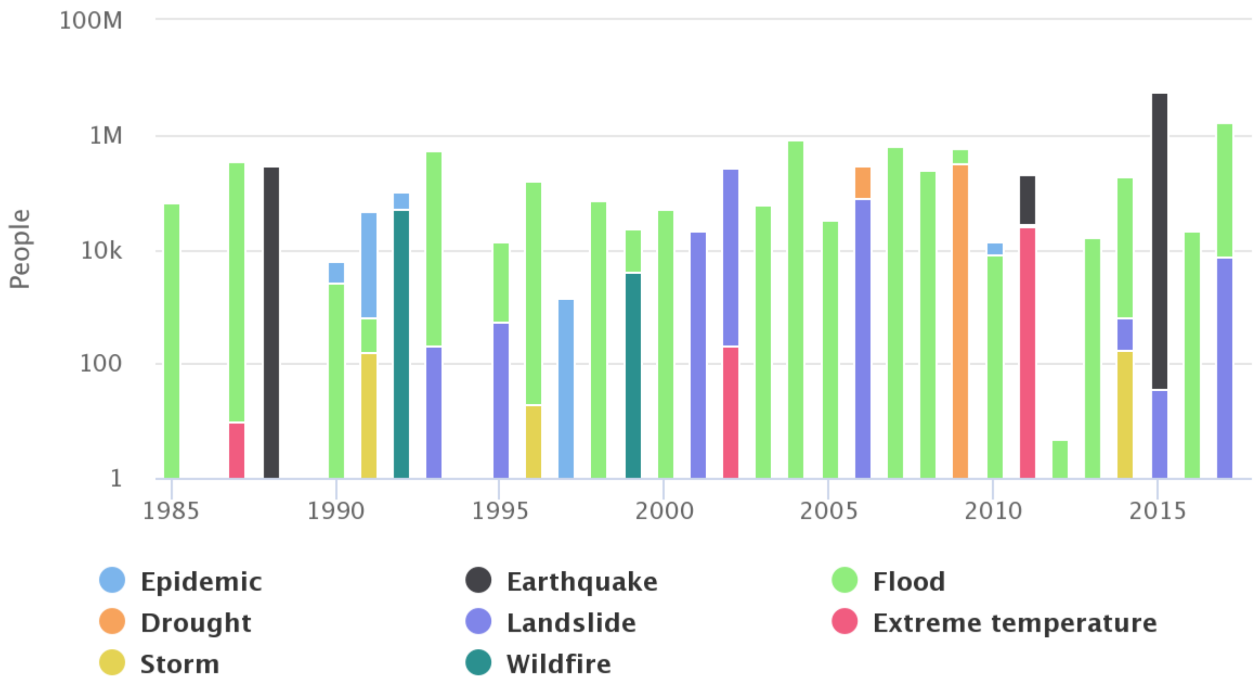

Figure 7. Natural hazards and the number of people affected in Nepal from 1985–2018[161]**.**

During the heavy monsoon rainfall mentioned earlier, landslides and flash floods occur in the Nepali mountains. On the southern plains, these intense monsoon rains lead to water breaching riverbanks and inundating large areas of land. In regions such as Terai Plains, the impacts of these flash floods are aggravated by rapid urbanisation, with construction along the embankments interfering with the existing patterns of surface water flow and subsequently causing drainage congestion[162]. These extensive changes in local hydrology have resulted in flooding in regions that have no history of similar disasters and flooding in particular. The rapidly growing construction industry has also increased the demand for sand and gravel, usually mined from upstream riverbeds during the dry season. These loosened sediments are transported downstream during the monsoon rains, which elevates the beds of rivers, causing them to meander and flood.

Since 1950, a total of 51 floods have been recorded in Nepal. Of these, 17 occurred within the last decade, becoming a nearly annual occurrence from 2016 to 2021. All floods in Nepal since 2010 have been attributed to monsoon rainfall[163]. These floods have resulted in 1,340 deaths over the last decade, with 476 injuries and a total of 2,019,845 people directly and indirectly impacted in Nepal alone[164]. Without adequate recovery and reconstruction efforts, the frequent occurrence of floods will increase already-existing national socioeconomic disparities across Nepal. For example, because more people live below the poverty line in the Terai Plains than in Nepal's hill areas, flooding could increase the difference in income and access to basic services between the Terai population and

[161] https://climateknowledgeportal.worldbank.org/country/nepal/climate-data-historical Accessed: 11 August 2020
[162] Dixit A. et. al., Flood Disaster Impact and Responses in Nepal Tarai's Marginalised Basins, in: Working with the Winds of Change. Towards Strategies for Responding to the Risks Associated with Climate Change and other Hazards. Moench, Dixit, A, (eds), ProVention Consortium, Institute for Social and Environmental Transition-International and Institute for Social and Environmental Transition-Nepal, Second Edition, Kathmandu, 2007, Chapter 6, pp. 119-157.
[163] UNDRR. DesInventar Sendai databank. Accessed: 5 August 2020.
[164] UNDRR. DesInventar Sendai databank. Accessed: 5 August 2020.

other parts of the country[165]. In addition, the economy in Terai is much less diversified, and more than 70% of its population depends on subsistence farming[166].

In 2017, Nepal experienced one of the most devastating floods in recent history. Incessant rainfall from 11 to 14 August resulted in widespread floods across 35 of the country's 77 districts, with several districts experiencing the heaviest rainfall recorded in over 60 years[167]. This led to the inundation of 80% of land in the Terai Plains, causing 134 deaths, affecting 1,688,474 people and causing a total of US$ 584.7 million in damages[168]. The heavy rains that led to the flood were a result of the monsoon trough — an elongated area of low pressure that formed parallel to the foothills of the Himalayas. The combination of this low-pressure system with moisture from the Bay of Bengal (BOB) released substantial rainfall on the southern parts of the Churia range and the mid-hills. The shifting of this monsoon trough towards and away from Nepal is a common phenomenon, however in this event it is extended to span from the east to the west of the country.

In 2020, monsoon rains resulted in flooding and landslides in several municipalities across Nepal. During this rainfall event, the greatest challenge was relief effort access, as many of the remote areas affected by landslides were only accessible with helicopters until conditions stabilised[169]. Moreover, given the occurrence of these floods during the Covid-19 pandemic, another concern was the depletion of personal protective equipment (PPE) supplies — in particular masks — as the minimum availability of PPE had to be secured for 'frontline workers'. Widespread landslides were triggered by heavy rain in several provinces of the country resulting in 141 deaths, primarily resulting from landslides in hilly districts, with at least another 57 missing. Reportedly, 15,307 families (76,535 people) have been affected across several districts and 7,106 families (35,530 people) have been displaced[170]. In June 2021, floods and landslides in Manang and Sindhupalchok — districts located in Nepal's mountainous regions — have resulted in five deaths and millions of USD in property damages. Nearly 1,000 households have been displaced, 400 homes have been fully destroyed and 100 homes partially damaged[171]. In addition to private property damages, the events have caused damage to 20 bridges, seven roads and 14 hydropower stations.

Along with the impacts mentioned above, floods also result in significant health impacts, as incidences of disease increase following floods[172]. Communities in Nepal are proven to be at risk of disease outbreaks such as diarrhoea, fever, infections — acute respiratory infection (ARI) in particular, and other skin and sexual diseases immediately after floods[173]. Moreover, during these events, there are immediate risks of cholera, typhoid, dysentery (*Shigella dysenteriae* type 1) and hepatitis A and E outbreaks. These diseases are common in flooding disasters and are primarily attributed to the displacement of affected populations in the aftermath of the floods[174]. As such, these negative health effects not only directly impact displaced populations but also surrounding communities as a result of the displacement or relocation process[175].

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[165] Devkota, R.P., Maraseni, T.N., Cockfield, G. and Devkota, L.P., 2013. Flood vulnerability through the eyes of vulnerable people in mid-western Terai of Nepal. Journal of Earth Science and Climactic Change, 4(1), pp.1-7.
[166] Post Flood Recovery Needs Assessment. 2017. Government of Nepal, National Planning Commission, Kathmandu.
[167] Post Flood Recovery Needs Assessment. 2017. Government of Nepal, National Planning Commission, Kathmandu.
[168] UNDRR. 2019. Disaster Risk reduction in Nepal. Status Report.
[169] https://reliefweb.int/disaster/fl-2020-000165-npl Accessed: 4 August 2020
[170] As of 31 July 2020
[171] Nepal National Disaster Risk Reduction and Management Authority (NDRRMA). More information available at: https://go.ifrc.org/reports/14423
[172] Kafle, K.R., Dahal, R.K. and Khanal, S.N., 2016. Postdisaster epidemiological assessment of Koshi flood 2008, in Nepal. International Journal of Health System and Disaster Management, 4(1), p.15.
[173] WHO. WHO country office Nepal Communicable disease risk assessment and interventions flooding disaster. Nepal: WHO; August, 2007.
[174] Watson, J.T., Gayer, M. and Connolly, M.A., 2007. Epidemics after natural disasters. Emerging infectious diseases, 13(1), p.1.
[175] Lowe, D., Ebi, K.L. and Forsberg, B., 2013. Factors increasing vulnerability to health effects before, during and after floods. International journal of environmental research and public health, 10(12), pp.7015-7067.

he primary drivers of disease outbreaks during or following natural disasters in Nepal are faecal contamination caused by the overflow of latrines, inadequate sanitation and contamination by dead animals[176,177]. Past floods have been followed by associated cases of Japanese encephalitis, dengue and faecal contamination with *Vibrio cholerae* (cholera) in regions of Nepal. Moreover, *Plasmodium falciparum* and *Plasmodium vivax* malaria are endemic in the low-lying (<1200 m), flood-affected areas of Nepal[178]. Communicable diseases are also prevalent after flood disasters, as many people stay in relief camps often for long periods after flood disasters. In addition, ocular diseases are prevalent as people are exposed to water contaminated by sewage during and directly after floods, resulting in cases of conjunctivitis and keratitis[179]. Many people also suffer from post-traumatic stress disorder (PTSD) for extended periods after traumatic events such as flood disasters[180], with an assessment conducted two years after the 2008 Koshi flood indicating the prevalence of PTSD among affected communities[181]. This may impact the quality of life for people in these communities, impeding their functioning and negatively impacting their mental health.

Landslides

Nepal experiences frequent landslides, which are largely attributable to heavy monsoon rainfall, the steep topography of the country and the location of most of the mountainous areas in Nepal being on a tectonically active zone[182,183]. Changes in rainfall patterns, which have become severe and erratic, contribute to extreme landslides. In addition, growing populations, illegal settlements in hazard-prone areas, and haphazard road constructions also trigger landslides in hilly areas[184]. Nepal's limited land-use planning, therefore, results in landslides leading to disasters, which causes numerous deaths and destruction of homes[185]. Most recently, in 2014, heavy rainfall generated a landslide along the Sunkoshi River, killing 156 people and blocking the river[186].

Losses resulting from landslides are extremely high, with a negative impact on households as landslides create more permanent loss of land with a longer rehabilitation period[187]. These severe impacts are exacerbated by the remote locations of many communities in the Middle Hills, where most landslides occur and where transportation costs are higher, increasing the cost of delivering relief resources and services[188]. Losses from landslides are similar among impoverished and wealthy

176 WHO. WHO country office Nepal Communicable disease risk assessment and interventions flooding disaster. Nepal: WHO; August, 2007.
177 Bhattachan, B., Bhattachan, A., Sherchan, J.B., Dhoubhadel, B.G. and Sherchand, J.B., 2017. Leptospirosis: An emerging infectious disease in Nepal. Journal of Institute of Medicine, 40(2).
178 Kafle, K.R., Dahal, R.K. and Khanal, S.N., 2016. Postdisaster epidemiological assessment of Koshi flood 2008, in Nepal. International Journal of Health System and Disaster Management, 4(1), p.15.
179 Sahu, S., Bhutia, T.W., Shrestha, V., Malla, T. and Singh, S.K., 2019. Spectrum of ocular diseases in aftermath of monsoon flood in Nepal. Journal of Chitwan Medical College, 9(4), pp.61-63.
180 Crabtree, A., 2013. Questioning psychosocial resilience after flooding and the consequences for disaster risk reduction. Social Indicators Research, 113(2), pp.711-728.
181 Kafle, K.R., Dahal, R.K. and Khanal, S.N., 2016. Postdisaster epidemiological assessment of Koshi flood 2008, in Nepal. International Journal of Health System and Disaster Management, 4(1), p.15.
182 Dhakal, S., 2015. Evolution of geomorphologic hazards in Hindu Kush Himalaya. In Mountain Hazards and Disaster Risk Reduction (pp. 53-72). Springer, Tokyo.
183 Bhandari, B.P. and Dhakal, S., 2019. Topographical and geological factors on gully-type debris flow in Malai River catchment, Siwaliks, Nepal. Journal of Nepal Geological Society, 59, pp.89-94.
184 Vuillez, C., Tonini, M., Sudmeier-Rieux, K., Devkota, S., Derron, M.H. and Jaboyedoff, M., 2018. Land use changes, landslides and roads in the Phewa Watershed, Western Nepal from 1979 to 2016. Applied geography, 94, pp.30-40.
185 Lennartz, T., 2013. Constructing roads—constructing risks? Settlement decisions in view of landslide risk and economic opportunities in Western Nepal. Mountain research and development, 33(4), pp.364-371.
186 Shrestha, B.B. and Nakagawa, H., 2016. Hazard assessment of the formation and failure of the Sunkoshi landslide dam in Nepal. Natural Hazards, 82(3), pp.2029-2049.
187 Sudmeier-Rieux, K., Jaquet, S., Basyal, G.K., Derron, M., Devkota, S., Jaboyedoff, M. and Shrestha, S., 2013. A neglected disaster: landslides and livelihoods in Central-Eastern Nepal. In Landslide Science and Practice (pp. 169-176). Springer, Berlin, Heidelberg.
188 Jones, J.N., Stokes, M., Boulton, S.J., Bennett, G.L. and Whitworth, M.R.Z., 2020. Seismic and monsoon-triggered landslide impacts on remote trekking infrastructure, Langtang Valley, Nepal. Quarterly Journal of Engineering Geology and Hydrogeology, 53(2), pp.159-166.

communities as measured by landholdings per household, literacy rates, livestock, consumer durables and expenditures. However, more impoverished communities are affected disproportionately, and wealthier communities demonstrate higher capacities to cope by diversifying livelihoods, seeking external assistance, their ability to spend more on repairs and purchasing food, greater technical knowledge and outmigration for higher skilled positions[189,190]. This disparity can be mitigated by investing in developing organisational skills in poorer communities while building on local knowledge about landslide mitigation for reducing landslide risk. Moreover, there is potential to improve coping strategies by incorporating skills training on landslide mitigation in existing outreach and training programmes in Nepal's rural areas.

Landslides are a secondary risk of GLOFs as the flood water can inundate soil and destabilise masses of land in the same way as intense rainfall events[191]. As the risk of GLOF occurrence grows under climate change, and if factors that contribute to landslide occurrence, such as deforestation, remain present, the risk of landslides in Nepal rises. Furthermore, landslides are not only a secondary risk of GLOFs, but also serve a s a trigger for GLOF events[192]. Thus, if landslide risk increases, for example as a result of heavier rainfall, then the risk that these landslides trigger a GLOF also increases.

Nepal is affected by numerous extreme climate events, including Glacial Lake Outburst Floods (GLOFs), monsoon rain-induced floods and landslides. In the 2020 Long-term Climate Risk Index (CRI)[193] assessment, Nepal was ranked 9th out of 10 countries that have had the most severe climate impacts for 1998–2018[194]. Nepal has a CRI score of 31.50 with 180 extreme climate events recorded over the last 20 years, an average annual death toll of 140 people and average annual losses of US$225 million in Purchasing Power Parity[195] (PPP) as a result of extreme climate events. Notable events that contribute to this ranking include: i) the 2002 monsoon floods and resulting landslides, during which more than 400 lives were lost and over 300,000 people were severely impacted; ii) the South Asian floods and landslides of 2007, which resulted in a death toll of 84 people in Nepal and directly impacted the wellbeing and livelihoods of over 300,000 people; iii) the 2008 Koshi floods in which 60 lives were lost and over 200,000 people had their wellbeing and livelihoods directly affected; iv) the Seti Kosi flood in 2012 which resulted in 72 deaths; and v) the 2014 Sunkoshi landslide — triggered by heavy rainfall — that claimed 156 lives and destroyed dozens of homes. Nepal is expected to experience increasingly severe damages and losses to infrastructure, major economic sectors and livelihoods of most vulnerable communities under future climate change conditions.

4.2. National historical climate trends for Nepal

4.2.1. Temperature

[189] Sudmeier-Rieux, K., Jaquet, S., Derron, M.H., Jaboyedoff, M. and Devkota, S., 2012. A case study of coping strategies and landslides in two villages of Central-Eastern Nepal. Applied geography, 32(2), pp.680-690.
[190] Oven, K.J., Petley, D.N., Rigg, J.R., Dunn, C.E. and Rosser, N.J., 2008. Landscape, livelihoods and risk: A study of community vulnerability to landslide events in Central Nepal. Climate Change and Disaster Impact Reduction, p.94.
[191] Chahal, P., Rana, N., Bisht, P., Bagri, D.S., Wasson, R.J. and Sundriyal, Y., 2017. Identification of landslide-prone zones in the geomorphically and climatically sensitive Mandakini valley (central Himalaya), for disaster governance using the Weights of Evidence method. Geomorphology, 284, pp.41-52.
[192] Byers, A.C., Rounce, D.R., Shugar, D.H., Lala, J.M., Byers, E.A. and Regmi, D., 2019. A rockfall-induced glacial lake outburst flood, Upper Barun Valley, Nepal. Landslides, 16(3), pp.533-549.
[193] The Climate Risk Index quantifies impacts of extreme weather events on individual countries by considering fatalities and economic losses relating to these events over a specific timeframe.
[194] Eckstein, D., Künzel, V., Schäfer, L. and Winges, M., 2019. Global climate risk index 2020. Germanwatch Available at: https://germanwatch. org/sites/germanwatch. org/files/20-2-01e% 20Global, 20.
[195] Purchasing power parity (PPP) is a metric used for macroeconomic analysis that compares different countries' currencies through a "basket of goods" approach.

Nepal's second national communication suggests that the spatial distribution of warming across the country is complex, and not homogenous across the country's surface area, nor defined consistently by altitude[196]. This is evident in Figure 8 which shows thirty-year time series data prior to 2010 observed at 110 stations for surface temperature. These stations are in general well distributed in lower altitude regions of the country; however, at higher altitude regions the numbers of stations are few, which results limitations in understanding the climate of Nepal. The data was used by the Department of Hydrology and Meteorology (DHM), Government of Nepal to analyse maximum and minimum temperature.

The observed annual mean temperature across Nepal as well as the temperature trend change is depicted in Figure 8. In the mean annual temperature, maximum temperature of more than 24˚C is observed over the Terai region, while the northern high mountainous region has the lowest minimum temperature of less than 4˚C. The annual mean maximum temperature across the country is 23.6˚C and the annual mean minimum temperature is 11.6˚C.[197] Historically, Nepal's average annual temperatures have been increasing since 1901 (Figure 10). Increases have been observed in maximum temperatures of 0.6°C–1°C per decade in the high mountainous and Himalaya areas, with the highest changes observed in the winter season[198]. Furthermore, the distribution of annual mean temperature trends, except for small, isolated pockets, across most of Nepal has an increasing trend of up to 0.55 ˚C per decade (Figure 8).

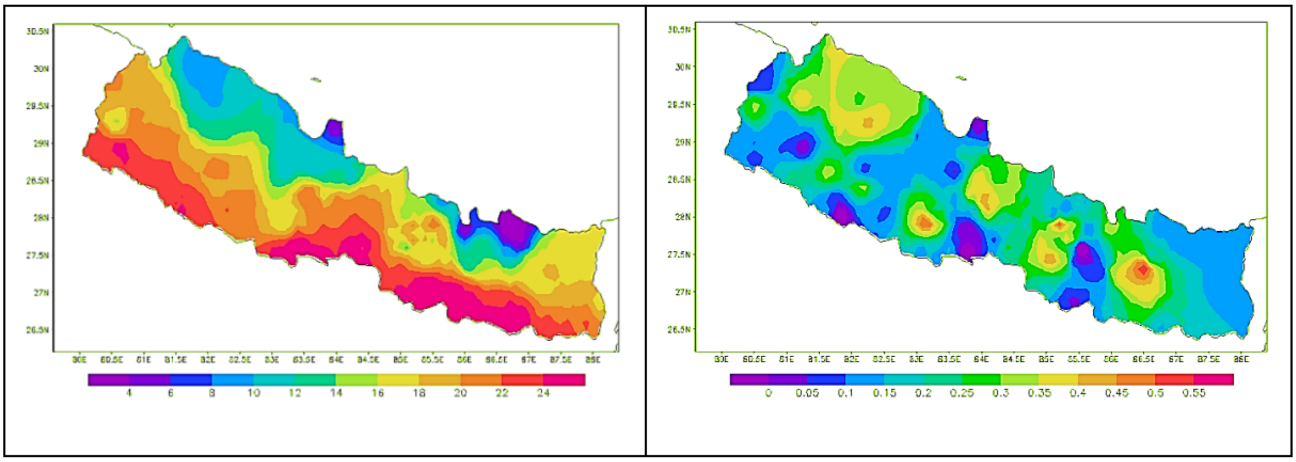

Figure 8. Annual mean temperature (˚C) (left) and temperature trend (˚C/ decade) (right) for Nepal (1980-2010)[199].

[196]Government of Nepal. Ministry of Science, Technology and Environment. 2014. Second National Communication to UNFCCC.
[197] Government of Nepal. Ministry of Science, Technology and Environment. 2014. Second National Communication to United Nations Framework Convention on Climate Change.
[198] DHM, 2017. Observed Climate Trend Analysis of Nepal (1971-2014). Department of Hydrology and Meteorology, Kathmandu
[199] Government of Nepal. Ministry of Forests and Environment. 2021. Third National Communication to United Nations Framework Convention on Climate Change.

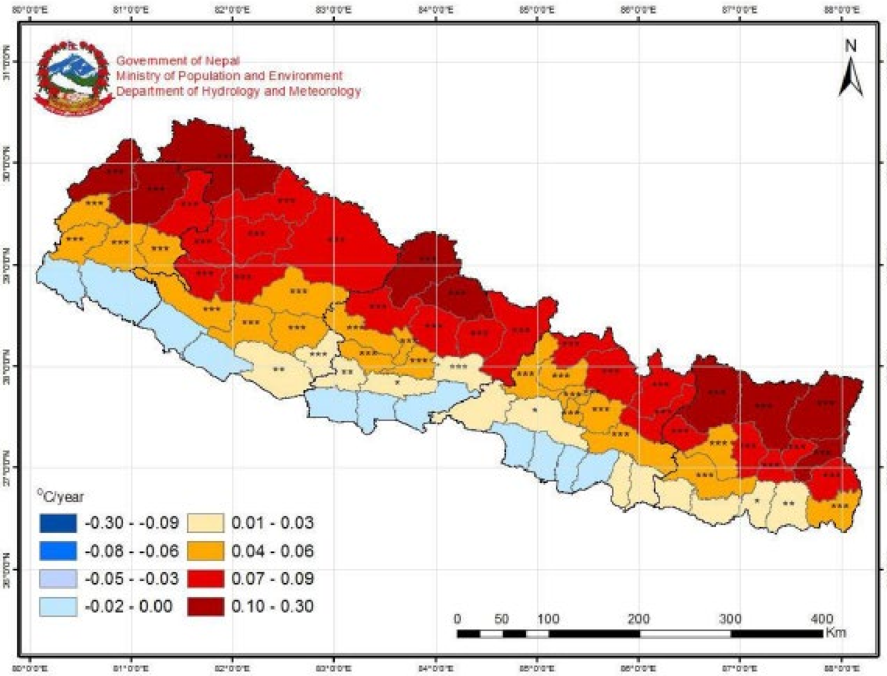

Figure 9. Winter Maximum Temperature trend for districts

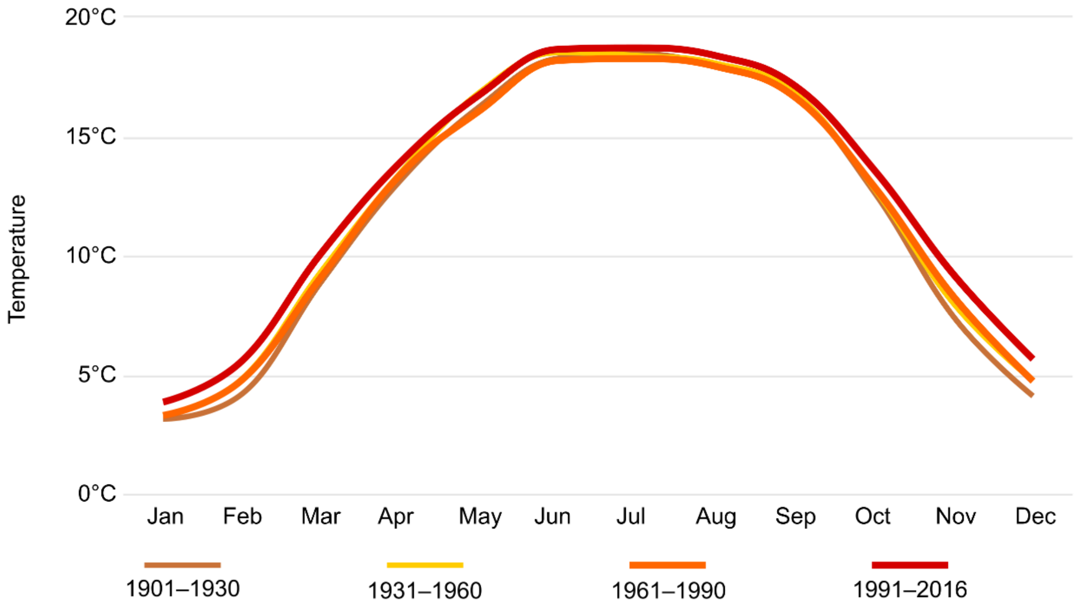

Figure 10. Average monthly temperatures in Nepal from 1901–2016[200]**.**

The average mean temperature of Nepal in the different seasons for the period of 1981–2010[201] is shown in Table 6**.** and this reveals that the average mean temperature is highest in the monsoon season at 17.7°C. In addition, the seasonal trend of annual maximum and minimum temperature (Figure 11) and the significance of the observed trend of seasonal changes (Table 7) is shown. Historical warming in Nepal is estimated at between 1°C–1.3°C, based on temperature changes

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[200] https://climateknowledgeportal.worldbank.org/country/nepal/climate-data-historical Accessed: 11 August 2020

[201] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu

between the periods 1900–1917 and 2000–2017[202]. Maximum temperature trend across the country is 0.056°C/yr and is significantly positive at 99.9% confidence level (CL)[203] (Table 7). Nepal's monsoon season has the significantly highest positive trend of 0.058°C/yr, while the pre-monsoon has the lowest trend of 0.051°C/yr (Table 7). The seasonal and annual time series of maximum temperature in Nepal shows an increasing trend with inter-annual variability in all seasons (Figure 11). Similarly, average minimum temperature trends show increasing trend annually (Figure 11), but only monsoon trend is significant at 95% CL (Table 7). Therefore, the observed annual maximum temperature is revealing an increasing trend across all seasons.

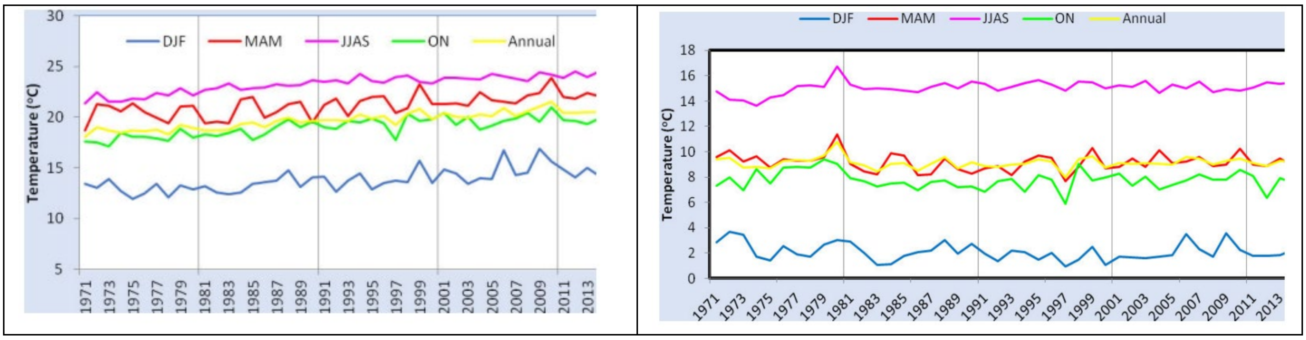


Figure 11. Seasonal and annual maximum temperature (˚C) (left) and seasonal and annual minimum temperature (˚C) (right) time series of Nepal[204].Note: DJF means months of December, January and February; MAM is for March, April and May; JJAS is for June, July, August and September; and ON denotes for October and November.

Table 6. Average mean temperature of Nepal for different seasons for the period of 1981–2010[205].

Seasons	Mean temperature (°C)
Winter (Dec–Feb)	4.6
Pre-monsoon (Mar–May)	12.5
Monsoon (Jun–Sept)	17.7
Post-monsoon (Oct–Nov)	11.4
Annual	12.1

Table 7. Climatic trend of Nepal (1971-2014)[206]. Note: Significant: * 95% CL, ** 99% CL and * 99.9% CL; insignificant at 95% CL : + ,0.**

Seasons	Maximum Temperature (°C/yr)		Minimum Temperature (°C/yr)	
		Q		Q
Winter	***	0.054	0	-0.009
Pre-monsoon	***	0.051	0	-0.003
Monsoon	***	0.058	*	0.014
Post-monsoon	***	0.056	0	-0.005
Annual	***	0.056	0	0.002

[202] World Bank. 2021. Climate Risk Country Profile: Nepal.
[203] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).
[204]https://www.dhm.gov.np/uploads/climatic/467608975Observed%20Climate%20Trend%20Analysis%20Report_2017_Final.pdf
[205] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu
[206] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).

Statistically, extreme climate events are considered low-probability events differing greatly from typical occurrences, or as defined by the Intergovernmental Panel on Climate Change (IPCC), extremes are 1-10% of the largest or smallest values of a distribution[207]. The joint Commission for Climatology of the World Meteorological Organization's World Climate Data and Monitoring Programme (CCl)/Climate Variability and Predictability Programme of the World Climate Research Programme (CLIVAR)/Joint World Meteorological Organization-Intergovernmental Oceanographic Commission Technical Commission for Oceanography and Marine Meteorology (JCOMM) Expert Team on Climate Change Detection and Indices (ETCCDI) identified 27 core indices (11 for precipitation and 16 for temperature) for the study of extreme climate events across the globe[208]. An extensive climate change scenario analysis developed to support Nepal's National Adaptation Plan[209] identified 11 of the ETCCDI indices — five for precipitation and six for temperature — as the most important climate change indicators in Nepal to understand the historical and future change of climatic parameters (Table 8). This study focuses on those 11 indices to investigate climate change projections and the potential impacts on Nepal, as well as their relationship to GLOFs and other extreme climate events.

Table 8. Definitions of climate extreme indices [210].

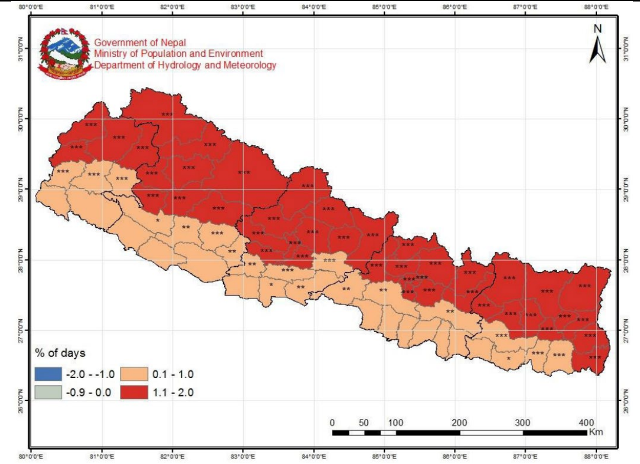
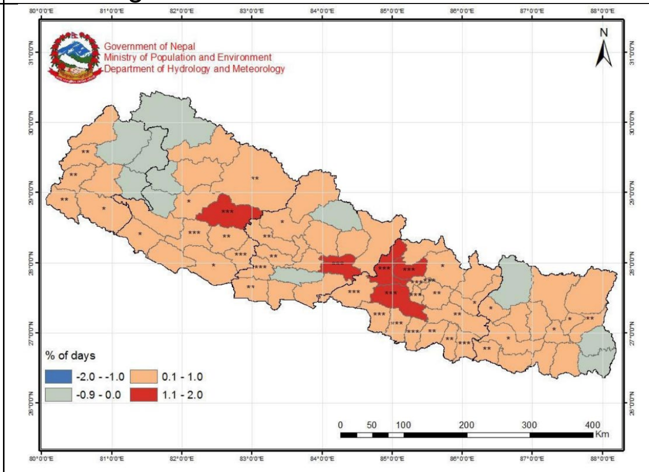
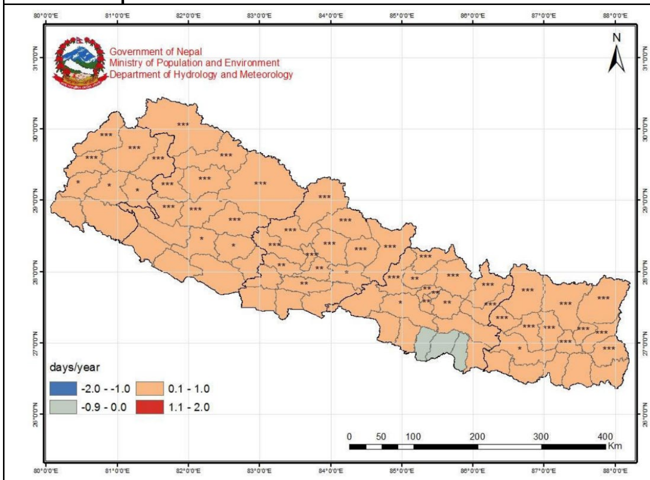
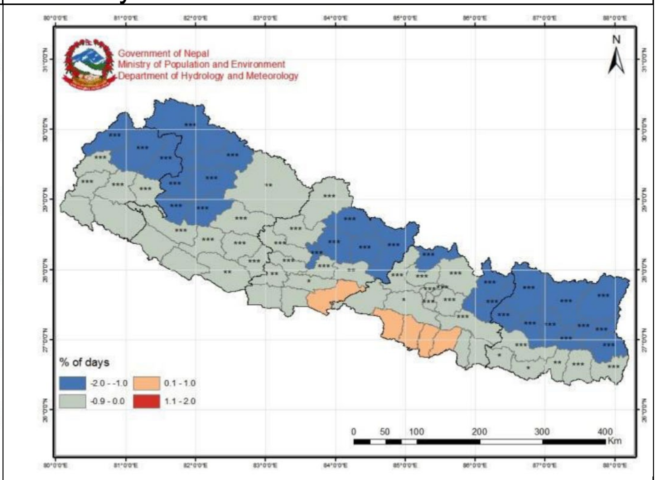
Indices	Definition
Very wet days (P95)	Annual total days when the precipitation is higher than 95th percentile
Extreme wet days (P99)	Annual total days when the precipitation is higher than 99th percentile
Number of rainy days	Annual total days when the precipitation is greater than 1 mm
Consecutive dry days	Maximum length of consecutive days when daily precipitation is less than 1 mm
Consecutive wet days	Maximum length of consecutive days when daily precipitation is higher than 1 mm
Warm days	Days when the maximum temperature is higher than the 90th percentile
Warm nights	Days when the minimum temperature is higher than the 90th percentile
Cold days	Days when the maximum temperature is lower than the 10th percentile
Cold nights	Days when the minimum temperature is lower than the 10th percentile
Warm spell duration index	Annual count of days with at least six consecutive days when the maximum temperature is higher than the 90th percentile
Cold spell duration index	Annual count of days with at least six consecutive days when minimum temperature is lower than the 10th percentile

The six extreme temperature indices are spatially presented across Nepal for the time period of 1971–2014[211] (Table 9). The analysis reveals significant extreme temperature trends in most of the districts across the elevations of Nepal. Both warm days and nights show an increasing trend significantly in most of the districts. Warm spell duration is increasing in majority of the districts while cold spell duration is only increasing in the Far Western Development Region significantly[212]. Cold days are decreasing in majority of the districts significantly, however cold nights are increasing significantly in few districts in the northern and north-western parts and decreasing significantly in the south-eastern

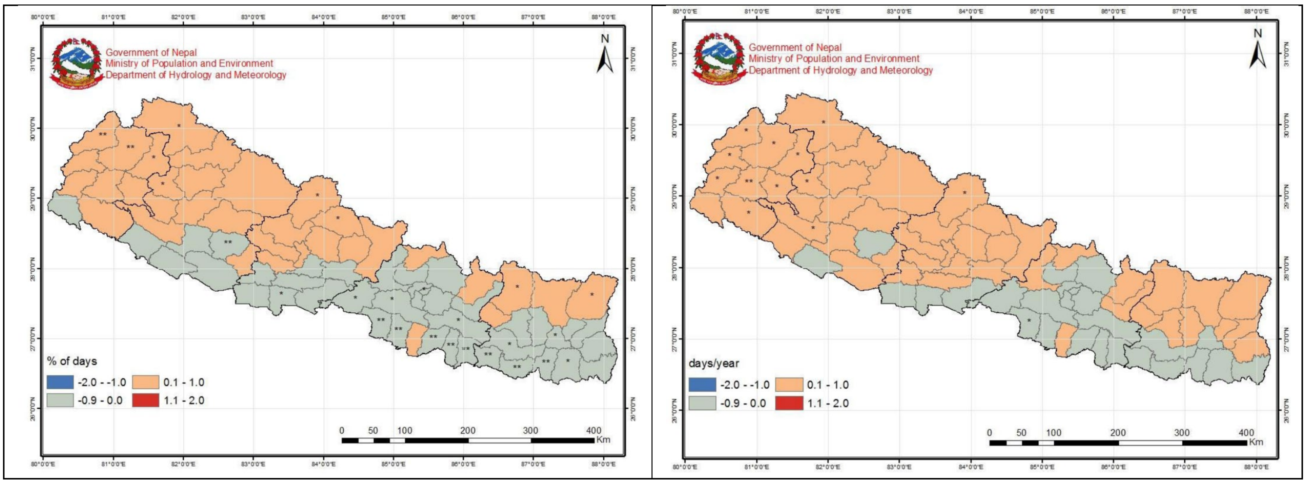
[207] Trenberth, K.E., Jones, P.D., Ambenje, P., Bojariu, R., Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M. and Soden, B., 2007. Observations: surface and atmospheric climate change. Chapter 3. Climate change, pp.235-336.
[208] Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F. and Tagipour, A., 2006. Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research: Atmospheres, 111(D5).
[209] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu
[210]https://www.dhm.gov.np/uploads/climatic/467608975Observed%20Climate%20Trend%20Analysis%20Report_2017_Final.pdf
[211] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).
[212] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).

districts [213]. Furthermore, the frequency of cold days and nights per year has decreased significantly, by 5% and 8%, respectively [214].

Table 9. Spatial distribution of temperature extreme indices among 75 districts in Nepal based on data analysed for 1971–2014 [215].(Significance: * 95% CL, ** 99% CL, * is 99.9% CL; blank means insignificant at 95% CL).**

<table>
<tr><td>Warm days</td><td>Warm nights</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Warm spell duration</td><td>Cold days</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Cold nights</td><td>Cold spell duration</td></tr>
</table>

[213] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).
[214] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).
[215]https://www.dhm.gov.np/uploads/climatic/467608975Observed%20Climate%20Trend%20Analysis%20Report_2017_Final.pdf



4.2.2. Precipitation

Nepal has recorded a significant decrease in mean rainfall between 1901 and 2016 and this decrease is particularly significant during the monsoon period from June–September (Figure 12)[216]. However, on a smaller time scale of 30 years (1981—2010), the country's second national communication suggests that there have been only minor changes to historical annual precipitation rates in the country and these vary both spatially and include both positive and negative trends. This is evident in Figure 13 which shows thirty-year time series data prior to 2010 observed at 309 stations for precipitation. These stations are in general well distributed in lower altitude regions of the country; however, at higher altitude regions the numbers of stations are few, which results limitations in understanding the climate of Nepal. The data was used by the Department of Hydrology and Meteorology (DHM), Government of Nepal to analyse precipitation.[217]

The annual distribution of precipitation over Nepal reveals that the highest precipitation, of more than 5000 mm, is centered over southern flank of Annapurna range and the driest part, with about 500 mm, on the lee side of the same range (Figure 13). This difference highlights the importance of topography on spatial variations of precipitation distribution in the country. Furthermore, eastern high altitude regions are observed to have two pockets of about 3,000 mm annual precipitation, while the rest of the country have precipitation distribution of approximately 1,000-2,000 mm, which increases towards northern mountains, except over western part of the country where it decreases towards north. Furthermore, Nepal's average annual precipitation is 1,683 mm of which 1,330 mm falls during summer monsoon.[218]

Observed precipitation trends for 1971–2014 reveal that in most of the High Mountain districts, annual precipitation is decreasing, with a higher rate in the east. Precipitation is in decreasing trend mainly in the High Mountains and High Himalayas during all seasons in the country. Particularly, in monsoon, the highest significant increasing precipitation trend (9.0 mm yr-1) is found in Syangja district and decreasing trend (-7.5 mm yr-1) in Ilam. Winter precipitation is increasing in the Terai, Chure (Siwalik), and Middle Mountains while it is decreasing in High Mountains and Himalayas.[219]

[216] https://climateknowledgeportal.worldbank.org/country/nepal/climate-data-historical Accessed: 11 August 2020
[217] Government of Nepal. Ministry of Science, Technology and Environment. 2014. Second National Communication to United Nations Framework Convention on Climate Change.
[218] Government of Nepal. Ministry of Science, Technology and Environment. 2014. Second National Communication to United Nations Framework Convention on Climate Change.
[219] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).

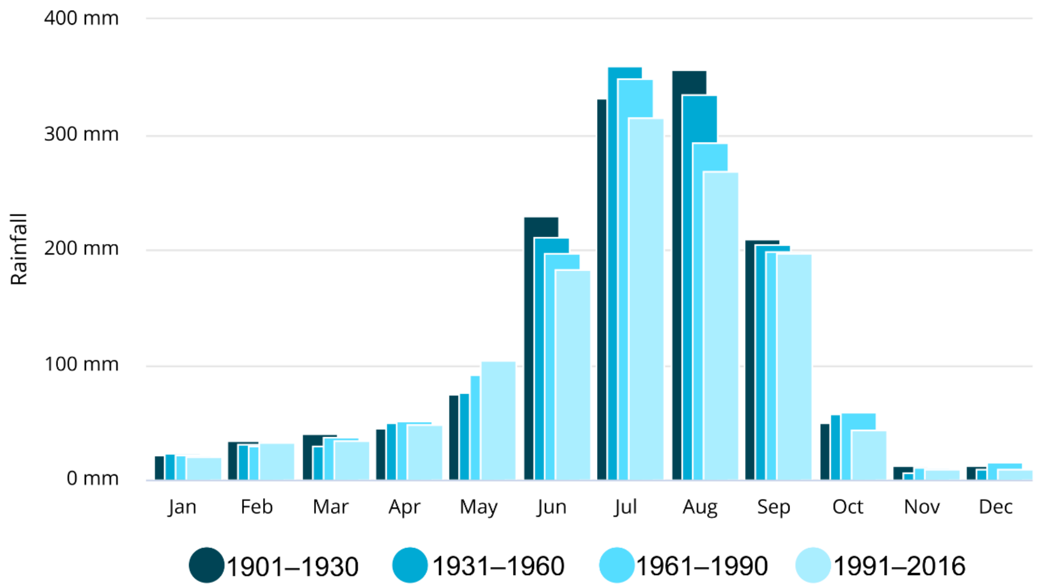


Figure 12. Historic average monthly rainfall for Nepal[220].

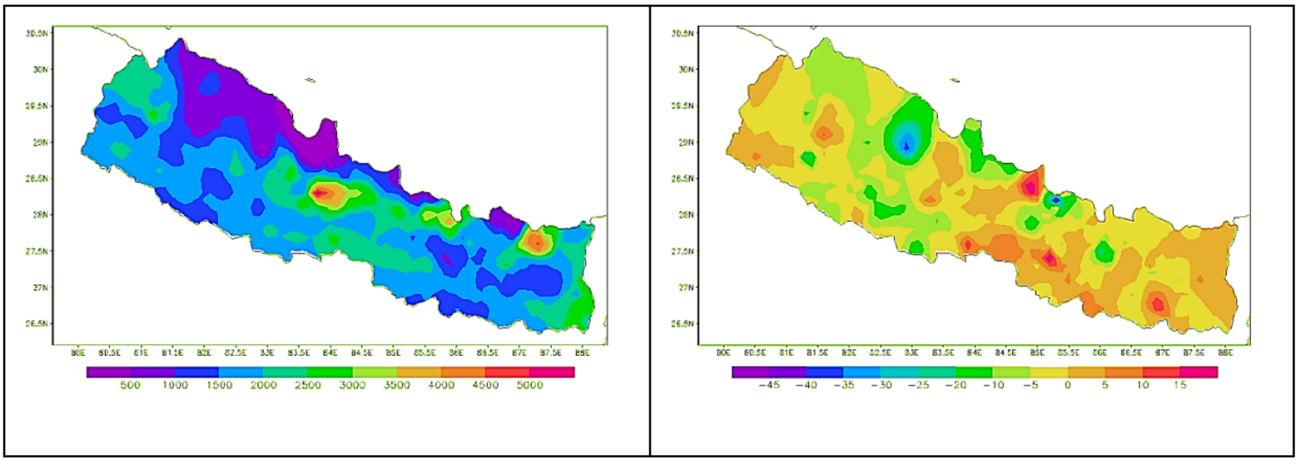


Figure 13. Annual precipitation (mm) (left) and precipitation trend (% of annual /decade) (right) for Nepal[221]

The monsoon season of June–September has remained the predominant period for the majority of the country's rainfall, with 77% of total annual precipitation occurring in that season alone, while the post-monsoon and winter seasons are very dry, with only 5% of total annual precipitation (Table 10)[222]. In addition, the seasonal trend of precipitation (Figure 14) and the significance of the observed trend of seasonal changes (Table 11) is shown. Annual decrease in precipitation in Nepal is 1.3 mm/year[223], although the change is insignificant (Table 11). The seasonal and annual time series of precipitation in Nepal shows inter-annual variability in all seasons (Figure 14). Seasonal and annual precipitation trends in Nepal show decreasing precipitation in all seasons with the highest

[220] https://climateknowledgeportal.worldbank.org/country/nepal/climate-data-historical Accessed: 11 August 2020
[221] Government of Nepal. Ministry of Forests and Environment. 2021. Third National Communication to United Nations Framework Convention on Climate Change
[222] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu
[223] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).

decreasing trend (-0.3 mm/yr) in the post-monsoon season (Table 11). However, all the decreasing trends are insignificant[224].

Table 10. Precipitation of Nepal for different seasons for 1981–2010 [225].

Seasons	Average precipitation	
	mm	%
Winter (Dec–Feb)	84	5
Pre-monsoon (Mar–May)	232	13
Monsoon (Jun–Sept)	1,418	77
Post-monsoon (Oct–Nov)	96	5
Annual	1,830	100

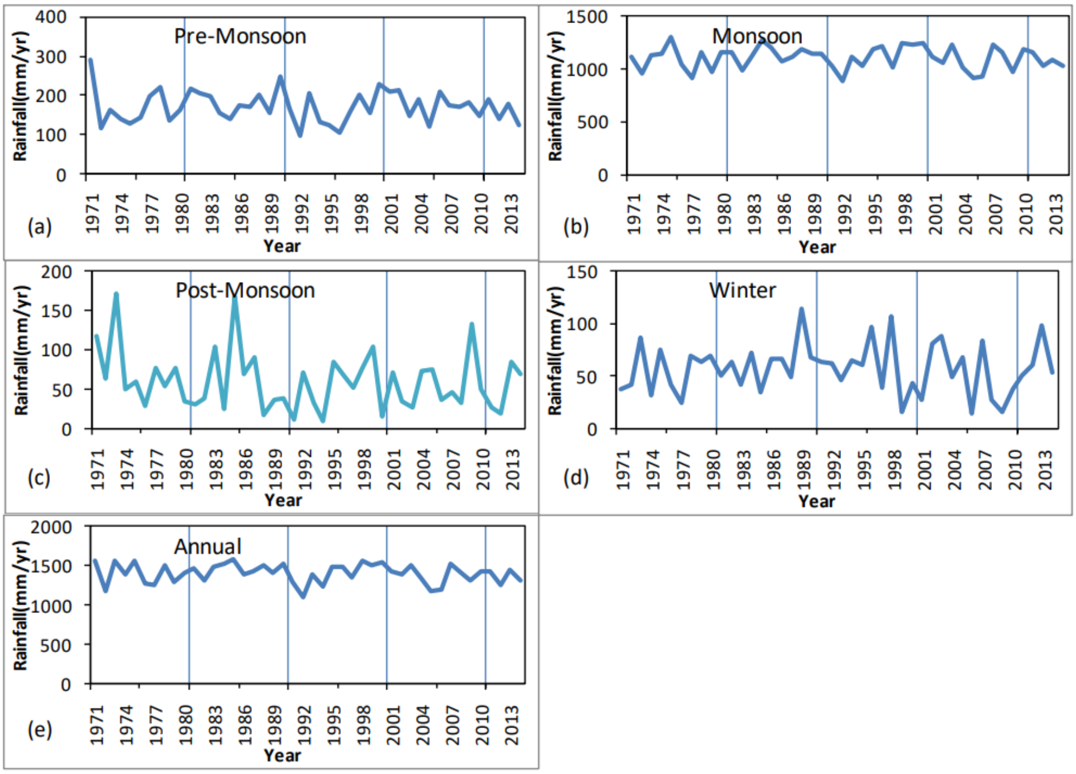


Figure 14. Precipitation time series of Nepal (a) Pre-Monsoon (b) Monsoon (c) Post-Monsoon (d) Winter (e) Annual for the time period 1971—2014[226].

Table 11. Precipitation trend of Nepal for the time period 1971—2014[227]. Note: Significant: * 95% CL, ** 99% CL and * 99.9% CL; insignificant at 95% CL : + ,0.**

Seasons	Precipitation (mm/yr)	
	α	Q
Winter	0	-0.072
Pre-monsoon	0	-0.081
Monsoon	0	-0.085
Post-monsoon	0	-0.324
Annual	0	-1.333

[224] Ibid
[225] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu
[226] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).
[227] Ibid

While the trends for the country as a whole are on average negative, there is spatial variation, with approximately one third of districts showing a positive trend. Positive trends are particularly evident in the pre-monsoon season, where the number of districts with a positive trend outnumber those with a negative. Considering more localised data, observations for the period 1970–2012 indicate that monsoonal precipitation is increasing in middle mountains in the western region and central high mountains of Nepal[228]. Additionally, between 1981 to 2012, observed rainfall trends over the Gandaki River Basin in central Nepal reveal that although the post-monsoon, pre-monsoon and winter rainfalls are significantly decreasing, the monsoonal rainfall is increasing throughout the basin[229]. Furthermore, observations show that there is a tendency toward later departure of monsoon from the country, indicating an increase at a rate of five days/ten years in its duration[230].

Some studies[231,232] for Nepal found that although number of rainy days is decreasing, the total amount of annual precipitation does not show any trend. This can be accredited to intense precipitation in rainy days accompanied by prolonged drought periods. Similarly, observed precipitation trends between 1975 and 2010 indicate that the frequency and intensity of weather extremes are increasing in the Koshi River Basin. This is as a result of the monthly maximum consecutive 5-day precipitation which increased on average by 6.1 mm/decade[233], while the annual total precipitation on very wet days[234] and on extremely wet days[235] increased over the Koshi basin in Nepal across the same time period. Observed increases in total precipitation on very and extremely wet days, coupled with increases in observed rainfall during the monsoon periods and with decreases in annual rainfall suggests the intensification of daily extreme precipitation indices over the country leading to an intensification of region-specific risks of floods, landslides and drought[236].

Five extreme precipitation indices are spatially presented across Nepal for the time period of 1971–2014 (Table 12). The analysis reveals significant extreme precipitation trends in the north-western and northern districts in Nepal. The number of rainy days has been observed to be increasing significantly mainly in the north-western districts. However, the number of very wet days and extremely wet days are decreasing significantly, mainly in the northern and mountain districts of the country. Furthermore, consecutive wet days are increasing significantly in the northern districts of Mid-Western Development Region and central parts of Western Development Region and Eastern Development Region, while consecutively dry days are decreasing significantly, mainly in the north-western districts.[237]

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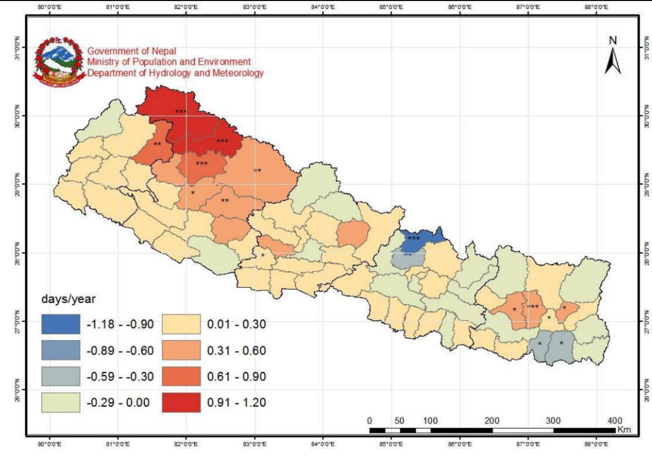
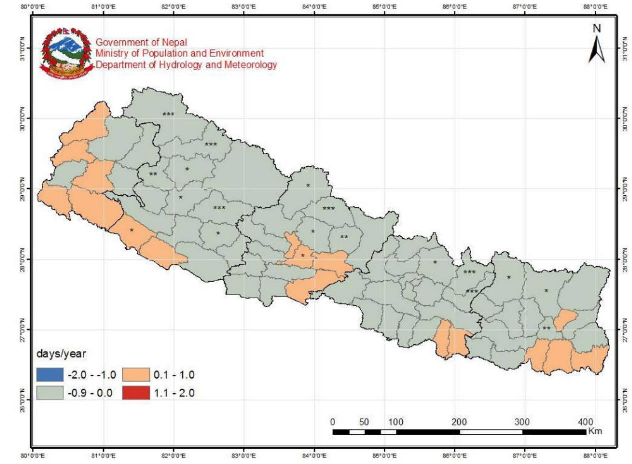
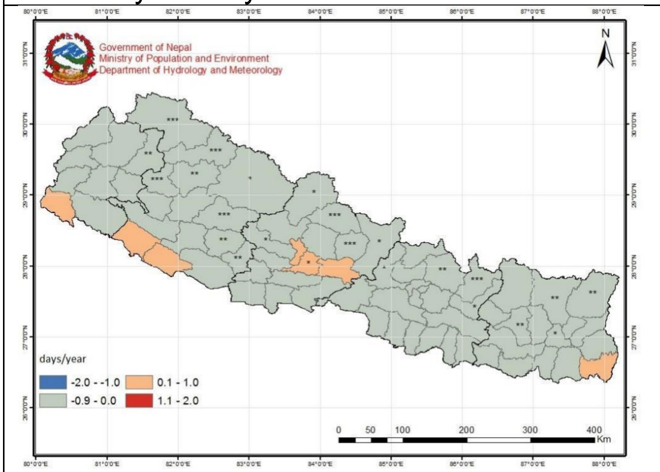
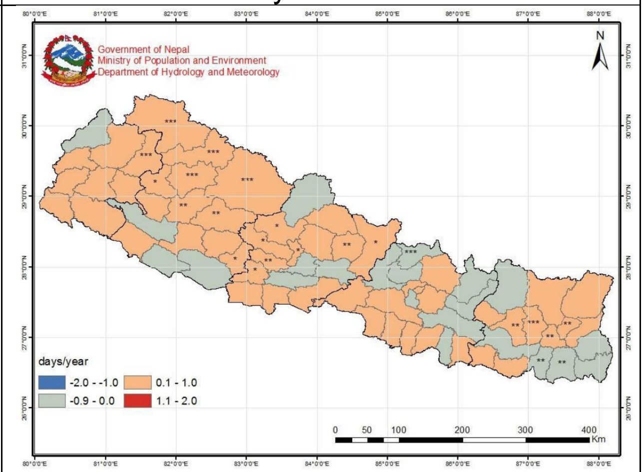
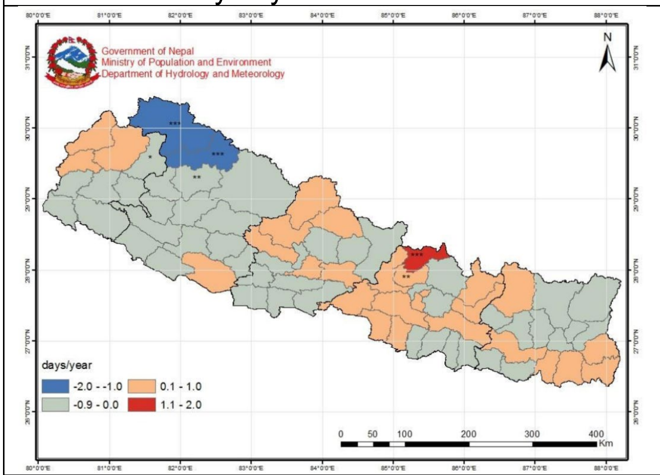
[228] Karki, R., Hasson, S.U., Schickhoff, U., Scholten, T. and Böhner, J., 2017. Rising precipitation extremes across Nepal. Climate, 5(1), p.4.
[229] Panthi, J., Dahal, P., Shrestha, M.L., Aryal, S., Krakauer, N.Y., Pradhanang, S.M., Lakhankar, T., Jha, A.K., Sharma, M. and Karki, R., 2015. Spatial and temporal variability of rainfall in the Gandaki River Basin of Nepal Himalaya. Climate, 3(1), pp.210-226.
[230] Panthi, J., Dahal, P., Shrestha, M.L., Aryal, S., Krakauer, N.Y., Pradhanang, S.M., Lakhankar, T., Jha, A.K., Sharma, M. and Karki, R., 2015. Spatial and temporal variability of rainfall in the Gandaki River Basin of Nepal Himalaya. Climate, 3(1), pp.210-226.
[231]Malla, G. Climate change and its impacts on Nepalese agriculture. J. Agric. Environ. 2008, 9, 62–71
[232] Panthi, J., Dahal, P., Shrestha, M.L., Aryal, S., Krakauer, N.Y., Pradhanang, S.M., Lakhankar, T., Jha, A.K., Sharma, M. and Karki, R., 2015. Spatial and temporal variability of rainfall in the Gandaki River Basin of Nepal Himalaya. Climate, 3(1), pp.210-226.
[233] Shrestha, A.B., Bajracharya, S.R., Sharma, A.R., Duo, C. and Kulkarni, A., 2017. Observed trends and changes in daily temperature and precipitation extremes over the Koshi river basin 1975–2010. International Journal of Climatology, 37(2), pp.1066-1083.
[234] Very wet days were defined as days of rainfall greater than the 95th percentile in the Shrestha et al. study.
[235] Extremely wet days were defined as days of rainfall greater than the 99th percentile in the Shrestha et al. study.
[236] Karki, R., Hasson, S.U., Schickhoff, U., Scholten, T. and Böhner, J., 2017. Rising precipitation extremes across Nepal. Climate, 5(1), p.4.
[237] Government of Nepal. Department of Hydrology and Meteorology. 2017. Observed Climate Trend Analysis of Nepal (1971-2014).

Table 12. Spatial distribution of precipitation extreme indices among 75 districts in Nepal based on data analysed for 1971–2014[238].(Significance: * 95% CL, ** 99% CL, * is 99.9% CL; blank means insignificant at 95% CL).**

Number of rainy days	Very wet days
	
Extremely wet days	**Consecutive wet days**
	
Consecutive dry days	
	

238Ibid

4.3. National future climate projections for Nepal

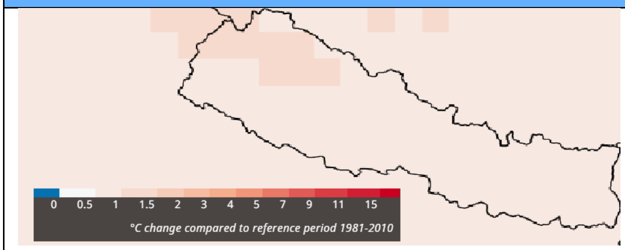
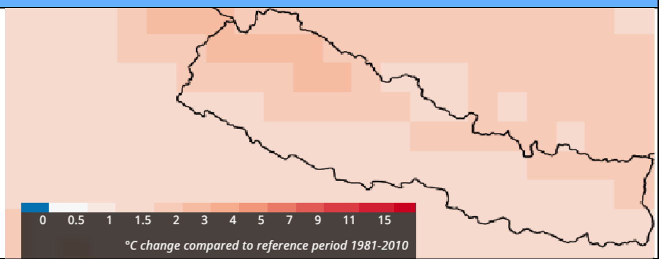
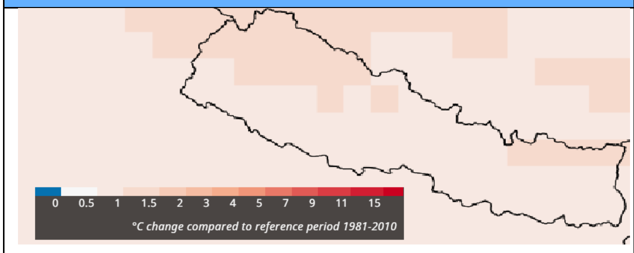
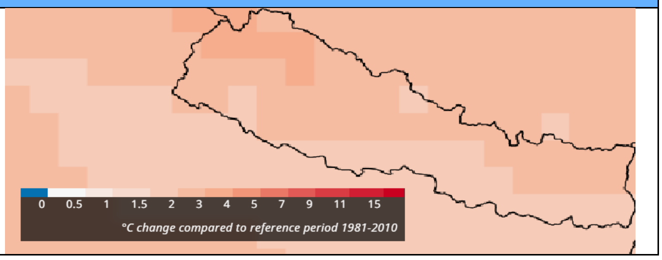
4.3.1. Temperature

All future climate predictions indicate a trend of increasing temperatures for Nepal over the next century[239] (Table 13). Under the RCP4.5 scenario, average temperatures in Nepal are predicted to increase in the medium term, with a total increase of 0.92°C by 2045. This trend is expected to continue in the long term, with increases of 1.3°C and 1.72°C projected by 2065 and 2100, respectively. Temperature increases are more extreme under the RCP8.5 scenario, reaching 1.07°C by 2045, 1.82°C by 2065, and 3.58°C by 2100 — more than double the projected temperature changes expected under the RCP4.5 scenario. The South Asia Cordex model maps (Table 14) showing the temperature change in annual mean temperature for RCP4.5 and RCP8.5 for medium term (2011—2040) and long term (2041—2070) periods agree with the above mentioned increases in projected temperatures in Nepal and depict how these changes vary spatially.

Table 13. Multi-model ensemble[240] mean change in temperature over the medium-term and the long-term periods for Nepal[241].

	RCP4.5			RCP8.5		
Time period	2016–2045	2036–2065	2071–2100	2016–2045	2036–2065	2071–2100
Change in temperature (°C)	0.92	1.3	1.72	1.07	1.82	3.58

Table 14. Projected changes to the annual mean temperature from the reference period (1981-2010) to the medium (2011-2040) and long-term (2041-2070) periods for RCP 4.5 and RCP 8.5 Cordex South Asia model ensembles[242].

RCP4.5	
2011-2040	2041-2070
	
RCP8.5	
2011-2040	2041-2070
	

[239] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu

[240] Four models were used each for RCP4.5 and RCP8.5 multi-model ensemble. Further information on the model selection can be found in the National Adaptation Plan: Climate Change Scenarios for Nepal (2019).

[241] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu

[242] https://dap.climateinformation.org/

Under the RCP4.5 scenario, the increases in temperature over the next century are expected to be greatest in the High Mountain regions of Nepal (1.79°C), exceeding the average projected increase for the country (Table 15). The Terai region has the second highest projected increases (1.73°C), followed by the Siwalik region (1.72°C), and then the Hills region (1.69°C). The Middle Mountains region have the lowest projected temperature increases overall (1.66°C).

Table 15. Multi-model ensemble mean change in temperature (in °C) in the medium-term and long-term period for different regions of Nepal[243].

	RCP4.5			RCP8.5		
Time period	2016–2045	2036–2065	2071–2100	2016–2045	2036–2065	2071–2100
High Mountain	0.95	1.36	1.79	1.09	1.86	3.61
Middle Mountain	0.89	1.27	1.66	1.04	1.76	3.44
Hill	0.9	1.26	1.69	1.06	1.8	3.56
Siwalik	0.94	1.29	1.72	1.1	1.87	3.66
Terai	0.93	1.29	1.73	1.11	1.87	3.69

When exploring the projections of temperature by season under both the RCP4.5 and RCP8.5 scenarios, the post-monsoon season indicates the greatest temperature increase (Table 16). Across Nepal, the dry winter season has the second greatest increase, followed by the pre-monsoon season. In both scenarios, the monsoon season has the lowest rise in temperature, with more than a full degree Celsius lower than the post-monsoon season.

Table 16. Multi-model ensemble mean change in temperature (in °C) in the medium-term and long-term periods of different seasons in Nepal[244].

	RCP4.5			RCP8.5		
Time period	2016–2045	2036–2065	2071–2100	2016–2045	2036–2065	2071–2100
Winter	1.0	1.5	2.1	1.2	2.0	4.0
Pre-monsoon	0.7	1.0	1.2	1.0	1.6	3.4
Monsoon	0.8	1.1	1.4	0.8	1.5	3.0
Post-monsoon	1.3	1.8	2.5	1.4	2.4	4.5

In both the medium and long term, the number of warm days and warm nights in Nepal will consistently increase while warm spells extend over longer time periods. This will simultaneously occur with a reduction in the number of cold days and nights, as well as a reduction of the cold spell duration (Table 17). Long-term projections for the year 2065 show an increase in the number of warm days by 87.33% under the RCP4.5 scenario and by 124.7% under the RCP8.5 scenario. Warm nights will also increase by 2065, by 115.7% under RCP4.5 and by 159.2% under RCP8.5 for the same time period. These projections for 2065 also indicate expanding warm spell durations, with an increase of 149% under RCP4.5 and an extremely large increase of 244.8% under RCP8.5. Inversely, cold spell duration will reduce under both scenarios, dropping by 63.9% and 73.3% under the RCP4.5 and RCP8.5 scenarios, respectively. These changes in extreme temperature indices are consistent with the historical trend of overall warming in Nepal, with warm events increasing and cold events decreasing. In addition, the projections also align with the projected temperature trend of overall

[243] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu

[244] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu

warming conditions in Nepal, which results in increased warm temperature extremes and reduced cold temperature extremes.

Table 17. Percentage change in temperature extreme indices in the medium-term and long-term periods for Nepal[245].

Indices	RCP4.5				RCP8.5			
	2016–2045		2036–2065		2016–2045		2036–2065	
	%	Days	%	Days	%	Days	%	Days
Warm days	64.5	23.9	87.3	32.3	71.4	26.4	124.7	46.1
Warm nights	81.4	30.5	115.7	43.3	101.0	37.8	159.2	59.6
Cold days	-42	-15.4	-52.6	-19.3	-55.8	-20.5	-75.0	-27.5
Cold nights	-40.7	-15	-53.5	-19.7	-54.1	-19.9	-74.0	-27.3
Warm spell duration index	110	19.3	149	26.2	157.4	27.6	244.8	43
Cold spell duration index	-51.8	-10.5	-63.9	-12.9	-55.1	-11.2	-73.3	-14.8

4.3.2. Precipitation

Climate projections show a trend of increasing amounts of precipitation under both the RCP4.5 and 8.5 scenarios for the entire century (Table 18, Figure 15, Table 19), but this increase will be isolated to the monsoon and post-monsoon seasons with pre-monsoon season projected to be drier (Table 20)[246]. This precipitation pattern could result in more frequent summer floods and dry-season droughts. The High Mountains will be most affected by these increases in precipitation based on projections under both scenarios (Table 21). Increased precipitation in the High Mountains have the potential to ultimately increase GLOF events (see Section 4.4). The South Asia Cordex model maps (Table 19) showing the change in annual mean precipitation for RCP4.5 and RCP8.5 for medium term (2011—2040) and long term (2041—2070) periods agree with the above-mentioned increases in projected precipitation in Nepal and depict how these changes vary spatially.

Table 18. Multi-model ensemble[247] mean change in precipitation in the medium- and long-term period for Nepal[248].

	RCP4.5			RCP8.5		
Time period	2016–2045	2036–2065	2071–2100	2016–2045	2036–2065	2071–2100
Change in precipitation (%)	2.1	7.9	10.7	6.4	12.1	23

[245] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu
[246] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu
[247] Four models were used each for RCP4.5 and RCP8.5 multi-model ensemble. Further information on the model selection can be found in the National Adaptation Plan: Climate Change Scenarios for Nepal (2019).
[248] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu

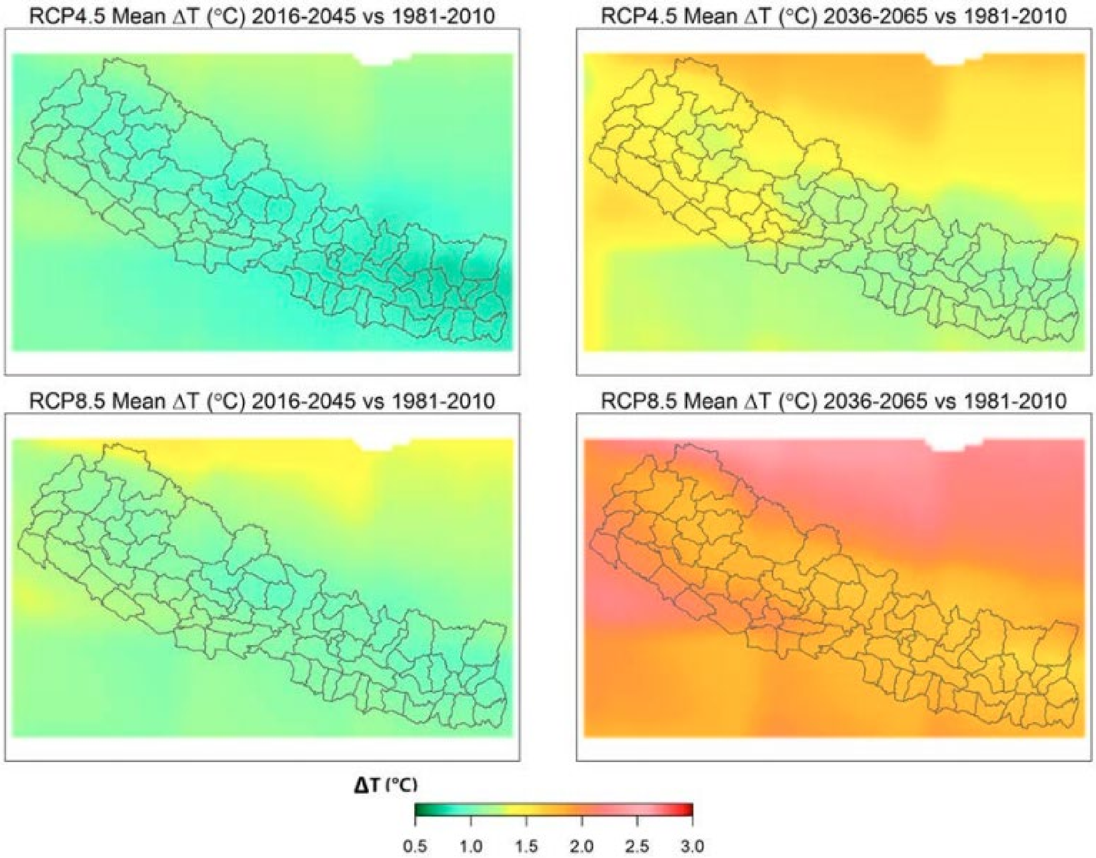
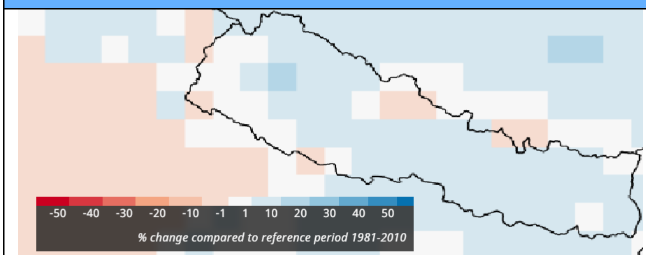
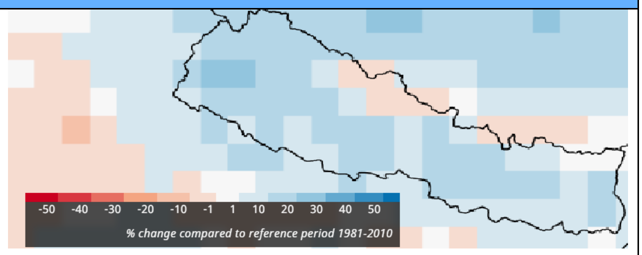


Figure 15. Projected changes in average annual mean temperature between the reference period (1981-2010) and the medium-term (2016-2045) and the long-term (2036-2065) periods for RCP4.5 and RCP8.5 model ensembles.

Table 19. Projected changes to the annual mean precipitation from the reference period (1981-2010) to the medium (2011-2040) and long-term (2041-2070) periods for RCP 4.5 and RCP 8.5 Cordex South Asia model ensembles[249].

RCP 4.5	
2011-2040	2041-2070
	
RCP 8.5	
2011-2040	2041-2070

[249] https://dap.climateinformation.org/

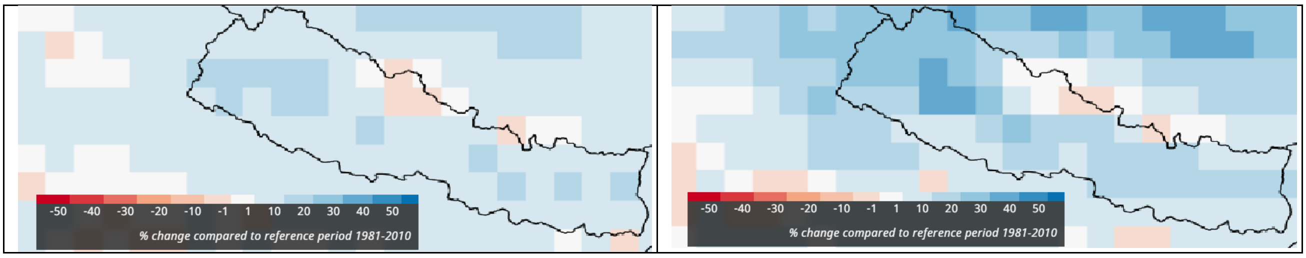


Table 20. Multi-model ensemble mean change in precipitation (%) in the medium- and long-term periods for different seasons in Nepal[250].

	RCP4.5			RCP8.5		
Time period	2016–2045	2036–2065	2071–2100	2016–2045	2036–2065	2071–2100
Winter	-5.8	13.6	24.4	7.2	5.0	20.9
Pre-monsoon	-5.0	-7.4	-7.8	-4.0	4.2	-3.1
Monsoon	2.7	9.4	12.4	7.8	13.6	27.1
Post-monsoon	18.6	20.3	16.5	6.0	19.0	22.9

Table 21. Multi-model ensemble mean change in precipitation (%) in the medium- and long-term period for different regions of Nepal[251].

	RCP4.5			RCP8.5		
Time period	2016–2045	2036–2065	2071–2100	2016–2045	2036–2065	2071–2100
High Mountain	2.6	9.5	12.6	8.0	14.4	25.1
Middle Mountain	1.7	7.6	10.3	6.3	12.4	21.7
Hill	2.1	7.2	9.9	5.8	11.2	22.6
Siwalik	1.6	7.4	9.9	5.8	11.1	21.9
Terai	2.1	7.3	10.2	5.4	10.6	22.7

Intense precipitation events are likely to increase in frequency, with extremely wet days projected to increase at a higher rate than very wet days (Table 22). The number of rainy days is likely to decrease in the future which, in combination with the increase in precipitation intensity, emphasises that rainfall will tend to fall in fewer but more intense events which will pose increased risks for rainfall-induced landslides, floods and rainfall-triggered GLOF events.

Table 22. Percentage change in precipitation extreme indices in the medium- and long-term periods for Nepal[252].

Indices	RCP4.5				RCP8.5			
	2016–2045		2036–2065		2016–2045		2036–2065	
	%	Days	%	Days	%	Days	%	Days
Very wet days (P95)	1.5	0.3	12	2.2	12.1	2.2	18.6	3.4
Extreme wet days (P99)	26.3	0.9	41.3	1.4	28	1.0	59.8	2.1
Rainy days	-1.8	-3	-1	-1.7	-0.9	-1.6	-0.5	-0.8
Consecutive dry days	6	2.7	2.4	1.1	-1.6	-0.7	-2.9	-1.3
Consecutive wet days	-4.2	-3.3	-1.3	-1	3.1	2.5	2.2	1.7

[250] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu
[251] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu
[252] MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu

4.4. Climate change impacts

The receding of glaciers worldwide is evidence of a changing global climate as glaciers are particularly sensitive to rising temperatures[253]. The evidence presented above suggests that climate change will have a more severe impact at higher elevations in Nepal, particularly on glaciers and glacial lakes[254,255]. The increased warming at higher altitudes (see Section 4.3.2) has accentuated rapid glacier melt and reduced glacier mass and area, leading to multiple hazards such as floods, avalanches, and GLOFs. These hazards present a significant risk to human settlements and infrastructure in Nepal — further details in Section 2.5. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) stated that the mass budget of Himalayan glaciers has decreased over the last five decades[256]. Additionally, the Sixth Assessment Report of the IPCC stated with high confidence that snow-covered areas and snow volumes in the Himalayas will decrease while snowline elevation will increase[257]. The report projects a continuous loss of glacier mass throughout the 21st century[258].

A 2017 study on High Mountain Asia (HMA) glacier mass balance shows that the loss of glacier mass between 2000 and 2016 in Nepal was higher than the total mass loss in the entire HMA[259]. Similarly, consistent warming of HMA at a higher rate than the global average combined with a reduction in glacier mass has been reported[260,261]. Glacial lakes tend to grow in response to higher glacier melt[262], which can increase the hydrostatic pressure that causes structurally weak and unstable dams to suddenly breach. This can result in a sudden, strong discharge of debris and water in a few hours, causing catastrophic floods. GLOFs are likely to occur as a result of these local-level climate change impacts weakening moraines and expanding glacial lakes[263].

Nepal's Himalayan glaciers are particularly vulnerable to climate change and have been melting at a rapid rate over the second half of the 20th century[264], with a total reduction in glacial area of 1,200 km^2 between 1980 and 2010[265] (Table 23) recorded in Nepal. The shrinking, thinning, and retreating of glaciers as a result of climate change not only impacts water resources and river flows but also leads

253 Horstmann, B., 2004. Glacial Lake Outburst Floods in Nepal and Switzerland: New Threats Due to Climate Change. Germanwatch. https://germanwatch.org/en/2753 Accessed: 18 August 2020
254 Karki, M., Mool, P. and Shrestha, A., 2009. Climate change and its increasing impacts in Nepal. The initiation, 3, pp.30-37.
255 MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu.
256 IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
257 IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.
258 Jimenez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G. Cogley, J. G., Doll, P., …Mwakalila, S. S. (2014). Freshwater Resources. In C. B. Field, V. R. Barros, D. J. K. J. Mach, M. D. Mastrandrea, T. E. Bilir L. L. White (Eds.), Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 229–269). Cambridge and New York: Cambridge University Press.
259 Brun, F., Berthier, E., Wagnon, P., Kääb, A. and Treichler, D., 2017. A spatially resolved estimate of High Mountain Asia glacier mass balances from 2000 to 2016. Nature geoscience, 10(9), pp.668-673.
260 Kraaijenbrink, P.D., Lutz, A.F., Bierkens, M.F. and Immerzeel, W.W., 2017. Impact of a 1.5° C global temperature rise on the glaciers of High Mountain Asia. AGUFM, 2017, pp. GC42A-05.
261 Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y.U.N. and Wilkes, A., 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. Conservation Biology, 23(3), pp.520-530.
262 Chalise, S.R., Shrestha, M.L., Bajracharya, O.R. and Shrestha, A.B., 2006. Climate change impacts on glacial lakes and glacierized basins in Nepal and implications for water resources. IAHS PUBLICATION, 308, p.460.
263 Horstmann, B., 2004. Glacial Lake Outburst Floods in Nepal and Switzerland: New Threats Due to Climate Change. Germanwatch. https://germanwatch.org/en/2753 Accessed: 18 August 2020
264 MoFE, 2019. Climate change scenarios for Nepal for National Adaptation Plan (NAP). Ministry of Forests and Environment, Kathmandu.
265 Bajracharya, S.R., Maharjan, S.B. and Shrestha, F., 2014. Understanding dynamics of Himalayan glaciers: scope and challenges of remote sensing. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(8), p.1283.

to the formation of new lakes and the expansion of existing glacial lakes[266]. These factors increase the risk of Glacial Lake Outburst Floods (GLOFs). Climate change is expected to continue influencing temperature and rainfall in Nepal, as described above in Section 4.3, which will drive increased rates of glacier mass loss and shrinkage. These changes will, in turn, affect the formation and expansion of glacial lakes and consequently increase the occurrence of GLOFs and other glacial hazards occurring in Nepal.

Table 23. Decadal glacier area changes at below and above 5800 masl in Nepal from 1980 to 2010[267].

Elevation (masl)	Decade			Full time period
	1980–1990	1990–2000	2000–2010	1980–2010
	Glacier area change (km^2)			
<5,800	-450.1	-243	-245.7	-938.8
≥5,800	-211.9	-52.4	-62.8	-327.1
Total	-662	-295.4	-308.5	-1,265.9

The risk of GLOFs will also increase as climate change affects the trigger mechanisms, such as avalanches, landslides and intense rainfall events. As temperatures rise, snowmelt will increase, reducing the stability of snow coverage in the mountainous regions, which may result in more frequent avalanches that could trigger GLOFs if the avalanches occur near a glacial lake. This snowmelt also contributes to the expanding volume of glacial lakes, which adds strain to their moraines and increases the potential intensity of the flood event. The rising temperatures also increase the rate at which ice melts, which could destabilise large ice deposits, potentially collapsing and triggering GLOFs. The ice within moraines will also melt at a faster rate and contribute to further destabilisation of these weak structures. The climate change projection for precipitation in Nepal also presents a potential rise in GLOF risk with the occurrence of more frequent, high-intensity rainfall events, which may overflow the glacial lakes or destabilise the moraines. Additionally, high rainfall can trigger landslides which slip into the lakes causing a sudden rise in water level and a propagating wave which may overtop or trigger a moraine wall collapse. The occurrence of a GLOF during an intense rainfall event would have a compounding impact with high volumes of water, leading to extremely dangerous and destructive floods.

It is clear from the above discussion that there are impacts of climate change which potentially may compound and further increase the risks of direct impacts on GLOFS. An extensive assessment of the glacial lakes in the Himalayas was carried out by The International Centre for Integrated Mountain Development (ICIMOD) and United Nations Development Programme (UNDP) to identify Potentially Dangerous Glacial Lakes (PDGLs)[268]. From this, the glacial lakes were ranked based on their respective hazard levels determined by the characteristics of the lakes and their dams, the activity of the source glacier and morphology of the surroundings. The critical lakes were classed under Rank 1, and these warrant the immediate implementation of potential measures for GLOF mitigation. Lakes classed under Ranks 2 and 3 need close and regular monitoring.

Several Rank 1 glacial lakes were identified within Nepal, and while all pose a serious risk, four of the lakes at the highest risk of bursting have been selected for interventions under the proposed project to reduce the risk they pose to the population of Nepal. The motivation for selecting these lakes is

[266] Bajracharya, S.R., Mool, P.K. and Shrestha, B.R., 2007. Impact of climate change on Himalayan glaciers and glacial lakes: case studies on GLOF and associated hazards in Nepal and Bhutan. International Centre for Integrated Mountain Development (ICIMOD).
[267] Bajracharya, S.R., Maharjan, S.B. and Shrestha, F., 2014. Understanding dynamics of Himalayan glaciers: scope and challenges of remote sensing. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(8), p.1283.
[268] ICIMOD and UNDP. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905

detailed in Section 3 of this Feasibility Study. The glacial lakes that were selected are: i) Hongu 2; ii) Lower Barun; iii) Lumding Tsho; and iv) Thulagi. Breach modelling assessments were commissioned by UNDP to assess the potential intensity of a GLOF at these four lakes.

In order to inform the selection of appropriate interventions within the Arun and Dudhkosi River Basins, residual risk modelling and vulnerability assessments (Annex 23) were commissioned by UNDP at the watershed and sub-watershed level for the three lakes within these basins — Hongu 2, Lower Barun and Lumding Tsho. The likely impacts of the GLOF and riverine flood, the expected peak discharge was empirically derived utilising the established methods for three scenarios of glacial lake breaching (e. g. Scenario 1: complete breach of moraine dam of glacial lake before lowering, Scenario 2: complete breach of moraine dam after lowering the recommended depth, and Scenario 3: partial breaching of glacial lake after lowering; and iv) Scenario 4 (S4) — GLOF at the Glacial Lake with a partial breach[269] after lowering by the prescribed amount and with downstream adaptation interventions.)[270]. The peak flood discharge was fitted into the HEC-RAS model and modelled the flood for the most vulnerable river reach of 100km downstream from the sources of GLOF. HEC-RAS model was established and assessed the vulnerable location and effectiveness of downstream flood risk reduction measures. By overlaying the digital data of physical elements such as households, agricultural land and infrastructures (e. g. road, trail, motorable bridges, etc.) on top of the flood model (i. e. flood-depth and velocity) to achieve the expected damage for the three scenarios[271]. Furthermore, expected damage using the flood depth-damage model was estimated. The expected direct damage of physical elements was estimated considering the likely flood-depth and velocity, local knowledge and geo-morphology of the identified vulnerable areas. Further details on the methodology of the residual risk modelling and vulnerability assessments can be found in Section 3 of Annex 23.

These models were also used to inform the Financial and Economic Appraisal (Annex 3) for the proposed project. Multiple scenarios were modelled for the glacial lakes, with projected impacts developed for the full drainage of the lake during a GLOF event. This is unlikely, with past GLOFs showing an average drainage of 5 m in the depth of the glacial lake, and so drainage to this level is considered the most likely model for these lakes and the results of that scenario are presented below. These models do not account for the potential loss of human life as there is great variability in the distribution of people relative to the flood flow channel depending on the time of day, season and other factors. The potential risk of loss of human life remains high for GLOFs as many settlements are vulnerable because of their proximity to the river channels and poorly developed infrastructure.

4.4.1. Hongu 2

Hongu 2 glacial lake (Figure 16,Figure 18) was classed a Rank 1 PDGL[272] based on: i) the hanging nature[273] of its parent glacier; ii) the high potential for avalanches in the direct vicinity of the lake; iii) the short moraine length; and iv) the steep slope of its local topography with many erosional features. The lake has an average depth of 53.42 m and a surface area of 0.89 km^2. Modelling — using the

[269]Partial breach depth - 5 m for Hongu 2 and Lower Barun, and 3 m for Lumding Tsho.
[270] Residual Risk Modelling & Watershed/sub-watershed Environmental Vulnerability Assessment. 2021. UNDP
[271] Residual Risk Modelling & Watershed/sub-watershed Environmental Vulnerability Assessment. 2021. UNDP
[272] ICIMOD. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905
[273] When a major valley glacier system retreats and thins, the tributary glaciers may be left in smaller valleys high above the shrunken central glacier surface and are then referred to as hanging glaciers.

physically based, but empirical in nature Froehlich Dam Breaching Model[274,275,276] — shows that without intervention, a GLOF at Hongu 2 would have a peak flood discharge of 24.935 m^3/s, and the breach within the moraine would take 19 min to form[277]. Models show the resulting flood would follow the flow path of the Dudhkosi River as it flowed downstream. The peak discharge of the flood would increase with the river, beginning at 15.224 m^3/s and rising to 19,592 m^3/s after travelling 100 km downstream. The depth of the flood would reach a maximum of 31 m, and the flood waters would travel with a peak velocity of 30 m/s. Direct damage to land and infrastructure is projected to be: i) 115 ha of agricultural land; ii) 83 households; iii) 6 km of road; iv) 13 trail bridges; v) 2 motorable bridges; and vi) 2 km of trails. A Nepal Army barracks[278], located along the bank of the river, and the Solukhola hydropower station[279], which produces 82MW of electricity, would both be highly vulnerable to the impacts of the flood, falling within the projected flood zones for a GLOF events under all modelled flood scenarios. The Rabuwa Bazar further downstream would also be vulnerable, with a flood depth of 15 m and velocity of 6.5 m/s projected at the site of this market.

Figure 16. Hongu 2 glacial lake[280].

[274] Froehlich, C.D., 2008. Embankment Dam Breach Parameters and Their Uncertainties. Journal of Hydraulic Engineering, 134(8): 14

[275] Primary parameters were obtained from ICIMOD for the equation: $Q_p = 3.1B_{avg}H_w^{1.5}\left(\frac{\gamma}{\gamma+T_f\sqrt{H_w}}\right)$ where, H_b = Height of breach; B_{avg} = Average breach width; Z_b = Breach side slope; B_b = breach Bottom Width; Z_u & Z_d = U/S & D/S Dam Slopes; H_w = Height of Water; C = Crest Width; W_{avg} = Average Width; γ = Reduction factor (γ=23.4As/B_{avg})

[276] In addition, following variables will also be considered: T_r = Breach Development Time; H_wV_w = Breach Formation Factor, BFF; V_w/H_w = Storage Intensity, SI; V_{er} = Volume Eroded; B_{avg}/T_f = Erosion rate; A_s = Reservoir Surface Area

[277] The Froehlich empirical method is based on the following equations for the calculation of the average breach width: $B_{avg} = 0.27K_0V_w^{0.32}H_b^{0.04}$ where, K_0 = 1.0 for piping; K_0 = 1.3 for overtopping; V_w= volume of water in GL; and H_b=height of breach; $T_f = 63.2\sqrt{(Vw/(gH_b{}^2))}$

[278] Impacts of a GLOF on the army barracks would be considered 'catastrophic'

[279] The Solukhola hydropower station was designed without considering the GLOF in Dudhkosi, with the main powerhouse located on the bank of the Dudhkosi river

[280] Photo taken by Deepak KC (UNDP). Available in ICIMOD and UNDP. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905

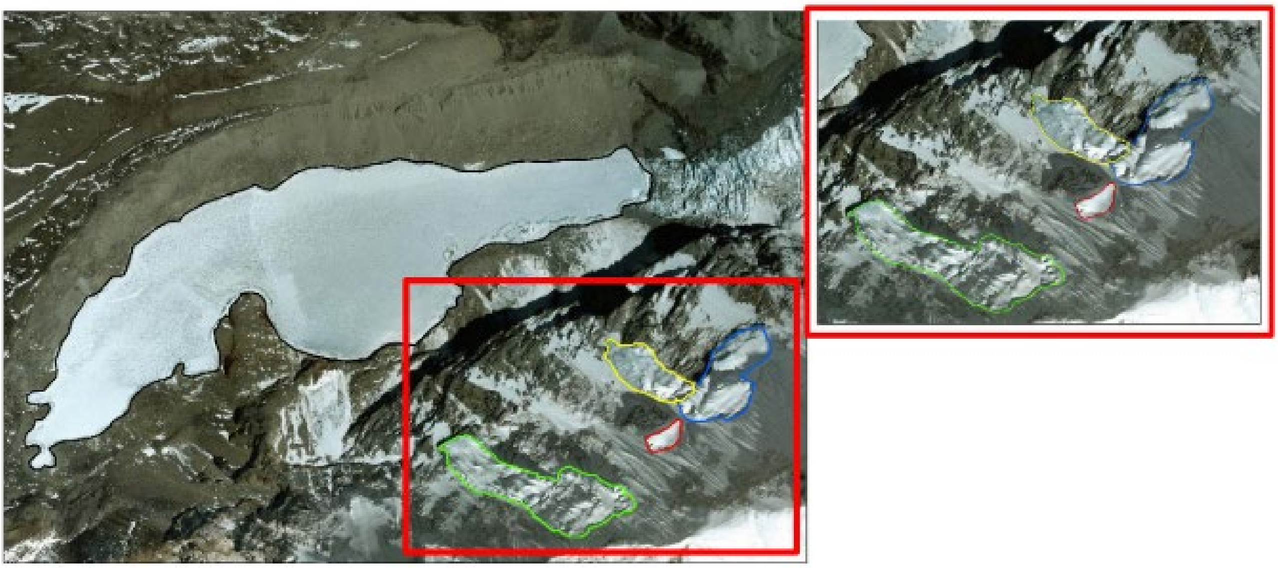


Figure 17. Hongu 2 Glacial Lake, and its surrounding with the four hanging glaciers (zoomed-in view in the red box) on the southern slopes of the lake or the northern slopes of Chamlang Peak[281].

4.4.2. Lower Barun

The Lower Barun glacial lake (Figure 18, Figure 19) received a PDGL Rank 1 because of: i) the strong possibility of expansion of the glacial lake; ii) the lake having a calving[282] source glacier — which refers to the sudden release and breaking away of a mass of ice from a glacier; iii) the high risk of landslides and ice avalanches at the wall to the right of the lake; and iv) the presence of three other smaller lakes in the upper catchment area. The lake area of Lower Barun has increased from 0.64 km^2 to 2 km^2 since 1990. The average depth of Lower Barun is 65.32 m and, at its current size and volume, a GLOF would have a peak flood discharge of 40.65 m^3/s with the breach forming in 41 min. Modelling — using the Froehlich Dam Breaching Model[283]— has shown that the flood would follow the channel of the Arun River as it flowed downstream. As the flood progressed down the Arun River, the flood peak would grow with the river flow, rising to 49.22 m^3/s approximately 30 km downstream of the lake at the location of Sibung village. This figure would rise further and be greatest 103 km downstream, where the 52.23 m^3/s flood peak would reach the confluence of the Arun and Sabha Khola rivers. Flood depths would reach 23 m and the flood would travel with a velocity of 33.5 m/s along the main flow channel of the Arun River and would likely collapse the riverbanks. The amount of land and infrastructure projected to be directly damaged by the flood include: i) 20 ha of agricultural land; ii) 10 households; iii) 1.9km of road; iv) four trail bridges; v) one motorable bridge; and vi) 2.8 km of trails. The Arun-III hydropower station, which generates 900MW of electricity, would also be impacted[284], affecting local and regional electricity supply.

[281] Feed (P) Ltd. 2020. Protecting livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal
[282]This falling ice may trigger a GLOF in a glacial lake by generating a large wave or damaging the moraine.
[283] Froehlich, C.D., 2008. Embankment Dam Breach Parameters and Their Uncertainties. Journal of Hydraulic Engineering, 134(8): 14
[284] GLOFs can have multiple impacts on hydropower production. Primary among these is the direct damage to turbines from sediment and debris in the flood waters. Arun-III was designed for a lower peak discharge from a GLOF than would be anticipated from the modelling.

Figure 18. Lower Barun glacial lake[285].

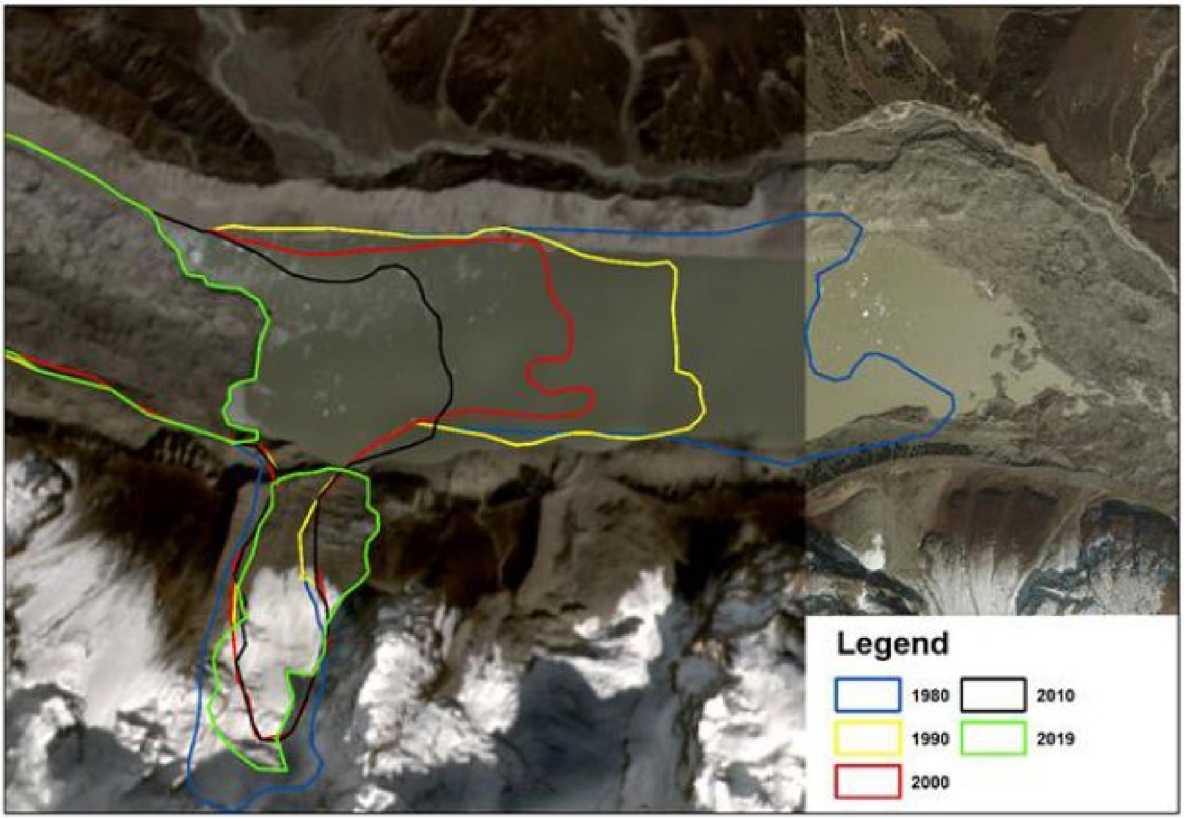


Figure 19. Lower Barun Glacier area change and terminus retreat from 1980 to 2019[286].

[285] Photo taken by Deepak KC (UNDP). Available in ICIMOD and UNDP. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905

[286] Haritashya, U.K., Kargel, J.S., Shugar, D.H., Leonard, G.J., Watson, C.S., Furfaro, R., Chase, D., Kirschbaum, D. and Anderson, E., 2018, December. Growth of Lower Barun glacial lake, Nepal Himalaya. In AGU Fall Meeting Abstracts (Vol. 2018, pp. C21E-1396).

4.4.3. Lumding Tsho

The PDGL Rank 1 of Lumding Tsho glacial lake (Figure 20,Figure 21) was attributed to: i) the rapid expansion of the lake; ii) the lake being in contact with calving glacier; iii) the presence of three hanging lakes in the side valley of the lake; and iv) the continuous slope of the moraine. The average depth of the lake is 59.5 m, and the surface area is 1.37 km^2. At this size, a GLOF would result in a peak flood discharge of 30.61 m^3/s, with the breach forming in 41 min. Modelling of a GLOF from the Lumding Tsho glacial lake shows that it would follow the channel of the Dudhkosi River, the same pathway as the Hongu 2 glacial lake. The proximity of these two lakes results in overlapping impacts and model results, despite their separate locations. The flow pathways from the lakes converge with the Dudhkosi River, upstream of any settlements and significant infrastructure. This results in the same modelled impacts for a GLOF at Lumding Tsho and Hongu 2, presented above. The only difference in impacts found were the expected direct damages, with a GLOF at Lumding Tsho projected to damage: i) 71 ha of agricultural land; and ii) 65 households. The risks presented to the Nepal Army barracks, Solukhola hydropower station and Rabuwa Bazar posed by Lumding Tsho are the same as those presented from Hongu 2 GLOF above.

Figure 20. Lumding Tsho glacial lake[287].

[287] ICIMOD and UNDP. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905

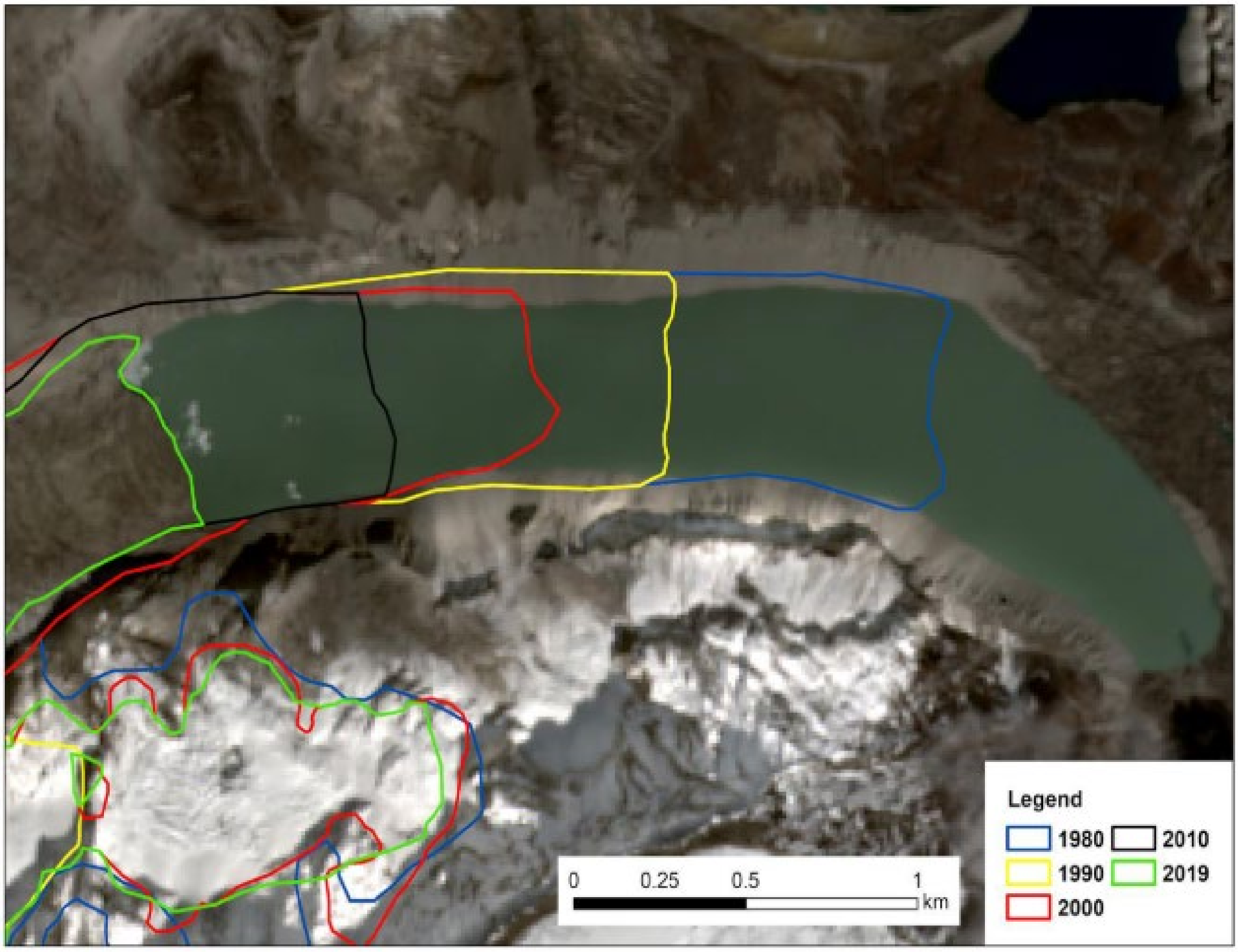


Figure 21. Lumding Tsho Glacier area change and terminus retreat from 1980 to 2019[288]**.**

4.4.4. Thulagi

The classification of Thulagi glacial lake (Figure 22,Figure 23) as a PDGL Rank 1 was based on: i) the large size of the lake; ii) the expansion of the lake on the debris-covered source glacier; iii) the risk of landslides and snow avalanches from the side walls around the lake; and iv) the evidence of subsidence of old and compact end moraine. Since the 1990s, the lake area of Thulagi has increased from 0.72 km^2 to 0.94 km^2 and it has an estimated volume of 36.1×10^6 m^3. This glacial lake was not included in the Residual Risk and Vulnerability Assessment commissioned by UNDP (Annex 23) as this lake was not targeted for downstream interventions by this project and will only be targeted by upstream interventions, namely lake lowering. Published peer-review articles that modelled GLOF characteristics for Thulagi lake predict a peak flood discharge between 4,736 m^3/s and 5,334 m^3/s at the lake's current size and volume[289,290,291]. Great risk is posed to the safety of people in the Tal village

[288] Haritashya, U.K., Kargel, J.S., Shugar, D.H., Leonard, G.J., Watson, C.S., Furfaro, R., Chase, D., Kirschbaum, D. and Anderson, E., 2018, December. Growth of Lower Barun glacial lake, Nepal Himalaya. In AGU Fall Meeting Abstracts (Vol. 2018, pp. C21E-1396).
[289] Maskey, S., Kayastha, R.B. and Kayastha, R., 2020. Glacial lakes outburst floods (GLOFs) modelling of Thulagi and lower Barun glacial lakes of Nepalese Himalaya. Progress in Disaster Science, 7, p.100106.
[290] ICIMOD. Glacial lakes and glacial lake outburst floods in Nepal. ICIMOD; 2011; 110.
[291] Khanal, N.R., Mool, P.K., Shrestha, A.B., Rasul, G., Ghimire, P.K., Shrestha, R.B. and Joshi, S.P., 2015. A comprehensive approach and methods for glacial lake outburst flood risk assessment, with examples from Nepal and the transboundary area. International Journal of Water Resources Development, 31(2), pp.219-237.

downstream of Thulagi lake as well as the village infrastructure, as flood heights are projected to reach 15 m[292].

Figure 22. Thulagi glacial lake[293].

[292] Maskey, S., Kayastha, R.B. and Kayastha, R., 2020. Glacial Lakes Outburst Floods (GLOFs) Modelling of Thulagi and Lower Barun Glacial Lakes of Nepalese Himalaya. Progress in Disaster Science, p.100106.

[293] Photo taken by Deepak KC (UNDP). Available in ICIMOD and UNDP. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905

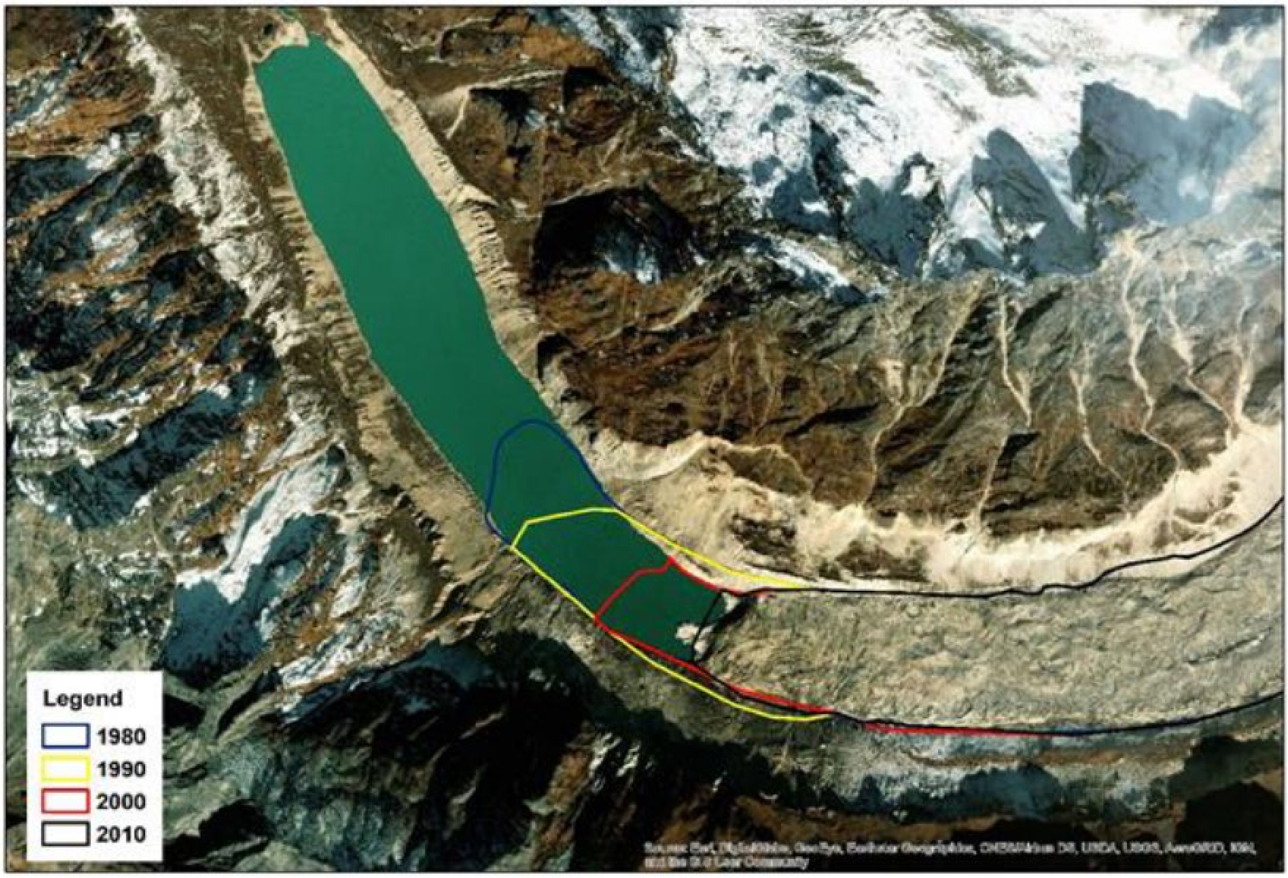


Figure 23. Thulagi Glacier area and terminus retreat from 1980 to 2010[294].

4.4.5. Additional climate vulnerability of target basins

As part of the Residual Risk and Vulnerability Assessment[295] commissioned by UNDP (Annex 23), modelling was conducted to assess the vulnerability of the Arun and Dudhkosi River Basins to the additional impacts of a GLOF under scenarios with and without climate change. This assessment combined a physical model of environmental vulnerability with a human settlement layer, through GIS, to assess the scale vulnerability at the sub-watershed level. Each basin was modelled for three scenarios considering rainfall as a variable attribute, namely: i) historical average rainfall; ii) rainfall projections under RCP4.5; and iii) rainfall projections under RCP8.5. Based on these three physical and one social factors, an Analytical Hierarchy Process was used to classify the sub watersheds for each river basin into five vulnerability categories: i) Very Low; ii) Low; iii) Moderate; iv) High; and v) Very High[296].

The sub watersheds within the Arun River Basin hosts an estimated 50,588 households and was ranked at predominantly Moderate risk (Table 24), with over 1,000 km^2 (34%) of land classified as High and Very High risk. This represents a significant portion of the Arun River Basin that is vulnerable to the impacts of flooding under climate change projections. As such an extensive area of land would be impacted, this highlights the widespread damage caused by these floods. Within the Arun Basin, the Arun Valley, Sabha Khola, Irkhu and Kasuwa sub-watersheds were identified as priority areas as the land within them was predominantly classified as High and Very High-risk areas and they have a

[294] Haritashya, U.K., Kargel, J.S., Shugar, D.H., Leonard, G.J., Watson, C.S., Furfaro, R., Chase, D., Kirschbaum, D. and Anderson, E., 2018, December. Growth of Lower Barun glacial lake, Nepal Himalaya. In AGU Fall Meeting Abstracts (Vol. 2018, pp. C21E-1396).
[295] Residual Risk Modelling & Watershed/sub-watershed Environmental Vulnerability Assessment. 2021. UNDP.
[296] Residual Risk Modelling & Watershed/sub-watershed Environmental Vulnerability Assessment. 2021. UNDP – Section 3.3.

substantial number of households that would be put at risk. Within the Dudhkosi River Basin, there are an estimated 63,368 households, and the majority of land was categorised as Very Low risk (Table 24). This represents a lower risk than the Arun basin, but a substantial amount of land would be vulnerable in the Dudhkosi River Basin, with 512 km^2 (12.9%) classified as High and Very High risk. Priority sub-watersheds within the Dudhkosi Basin were identified to be Dudhkosi valley, Solukhola, Thotnekhola and Rawakhola. It should be noted that this modelling did not account for the potential impact of landslides, which are difficult to predict but have been shown to often be triggered by intense rainfall events, which are expected to increase in frequency under future climate change conditions in Nepal. In the steep mountain slopes of the Arun and Dudhkosi Basins, as the risk of rainfall-induced floods rises, so does the potential risk of landslides and the threat they pose to vulnerable communities. The effects of GLOFs and monsoon rain-induced flooding are very similar and can be mitigated by many of the same interventions, providing an opportunity under the proposed project to reduce the impact of monsoon season flooding while also addressing GLOF risk.

Table 24. Summary of basin vulnerability within target river basins.

River basin		Risk category				
		Very Low	Low	Moderate	High	Very High
Arun	Area in km^2	417.9	751.7	1,185.6	858.6	173.3
	Area in %	12.3	22.2	35.0	27.7	6.4
Dudhkosi	Area in km^2	1,269.2	1,119.7	1,054.0	462.8	49.3
	Area in %	32.1	28.3	26.6	11.7	1.2

5. Climate change impact pathways, options analysis and preferred solution

Climate projections indicate that Nepal will experience increased temperatures, with these increases being more prominent at the higher altitudes of the Himalayas, where numerous glacial lakes are present. These changes are expected to increase the frequency and intensity of Glacial Lake Outburst Floods (GLOFs) in the country as glacial lakes expand in size and volume under rising temperatures[297]. Nepal is also expected to experience shifts in precipitation, with monsoon rainfall periods becoming shorter and more intense. This is likely to increase the frequency and intensity of floods, particularly in areas near and downstream of glacial lakes. Therefore, monsoonal rainfall has the potential to lead to GLOF events. Furthermore, projected increased precipitation can lead to landslides and these landslides have the potential to lead to GLOF events as rocks and other material form the landslide moves into the glacial lakes and displaces large amounts of water leading to GLOFs.

5.1. Impact of GLOFs on infrastructure

5.1.1. Impact chains

Figure 24 presents the impact pathways (IPs) from a GLOF at the Hongu 2, Lower Barun, Lumding Tsho and/or Thulagi Lakes that will affect Nepal's economy, as well as the health and well-being of the population. In this Feasibility Study, the focus is primarily on reducing the risk of GLOFs at four target lakes and mitigating the residual downstream impacts of a GLOF in the Arun and Dudhkosi Basins through implementing an Eco-Disaster Risk Reduction (Eco-DRR) approach. The areas where the proposed project interventions will disrupt the impacts of extreme climate events, particularly GLOFs, on the economy and population of Nepal are presented below, along with justification for the selection of the project interventions.

[297] Further details on climate projections and the associated impacts are presented in Section 4 of this Feasibility Study.

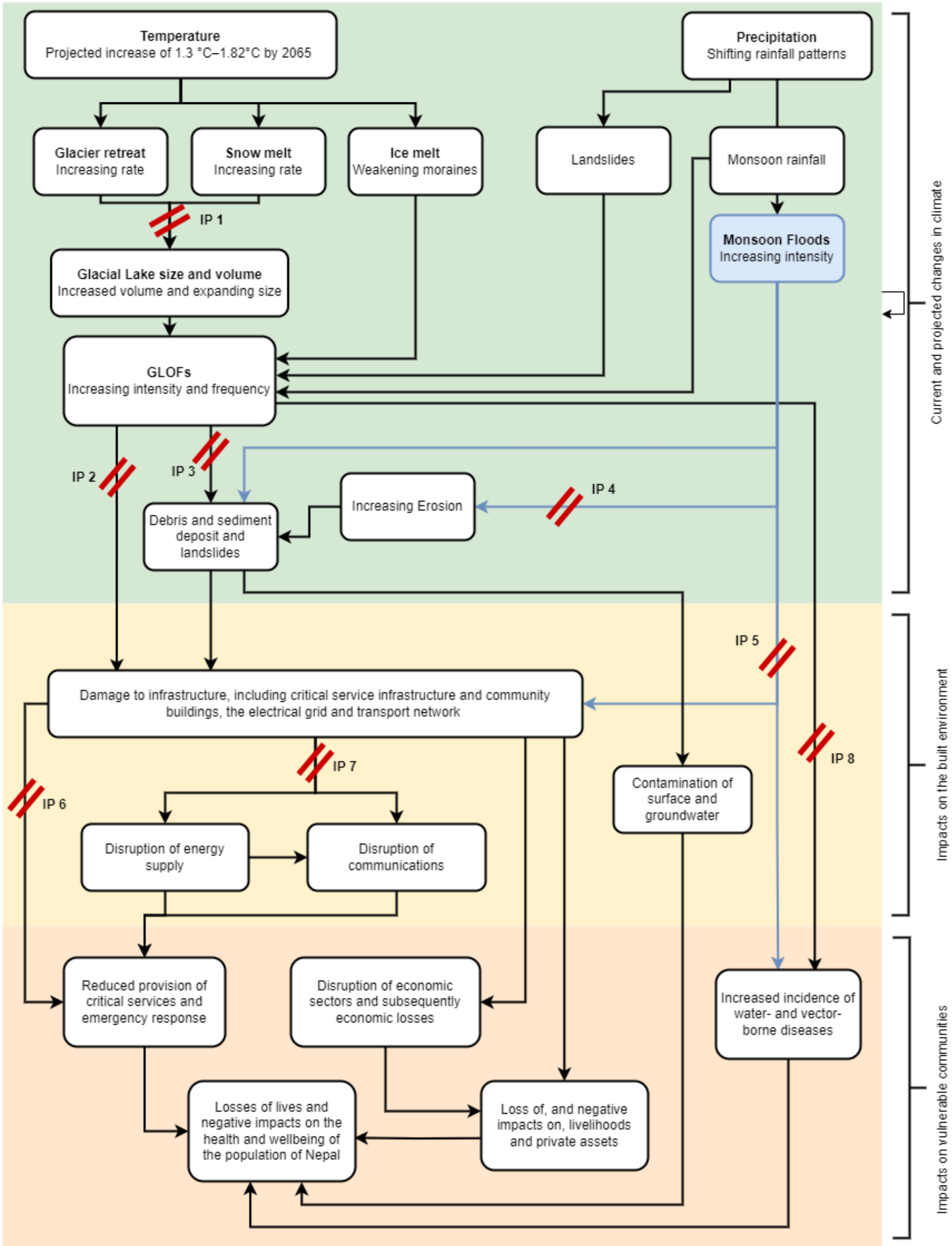


Figure 24. Schematic representation of expected climate change impact pathways (IPs) on vulnerable communities in Nepal. The direction of the arrows indicates the direction of the causal pathway. The red "//" symbol represents junctures along relevant impact pathways where project interventions will disrupt the impacts of extreme climate events.

- **IP 1 – Increased volume and size of glacial lakes:** The combination of increasing glacial retreat and snow melt resulting from rising temperatures leads to the increase in the volume and size of glacial lakes.
- **IP 2 – More frequent and intense GLOFs:** The large volume of water released suddenly from a GLOF at any of the four target lakes — Hongu 2; Lower Barun; Lumding Tsho; and Thulagi — causes severe damage to Nepal's infrastructure — including critical public service, community and private buildings — in basins downstream of the glacial lakes. Communities at higher altitudes in the Himalayas where flooding occurs immediately are at the highest risk of being impacted by such events. This is because these communities are mostly rural, with buildings and infrastructure that is not able to withstand the force of flood waters associated with a GLOF. Houses and other buildings are not set with foundations, and there is a network of trail bridges that are important for maintaining accessibility, but these simple structures are vulnerable to the intense floods from a GLOF.
- **IP 3 – Increased sediment and debris in flood water:** More intense GLOFS increase the volume of sediment and debris in flood waters, exacerbating damages to infrastructure. The steep slope of the terrain in these regions contributes to the impacts of this flooding by reducing infiltration that is needed to attenuate flow and increasing the rate of mobilised debris from the flood travelling downstream and being deposited in riverbeds and floodplains as well as damaging infrastructure and property. Therefore, in addition to the destructive effects of the water released during a GLOF, there is also the risk presented by the debris and sediment that will be carried and deposited by the flood. Deforestation has exacerbated this problem, contributing to soil erosion along the mountain slopes, leaving soil vulnerable to be mobilised by floods. The impacts of soil carried by floods include: i) the sediment being deposited downstream and affecting river channel flow; ii) the soil can clog drains and sewage systems; iii) soil and rocks deposited into hydropower installations can affect their operation or cause damage; iv) if enough soil is mobilised and deposited, roads and other infrastructure can be buried; and v) agricultural land can be covered in soil and rocks.
- **IP 4 – Erosion from intense rainfall:** Rainfall-induced floods that occur during the monsoon season have similar impacts to GLOFs, exacerbating the impacts of debris and sediment.
- **IP 5 – Flood damage from intense rainfall:** Floods resulting from intense monsoon rainfall events lead to loss of life, injuries and health risks within affected communities, as well as damage to infrastructure and the environment.
- **IP 6 – Disruption of critical services:** The damage caused by GLOFs lead to the disruption in the provision of critical services and emergency response, such as medical care and rescue services during and immediately after the GLOF event.
- **IP 7 – Disruption of communications and energy services:** GLOFs will likely also affect Nepal's power supply and communications (IP5), with the country being predominantly dependent on hydropower stations that will be particularly vulnerable to flood impacts. The resulting loss of power supply along with damages to communications infrastructure could result in many isolated communities being cut-off from critical emergency communications during and after the GLOF event. There will also be long-term impacts resulting from disrupted power supply and communications as economic activities the affected regions will be disrupted, leading to economic losses in vulnerable communities already dealing with the challenges of poverty.
- **IP 8 – Health risks from residual flood waters:** The water released during GLOF events can also contribute to increased incidence of water-and vector-borne diseases. With a large volume of water released from the glacial lakes and poor infiltration resulting from erosion, there is often a great amount of stagnant water — often contaminated with sewage — in the affected area that can become a source of disease.

The combined impacts of climate change result in extensive financial losses as well high costs for reconstruction and repair efforts. These costs place further financial burdens upon a developing national economy that currently faces numerous challenges — Nepal's LDC status, extensive poverty, limited socio-economic development and high trade deficits from fuel and energy imports. Similarly, to GLOFs, rainfall-induced monsoon floods also have secondary impacts in the form of landslides, erosion and the outbreak of water- and vector-borne diseases. Overall, the impacts of rainfall-induced monsoon flooding and GLOFs overlap extensively and result in similar impacts and economic losses.

5.1.2. Vulnerabilities to impact chains

At present, infrastructure in Nepal is vulnerable to the impacts of GLOFs from the target glacial lakes, as well as multiple other Rank 1 Potentially Dangerous Glacial Lakes (PDGLs) in the Himalayas. As the climate changes (see Section 4) these glacial lakes grow, so the expected impact of GLOFs increases, with the associated impacts on critical infrastructure also becoming more severe. The vulnerability of Nepal's infrastructure (buildings, houses, roads, etc.) will be compounded by increasingly intense and frequent monsoon rainfall as climate change continues to affect precipitation, resulting in flooding, which will impact communities and infrastructure and increase the likelihood of GLOFs as one of the trigger mechanisms. These impacts are exacerbated by Nepal's limited capacity to adopt climate-resilient approaches to infrastructural development that account for GLOFs. With remote and isolated settlements at high altitudes in the Himalayas, and prevalent poverty and limited socio-economic development, the country continues to rely on infrastructural development that is not climate resilient. These vulnerabilities will become more severe as climate change increases the risk of GLOFs.

5.1.3. Options and approach for reducing GLOF risk

While there are few to no interventions that have the potential to eliminate the impact of a GLOF, there are several interventions that have proven successful at significantly reducing its impact [298]. These interventions include: i) substantial draining of the glacial lake to reduce the volume of water stored within it; ii) artificially reinforcing structures such as the terminal moraine; and iii) constructing smaller flow channels feeding out of the glacial lake to gradually reduce the overall volume of water contained in a glacial lake at any time. Each intervention presents unique challenges and risks. Additionally, the volatility of structural instability of these lakes makes designing and implementing any interventions challenging, and specialised engineering studies and planning are required to inform these processes. During the project scoping phase, a panel of experts determined that draining of the four glacial lakes most at risk of bursting was the most suitable adaptation option. This selection was based on an analysis of risk reduction options that included an assessment of past initiatives. Draining glacial lakes has been successfully implemented previously in Nepal and other countries that face GLOF risks. For example, the project considered the experiences from the substantial draining of the Imja Glacial Lake (Imja Tsho) in Nepal, cited as one of the most dangerous glacial lakes in the Himalaya, and lowering the lake level by more than 3 m through the construction of an open channel, which proved successful in reducing the GLOF's hazard risk in 27 downstream settlements. According to UNDP, the Imja Tsho lowering averts the bursting of the lake and could help save the lives of the 87,782 people living downstream[299]. However, not all methods of lake lowering have proved successful. For example, a siphoning system to remove water from Tsho Rolpa Glacial Lake — Nepal's biggest Glacial Lake above 4500 metres of altitude — was installed in 1995 but met with limited success. Subsequently, an open channel was cut through the end moraine dam

[298] Wang, S. and Zhou, L., 2017. Glacial lake outburst flood disasters and integrated risk management in China. *International Journal of Disaster Risk Science*, *8*(4), pp.493-497.
[299] UNDP. 2021. Report on Protecting Livelihoods and Assets at Risk from Climate Change Induced Flooding in Glacial River Basins of Nepal.

and a 4 metres-deep artificial spillway created. This intervention, which was completed in 2000, succeeded in lowering the lake by 3 metres (ICIMOD 2011). Other options like “follow the nature” and “draining by a piercing,” were also not considered suitable options since they do not reduce the risk of lake outbursts. Draining by piercing even increases the risk of end moraine dam failure since the pipe will be inserted beneath the end moraine with heavy construction endeavor and knowledge. Structural lake lowering intervention was therefore selected because it is a reliable and proven option used in Tsho Rolpa and Imja Glacial lakes. The goal is to regulate water flow in a controlled way and prevent the scouring of end moraine (see Section 6.1.4 of Annex 26 for more details on options assessed).

As the climate change factors that influence GLOF risk are beyond the scope of anthropogenic intervention, and GLOFs have various trigger mechanisms, interventions that seek to disrupt climatic factors or trigger mechanisms are impractical and difficult to develop. Thus, reduction of the glacial lake volume is the most reliable method for reducing the impacts of GLOFs. This option also provides long-term benefits as the lake lowering gate structures built during this project will allow future drainage if the lakes rise to dangerous volumes under climate change, which is likely. The specific designs for the lowering mechanisms and structures for each lake were designed after a comprehensive assessment. These designs are presented in Section 12 of this Feasibility Study and Annex 22.

The lake lowering assessment commissioned by UNDP included modelling to determine the level of lake lowering required at the Thulagi, Lower Barun, and Lumding Tsho and Hongu 2 glacial lakes. Based on the literature review and learnings from Tsho Rolpa and Imja Glacial Lake, this assessment concluded that the lower Thulagi, Lower Barun, and Lumding Tsho glacial lakes should be drained by 3 m, and the Hongu 2 glacial lake should be lowered by 1 m under the proposed project to adequately reduce the impacts of a GLOF on nearby and downstream communities. The lake lowering depth is limited by the presence of the dead ice zones[300] that, if reached, will result in an unstable foundation and thus potential failure of the installed lake level lowering infrastructure. Draining these lakes to these depths will provide sufficient reductions in volume to significantly reduce expected GLOF impacts. This is based on past GLOF events in other glacial lakes, which have shown that when breached, the lakes do not drain completely but instead show a lowering of between 3 m and 5 m post-flood. The lowering of these glacial lakes will disrupt IP 1, IP 2 and IP 3 by reducing the destructive impact of GLOFs from these lakes, with lower volumes of water released, which will contribute to reduced flood intensity, height, velocity and duration.

Under the UNDP commissioned Residual Risk and Vulnerability assessment, modelling was carried out for four different scenarios of GLOF impacts at the Lower Barun, Hongu 2 and Lumding Tsho Glacial Lakes. The models accounted for the GLOF impacts on the entire river basin downstream of each Glacial Lake, with the Lower Barun Glacial Lake affecting the Arun River Basin and impacts in the Dudhkosi River Basin being divided into subsets with the Hongu 2 Glacial Lake affecting the Hongu-Dudhkosi River Basin subset and the Lumding Tsho Glacial Lake affecting the Lumding-Dudhkosi subset. The four modelled scenarios were: i) Scenario 1 (S1) — GLOF at the Glacial Lake without any interventions with a complete breach; ii) Scenario 2 (S2) — GLOF at the Glacial Lake after lowering the recommended depth with complete breach of moraine dam; iii) Scenario 3 (S3) GLOF at the Glacial Lake with a partial breach[301] after lowering by the prescribed amount of 3 m for Lower Barun and Lumding Tsho and by 1 m for Hongu 2; and iv) Scenario 4 (S4) — GLOF at the

[300] Dead ice refers to the part of the glacier that are no longer moving and end up buried under sediment – unstable terrain.
[301]Partial breach depth - 5 m for Hongu 2 and Lower Barun, and 3 m for Lumding Tsho.

Glacial Lake with a partial breach[302] after lowering by the prescribed amount and with downstream adaptation interventions. The downstream adaptation interventions were selected based on effectiveness in terms of cost and risk reduction, and this was Eco-DRR or Green-Grey construction, such as vegetative gabion embankments, vegetative gabion revetments and spurs to strengthen riverbanks (Annex 23). The GLOF impacts on agricultural land and infrastructure were projected for all four scenarios and are summarised in Table 25. There is a reduction in impacts between S1 and S2, which shows the effectiveness of lowering the Glacial Lakes by the prescribed amount to reduce damages and losses. Further reductions in the impacts are shown between S3 and S4, which indicates the importance of downstream adaptation measures to further offset the impacts of a GLOF at any of the three Glacial Lakes.

Table 25. Modelled impacts of GLOF events under different intervention scenarios.

River Basin	**Expected direct damage**											
	Agricultural land (ha)				**Household (No.)**				**Road (km)**			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Arun	1, 271	674	236	20	272	267	173	10	7	7	7	1.9
Hongu-Dudhkosi	256	256	115	5	124	123	83	4	6	6	6	1.6
Lumding-Dudhkosi	104	104	71	7	99	97	65	2	6	6	6	1.6
River Basin	**Expected direct damage**											
	Trail bridge (No.)				**Motorable bridge (No.)**				**Trail (km)**			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Arun	32	32	26	4	2	2	1	1	9	9	9	2.8
Hongu-Dudhkosi	17	17	13	1	3	3	2	1	2	2	2	1.5
Lumding-Dudhkosi	21	21	13	0	2	2	2	2	2	2	2	1.5

Further estimates of losses associated with GLOF events were projected for Thulagi glacial lake along with Imja glacial lake, Tsho Rolpa glacial lake and Lumuchimi glacial lake[303]. The results of this modelling show that significant amounts of real estate, agricultural land and infrastructure, public infrastructure and other revenue would be impacted by a GLOF at any of these lakes. A summary of these results is presented below in Table 26.

Table 26. Monetary value of elements potentially exposed to glacial lake outburst flood risk (USD thousands).

Sectors	Imja (Dudhkoshi)		Tsho Rolpa (Tamakoshi)		Thulagi (Marsyangdi)		Lumuchimi (Bhotekoshi/ Sunkoshi)	
	Model	Max	Model	Max	Model	Max	Model	Max
Real estate	8,917	31,729	1,411	6,524	2,036	6,685	15,889	40,606
Agriculture	932	1,680	117	330	234	519	246	996

[302]Partial breach depth - 5 m for Hongu 2 and Lower Barun, and 3 m for Lumding Tsho.
[303] Khanal, N.R., Hu, J.M. and Mool, P., 2015. Glacial lake outburst flood risk in the Poiqu/Bhote Koshi/Sun Koshi river basin in the Central Himalayas. Mountain Research and Development, 35(4), pp.351-364.

Public infrastructure	2,037	2,084	319	1,928	335,784	339,469	98,845	109,446
Revenue	7	7	0	0	68,678	68,678	37,762	37,762
Total	11,894	35,501	1,847	8,781	406,731	415,351	152,741	188,810
Model = modelled GLOF scenario. Max = maximum affected level.								

5.2. Impacts of GLOFs on livelihoods and the environment

5.2.1. Impact description

The impact of a GLOF from any of the four target lakes will affect critical infrastructure, disrupting the provision of critical services and emergency response (IP 3), such as medical care and rescue services. This will negatively impact the wellbeing of the affected communities by increasing the expected loss of life and the number of serious injuries resulting from the disaster. There will also be long-term effects on the wellbeing of communities as post-disaster relief efforts are more challenging to implement, and there is greater difficulty in providing recovery resources and services. The impacts will extend to the livelihoods of affected communities as damaged infrastructure, and critical service interruptions are expected to hinder community functioning and business operations. GLOFs will also affect Nepal's power supply and communications (IP 5), with the country being predominantly dependent on hydropower stations that will be particularly vulnerable to flood impacts. The resulting loss of power supply along with damages to communications infrastructure could result in many isolated communities being cut off from critical emergency services and communications during and after the GLOF event. Disruptions to power supplies and communications will have long-term impacts, as economic activities in the affected regions will be disrupted, leading to economic losses in vulnerable communities already dealing with the challenges of poverty. This will place already vulnerable livelihoods at further risk, increasing the challenges faced in these communities. The secondary impacts of GLOFs may also increase damages and losses as the floods trigger landslides on the mountain slopes (IP 6). Landslides will severely impact the wellbeing of affected communities and further delay the provision of critical services and local community and business functioning. The water released during GLOFs can also contribute to increased incidence of water-and vector-borne diseases (IP 7). With a large volume of water released from the glacial lakes and poor infiltration resulting from erosion, there is often a great amount of stagnant water — often contaminated with sewage — in the affected area that may become a source of disease. These factors combine to develop a situation where the wellbeing and livelihoods of affected communities are put at risk across multiple fronts following a GLOF — through immediate direct and secondary impacts as well as through prolonged challenges that delay the return to normal functioning and result in long-term impacts.

A GLOF will also have severe impacts on flora and fauna in affected areas, uprooting vegetation, as well as killing and injuring wildlife. The soil will be heavily eroded, remaining exposed and vulnerable to further erosion until vegetation is restored. Portions of the soil mobilised by the flood waters will be deposited in rivers, disrupting their flow, and the rest will be deposited on slopes downstream, burying vegetation. This will result in the local environment being severely degraded immediately after the GLOF, requiring long-term recovery to return to healthy functioning. Vegetation will likely take several seasons to re-establish, and wildlife numbers will only stabilise after multiple breeding seasons and, as a result, river systems may only clear after the rains of the subsequent monsoon season. The time needed for environmental recovery will be increased if secondary impacts such as landslides take effect, increasing the loss of flora and fauna, as well as the blockage of river systems. This will affect both the wellbeing and livelihoods of communities in the area as ecosystem services are disrupted by these impacts. Many people are dependent on natural resources — water supply, firewood, grazing land, hunting and foraging, subsistence agriculture — and this dependence will increase post-flood as demand rises during the recovery period. If the environment is too degraded to supply sufficient resources for local communities, the burden placed on external relief systems will increase, and the affected communities will suffer prolonged challenges as a result of the GLOF.

5.2.2. Gap analysis

Effective management of GLOF risks requires both risk reduction as well as timely warnings for rapid response to an impending GLOF. Risk reduction in Nepal is continuously developing through interventions to reduce the impacts of flooding on infrastructure and communities, but these efforts have focused on rainfall-induced flooding and have primarily been within low-lying regions. The impacts of GLOFs require interventions that account for the sudden, intense impacts of these events, which are currently lacking in Nepal. The rapid discharge of the high volume of water from a GLOF requires structural interventions to attenuate the flow of flood waters in order to protect people and infrastructure. Further reduction of GLOF impacts can be achieved with timely warnings that allow emergency service providers and communities to prepare and act before the onset of the disaster. Increasing the time available to prepare for GLOF impacts requires the installation and operation of Early Warning Systems (EWS) that account for the rapid onset of GLOFs and monitor climatic parameters linked to the various trigger mechanisms of these events. This EWS capacity is limited in Nepal, as existing EWS require expanded and upgraded hydrological and meteorological monitoring infrastructure and the Department of Hydrology and Meteorology (DHM) in need of the skills to effectively manage and utilise the EWS. Therefore, Nepal is limited in their EWS technical capacity and only with the improved EWS and the necessary skills will there be a tangible reduction in GLOF risks through improved warnings. Along with the specialised EWS, there is a need for emergency response plans within communities that are designed to account for the immediate dangers presented by GLOFs. With the likelihood and severity of GLOFs set to increase under climate change, the need for these specialised interventions grows more urgent.

5.2.3. Options analysis for preferred solution

In response to the abovementioned adaptation needs, the proposed project will address the adverse impacts that GLOFs have on the health and well-being of Nepal's population through disrupting IP 3, IP 5, IP 6, IP 7 and IP 8. Several options were considered for disrupting these impact pathways and the most beneficial interventions were identified. Three different alternatives of flood risk reduction measures were analysed, and these were: i) Structural measures; ii) Biological measures; and iii) Eco-DRR or the Green-Grey construction. Among the three approaches, the Green-Grey construction was found effective in terms of cost and risk reduction (see Annex 23). The combination of downstream structural and ecosystem-based adaptation (EbA) interventions with an improved EWS will provide effective mitigation of expected GLOF impacts. The strategic construction of revetments, check dams, flood walls and conservation ponds will offset the direct impacts of GLOF by: i) attenuating the flow of flood water; ii) reducing the velocity and volume of water travelling in the flood; iii) diverting part of the flow away from communities and critical infrastructure; and iv) dispersing the flood water to allow greater infiltration, gradually reducing flood volume. These grey structural interventions will be combined with EbA in the form of planting trees along vulnerable riverbanks and flood plains, the construction of vegetative gabions, walls and revetments, as well as planting of brush and grass in priority areas. The purpose of the EbA interventions will be to: i) stabilise soil to reduce sediment carried and deposited by the flood water; ii) catch dangerous debris carried by the flood; iii) improve infiltration to reduce flood volume; iv) reduce the velocity of flood water; and v) reinforce river structures to direct the flow of the flood water along the river channel. The hybrid construction at the selected locations is recommended to not only reduce the risk of flood but also contributes to improve the degraded physical environment and ecosystem, make the flood risk reduction works sustainable and adhere the long-term solutions (Annex 23). The grey structures and EbA interventions will disrupt the GLOF impacts through IP 3 and IP 5 by protecting infrastructure through the reduction of flood impacts Furthermore, under EbA interventions that will be implemented plant species grow, root systems that anchor the underlying soil mass develop, and these increase the slope stability and reduce the flood velocity. This project attempted to make use of the flexible gabion structures to be integrated with the plant species, which allows the plant to grow without any hindrance (Annex 23). The effectiveness of these interventions is demonstrated by the impact modelling results presented in Table 25 above, where there is a significant decrease in impacts on agricultural land and infrastructure when these interventions are included under Scenario 4. These interventions will also disrupt the secondary risks associated with GLOFs through IP 6 by stabilising soil and riverbanks, reducing the risk of landslides within the flood impact area. Improved infiltration will also disrupt secondary impacts through IP 7 by reducing the amount of stagnant water that remains post-GLOF.

The improvement of EWS systems will involve upgrading and expanding the meteorological and hydrological monitoring network, with a focus on parameters — such as size of lake, possibility of expansion, state of glaciers, parameters linked to the classification of lake ranks[304] — linked to GLOFs and their triggers — avalanches, rockfalls, seismic activity, intense rainfall and melting of ice-cored moraines. National capacity to utilise the EWS systems and respond to GLOFs will also be improved, as well as community-level responses to these disasters. This will disrupt GLOF impacts along with IP 3 and IP 5 by improving the effectiveness of emergency reaction and response efforts during GLOFs through greater reliability of GLOF prediction and extended lead-times for these disasters. The improved response systems at the community level will reduce the impacts of these disasters by providing more effective warnings and emergency action plans to keep people and property safe, as well as by safeguarding communication systems to distribute these warnings, implement action plans and aid relief efforts.

These interventions will also support the reduction of flood impacts from rain-induced flooding in Nepal. This will be through the disruption of IP 8, where rain-induced floods will be mitigated in the same ways as GLOFs as their impacts are very similar. The population in Nepal will benefit from the reduction of impacts of rain-induced flooding through: i) the improvement of EWS and response systems; ii) the protection of communities and infrastructure from floods; iii) the diversion and reduction of flood flow; iv) improved infiltration; and v) the stabilisation of soil and riverbanks.

5.3. Cost benefit analysis of lake lowering and downstream GLOF risk reduction measures

A cost-benefit analysis of the proposed project interventions was undertaken to calculate the extent of economic losses that would be incurred should a GLOF occur at any of the four target glacial lakes, and subsequently whether the proposed interventions would provide a significant offset of these losses, after accounting for their costs. To do this, the probability of GLOF occurrence needed to be assessed, as this would contribute to the models that were run to determine economic losses. GLOFs are highly unpredictable events, with numerous potential triggers that can develop independently or through interaction with each other, resulting in a variety of methods for calculating the likelihood of a GLOF at each of the target lakes. Consequently, two different methods were used for the cost-benefit analysis conducted for the project. The first method involved a review of published papers and ICIMOD documents for recorded GLOFs that had the potential of causing damages from 1980 to 2017. It was assumed that such events could only have occurred from lakes which at that time would

[304]Rank I – Large lake and possibility of expansion due to the calving of glaciers; lake close to the loose moraine end; no overflow through the moraine; steep outlet slope; hanging source glacier; chances of snow and/or ice avalanches and landslides in the surroundings impacting the lake and dam.
Rank II – Confined lake outlet; lake outlet close to compact and old end-moraine; hanging lake; distinct seepage at the bottom of end-moraine dam; gentle outward slope of moraine.
Rank III – Confined lake outlet; gentle outward slope of the dam; large lake but shallow depth; moraine more than 200 m wide; old and compact moraine.

have been classified as Potentially Dangerous Glacial Lakes (PDGLs)[305] if an inventory had been taken at that time, and so a proportion was calculated based on the number of GLOFs that occurred compared to the number of glacial lakes in existence. This model gave an annual probability of a GLOF at any one lake to be 1.16% and was used for "Scenario I: Annual Probability" in further modelling. The second method calculated GLOF probability using return period data from a published paper titled 'Hazard from Himalayan glacier lake outburst floods'[306]. This method used statistical models to infer lake volumes from lake areas known through satellite data and subsequently simulated scenarios to predict the sizes and frequency of future GLOF events. The probability from this study that was applicable to the four target lakes was used to derive return periods as an annual probability and this was used for "Scenario II: Return Period based Probability". The full details of the probability models and calculations are presented in Annex 3: Financial and Economic Appraisal.

As there is no standardised method for calculating the probability of GLOF occurrence, both of the above mentioned methods were considered to be viable representations of the risks posed by GLOFs, and neither is considered to be more accurate than the other. Therefore, the results of both scenarios have been presented and used to quantify the adaptation benefits that will be realised through the implementation of the proposed interventions. The two scenarios provide a range of GLOF likelihood and, subsequently, the resulting economic losses and benefits for each are presented as ranges between the lowest probability and highest probability. The two scenarios were used to calculate the Present Value (PV) of expected losses resulting from a GLOF in the absence of the proposed interventions in comparison to the expected losses after the interventions, which identified the value of the benefits of pursuing the interventions. The value of benefits was compared with that of intervention costs, the time value of money was factored in, using a discount factor to calculate the Net Present Value of the Programme (NPV). The NPV value is indicative of the overall economic value of loss and damages that will be offset by the project interventions after accounting for their costs. It was estimated that, without any intervention, the losses that would result from a GLOF at any of the four target lakes would be US$ 67.4 – 109.2 million, with 1,932 lives lost, 420 houses destroyed, 1,201 hectares of agricultural land damaged and 8,180 GWH of hydropower production lost (Table 27).

Table 27. Summary of proportion of loss for different sectors contributing to the overall Present Value (PV) of project costs and benefits as well as the Net Present Value (NPV) as the difference between the costs and benefits for two different probability models of a GLOF occurring at any of the four target glacial lakes – modelled over 25 years from 2021 to 2046. Scenario I used a 1.16% annual probability while Scenario II used a return period based probability. The details of these models and their results are available in Annex 3: Financial and Economic Appraisal.

Scenario	Proportion	PV (US$)	Number	Unit
Scenario I (1.16% Annual Probability)				
NPV		86,919,219		
PV of costs		22,303,854		
PV of benefits		109,223,072		
loss of life prevention	78%	85,601,182	1,932	lives
loss of buildings prevention	0.1%	127,148	420	houses

[305] UNDP and ICIMOD. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905

[306] Veh, G., Korup, O. and Walz, A., 2020. Hazard from Himalayan glacier lake outburst floods. Proceedings of the National Academy of Sciences, 117(2), pp.907-912.

loss of agricultural produce prevention	0.1%	98,392	1,201	hectares
loss to hydropower projects prevention	21%	23,291,647	8,180	GWH
loss of tourism income prevention	0.1%	104,703		
Scenario II (Return period based Probability)				
NPV		45,126,562		
PV of costs		22,303,854		
PV of benefits		67,430,416		
loss of life prevention	85%	57,019,274	1,932	lives
loss of buildings prevention	0.1%	84,694	420	houses
loss of agricultural produce prevention	0.1%	55,419	1,201	hectares
loss to hydropower projects prevention	15%	10,189,203	8,180	GWH
loss of tourism income prevention	0.1%	81,826		

It was calculated that by manually lowering the Thulagi, Lower Barun and Lumding Tsho Lakes by 3 m, and the Hongu 2 Lake by 1 m, and installing the proposed downstream GLOF risk reduction measures, the total potential damages associated with a GLOF could be reduced by an NPV amount of US$ 45.1 – 86.9 million (Table 28). For both scenarios, the interventions have the potential to save 1,932 lives, 420 houses, 1,201 hectares of cultivated land and 8,180 GWh of electrical production, resulting in a high benefit to cost ratio. The ratio indicates that it is a worthwhile pursuit to carry out the proposed interventions, as the offset losses significantly exceed the costs of the interventions and will provide benefits in the form of lives saved and livelihoods secured.

Table 28. Summary of the Net Present Value (NPV) of offset losses for the two different GLOF occurrence probability scenarios.

Scenario	NPV offset losses (US$)
Scenario I (1.16% Annual Probability)	86,919,219
Lower Barun	47,832,223
Hongu 2	10,786,354
Thulagi	16,814,961
Lumding Tsho	11,485,681
Scenario II (Return period based Probability)	45,126,562
Lower Barun	16,666,744
Hongu 2	13,255,431
Thulagi	12,090,478
Lumding Tsho	3,113,910

6. Legal, institutional and strategic framework

6.1. National development policies and strategies

6.1.1. Strategic development plans

Poverty Reduction Strategy Paper (PRSP) (2003)

Nepal's PRSP stipulates the alleviation of poverty as a national objective to be integrated across different sectors in the country[307]. In particular, the paper focuses on planning that prioritises: i)

[307] IMF. 2003. Nepal: Poverty Reduction Strategy Paper. Available at: https://www.imf.org/external/pubs/ft/scr/2003/cr03305.pdf

poverty reduction through sustainable economic growth; ii) improved social sector development; iii) social inclusion; and iv) strengthened governance[308]. Prepared by the GoN, the paper was developed based on engagement with numerous stakeholders and development partners, including the World Bank and IMF. The strategy is intended to be updated every three years, and although only the first version exists for Nepal, it remains valid for preparing periodic and sectoral plans relating to poverty reduction.

Nepal National Adaptation Programme of Action (NAPA) (2010)

Nepal's first action plan for climate change adaptation was prepared by the Climate Change Management Division, under the Ministry of Forests and Environment (MoFE), in 2010. The NAPA provides a pathway for Nepal — as a Least Developed Country (LDC) — to identify priority activities that respond to the country's immediate climate change adaptation needs[309]. Accordingly, the programme guides the implementation of projects with the objective of reducing the economic and social costs of climate change. Nepal's NAPA priority profiles on water-related risk reduction include: i) promoting community-based adaption (CBA) through integrated management of the agricultural, water, forest and biodiversity sectors; ii) community-based disaster risk management (DRM) to facilitate climate change adaptation; iii) glacial lake outburst flood (GLOF) monitoring and disaster risk reduction (DRR); iv) ecosystem management for climate change adaptation; and v) empowering vulnerable communities through sustainable water resource management and clean energy supply[310].

National Framework for Local Adaptation Plans for Action (LAPA) (2011)

During the development of the NAPA, participants in the inception workshop suggested the development of Local Adaptation Plans for Action to ensure the effective implementation of the NAPA. The National Framework for LAPA was, therefore, formulated to translate suggestions into actions and to assist in, *inter alia*: i) the identification of local adaptation actions as prescribed in the NAPA; ii) the development and implementation of action plans; and iii) supporting the integration of climate change adaptation into sectoral and area-specific plans[311].

The Country Programme Document for Nepal (2018–2022)

Nepal's Country Programme Document (CP), prepared by the GoN and UNDP, provides an overview of UNDP's five-year development ambitions for the country[312]. The key priority areas for Nepal's CP include: i) inclusive economic growth and reduced economic vulnerability; ii) strengthened governance systems for ensuring the rule of law; and iii) enhanced environmental management for increasing climate change adaptation and environmental resilience in Nepal[313]. The CP provides details on the approach and plans to address each of these areas. In addition, the CP's outcomes are also strongly aligned with Nepal's national priorities to: i) increase access to sustainable livelihoods, safe and decent employment and income opportunities by 2022, particularly for impoverished, economically vulnerable, unemployed and under-employed and vulnerable people; ii) promote good governance and human rights through effective and accountable public finance and clean, transparent and people-friendly public service; and iii) strengthen public service at all levels by 2022, particularly in relation to environmental management, sustainable recovery and reconstruction, and resilience to climate change and natural disasters.

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[308] IMF. 2003. Nepal: Poverty Reduction Strategy Paper. Available at: https://www.imf.org/external/pubs/ft/scr/2003/cr03305.pdf
[309] GoN. 2010. National Adaptation Programme of Action (NAPA) to Climate Change. Available at: https://www.adaptation-undp.org/sites/default/files/downloads/nepal_napa.pdf
[310] GoN. 2010. National Adaptation Programme of Action (NAPA) to Climate Change. Available at: https://www.adaptation-undp.org/sites/default/files/downloads/nepal_napa.pdf
[311] GoN, 2011. National Framework on Local Adaptation Plans for Action. Government of Nepal, Ministry of Environment, Singhdurbar
[312] UNDP. 2017. Nepal Country Programme 2018-2022.
[313] UNDP. 2017. Nepal Country Programme 2018-2022.

15th Five-Year Development Plan (2019/20–2023/24)

Since 1956, Nepal's National Planning Commission (NPC) — chaired by the Prime Minister[314] — has developed a mandatory periodic preparation of three- or five-year development plans for the country. Currently, in the 15th iteration, the plan provides the strategic framework for cross-sectoral development and national budgeting in the country. This version includes 18 projects that aim to achieve or contribute to the targets set out in the plan, which include: i) national and sector-specific economic growth; ii) poverty reduction; iii) increasing literacy rates; and iv) graduating Nepal from its status as a Least Developed Country (LDC)[315]. Given Nepal's climate change vulnerability, the GoN has incorporated DRM planning in the five-year development plan and across development and sectoral laws and policies.

6.1.2. <u>Disaster risk management policies</u>

Natural Calamity (Relief) Act (1982)

The relief act was established in 1982 with the intention to provide for relief work relating to a natural disaster by enabling the GoN to: i) declare disaster areas; ii) provide instructions and orders regarding relief work; and iii) form a central committee as well as necessary sub-committees for natural calamity relief[316]. The act also stipulates the functions of the committees and funding arrangements for natural calamities[317].

Disaster Risk Reduction and Management Act (2017)

This act was introduced as an updated replacement for the Natural Calamity Relief Act of 1982. The Act provides cooperation of national and local authorities in the framework of the Disaster Risk Reduction and Management Council in the case of natural disasters in Nepal. With a focus on protecting public life, public and private property, and natural and cultural heritages, the objective of this Act is minimising disaster risk.

Nepal Disaster Risk Reduction National Strategic Plan of Action (2018–2030)

This action plan was prepared by the GoN with the endorsement of Nepal's National Disaster Risk Reduction and Management Council. The plan's objectives are in line with the Disaster Risk Reduction and Management Act (2017) as well as the National Strategy on Disaster Risk Management (2009). Accordingly, the plan serves as the policy framework for DRR planning, guidance and management in Nepal. In particular, the action plan focusses on: i) improving understanding of disaster risk through multiple assessment types; ii) strengthening multi-level disaster risk governance; iii) promoting investment in DRR based on comprehensive risk information; and iv) improving disaster preparedness and integrating "build back better" approaches during recovery from extreme events[318]. Moreover, the plan highlights the following as some of the most pronounced types of disasters experienced by the country: i) road accidents; ii) epidemics; iii) earthquakes; iv) landslides; v) floods; vi) snowstorms and avalanches; and vii) droughts[319].

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[314] GoN. 2019. 15th Five Year Development Plan (2019/20-2023/24) of Government of Nepal. Available at: https://www.npc.gov.np/images/category/15th_Plan_Final1.pdf

[315] GoN. 2019. 15th Five Year Development Plan (2019/20-2023/24) of Government of Nepal. Available at: https://www.npc.gov.np/images/category/15th_Plan_Final1.pdf

[316] GoN. 1982. Natural Calamity (Relief) Act. 2039 B.S. http://www.lawcommission.gov.np/en/wp-content/uploads/2018/10/natural-calamity-relief-act-2039-1942.pdf

[317] GoN. 1982. Natural Calamity (Relief) Act. 2039 B.S. http://www.lawcommission.gov.np/en/wp-content/uploads/2018/10/natural-calamity-relief-act-2039-1942.pdf

[318] GoN. 2018. Disaster Risk Reduction Strategic Plan of Action. Available at: https://app.adpc.net/sites/default/files/public/publications/attachments/DRR%20National%20Plan%20of%20Action%20%28Nepal%29.pdf

[319] GoN. 2018. Disaster Risk Reduction Strategic Plan of Action. Available at: https://app.adpc.net/sites/default/files/public/publications/attachments/DRR%20National%20Plan%20of%20Action%20%28Nepal%29.pdf

The Sendai Framework for Disaster Risk Reduction (2015–2030)[320]

The Sendai Framework for Disaster Risk Reduction — of which the GoN is committed to implementing — aims to substantially reduce disaster risk and losses in lives, livelihoods and health, as well as in the economic, physical, social, cultural and environmental assets of people, businesses, communities and countries. The framework identifies four priority actions to achieve this goal, namely: i) Priority 1 — Understanding disaster risk vulnerability, capacity, exposure of people and assets, hazard characteristics and the environment; ii) Priority 2 — Strengthening disaster risk governance at national, regional and global levels to ensure effective and efficient management of disaster risk; iii) Priority 3 — Investing in disaster risk prevention and reduction through structural and non-structural measures to enable appropriate resilience; and iv) Priority 4 — Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

Disaster preparedness plans

Disaster preparedness plans (DPPs) are currently in place for 60 out of 75 districts in Nepal. Developed by the District Administration Office (DAO) and District Coordination Committee (DCC), the objective of DPPs is to reduce risk in Vulnerable Districts and Villages (DDCs/VDCs). There are plans for municipal level preparedness in some areas, known as Local Level Adaptation Plan of Action (LAPA), although their implementation has been hindered by limited funding. However, with the aid of international funding, Community Adaptation Plans of Action (CAPAs) for specific areas have been prepared.

6.1.3. <u>Other relevant policies in the areas of climate change, watershed management, forestry and land use</u>

Soil and Watershed Conservation Act (1982).

The intention of this act was to provide legislature around the conservation of Nepal's soil and watershed activities. The act achieved the following: i) makes it possible for the GoN to declare conserved watershed areas; ii) outlines permitted activities in conserved areas; iii) provides a declaration that technical knowledge and skills, as well as financial assistance, will be provided by the GoN to anyone intending to conduct activity in conserved areas; and iv) prohibits specific activities that could trigger land that is vulnerable to natural disasters[321]. In addition, watershed-level management has also been prioritised under the act and has subsequently led to the development of integrated management plans. This includes the Integrated Watershed Conservation and Management Plan, which was prepared in 2011 by the International Union for Conservation of Nature (IUCN) for watershed-level management of the Sardu watershed[322].

National Climate Change Policy (2011)

The GoN formulated its climate change policy and subsequently initiated relevant programmes to minimise the existing effects and likely future impacts of climate change across different ecological regions and sectors within the country[323]. While the policy was prepared primarily by the Ministry of Forests and Environment (MoFE), it is being implemented by several sectoral ministries. The key targets of the policy include: i) establishing a climate change centre with the mandate of conducting research, monitoring and providing guidance; ii) improving local climate change adaptation that is

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[320] UN. Sendai Framework on Disaster Risk Reduction (2015–2030). Available at: https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf
[321] GoN. 1982. Soil and Watershed Conservation Act, 2039. Available at: http://extwprlegs1.fao.org/docs/pdf/nep6223.pdf
[322] IUCN. 2011. Integrated Watershed Conservation and Management Plan. Available at: https://www.iucn.org/sites/dev/files/import/downloads/integrated_watershed_conservation_and_management_plan___sardu_watershed__dharan__suns.pdf
[323] GoN. 2011. Climate Change Policy, 2067.

community-based and in line with the NAPA; iii) developing a national carbon trade strategy; iv) assessing losses and benefits as a result of climate change for geographical areas and development sectors; v) promoting climate change adaptation; and vi) increasing the use of reliable forecasting systems in planning for DRR[324].

National Climate Change Policy (2019)

The 2019 National Climate Change Policy was formulated to effectively address the changes to national and international climate change management that emerged since the implementation of the 2011 National Climate Change Policy. The new policy was based on lessons learned from the implementation of the 2011 policy. The overarching goal of the new policy is to contribute to the socio-economic prosperity of the nation by building a climate resilient society. The objectives to achieving this goal are for Nepal to: i) enhance climate change adaptation capacity of persons, families, groups and communities vulnerable to, and at risk of, climate change; ii) build resilience of ecosystems that are at risk of adverse impacts of climate change; iii) promote a green economy by adopting the concept of low carbon emission development; iv) mobilize national and international financial resources for climate change mitigation and adaptation in just manner; v) conduct research, make effective technology development and information service delivery related to climate change; vi) mainstream or integrate climate change issues into policies, strategies, plans and programs at all levels of State and sectoral areas; and vii) mainstream gender equality and social inclusion (GESI) into climate change mitigation and adaptation programs. Furthermore, the policy outlines several sectoral and inter-sectoral policies, strategies and working policies to be adopted to attain the goal and these objectives.

National Biodiversity Strategy and Action Plan (NBSAP) (2014-2020)

The NBSAP addressed biodiversity conservation in Nepal for the 2014–2020 period. The NBSAP contains, *inter alia,* details for: i) strengthening institutional capacity; ii) improving the synthesis of biodiversity management plans and mandates; iii) establishing and maintaining sustainable and equitable resource management; and iv) increasing recognition and integration of Indigenous knowledge and community-based forestry management[325]. Given the country's high vulnerability to flooding, many areas with different land uses are susceptible to the negative consequences of heavy monsoon rainfall as well as GLOFs, including farmlands, buffer zones and protected areas[326]. Consequently, addressing flooding — both rain-induced and from GLOFs — is critical in the planning of effective biodiversity conservation and management as guided by the NBSAP.

The Third National Communication (TNC) to the UNFCCC (2021)[327]

Nepal's TNC presents an overview on the projected climate change impacts for Nepal and identifies the national climate change adaptation and mitigation priorities which includes an indication of the country's current greenhouse gas (GHG) inventory. The adaptation priorities in the TNC focus on the need to adapt to the impacts of increasing annual mean temperature and increasingly frequent extreme climate events such as GLOFs and monsoon flooding. The TNC highlights the need for actions that reduce risks associated with climate change impacts — particularly the vulnerability of downstream communities to glacier retreat and Glacial Lake Outburst Floods (GLOFs) — including eco-DRR reducing measures and lake lowering.

National Land Use Policy (2015)

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[324] GoN. 2011. Climate Change Policy, 2067.
[325] GoN. 2014. National Biodiversity Strategy and Action Plan. Available at: http://extwprlegs1.fao.org/docs/pdf/nep163672.pdf
[326] GoN. 2014. National Biodiversity Strategy and Action Plan. Available at: http://extwprlegs1.fao.org/docs/pdf/nep163672.pdf
[327] Ministry of Forests and Environment. 2021. Third National Communication to United Nations Framework Convention on Climate Change

Nepal's Ministry of Land Reform and Management is responsible for preparing the country's land use policy, which is implemented by several relevant sectors, including the: i) Ministry of Forests and Environment (MoFE); ii) Ministry of Local Development and Federal Affairs; iii) Ministry of Agriculture Development; and iv) Ministry of Land Reform and Management. The aim of the policy is to i) strengthen land use management and thereby improve food security; ii) reduce disaster risk; iii) plan for urbanisation and settlements; and iv) achieve sustainable development that considers the impact of and on the ecosystems[328]. The policy includes, *inter alia,* zoning law, uses of land and land resources, as well as multiple strategies for the optimal use and conservation of forests and forest resources[329].

Second Nationally Determined Contributions (NDC) (2020)[330]
Nepal identifies mitigating GHG emissions and undertaking studies and actions for adaptation as critical actions to reduce the impacts of climate change in the country. Nepal's contributions are conditional on bilateral and multilateral grant support to strengthen limited national resources and technical capacities for scaling up climate action. While this project will not directly contribute towards mitigation objectives, it recognises the need for climate change mitigation as global warming is causing the accelerated rate of glacial melt, increasing GLOF risk.

The Environmental Protection Act (2019) and Environment Protection Regulation (2020)
The Environmental Protection Act aims to amend and consolidate legislation relating to the natural environment. The act includes, *inter alia*: i) the required information for approving the preparation of environmental studies — including strategic environmental analyses and EIAs — while granting powers to relevant agencies to conduct these studies; ii) necessary legislation to control pollution and hazardous material disposal and their inspection; iii) provisioning for climate change adaptation and mitigation plans; iv) the safeguarding of national heritage sites and environmentally protected areas; and v) penalties for environmental transgressions[331]. In addition, the act legislates climate change risk management and the production of technical standards to determine priority areas. Carbon trading for mitigation purposes is also legalised under the act, which subsequently makes provision for the prescribed legislature to regulate the trade[332].

Public Private Partnership and Investment Act (PPPI Act; 2019)
The PPPI Act aims to create a more unified enabling environment for public private partnerships (PPPs) in Nepal, targeting both local and foreign investment in infrastructure development and the services sectors. The Act also outlines arrangements to manage projects conducted through PPPs as well as consolidates and amends legal provisions relating to investment. While the Act lays out structures and processes for engaging in PPPs, it does not make specific provisions to enable the establishment of blended finance mechanisms for such investments.

6.2. Institutional framework relevant to the project

Nationally Determined Contribution (NDC) Implementation Mechanism

[328] GoN. 2015. Land Use Policy. Available at: https://molcpa.gov.np/downloadfile/land%20use%20policy__2015_1505895657_1536124080.pdf
[329] GoN. 2015. Land Use Policy. Available at: https://molcpa.gov.np/downloadfile/land%20use%20policy__2015_1505895657_1536124080.pdf
[330] GoN. 2020. Second Nationally Determined Contribution (NDC). Available at: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Nepal%20Second/Second%20Nationally%20Determined%20Contribution%20(NDC)%20-%202020.pdf
[331] GoN. 2019. Environmental Protection Act (2076). Available at: www.lawcommission.gov.np
[332] GoN. 2019. Environmental Protection Act (2076). Available at: www.lawcommission.gov.np

Nepal's NDC will be implemented through federal, provincial and local governments — in collaboration with other relevant stakeholders such as youth, women and Indigenous People — coordination with which will be important for the proposed project. Institutions involved in the coordination of this implementation include: i) the Environment Protection and Climate Change Management National Council; ii) the Inter-Ministerial Climate Change Coordination Committee (IMCCCC); iii) Thematic and Cross-Cutting Working Groups; and iv) Provincial Climate Change Coordination Committees.

National Emergency Operations Centre (NEOC)

Opened on the 17 December 2010, the National Emergency Operations Centre (NEOC) is a coordination and communication point for disaster information across Nepal[333]. The centre facilitates communication between government agencies and other response and recovery stakeholders such as Nepal Red Cross Society, UN agencies, INGOS and NGOs. It operates under the Planning and Special Services Division of the Ministry of Home Affairs and is run by a nine-member personnel team under the leadership of an under-secretary. In addition to the NEOC, Nepal has established Emergency Operations Centres at the provincial, district and local levels to facilitate disaster response at different levels. These different levels of EOC enable rapid and effective disaster response that is appropriate to the scale of the disaster, without necessarily requiring the intervention of the full NEOC[334].

The centre has a control room with emergency equipment for its functioning, an Emergency Operations Room, Communications Room, as well as a Media Room. There are four phases of functioning at the NEOC: i) Normal Phase; ii) Alert Phase; iii) Response Phase; and iv) Recovery Phase. During the Normal Phase, the centre operates with the objective of preparedness and information monitoring. When elevated to the Alert Phase, the centre communicates with authorities and agencies to warn of an imminent disaster. In the Response Phase, the centre is used to lead coordination and communication for response efforts. Finally, the Recovery Phase is active when the centre is used to coordinate early recovery efforts. The centre is deactivated to Normal Phase post-recovery at the recommendation of the Chief to the Central Natural Disaster Relief Committee (CNDRC).

Ministry of Energy, Water Resources and Irrigation (MoEWRI)

The Ministry of Energy, Water Resources and Irrigation (MoEWRI) will lead the project execution on behalf of the government, while several government agencies will implement different components of the project as outlined in the funding proposal. The government will follow its prevailing budgetary and fund management system as defined by the legislation and regulatory frameworks to manage public funds. The implementation of project activities under output 1 and output 2 will be led by the Department of Hydrology and Meteorology within MoEWRI.

Department of Hydrology and Meteorology (DHM)

Operating within MoEWRI, the main objective of DHM is to collect hydrological and meteorological data throughout Nepal then process, publish, and disseminate the data[335]. Additionally, the DHM manages flood Early Warning Systems (EWS) and generates information on extreme hydrological and meteorological events and delivers the information publicly in an effort to reduce the impacts of these events. Within the DHM, responsibility for flood EWS has shifted from a small flood forecasting section to a larger flood forecasting Division, accompanied by an increase in staff. Each provincial

[333] http://neoc.gov.np/en/ Accessed: 20 August 2020
[334] GIZ. 2020. A Guidebook for Establishment of Local Emergency Operation Centre. Available online at: https://narmin.org.np/wp-content/uploads/2020/11/LEOC_Handbook-for-LGs.pdf
[335] https://www.dhm.gov.np/contents/about-us Accessed: 20 August 2020

administration is responsible for developing and implementing its own Disaster Risk Reduction and Management (DRRM) policy and plan, including the allocation of funds.

The DHM is responsible for a range of manual and automated rain and stream gauges across the country and for the production of national and sub-national forecasts —including probabilistic forecasts— and the incorporation of regional and global forecasts such as the Global Flood Awareness System (GLoFAS). The DHM is in the process of upgrading the network of automated river gauges[336].

The DHM in Kathmandu is responsible for preparing flood hazard maps using hydraulic modelling techniques, with support from regional offices[337]. The DHM maintains a library of flood hazard maps for most major river basins in Nepal. These can be used by the central DHM office for flood risk assessments when river levels begin to rise or pass certain thresholds. These flood hazard maps can be accessed by DHM regional offices through the DHM website.

Limitations are present at the DHM, with national-level maps not widely being used by communities or decision-makers below the regional office level – most use maps produced locally by NGOs or community projects. Current flood hazard maps used by the DHM are based on freely available digital elevation data acquired during 2001[338] , which do not account for recent changes to the river system due to the movement of sediment during the monsoon or recent embankment construction[339]. The use of outdated maps limits the effectiveness of flood risk management planning and could undermine confidence in the reliability of flood hazard maps[340].

Ministry of Forests and Environment (MoFE)
Two departments under the Ministry of Forests and Environment (MoFE) — namely the Department of Forest and Soil Conservation (DoFSC) and the Department of National Parks and Wildlife Conservation (DNPWC) — will support DHM in the implementation of project activities in the downstream areas of the four glacial lakes, as outlined in output 3, as well as select activities under outputs 1 and 2.

National Disaster Risk Reduction and Management Authority (NDRRMA) of Nepal
The National Disaster Risk Reduction and Management Authority (NDRRMA) is the national institution mandated, by the DRRM Act of 2017, to coordinate and implement DRRM-related functions in Nepal. The DRRM Act (2017) assigns overall and specific mandates to the NDRRMA to lead, facilitate and support federal, provincial and local governments on disaster risk reduction, response and reconstruction. The DRRM Act (2017) is also supported by several other policy instruments, such as the national Climate Change Policy. The NDRRMA is the central resource body for disaster risk reduction and, as a result, is mandated to coordinate federal departments and between federal, provincial and local governments — including government agencies, civil society and private sector organizations. The NDRRMA is required to coordinate with relevant federal ministries and

[336] Brown, S., Budimir, M., Lovell, E., Wilkinson, E. and Meechaiya, C., 2019. Report: The governance of Nepal's flood early warning system: opportunities under federalism. Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED). Available at: http://www.braced.org/resources/i/The-governance-of%20Nepal's-flood-early-warning-system
[337] Brown, S., Budimir, M., Lovell, E., Wilkinson, E. and Meechaiya, C., 2019. Report: The governance of Nepal's flood early warning system: opportunities under federalism. Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED). Available at: http://www.braced.org/resources/i/The-governance-of%20Nepal's-flood-early-warning-system
[338] Some flood hazard maps for river basins use updated Digital Elevation Models from 2013, 2014, 2015 and 2016, but this is not consistent across the whole of Nepal.
[339] Pedreschi, R., Sinclair, H., Sharma, J., Attal, M., Borthwick, A., Dingle, E., Ruwanpura, K.N. and Creed, M., 2017. Improving understanding of flooding and resilience in the terai, Nepal.
[340] Delalay, M., Ziegler, A.D., Shrestha, M.S., Wasson, R.J., Sudmeier-Rieux, K., McAdoo, B.G. and Kochhar, I., 2018. Towards improved flood disaster governance in Nepal: a case study in Sindhupalchok District. International journal of disaster risk reduction, 31, pp.354-366.

departments to enhance capacity for disaster management, such as, *inter alia*: i) monitoring; ii) forecasting; and iii) search and rescue[341]. The functions, duties and powers of the NDRRMA are outlined in the Disaster Risk Reduction and Management (DRRM) Act (2017) and include, *inter alia*: i) Ensuring that plans, programs and decisions made by the National Council for Disaster Risk Reduction and Management and its Executive Committee are implemented; ii) ensuring that programs on study and research on river training, flood control, landslide, earthquake, global warming, climate change, land use and various other hazards prevention and threatening situations to disaster, and mitigation measures are implemented; and iii) providing financial and technical assistance to the provincial and local levels to formulate periodic plans on disaster management[342].

Nepal Army

The Nepal Army has experience assisting in the construction of lake lowering interventions, as demonstrated when it was engaged to assist in the lowering of Lake Imja during the Community Based Flood and Glacial Lake Outburst Risk Reduction Project. This was facilitated through a cabinet decision of the Government of Nepal. This decision was formalised through the signing of a Letter of Agreement between DHM and the Engineer Department of the Nepal Army[343].

International Centre for Integrated Mountain Development (ICIMOD)

The International Centre for Integrated Mountain Development (ICIMOD) is an intergovernmental knowledge and learning centre that works to improve the lives and livelihoods of people living in the Hindu Kush Himalaya and to protect mountain environments and cultures. ICIMOD's work is centred around: i) the influencing and advancement of policy; ii) the creation of knowledge; iii) the sharing of information; iv) awareness raising in vulnerable communities; v) facilitating regional cooperation and the strengthening of intergovernmental relations; and vi) embracing diversity.

Micro Enterprise Development Programme (MEDEP)/Micro Enterprise Development for Poverty Alleviation (MEDPA)

The Micro Enterprise Development Programme (MEDEP) is a poverty reduction initiative implemented in partnership between UNDP and GoN and has been internalised as a programme within GoN as Micro Enterprise Development for Poverty Alleviation (MEDPA). Through MEDEP, systems, structures and an enabling environment for sustainable development of micro enterprise have been created in Nepal. The objective of MEDEP is to increase employment opportunities and the level of income of the people living below the poverty line by developing micro enterprises through Entrepreneurship development.

High Mountain Glacial Watershed Program

The High Mountain Glacial Watershed Program is a Community of Practice (CoP) established by the United States Agency for International Development (USAID) and operates in the Hindu Kush-Himalaya, Andes, Central Asian and other high mountain regions[344,345]. The goal of the program is to address the perceived gaps in knowledge and collaboration and to develop follow-on pilots and capacity building activities. Initial funding for the program was provided by USAID through the Climate Change Resilience Development (CCRD) Project, and co-financing is supplied by the U.S. Department of State as part of their support for the Adaptation Partnership.

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341 Bhandari, D., Neupane, S., Hayes, P., Regmi, B., Marker, P., 2020. Disaster risk reduction and management in Nepal: Delineation of roles and responsibilities.
342 Disaster Risk Reduction and Management Act, 2074 And Disaster Risk Reduction and Management Rules, 2076 (2019). Available online at: https://bipad.gov.np/uploads/publication_pdf/DRRM_Act_and_Regulation_english.pdf
343 CFGORRP Annual Progress Report 2016 - United Nations. Available online at: https://www.undp.org/content/dam/nepal/docs/reports/CFGORRP Annual Progress Report 2016.pdf
344 https://www.climatelinks.org/resources/high-mountain-glacial-watershed-program Accessed: 20 August 2020
345 https://www.adaptation-undp.org/partners/high-mountain-glacial-watershed-program Accessed: 20 August 2020

The program combines international scientific experience with local knowledge and resources to promote global awareness of the critical importance of high mountain glacial watersheds. Particular focus is placed on the impacts of climate change, interactions between highland and lowland communities, and services for protecting fragile ecosystems. The program aims to develop innovative tools and practices for facilitating adaptation to climate change. Additionally, the program creates conditions necessary for all stakeholders who are dependent on glacial watersheds, including local communities, government agencies, and downstream populations, to become more resilient to the impacts of climate change.

Environment and Child Concern Organisation (ECO-Nepal)

Environment and Child Concern Organisation (ECO-Nepal) is a non-profit, non-governmental national organisation established in 2000, registered under the non-government organisation act and affiliated with the Social Welfare Council of Nepal, and headquartered in Kathmandu[346]. It works with national stakeholders and international organisations to generate mass awareness, improve capacity building and advocacy for disaster risk reduction, environment protection, climate change and natural resources conservation. The organisation takes a rights-based approach to the community people as well as policy makers, development workers and civil society.

The goal of ECO-Nepal is to 'Ensure people's capacity to access resources for sustainable livelihoods, improve quality of life, and improve resilience to disasters and environmental degradation for their secure future. Create awareness and empower the people to secure their future through wise use of resources, supporting livelihoods and disaster risk reduction. Ensuring all people have knowledge and capacity to cope with environmental hazards and resilience to disasters through best practices, poverty reduction and environmental and disaster justice across the nation.'

Eco-Nepal's objectives are to:

- enhance knowledge of disaster management, environment conservation and natural resource management;
- build capacity of stakeholders for environmental, natural resource and disaster management; and
- support building disaster-resilient communities.

The programme has multiple active projects, but those relevant to the proposed GCF project include:

a) Safe School and Child Centre Urban Disaster Risk Reduction (CCUDRR)[347]

The safe school (SC) and Child Centre Urban Disaster Risk Reduction (CCUDRR) project was launched in five municipalities of the Kathmandu valley with the support of Plan Nepal. Each school is taken as the pilot project of the safe school initiative in each location, along with child homes and a hostel which were chosen for CCUDRR follow-up in the Kathmandu valley. Some of the aspects the project incorporates include: i) awareness raising; ii) development of Safe School Toolkit; iii) capacity development programs; iv) Information, Education and Communication (IEC) materials; and v) disaster orientation, mock drills and street dramas targeting students.

b) Integrate Riu-Khola Sub Watershed Management Plan (Research and Planning Project)[348]

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[346] http://www.econepal.org/index.php Accessed 20 August 2020
[347] http://www.econepal.org/prog_safe_school.php Accessed 20 August 2020
[348] http://www.econepal.org/prog_ruikhola.php Accessed 20 August 2020

This program contributes to the larger "Climate Risk Assessment and Integrated Watershed Management Plan of Riu-Khola Sub Watershed, Madi, Chitawan with support of UNDP" research and planning project. The objective of the assessment was to carry out the detailed climate risks assessment of the Riu-Khola Sub-watershed and to propose an integrated watershed management plan that addresses the Disaster Risk Management (DRM) cycle — including preparedness, response, adaptation and mitigation — and proper land use planning to reduce the risks and adopt appropriate livelihood promotion activities — such as farm and non-farming practices — so as to adapt to the changing climate. The scope of this project covered: i) integrated watershed management; ii) bio-physical, morphometric and socio-economic watershed studies; iii) agriculture and food security; iv) water resources and energy; v) forests and biodiversity; vi) urban settlement and infrastructure; vii) climate risk assessments and management; viii) climate vulnerability and climate change related disasters; and ix) cross-cutting issues of education, gender, ethnicity.

c) Multiple Disaster Risk Reduction (DRR) Projects[349]

Initiated in partnership with Oxfam, four projects were implemented between 2007 and 2013, which focused on raising awareness, capacity building, advocacy, policy and planning support, and research and knowledge management. These projects were: i) Urban DRR Project (2012-2013); ii) Disaster Management for Secure Future (2010-2012); iii) Awareness and Advocacy Initiatives for DM (2007-2010); and iv) Awareness and Advocacy Initiatives for Disaster Management (2007-2009).

Clean Energy Nepal (CEN)

Clean Energy Nepal (CEN) is a non-profit, non-governmental policy, research and implementation organisation focused on research-based education and advocacy campaigns with policy inputs and implementation on issues related to climate change, sustainable energy use and environmental conservation. CEN also works to reduce the impacts of air pollution and global warming on natural and human systems. CEN has experience working on projects involved in urban mobility, clean air, energy, climate change and water and sanitation.

CEN’s objectives are to:

- investigate issues relevant to energy, environment and climate change;
- facilitate discussions, information sharing and knowledge management among key stakeholders;
- educate the public on the importance of these issues and what they can do about them;
- advocate for change; and
- initiate and conduct projects that benefit the most vulnerable section of society.

Prakriti Resource Centre (PRC)

Prakriti Resources Centre (PRC) is a non-governmental organization working for sustainable development and environmental justice in Nepal. They conduct research and study, carry out policy intervention, build awareness, knowledge and capacity of civil society organizations, government and the private sector — in the fields of national and international climate policy processes, climate finance, climate-resilient and low carbon development practices, and loss and damage associated with climate change impacts. PRC has experience working on projects involved in renewable energy and mobilising development finance for investment in climate adaptation.

PRC’s objectives include:

- the development of a common platform for climate and development practitioners;

[349] http://www.econepal.org/prog_drr.php Accessed 20 August 2020

- research and knowledge sharing;
- policy engagement; and
- capacity building.

Local Initiatives for Biodiversity, Research and Development (LI-BIRD)

Local Initiatives for Biodiversity, Research and Development (LI-BIRD) is a non-profit, non-governmental organisation committed to capitalizing on local resources, innovations, and institutions for sustainable management of natural resources for improving livelihoods of smallholder farmers. LI-BIRD's mission is to diversify choices and secure the livelihoods of smallholder farmers through innovative approaches to research and development in agriculture, biodiversity and natural resources. They have experience working on projects involved in enhancing the livelihoods and resilience of marginal peoples and farmers.

Nepal Centre for Disaster Management (NCDM)

Nepal Centre for Disaster Management (NCDM) aims to help effectively mitigate the impact of disasters in the country. NCDM generates nationwide awareness on disaster risks and their management and works on building the capacity of local communities on disaster risk mitigation, preparedness, rescue, relief, rehabilitation and reconstructions. NCDM has experience working on projects involved in flood and landslide response.

NCDM's objectives are to:

- carry out study, research, survey and other related activities for disaster mitigation and preparedness;
- develop appropriate technology for disaster risk reduction and disseminate them to vulnerable communities;
- organise trainings, seminars, workshops, interactions, and exhibitions at the national and international level on disaster risk mitigation and management;
- organise community level programs to enhance their coping capacity against disasters;
- work with concerned organisations, including the Government, and the affected people and institutions to manage and mitigate the risk of natural or other disasters. Also work as a contact point and liaison between the victims of disasters and the government agencies at times of disasters;
- publish posters, pamphlets, booklets, journals, and produce audio-visuals to raise disaster awareness among people;
- help to enhance coordination between the government and non-government organizations in disaster preparedness, prevention, mitigation, rescue, relief, and rehabilitation;
- play an active role to assist the government in providing immediate rescue, relief and rehabilitation to the victims of disasters;
- establish coordination and cooperation with national and international institutions and individuals and exchange expertise and knowledge in disaster mitigation, rescue, relief, and rehabilitation;
- establish and operate database on disasters in the country and carry out damage assessment after disasters; and
- work for the protection of the environment in order to mitigate natural disasters, particularly floods and landslides.

Sagarmatha Pollution Control Committee (SPCC)

Sagarmatha Pollution Control Committee (SPCC) is a non-profit, non-governmental organisation working to manage waste in Khumbu Region, which comprises the Sagarmatha National Park and its

Buffer Zone and also encompass the core Everest trekking area. SPCC has experience working on projects involved in solid waste management, awareness raising and earthquake response.

SPCC's objectives are to:

- check climbing permits;
- monitor illegal climbing;
- implement waste management strategies at the base camps of the Khumbu area's mountains and peaks, including Mt. Everest;
- manage garbage in settlements and along trekking trails in direct coordination with local communities;
- conduct all waste management activities, including the building of waste management infrastructures, waste collection, segregation and treatment/disposal; and
- develop sustainable waste management strategies with a long-term goal of keeping Khumbu clean.

National Trust for Nature Conservation (NTNC)
The National Trust for Nature Conservation (NTNC) is a non-profit, non-governmental organisation mandated to work in the field of nature conservation in Nepal. Its work covers several thematic areas, including protected areas and ecosystems, conservation economy, climate change, environmental education and research and knowledge management. NTNC has experience working on projects involved in large scale conservation.

NTNC's objectives are to:

- ensure a balance between human needs and the environment to guarantee long-term sustainability;
- ensure maximum community participation with people recognized both as the actors and clients; and ensuring equity and gender sensitivity in all its work;
- link economic, environmental and ethical factors in conservation activities;
- manage operations based on sound business-oriented principles (high quality work, efficiency, effectiveness, quick decision making based on facts/evidence, client-oriented, responsive to environmental changes and requirements);
- work towards fostering strong partnerships with various stakeholders (community, Government, civil society and international stakeholders) so as to ensure quality in all its activities and conforming to client requirements; and
- abiding by principles of good governance.

Nepal Forum of Environmental Journalists (NEFEJ)
The Nepal Forum of Environmental Journalists (NEFEJ) is a forum to debate, report, and influence public policy for sustainable development. NEFEJ includes both journalists and experts in different natural sciences who advocate for environmental protection and sustainable development. Its objective is to raise public awareness of sustainable development and to support lobbying and advocacy for environment-friendly public policies. NEFEJ has experience working on projects involved in media advocacy, media engagement and climate communication.

National Society for Earthquake Technology— Nepal (NSET)
The National Society for Earthquake Technology — Nepal (NSET) is Nepal's foremost professional, non-governmental scientific institution working on earthquake risk management. NSET was founded to reduce the impacts of future earthquakes, to raise awareness on earthquake disaster reduction, to contribute to the development of science and technology related to earthquake disaster mitigation

and the implementation of earthquake-resistant measures in construction. NSET has experience working on projects involved in flood early warnings, water resource mapping, pollution stress assessments and mainstreaming of Sustainable Development Goals at a local level.

NSET's objectives are to:

- sensitise, educate and facilitate all institutions to undertake organised approaches to managing and minimising earthquake risk by transferring information, technical knowledge, and skills, and helping them to mobilise resources for this purpose;
- advocate for favourable and supportive policies, legal mechanisms, increased investments and a unified and effective national earthquake response mechanism and a system of incentives and disincentives to enable communities to become earthquake-safe; and
- build a strong, well-resourced and credible institution that will be the national focal point for earthquake risk management actions, a facilitator and coordinator in the network of earthquake disaster management, and a source of all available information on the subject.

Nepalese Youth for Climate Action (NYCA)

Nepalese Youth for Climate Action (NYCA) is a youth lead coalition of the Nepalese youth and youth groups tackling climate change to protect Nepal and the Nepalese people from the adverse impacts of climate change by spreading awareness, advocating policies and taking action.

NYCA's objectives are to:

- raise awareness at local, national and international levels regarding climate change.
- educate, empower and mobilise youth to achieve NYCA's goals and vision;
- establish the network of youths at the Local, National, Regional and Global levels for climate campaigning;
- conduct research on the different components of climate change;
- support the Nepalese government in international negotiations for lobbying on Nepal's and Nepal member coalition's position;
- pressurise the large GHGs emitting countries for greater cuts in their emissions;
- pressurise developed countries to assist with adequate and reliable financial support for the adaptation and transfer of technology in developing countries; and
- pressurise Nepalese government towards switching to a low carbon economy.

Alternative Energy Promotion Centre (AEPC)

The Alternative Energy Promotion Centre (AEPC) is the national institution mandated to mainstream renewable energy in Nepal through increasing access, knowledge and adaptability.

AEPC's objectives are to:

- popularize and promote the use of alternative/renewable energy technology;
- raise the living standard of the rural people;
- protect the environment; and
- develop the commercially viable alternative energy industries in the country.

Adaptation for Smallholders in Hilly Areas (ASHA) Project

Adaptation for Smallholders in Hilly Areas (ASHA) Project is a six-year climate change adaptation project which works in several Nepalese districts and intends to provide support for vulnerable smallholders to improve their climate resilience. The objectives of the project are that:

- 100,000 direct beneficiary HHs 70% of target HHs) move down the climate change vulnerability scale by at least one step (disaggregated by gender, caste and ethnicity of HH-head);

- each US$ one of ASAP financing leverages at least US$ two from other sources for LAPA implementation in at least six ASHA districts; and
- 560,000 tons of greenhouse gas emissions (CO2E) avoided and/or sequestered.

HELVETAS
HELVETAS is an independent organization for development based in Switzerland that supports poor and disadvantaged women, men and communities in approximately thirty developing countries across the world.

HELVETAS objectives are to:
- support poor and disadvantaged women, men and communities in developing and transition countries in their efforts to improve their living conditions;
- support and empower women and men to improve their livelihoods themselves in a sustainable manner;
- promote equitable access to the resources and services necessary for life and thus contribute to overcoming the root causes of poverty;
- uphold the protection and promotion of social, economic, political, environmental and cultural rights and responsibilities, and seek to ensure their practical implementation;
- support their partners in engaging in development policy issues;
- advocate for a coherent Swiss foreign and economic policy, responsive to the needs of men and women in developing and transition countries; and
- accompany and support their partners on a long-term basis.

High-Value Agriculture Project (HVAP) in Hill and Mountain Areas
This project mainly focuses on one leading intervention: the development of pro-poor value chains, with other project initiates in direct support of this intervention, such as service market strengthening and arrangements for project management. The expected outcomes of the project are:
- improved commercial relations and partnerships between agricultural/NTFP/MAP market operators and producers result in profitable, efficient, market-orientated production of high value commodities for 13500 beneficiary households;
- increased participation and access of poor marginal producers in high value commodity value chains and agricultural/NTFP markets;
- smallscale, poor farmers and other rural producers benefit from sustainable increases in volume and value of production as a result of improved production/collection, value addition and sales of high value niche market products; and
- enhanced environment and strengthened local capacity to support market driven/value chain initiatives.

iDE Nepal
iDE is a global organization that advances market-based approaches in agriculture; access to finance; and water, sanitation, and hygiene (WASH) to create income and livelihood opportunities for low-income rural households.

iDE's objectives are to:
- rapidly increase incomes through high-value commodities for which smallholders have a comparative advantage;
- improve local economic governance by establishing sustainable rural enterprises and markets;
- empower women through increased income and participation in local economic institutions in decision making roles;

- improve health and nutrition through innovative training programs and cultivation of nutritious foods;
- build government capacity to support the private sector and facilitate public-private partnerships to effectively;
- utilise public resources to develop market opportunities; and
- build resilience to climate change by helping farmers improve water efficiency and planning, developing feedback.

Local Initiatives for Biodiversity, Research and Development (LI-BIRD)

Local Initiatives for Biodiversity, Research and Development (LI-BIRD) is a non-profit making, non-governmental organisation that is dedicated to capitalising on local resources, innovations and institutions for sustainable management of natural resources for bettering livelihoods of smallholders in Nepal. LI-BIRD's mission is to expand choices and secure the livelihoods of smallholders through innovative approaches to both research and developments in agriculture, biodiversity as well as natural resources. The objectives of this initiative are to:

- improve the food and nutrition security of beneficiaries through investment in knowledge, innovations, and solutions;
- transform subsistence agriculture into business opportunities for generating income and local employment;
- build the adaptive capacity of climate-vulnerable and disaster-prone communities for resilient livelihoods; and
- empower and mobilise communities, local institutions and networks for up-scaling integrated management of resources at sub-watershed, watershed and river basin levels.

Disaster Preparedness Network Nepal (DPNet-Nepal)

Established in 1996, Disaster Preparedness Network-Nepal (DPNet-Nepal) is a national network of organisations and professionals working in the field of DRR in Nepal[350]. It is envisioned to reduce the disaster risk in the country by working with partners from like-minded institutions, organisations and professionals and its mission is to advocate the issues of disaster management and establish an effective link between the government, UN agencies and civic society to reduce the risks of disasters in the country.

Past and current policies and programmes of DPNet-Nepal include:

- DPNet-Nepal's four year National Strategy for DRR.
- Partners' Capacity Building on DRR.
- Monthly Dialogue Program on DRR/climate change and vulnerability.
- Organisation Strengthening Project for national networking for DRR.
- Resources and Knowledge Sharing Project.
- Publication of Nepal Disaster Report 2010/Good Practices of the partner organisations/Research Reports.
- Six Inclusive Disaster Resource Centres in Nepal.
- Conclave for DRR/climate change adaptation/better livelihood/sustainable development.

Himalayan Risk Research Institute (HRI)

Himalayan Risk Research Institute (HRI) is an interdisciplinary organization and network of young scientists and professionals working in disaster risk research, humanitarian actions and voluntarily

[350] https://www.preventionweb.net/organizations/4168/view Accessed: 21 August 2020

social work[351]. They carry out work in line with the four priorities for actions according to the Sendai Framework for Disaster Risk Reduction (SFDRR). The objectives of HRI are to:

- identify, study and investigate risks and hazards;
- conduct risk assessments, vulnerability assessments as well as environmental impact assessments;
- conduct preparedness activities that include capacity building and development, training, seminars and conferences for professionals, engineers, masons and all other stakeholders;
- conduct programs on public awareness;
- assist disaster risk research activities and researchers;
- aid with response activities during disasters; and
- aid in recovery activities, including reconstruction and rehabilitation.

The institute is currently conducting geo-hazard research in the Hindu-Kush Himalaya within Nepal, with a focus on landslide risks. An urban risk study is also ongoing, assessing vulnerabilities to natural hazards. Previous work by the institute has included research into the causes of the Terai flood in 2017 as well as the effectiveness of response procedures. GIS analyses of landslides within the Jajarkot district in Nepal have also been carried out by the institute to aid future development planning.

Micro Enterprise Development Program for Poverty Alleviation (MEDPA)

The goal of this program is the improvement of both the economic and social conditions of low income and socially backward families through Micro Enterprises. Through the Micro Enterprise Development Program (MEDEP), which saw the launching and success of three phases, the MEDPA was adopted as the internalised model by the Government of Nepal. This was successful in producing entrepreneurs in a micro-enterprise development model that supplies business services through phased and integrated services. The objective of the program is to increase the employment opportunities and level of income of the people living below the poverty line by developing micro enterprises through Entrepreneurship development. The target group of this program is defined as the members of the family below the poverty line, focusing on the most deprived and marginalised groups as well as people living in remote and inaccessible areas.

National Trust for Nature Conservation (NTNC)

The National Trust for Nature Conservation (NTNC) is an autonomous and not-for-profit organization designated to work in the sphere of nature conservation in Nepal. The mission statement of the Trust is to “promote, conserve and manage nature in all its diversity balancing human needs with the environment on a sustainable basis for posterity - ensuring maximum community participation with due cognizance of the linkages between economics, environment and ethics through a process in which people are both the principal actors and beneficiaries”. Over the past three decades, NTNC has successfully taken on more than 300 small and large projects in the area of nature and biodiversity conservation, clean energy and climate change, cultural heritage protection, ecotourism as well as sustainable development. NTNC works directly with the Government of Nepal in the management of protected areas by directly managing three mountain protected areas and assisting the government in all the low land parks. NTNC’s research outcomes have been instrumental in evidence-based decision making at the policy level.

Pakhribas Agriculture Centre, Dhankuta

[351] https://hri.org.np/ Accessed: 21 August 2020

The Agriculture Research station in Pakhribas is a multidimensional, multi crop and multisubject research centre[352]. The station mainly focuses on training and agricultural extension and, at present, it gives importance to work on agriculture research as well. Its major working area is the 10 districts of Purwaanchal Development Region, i.e.Taplejung, Panchthar, Ilam, Dhankuta, Terathum, Bhojpur, Sankhuwasawa, Khotang, Okhaldhunga and Solukhumbhu. The objectives of the centre are to:

- develop agriculture, animal and agriculture-related techniques on high, mid and low hills of the eastern development region;
- increase the economic levels of farmers living on the eastern hills through improving their agricultural systems;
- train farmers and agricultural technicians and provide technical support to the Nepal government's agriculture and rural development program;
- establish contact and coordinate with different stakeholders to transfer techniques; and
- produce, sell and distribute different crops such as vegetable crops, fruit crops, cardamom, tea, timber plants, saplings and respective crop's seeds.

Paani Program, USAID

The USAID Paani Program (Paani) works toward enhancing Nepal's ability to manage water resources for multiple uses and users through an integrated, whole-of-basin approach, with a focus on climate change adaptation and the conservation of freshwater biodiversity[353]. Through multiscale activities: watershed, basin and national scales, the project aims to reduce threats to freshwater biodiversity and strengthen the resilience of targeted communities in the Karnali, Mahakali and Rapti river basins to adapt to the adverse impacts of climate change through improved water resource management. The project objective is working to improve capacity at the watershed, basin and national levels.

National level objectives are to:

- help the Government of Nepal to formulate and achieve results associated with several national policies, strategies and action plans; and
- support provisions in Nepal's new Constitution to integrate improved water governance in newly established provinces.
-

Basin level objectives are to:

- adapt to climate change, including disaster risk reduction;
- strengthen basin-level planning; and
- support sustainable hydropower.

Watershed level objectives include:

- management of capture fisheries;
- integrated water management;
- regulation and management of local road construction and maintenance;
- regulation of riverbed aggregate mining; and
- managing invasive species.

People, Energy & Environment Development Association (PEEDA)

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352 ASLF. 2016. Agriculture Research Station Pakhribas, Dhankuta. Available at: https://aslframpur.wordpress.com/2016/10/16/agriculture-research-station-pakhribas-dhankuta/

353 USAID. 2019. Paani program. Available at: https://www.usaid.gov/sites/default/files/documents/1865/Paani_Fact_Sheet.pdf

People, Energy & Environment Development Association (PEEDA) is an NGO dedicated to improving the livelihoods of communities, particularly the poor, by collective utilisation of renewable energy resources while ensuring care for the environment[354]. PEEDA aims to promote activities for economic development and poverty alleviation through mobilising both local and external resources to harness Nepal's indigenous resources. The objectives of the organisation are to:

- collect information, investigate and carry out research on the physical, environmental, economic, social, legal and technical aspects of different energy resources;
- facilitate Nepalese, especially the rural communities, with the utilisation of different energy resources;
- provide information regarding the generation and utilisation of renewable energy to the public and raise awareness of renewable energy;
- faction government and legislators to create favourable policies for development, particularly by the poor, of renewable energy resources;
- encourage and promote the development of small enterprises such as: ropeway, agricultural development, pumped irrigation etc. which use electrical energy in the rural areas;
- implement and promote projects associated with renewable energy for the welfare of people and for economic development;
- promote technology transfer in the fields requiring special consultation;
- establish and develop institutions that contribute to and serve the renewable energy sector in Nepal; and
- serve as a channel for lending foreign support to the Nepalese hydroelectric projects.

The Group of Helping Hands (SAHAS) Nepal

The Group of Helping Hands (SAHAS) Nepal is a non-profit, non-governmental, social development organisation that has been working in remote rural areas working with vulnerable and socially excluded groups who are disadvantaged of development opportunities in Nepal[355]. The programmes focus is mainly food security and livelihoods, natural resource management and climate change, empowerment, advocacy and action research. The objective of the SAHAS-Nepal is to improve the capacities of the poor and excluded people and their organisations in the economic, political and social sectors through its development, research and advocacy at all levels. This is achieved through:

- empowering the local people to resolve the issues causing suffering to them;
- bringing together potential partners for collective action for community-based development activities;
- conserving biodiversity and management of ecosystem services;
- developing climate resilience communities; and
- empowering women and youth.

Comprehensive Disaster Risk Management Programme (CDRMP)

The Comprehensive Disaster Risk Management Programme (CDRMP) began in 2011 to build on the accomplishments of preceding UNDP support[356]. This programme has been formulated in accordance with the Nepal Risk Reduction Consortium (NRRC), with the aim of strengthening both the institutional and legislative aspects of disaster risk management (DRM) in Nepal, through building the capacities of government ministries and local bodies to establish strategies linkages between DRM and development sectors. This programme has six objectives across all the interconnected concerns of DRM. It is important to note that gender, social inclusion and knowledge management are addressed within all project activities. The six objects include:

[354] PEEDA. 2017. Available at: http://peeda.net/
[355] https://www.sahasnepal.org.np/. Accessed: 6 October 2021.
[356] https://www.undp.org/content/dam/nepal/docs/projects/UNDP_NP_CDRMP%20factsheet.pdf. Accessed: October 2021.

- strengthening the institutional and legislative system for disaster risk reduction;
- building strategic linkages with other sectors to mainstream disaster risk reduction;
- promoting climate change related risk management;
- reducing communities' vulnerability to natural disasters;
- improve emergency preparedness and response capacities; and
- building UNDP Nepal's capacity for providing early recovery support to help the government and victims in post-emergency recovery periods.

Hariyo Ban Program

The first phase of the Hariyo Ban Program ended in December 2016, and the second phase will be developed from the foundation of the first (applying lessons learned and scaling up capable approaches), which is set to run for five years[357]. The Hariyo Ban Program works to empower the local communities of Nepal in safeguarding the country's living heritage and adapting to climate change through both comprehensive conservation and livelihood approaches. The program focuses on two interlinking components: biodiversity conservation and climate change adaptation, including market based livelihoods. These components are supported the cross-cutting themes of governance and gender and social inclusion. This program intends to reduce the adverse impacts of climate change and biodiversity threats in Nepal and will be achieved through working with the government, communities, civil society and private sector. Therefore, the objectives of this program are to:

- improve the conservation and management of Government of Nepal – identified biodiverse landscapes, Chitwan-Annapurna Landscape (CHAL) and Terai Arc Landscape (TAL); and
- reduce climate change vulnerability in CHAL and TAL.

Women Organising for Change in Agriculture and Natural Resource Management (WOCAN)

WOCAN is a women-led international membership system of women and men professionals and women's associations[358]. The organisation's purpose is to advance women's empowerment and combine action to tackle climate change, poverty and food insecurity within supporting environments. WOCAN has the objective of addressing three core gaps that arise from the knowledge and experiences of sustainable and rural development methods. These gaps are: i) policies regarding gender within the agriculture and natural resource management sectors; ii) roles of professional women in implementing policy objectives for rural women's empowerment and gender equality within these sectors; and iii) organizational barriers that obstruct women from realizing positions of leadership and influence to take on such roles. In applying five core leadership practices in its work with individuals and with local and international organisations, WOCAN will:

- work strategically and collaboratively to support women professionals to assist their organizations to become more gender sensitive;
- provide capacity building through training and professional opportunities so women professionals in agriculture and natural resource management sectors become effective "change agents" for gender equality;
- focus on networking, partnerships and alliance building, so women will influence the policies and practices of organizations working at the policy, research, planning and implementation levels in agriculture and natural resource management;
- create visible fora for women's voices to be heard within international agencies and global processes concerned with food security, natural resource management and climate change;
- encourage the commitment and support of men so that the vision and mission of WOCAN can be achieved; and

[357] https://www.wwfnepal.org/hariyobanprogram/who_we_are/. Accessed: October 2021.
[358] https://www.wocan.org/. Accessed: October 2021.

- practise teamwork, open communication, trust, awareness, reflection, and a culture of mutual support.

Stakeholder Engagement

Stakeholder engagement forms a necessary part of the institutional framework important for the project. The project was developed in a participatory way, in collaboration with stakeholders from relevant Nepalese government ministries and departments, civil society organisations (CSOs), and private sector entities. The Nepalese Ministry of Finance (MoF), which is the Nationally Designated Authority (NDA) for the project, is responsible for the overall management of GCF engagement in Nepal and has been engaged throughout the project development phase. All entities engaged during project development and the roles they have and/or will play are listed below.

- The Ministry of Energy Water Resources and Irrigation (MoEWRI): The MoEWRI is the Executive Entity of the proposed project and is facilitating the internal GoN project advisory council- Project Steering Committee and providing support for the project. This ministry also houses the DHM, one of the project implementing units (PIU) for the proposed project.
- The Ministry of Finance (MoF): As NDA for the proposed project, the MoF is involved in project oversight and internal government coordination.
- The International Centre for Integrated Mountain Development (ICIMOD): This pan-Himalayan research intergovernmental organisation (NGO) has provided scientific background information and shared their expertise on glacial and high-mountain regions to the proposal development team. ICIMOD plans to work closely with UNDP and the Executing Entity/Implementing Partner (EE/IP) to help perform risk analyses, provide mapping support, and enable capacity development for DHM and other GoN stakeholders.
- Nepal Federation of Indigenous Nationalities (NEFIN): This organisation, in collaboration with their partners, will be involved in stakeholder consultations in the field with beneficiaries and IP communities.
- Department of National Parks and Wildlife Conservation (DNPWC): The DNPWC will be closely consulted for all GLOF risk areas lying within protected lands.
- Department of Forests and Soil Conservations (DoFSC): The DoFSC, also under the MoFE, will be an implementation partner along with DHM and has been consulted about linkages with this project and ongoing basin planning in Nepal.
- Hydropower companies and numerous coordinating organisations have readily participated in stakeholder workshops and will be consulted separately as part of a market analysis and other market-related efforts.
- The National Trust for Nature Conservation (NTNC) and Alternative Energy Promotion Centre (AEPC): These are the two GCF Direct Access Entities (DAEs) in Nepal and will be involved in the proposal and project implementation processes to enable capacity development in the country.
- Ministry of Federal Affairs and General Administration (MoFAGA) is the ministry of Nepal accredited with the role of coordination, cooperation, facilitation, and monitoring and

evaluation of activities undertaken by local governments, as well as the regulation and management of the civil service in the country.

- The Ministry of Home Affairs (MoHA) objective is to maintain peace and security and protect the lives, wealth and freedom of the people. The ministry consists of six departments, including, specifically, the National Disaster Risk Reduction Management Authority (NDRRMA).
- National Disaster Risk Reduction and Management Authority (NDRRMA) will be a joint implementing partner and will be responsible for coordinating with the Local Disaster Management Committees (LDMCs) from the project areas and for setting up Inter-LDMCs to ensure a coordinated approach for GLOF and flood risk reduction. NDRRMA will work closely with existing and/or new Emergency Operation Centers (EOCs) in the municipalities or rural municipalities of the project areas.
- Department of Water Resources and Irrigation (DoWRI) works under the Ministry of Energy, Water Resources and Irrigation (MoEWRI). The mission of the department is to achieve economic and social prosperity for the country through proper development, effective utilisation and sustainable management of water resources and irrigation.
- The Water and Energy Commission (WEC) is concerned with rendering opinions, advice and recommendations on the bilateral and multilateral issues relating to water resources and energy.
- The National Planning Commission (NPC) is the specialised advisory body of the Government of Nepal for formulating: i) a national vision; ii) development policy; iii) periodic plans; and iv) sectoral policies for the overall development of the nation. The NPC assesses resource needs, identifies sources of funding, and allocates budget for socio-economic development and serves as a central agency for monitoring and evaluating development policy, plans and programs. The NPC also serves as an intellectual hub for the exchange of new development ideas and proposals from scholars, private sector, civil society, and development partners.
- Kathmandu University (KU) houses a Department of Environmental Science and Engineering which conducts research work in glaciers, glacier-climate interactions, effects of changes on snow, glaciers, glacial lakes and permafrost on mountain ecosystems.
- Nepal Federation of Indigenous Nationalities (NEFIN) undertook consultations with indigenous peoples of the project area. The consultations conducted with indigenous peoples, including indigenous women and with the representatives of indigenous peoples' organizations/networks of specific villages of Koshi and Gandaki river basin, that are positively and/or negatively affected by the glacial lakes, glacial lake outbursts, flooding, and other climate-induced disasters for Green Climate Fund (GCF) project formulation, implementation and its sustainability. Consultation details can be found in Annex 7: Project Governance and Institutional Arrangement.
- Youth Alliance for Environment (YAE) undertook consultations at the district headquarters, NEFIN local chapter participated in the consultations in their respective districts.

Regular consultation to engage the Federation of Community Forestry Users Nepal (FECOFUN), their member networks and Community Forestry User Groups (CFUGs) were carried out during project development. During the project implementation, FECOFUN or their members will be able to engage at different scales from central level Project Steering Committee (PSC) to local level project implementation. They may also represent the Local-level Disaster Management Committee (LDMC).

7. Past and ongoing projects and initiatives

The urgency of addressing climate change-induced increases in flooding and GLOF events in Nepal has been recognised in several projects and programmes, which are aimed at mitigating the impact of floods on vulnerable communities. To achieve this objective, numerous projects, programmes and initiatives focussing on enhancing the climate resilience of Nepal's vulnerable communities have been implemented. Those relevant to the project are summarised in the sections below.

7.1. National projects and initiatives with a focus on climate change

Improving Climate Resilience of Vulnerable Communities and Ecosystems in the Gandaki River Basin, Nepal (2020-2026; GCF; US$27,4 million)
Mainstreaming sustainable river-basin approaches to watershed management for enhancing the resilience of climate vulnerable communities and ecosystems is the focus of this IUCN project[359]. The project is being implemented in the Gandaki River Basin and will be upscaled across the country through the paradigm-shifting transition from district to basin approaches to management. The project has seven core areas, namely: i) improve climate resilient agroforestry and livelihood, ii) improve water availability and water use efficiency; iii) incorporate natural ecosystem restoration based actions for reducing impacts of landslides and floods, iv) enhance the technical capacity of GRB communities in maintaining and supporting climate resilient ecosystems, v) enhance community-based mechanism for planning, restoration, monitoring, and maintenance of ecosystems, vi) incorporate ecosystem-based climate change adaptation approaches into government policies and plans, and vii) establish a knowledge management system for climate resilient River Basin Management[360]. Over 800,000 people in the region are expected to benefit directly as a result of the project's interventions, with a further 1 million indirect beneficiaries[361]. There is strong complementarity with the proposed project in that the IUCN project area overlaps with the Thulagi Lake area, therefore providing a foundational entry point for implementation in the Thulagi region. Thulagi is rated as very high risk, and so this overlap will ensure effective adaptation. However, the proposed project will focus more on lake-based interventions for Thulagi so as not to duplicate efforts as the IUCN project includes EbA and community resilience activities. Nonetheless, the proposed project will build on knowledge management, technical capacity building and ecosystem restoration work by expanding similar approaches into the other project sites (Activity 1.1, Activity 2.2 and Activity 3.3). Similarly, the proposed project will work in synergy with the IUCN project implementation unit to incorporate ecosystem-based climate change adaptation approaches into government policies and plans (Activity 1.2).

Building a Resilient Churia Region in Nepal (BRCRN) (2020-2026; GCF; US$47 million)
The recently launched BRCRN project aims to enhance the climate resilience of ecosystems and vulnerable communities in the Churia region of Nepal through integrated sustainable rural development and natural resource management approaches. The project is funded by the GCF with co-financing from the GoN[362]. The Executing Entities for the project are the Ministry of Forests and

[359] GCF FP131: Improving Climate Resilience of Vulnerable Communities and Ecosystems in the Gandaki River Basin, Nepal. 2021. Available at: https://www.greenclimate.fund/sites/default/files/document/fp131-iucn-nepal_0.pdf
[360] GCF FP131: Improving Climate Resilience of Vulnerable Communities and Ecosystems in the Gandaki River Basin, Nepal. 2021. Available at: https://www.greenclimate.fund/sites/default/files/document/fp131-iucn-nepal_0.pdf
[361] GCF FP131: Improving Climate Resilience of Vulnerable Communities and Ecosystems in the Gandaki River Basin, Nepal. 2021. Available at: https://www.greenclimate.fund/sites/default/files/document/fp131-iucn-nepal_0.pdf
[362] GCF FP118: Building a Resilient Churia Region in Nepal (BRCRN). 2019. Available at: https://www.greenclimate.fund/sites/default/files/document/funding-proposal-fp118-fao-nepal.pdf

Environment (MoFE) and the Food and Agriculture Organization (FAO). The project targets climate change-induced erosion, sedimentation and flooding risks and includes activities for the construction of check dams, gully stabilisation measures and other local climate-resilient infrastructure. In addition, the project will improve resilience and reduce exposure to flooding through sustainable natural resource management (SNRM) and accordingly directly benefit 200,000 people in the region[363]. The proposed project will also address flood risk via several measures, including upstream and downstream stabilisation interventions (Output 3), as well as enhance institutional capacity to manage resources and environmental risk more effectively (Output 1).

The Pilot Program for Climate Resilience (PPCR) and Nepal's Strategic Program for Climate Resilience (SPCR) (CIF; US$86 million)
The PPCR was a pilot programme for building resilience that targeted nine countries, including Nepal[364]. The programme funded the development of Nepal's SPCR and associated projects aimed at climate change-induced DRR. These projects were implemented country-wide and were collaboratively managed by Nepal's Ministry of Population and Environment (MoPE) and the Climate Investment Fund (CIF)[365]. Through evaluations under the programme, climate vulnerability focus areas were identified for Nepal, including water availability, food security and ecosystem health. The SPCR outlined five components of Nepal's programme to respond to climate risk, namely: i) building climate resilience of watersheds in mountain eco-regions; ii) building resilience to climate-related hazards; iii) mainstreaming climate change risk management in development; iv) building climate-resilient communities through private sector participation; and v) enhancing the climate resilience of endangered species[366]. The PPCR has subsequently expanded three-fold to 28 countries. Moreover, the CIF's investment in Nepal now includes renewable energy projects, sustainable forestry and a biogas programme[367]. The proposed project aims to enhance resilience and to improve risk management with a focus on GLOFs and flood disasters (Output 1, Output 2 and Output 3).

Building Resilience to Climate Related Hazards (BRCH) (2013-2020, The World Bank, US$31 million)
Currently in its conclusion stage, the aim of the BRCH project was to enhance the GoN's capacity to withstand climate-related hazards[368]. The project focus was two-fold — to improve forecasting and warning systems for vulnerable communities and to develop farmer information systems for adaptive agricultural management[369]. Nepal's Department of Hydrology and Meteorology (DHM) is the central institution responsible for, *inter alia*, weather, climate and hydrological information, as well as overseeing future networks and supporting the implementation of climate- and weather-related projects[370]. As such, this project sought to strengthen the institutional, legal and regulatory frameworks of the DHM to support their capacity to fulfil their mandate[371]. In addition, the project included a component for improving observation networks and forecasting technology. The subsequently improved weather data was complemented with the creation of a public weather service to make critical forecasting and warning information available to weather-dependent sectors and

[363] GCF FP118: Building a Resilient Churia Region in Nepal (BRCRN). 2019. Available at: https://www.greenclimate.fund/sites/default/files/document/funding-proposal-fp118-fao-nepal.pdf
[364] CIF. 2018. Available at: https://www.climateinvestmentfunds.org/country/nepal
[365] Khanal. 2012. Presentation on Nepal's Strategic Program for Climate Resilience Maintaining a Programmatic Approach: SPCR Institutional Coordination. Available at: https://www.climateinvestmentfunds.org/sites/cif_enc/files/meetingdocuments/spcr_institutional_arrangements_-_nepal_0.pdf
[366] Khanal. 2012. Presentation on Nepal's Strategic Program for Climate Resilience Maintaining a Programmatic Approach: SPCR Institutional Coordination. Available at: https://www.climateinvestmentfunds.org/sites/cif_enc/files/meetingdocuments/spcr_institutional_arrangements_-_nepal_0.pdf
[367] CIF. 2018. Available at: https://www.climateinvestmentfunds.org/country/nepal
[368] GoN. 2020. Available at: http://brch.dhm.gov.np/about-us/
[369] The World Bank. 2020. Available at: https://projects.worldbank.org/en/projects-operations/project-detail/P127508#
[370] GoN. 2020. Available at: http://brch.dhm.gov.np/about-us/
[371] The World Bank. 2020. Available at: https://projects.worldbank.org/en/projects-operations/project-detail/P127508#

vulnerable communities[372]. An Agriculture Management Information System (AMIS) was also established under the Ministry of Agriculture Development (MoAD) through this project[373]. The proposed project will similarly work closely with the DHM to enhance its capacity to better generate, monitor and disseminate vital weather information (Output 2).

The Nepal Climate Change Support Programme I (NCCSP) (2013–2017); Nepal Climate Change Support Programme I - Transition Extension (NCCSP I-TE) (2018–2019); and Nepal Climate Change Support Programme II (NCCSP II) (commenced 2019)
The NCCSPs have been implemented by the Ministry of Forest and Environment (MoFE) and 26 local governments in 14 districts in Nepal, with support from UNDP[374]. In the first phase (NCCSP I), UNDP provided technical assistance to the MOPE and GoN to implement the NAPA[375]. The focus was 80% on local level actions to implement local adaptation programmes of action (LAPA) and 20% on strengthening institutional capacity and national-level coordination of Nepal's climate change efforts. In the forthcoming second phase (NCCSP II) — which is still under preparation — these efforts will be expanded. To bridge these two phases, the NCCSP I-Transition Extension (TE), was developed to focus on providing technical assistance and support to the 26 local governments across 14 districts with multiple Climate Resilient Development Projects (CRDPs)[376]. The NCSSPs were funded by the UK government and the EU, with NCCSP I receiving an estimated $18.7 million, while NCCSP I-TE has received $2.67 million. The NCCSP II's estimated worth is $20.4 million[377]. The NCCSP I-TE implemented 78 CRDPs in 2018–2019 and is currently engaging with the abovementioned local governments to expand this number[378]. CRDPs under the NCCSP have created multiple benefits, including: i) employment for local people; ii) enhanced drought resilience through improved irrigation schemes, drinking water storage and distribution; iii) protection of wetlands and settlements through gabion construction and recharge ponds; iv) maintenance of hydropower infrastructure; v) construction of two disabled-friendly flood-resilient community shelters; and vi) improved institutional capacity through climate risk and development training for local government officials and community representatives[379]. The programme is estimated to benefit 84,443 people. The proposed project will also address community resilience through the co-development of community response mechanisms (Activity 2.2). The proposed project will also expand on protecting wetlands and settlements (Output 3).

7.1.1. Projects with a focus on GLOF and rain-induced flood risk reduction

Community Based Flood and Glacial Lake Outburst Risk Reduction (2013-2017; GEF, GoN, UNDP; US$26.6million)
Completed in 2017, the goal of this risk reduction project was to minimise material losses from flooding events in the Terai and Churia Ranges as well as to reduce the risk associated with GLOFs in the Solukhumbu District[380]. Nepal's Department of Hydrology and Meteorology (DHM) was the Executing Entity for the project with assistance from UNDP, USAID and ICIMOD. This project formed part of a larger UNDP programme for comprehensive disaster risk management (DRM), focussing on EWS

[372] The World Bank. 2020. Available at: https://projects.worldbank.org/en/projects-operations/project-detail/P127508#
[373] GoN. 2020. Available at: http://brch.dhm.gov.np/about-us/
[374] UNDP. 2020. Available at: https://www.np.undp.org/content/nepal/en/home/projects/nccsp.html
[375] UNDP. 2017. Annual progress report: Nepal Climate Change Support Programme.
[376] UNDP. 2017. Annual progress report: Nepal Climate Change Support Programme.
[377] UNDP. 2017. Project document: Nepal Climate Change Support Programme I (Transition extension).
[378] UNDP. 2017. Project document: Nepal Climate Change Support Programme I (Transition extension).
[379] UNDP. 2017. Project document: Nepal Climate Change Support Programme I (Transition extension).
[380] UNDP. 2012. Project document: Community Based Flood and Glacial Lake Outburst Risk Reduction. Available at: https://www.adaptation-undp.org/sites/default/files/downloads/submission_october_2012_nep_ldcf_prodoc_15nov2012.pdf

and flood preparedness training for increased preparedness and improved response to disasters[381]. While infrastructural risk at Tsho Rolpa Lake had been significantly reduced after engineering to lower the lake by 3.5 m was completed in 2000, the community-based EWS (CBEWS) aspect of the project included the installation of EWS 50 km downstream from Tsho Rolpa Lake, specifically in the Tamakoshi basin. Based on lessons learned from Tsho Rolpa as well as research undertaken by ICIMOD and the University of Kathmandu and AdaptASIA, Imja Lake — a hazardous glacial lake — was reduced by 3.5 m through the construction of artificial drainage systems, reducing the likelihood of GLOF events. In addition, CBEWS were also installed for communities vulnerable to flooding from Imja.[382]

The Nepalese Army were employed for construction work on this project, and geophysical, hydro and bathymetry assessments had to be conducted under the technical preparation. Special permits had to be secured as construction took place in a World Heritage Site and explosives could not be used. For this reason, construction was primarily done with hammers and chisels. Under the project, the following was achieved: i) six sirens were installed in areas considered vulnerable; ii) evacuation centres were established; iii) community members were trained in life saving and mock drills undertaken; and iv) a campaign for raising awareness on flood risk was implemented. The project reduced risk posed by the Imja Glacial Lake for over 12,000 vulnerable people living downstream and CBEWS was improved among settlements exposed to Tsho Rolpa Lake.[383] The proposed project includes numerous similar interventions for increasing flood and GLOF resilience through physical interventions (Activity 3.1 and Activity 3.2), improving EWS (Activity 2.1 and Activity 2.2) and strengthening response procedures. There is overlap in the target site of Solukhumbu District, which will further ensure risk is reduced for this highly vulnerable area. Given the closely related objectives of this and the proposed projects, GLOF and flood disaster prevention and response in Nepal will be further strengthened.

Strengthening Flood Resilience in Nepal's Kamala River Basin Through End to End (E2E) Early Warning System (2012-2017; USAID; US$340,000; USAID/OFDA)[384]

The objective of this project was to strengthen the technical capacity of the DHM for improved flood resilience in the Kamala River Basin in central south Nepal. The project was implemented by Practical Action and Nepal Red Cross, in partnership with the Office of U.S. Foreign Disaster Assistance (USAID/OFDA) and the DHM. Through the project, the DHM was supported to establish new flood and rainfall monitoring stations and upgrade existing stations to inform EWS in Nepal. The project piloted technologies, including the South Asia Flash Flood Guidance System (FFGS), aimed at reaching affected communities swiftly, which has improved flood forecasting lead-time and effective integration of climate information. In turn, this has reduced the level of flood risk to individuals and property, benefitting 36,000 people. Moreover, hydrometeorological-related training was conducted for 50 decision-makers from the DHM, local government and NGOs. Several policy and procedures were also updated with improved actions for preparedness for hydrometeorological events. The proposed project will build on the lessons learned from the piloted technologies for improving EWS and preparedness (Activity 2.2). In addition, it will build on the USAID training for technical capacity within the DHM by increasing the monitoring and observation networks at key sites in GLOF watersheds (Activity 2.1).

381 UNDP. 2012. Project document: Community Based Flood and Glacial Lake Outburst Risk Reduction. Available at: https://www.adaptation-undp.org/sites/default/files/downloads/submission_october_2012_nep_ldcf_prodoc_15nov2012.pdf

382 Fakhruddin B and Basnet G. 2018. Terminal evaluation report for the project: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP) PIMS #4657 (GEF ID 4551).

383 Fakhruddin B and Basnet G. 2018. Terminal evaluation report for the project: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP) PIMS #4657 (GEF ID 4551).

384 USAID. [n.d.]. Available at: https://2012-2017.usaid.gov/nepal/fact-sheets/strengthening-flood-resilience-nepals-kamala-river-basin-through-ews

Practical Action: The Zurich flood resilience program (2013-2018; Zurich Insurance Co and Z Zurich Foundation; US$1.63 million)

The objective of this project was to increase flood resilience among exposed communities in Mexico, Bangladesh, Indonesia, Peru and Nepal. The project aimed to achieve this objective through policy updates based on effective risk reduction practices[385]. For Nepal in particular, the project focussed on sites in the Koshi and Karnali river basins. Practical Action was the primary implementing organisation and the Nepal Red Cross Society and Centre for Social Development Research were key partners. The International Institute for Applied Systems Analysis (IIASA), the Wharton Risk Management and Decision Processes Centre at the University of Pennsylvania as well as the International Federation of Red Cross and Red Crescent Societies (IFRC) were also closely involved[386]. The project sought to: i) measurably enhance flood resilience in vulnerable communities; ii) enhance the effectiveness of disaster risk reduction (DRR) solutions; iii) develop and promote knowledge and expertise on flood risk and resilience; and iv) improve awareness and public dialogue around flood resilience and flood risk reduction solutions at the national, regional and global level[387]. In addition, the project facilitated the testing of numerous approaches, including through a community measurement framework, to increase flood resilience and analysed the effectiveness of each to establish an empirical base for disaster resilience[388]. The project also supported post-event research, producing 13 Post Event Review Capability (PERC) reports and over 40 articles and other publications. The findings of this research aimed to inform the project's lessons learned to support the scaling up of successful practices through multi-level policy updates. The proposed project will build on lessons learned and relevant best practices to inform interventions for flood risk reduction and improved DRR measures to expand these ambitions into the four target sites (Output 3).

7.1.2. Projects with a focus on Ecosystem-based Adaptation

Ecosystem-based Adaptation (EbA) in Mountain Ecosystems (2011-2016; UNDP, UNEP & BMUB; US$3.3 million)

The primary objective of the EbA in Mountain Ecosystems project was to reduce the vulnerability of exposed communities to climate change impacts — in particular, drying water sources, changing vegetation and increased landslide incidences — by improving institutional management of ecosystems and ecosystem services and promoting EbA solutions[389]. The pilot sites were located in the area surrounding Nepal's Panchase Protected Forest, namely the Kaski, Parbat and Syangja Districts[390]. The project was implemented by the Department of Forests and Soil Conservation under Nepal's Ministry of Forests and Environment (MoFE) and the Ministry of Science, Technology and Environment (MoSTE) with support from UNDP, UNEP and IUCN. Through the support of these agencies, along with the Government of Germany's Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Building (BMUB), the project received US$3.3 million. Primarily, the project formulated tools, strategies and policies at the national level for mountain ecosystem planning[391]. In particular, the development of defined methodologies and national policy was developed to build support for increasing EbA interventions in response to climate change[392]. Accordingly, several EbA pilot studies were implemented, focussing on local development planning, gender responsiveness and social inclusion and environmental rehabilitation. Over 6,000 residents in

[385] Practical Action. 2020. Available at: https://practicalaction.org/where-we-work/nepal/
[386] Zurich Insurance Company Ltd. 2018. Executive summary: The Zurich flood resilience program – Phase 1 from 2013-2018.
[387] Zurich Insurance Company Ltd. 2018. Executive summary: The Zurich flood resilience program – Phase 1 from 2013-2018.
[388] Zurich Insurance Company Ltd. 2018. Executive summary: The Zurich flood resilience program – Phase 1 from 2013-2018.
[389] UNDP. 2020. Available at: https://www.adaptation-undp.org/projects/mountain-eba-nepal
[390] UNDP. 2020. Available at: https://www.adaptation-undp.org/projects/mountain-eba-nepal
[391] IUCN. 2020. Available at: https://www.iucn.org/asia/countries/nepal/ecosystem-based-adaptation-mountain-ecosystems
[392] IUCN. 2020. Available at: https://www.iucn.org/asia/countries/nepal/ecosystem-based-adaptation-mountain-ecosystems

the pilot communities have benefitted from the project through the: i) restoration of 60 water sources to ensure potable water supply and irrigation; and ii) restoration of over 65 ha of degraded ecosystems[393]. From 2017–2019 a successive project with continued funding from the German government was implemented to upscale the successful implementation of EbA approaches and interventions. The proposed project will also make use of EbA approaches to reduce the impact of GLOFs, flash floods and landslides (Activity 3.3).

High Mountain Glacial Watershed Partnership (HMGWP) programme (2012–present; USAID)
Established in 2012 with funding from the USAID's Climate Change Resilient Development (CCRD) Project, the HMGWP programme targets remote, high-altitude mountain ecosystems and vulnerable communities in Nepal to build climate resilience[394]. The programme is primarily focused on improving research initiatives to develop innovative tools and practices for facilitating adaptation to climate change and increasing the climate resilience of vulnerable communities[395]. To achieve this, the programme aimed to facilitate wide-scale partnerships between researchers and practitioners working in glacial and watershed areas. The programme provides support and collaboration for a strengthened knowledge base, which improves awareness on climate change and its impacts on high mountain watersheds, as well as interactions with lowlands and ecosystem services[396]. Moreover, the programme contributes to strengthening CBEWS in the Imja Lake region, which was established under CFGORRP- the joint initiative of GoN, GEF and UNDP. The proposed project is aligned with the ongoing USAID project, aiming to strengthen the information base for effective disaster response and preventative interventions for vulnerable, high-altitude communities in Nepal. In particular, the proposed project will extend the CBEWS methods and networks of the USAID project beyond the Imja Lake region in the Solukhumbu district and into Hongu 2 and Lumding Tsho regions also region in the Solukhumbu district as well as the Thulagi region in the Manang district and Lower Barun in the Sankhuwasabha district (Activity 2.1 and Activity 2.2).

7.2. Regional projects and initiatives

7.2.1. <u>Projects focused on reducing the risk of GLOFs</u>

Reducing Glacier Lake Outburst Flood Risks in Northern Pakistan (2011-2016; AF, US$3.9 million)
This GLOF project — funded by the Adaptation Fund (AF) — was implemented in the Himalayan Karakorum Hindu Kush Mountain regions in Pakistan. The project was aimed to improve resilience to GLOF risks among communities living in exposed areas of the Himalayas in Pakistan[397]. An important focus of the project was on strengthening the capacity of public institutions to understand and address the immediate risk associated with GLOFs[398]. In addition, the project supported response capacity building by educating vulnerable communities on climate change and its effects in addition to risk management to improve communities' understanding and response to GLOFs[399]. To achieve these objectives, the project components included: i) establishing policy guidelines; ii) improving research and knowledge on GLOFs as well as community-based preparedness and EWS; and iii) risk reduction

[393] International Climate Initiative. 2020. Available at: https://www.international-climate-initiative.com/en/details/project/scaling-up-mountain-ecosystembased-adaptation-building-evidence-replicating-success-and-informing-policy-17_II_150-2877
[394] USAID. 2012. Available at: https://www.caee.utexas.edu/prof/mckinney/high-mountain-glacial-water/newsletter/Newsletter%201%20-%20Spring%202012_final.pdf
[395] USAID. 2012. Available at: https://www.caee.utexas.edu/prof/mckinney/high-mountain-glacial-water/newsletter/Newsletter%201%20-%20Spring%202012_final.pdf
[396] USAID. 2012. Available at: https://www.caee.utexas.edu/prof/mckinney/high-mountain-glacial-water/newsletter/Newsletter%201%20-%20Spring%202012_final.pdf
[397] Arun R and Ali J. 2015.Terminal evaluation report for the project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan
[398] Adaptation Fund. 2010. Available at: https://www.adaptation-undp.org/sites/default/files/downloads/pakistan_af_proposal.pdf
[399] UNDP. 2020. Available at: https://www.adaptation-undp.org/projects/af-reducing-glacier-lake-outburst-flood-risks-northern-pakistan

through infrastructure, including check dams, spillways, slope stabilisation, or controlled drainage in vulnerable communities[400]. Also known as 'GLOF I', this project was implemented by the Ministry of Environment of the Government of Pakistan and UNDP[401]. The project improved technical, infrastructural, institutional and community capacity, which reduced the risk of vulnerable communities in Pakistan to GLOFs[402]. In particular, the proposed project will draw on lessons learned and best practices suggested for activities relating to improved risk reduction through strengthening national and local technical and institutional capacity to respond rapidly to GLOFs and other extreme climate events (Output 1) and improving GLOF EWS and flood risk information services (Output 2).

Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan (2017-2021; GCF; US$37.5 million)
The objective of this project is to strengthen the technical capacity of sub-national decision-makers to integrate climate change and disaster risk management into medium- and long-term development planning processes, thereby reducing risk for vulnerable communities[403]. The project is being implemented in 12 districts in the Gilgit-Baltistan and Khyber Pakhtunkhwa Provinces of Pakistan by the Ministry of Environment with support from UNDP[404]. GLOF risk management will be improved through the upscaling of ongoing initiatives for EWS and the construction of local-scale infrastructure[405]. The project involves the construction of 250 structures including dams, ponds, spillways, tree plantations and drainage infrastructure to reduce the risk of GLOFs and climate change-induced flooding. To improve information systems geared towards rapid response to disasters, automatic weather stations, rain gauges and discharge equipment will be installed[406]. The project is currently underway, facilitating interventions based on the aforementioned activities at multiple sites. These interventions were selected based on previously impactful projects that were implemented in two pilot districts in Pakistan[407]. Like the activities undertaken for Northern Pakistan, the proposed project involves the construction and implementation of several interventions to reduce risk, including lowering lake levels (Activity 3.1), installing check dams and GLOF diversion infrastructure (Activity 3.2) and eco-disaster risk reduction and EbA solutions (Activity 3.3). Further parallels between the Northern Pakistan project and the proposed project is the shared aims to strengthen rapid response through improved decision-making to reduce GLOF and flooding impacts through strengthening the knowledge base for climate change considerations (Activity 1.1) and activities to support the development of policy and financial mechanisms for sustainable GLOF and flood risk information services (Activity 1.2).

7.2.2. Projects focussed on disaster planning, research and monitoring

ICIMOD Cryosphere Monitoring Programme (2010-ongoing; Government of Norway; US$5.5million)
This ongoing ICIMOD programme — established between 2010-2015 and funded by the Government of Norway — focuses on creating, supporting and strengthening inter-governmental cooperation, data generation and information exchange in the Hindu Kush Himalaya region, including sites located in

[400] Adaptation Fund. 2010. Available at: https://www.adaptation-undp.org/sites/default/files/downloads/pakistan_af_proposal.pdf
[401]UNDP. 2020. Available at: https://www.adaptation-undp.org/projects/af-reducing-glacier-lake-outburst-flood-risks-northern-pakistan
[402]Arun R and Ali J. 2015.Terminal evaluation report for the project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan.
[403]UNDP. 2020. Available at: https://www.adaptation-undp.org/projects/scaling-glacial-lake-outburst-flood-risk-reduction-northern-pakistan#:~:text=The%20project%20Scaling%2Dup%20of,and%20drainage%20to%20reduce%20risk.
[404] GCF FP 018: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. 2020. Available at: https://www.greenclimate.fund/project/fp018
[405] GCF FP 018: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. 2020. Available at: https://www.greenclimate.fund/project/fp018
[406] GCF FP 018: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. 2020. Available at: https://www.greenclimate.fund/project/fp018
[407] UNDP. 2020. Available at: https://www.adaptation-undp.org/projects/scaling-glacial-lake-outburst-flood-risk-reduction-northern-pakistan#:~:text=The%20project%20Scaling%2Dup%20of,and%20drainage%20to%20reduce%20risk.

Nepal[408]. Through the cryosphere[409] programme — known as the HKH CryoHub — a regional information system network was established for glacial monitoring, which continues to generate data and make it publicly available[410]. This information has improved the understanding of glacial-lake risk in the region. The programme has also focussed on building regional capacity for observation and monitoring, remote sensing, and modelling of cryosphere-related processes[411]. In addition, the role of Indigenous knowledge has been prioritised for incorporation into scientific research and decision-making. The programme has helped to produce important data for improving water resource management and disaster planning in the Hindu Kush Himalayan region[412]. The proposed project will build on the cryosphere programme by developing GIS tracking technology for glaciers and glacial lakes, including geophysical, topographic and bathymetric surveillance (Activity 2.1 and Activity 2.2) and introducing methods and technology for GLOF modelling beyond the HKH region (Activity 2.1).

8. Existing hydrometeorological network in Nepal

As part of this project, UNDP commissioned a report on hydrological and meteorological stations in Nepal. The primary objective of this report was the identification of the optimum number of hydrometeorological stations in the four target glacierised basins. In addition to the primary objective, the report sought to: i) identify the required number of stations (hydrological, meteorological including climate, synoptic, aeronautical meteorological, and agro-meteorological) in Karnali, Gandaki, and Koshi river basins with a focus on the four glacierized sub-basins: Thulagi, Lumding Tsho, Hongu and Lower Barun; ii) prepare a GIS map of the identified stations; iii) identify parameters to be measured in each station; iv) complete a financial analysis for procurement, delivery, installations, maintenance, repairment, and monitoring of the stations; v) prepare an operation and maintenance plan for the station network; and vi) identify the possibility of establishment of an early warning system for last-mile connectivity of the proposed area.

The report has defined methodologies for identifying the optimum number of hydro-meteorological stations in high hill and mountain regions (east to west) of three basins: Koshi, Gandaki and Karnali, with special attention given to the four glacierized basins: i) Thulagi; ii) Lumding Tsho; iii) Hongu; and iv) Lower Barun. It includes data collection, analysis, reporting, and coordination with the stakeholders, consultations at all levels.

WMO has classified the horizontal meteorological scales as microscale (<100 m), toposcale (100 m to 3 km), mesoscale (3 km to 100 km), large scale (100 km to 3,000 km) and planetary scale (>3,000 km). It is difficult for a country like Nepal with highly complex topography and uneven terrain to establish meteorological stations at smaller scales that could spatially cover the whole area. WMO has laid down certain norms for minimum station network density, as presented in Annex 25. According to the guideline, the physiographic regions of Nepal lie in the flat regions of temperate, Mediterranean and tropical zones and the mountainous area of temperate, Mediterranean and tropical zones.

8.1. Methodology

[408] ICIMOD. 2020. Available at: https://www.icimod.org/hkhcryohub/
[409] The cryosphere refers to the areas of the Earth's surface where water is in solid form. It includes sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets, and frozen ground.
[410] ICIMOD. 2020. Available at: https://www.icimod.org/hkhcryohub/
[411] ICIMOD. 2020. Available at: https://www.icimod.org/hkhcryohub/
[412] ICIMOD. 2020. Available at: https://www.icimod.org/hkhcryohub/

Two different approaches were used to identify the optimum number of meteorological stations and hydrological stations and their locations in this study[413] (Figure 25). Three major steps were followed to accomplish the tasks assigned in the project, namely, desk study, data analysis and consultation with the stakeholders/experts. Based on secondary and already available data, the desk research was carried out by extensive literature review of existing stations and WMO/DHM guidelines and data analysis for determining an optimum station network density.

It should be noted that the measurement of precipitation is essential for both meteorological as well as hydrological purposes and so this common parameter is considered in the meteorological part of this study. It does not mean that other meteorological parameters are not important for hydrology. The hydrometric measurement related to hydrology is dealt with in the hydrology part of this study.

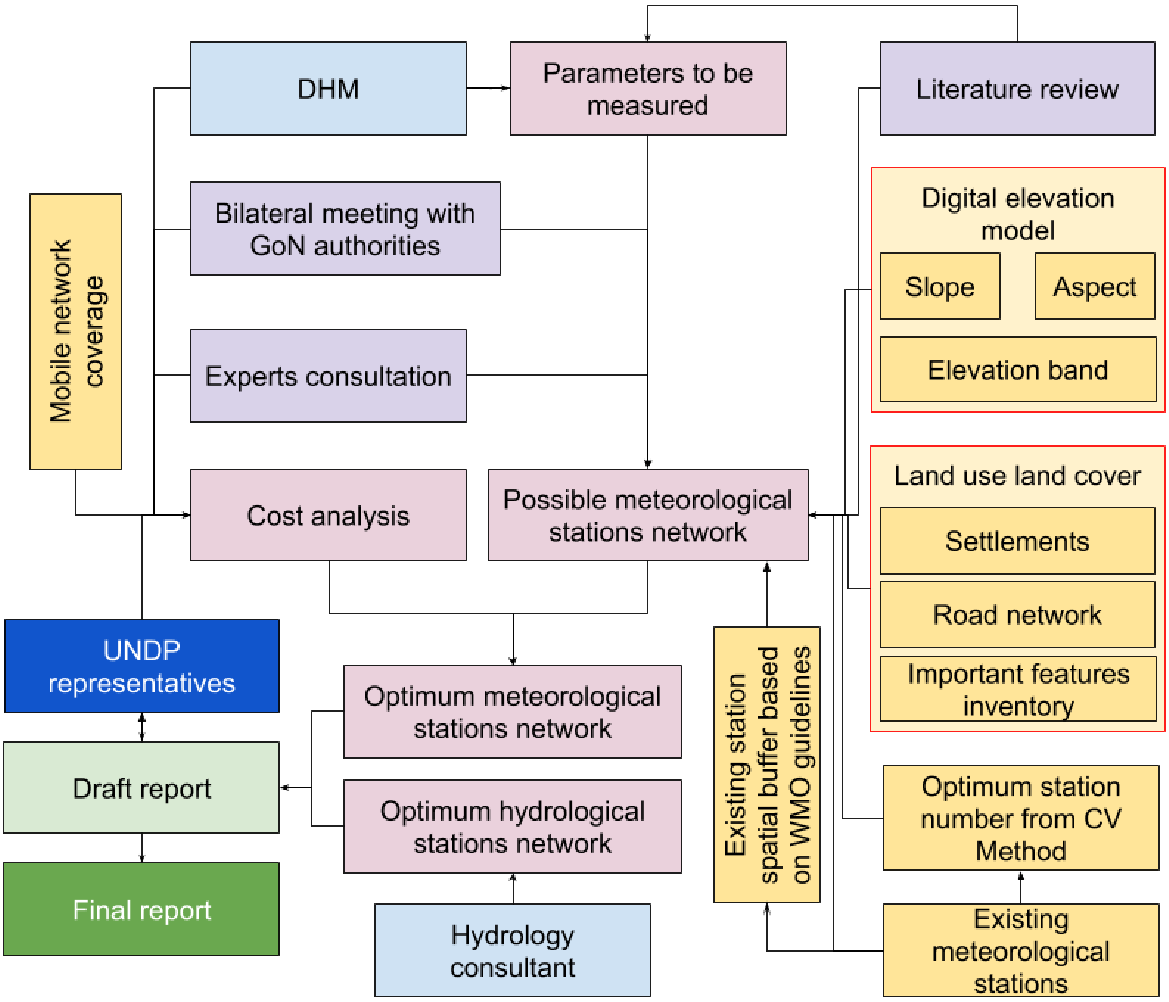

Figure 25. Framework of the methodology to determine the optimum number of hydro-meteorological stations.

8.2. Meteorological network

[413] The locations of the proposed additional network are presented in Chapter 5 of Annex 25.

The Department of Hydrology and Meteorology (DHM), as a member of the World Meteorological Organization (WMO), is responsible for maintaining a national network of meteorological and hydrological stations. To this, DHM currently has 510 climate monitoring stations throughout Nepal, although some of these stations are currently inoperable. The established stations include: i) 308 stations that monitor precipitation; ii) 158 climatic stations; iii) 28 agrometeorological stations; iv) nine synoptic stations; and v) seven aero-synoptic stations. In addition, DHM has established nine hydro-meteorological stations for snow and glacier monitoring, however only one of these stations is currently operational (Langtang at Kyangjing).

These existing stations are spatially distributed in five physiographic regions of Nepal, as follows (Figure 26): i) 31 stations in the high Himalayas; ii) 108 stations in the high mountain; iii) 227 stations in the middle mountain; iv) 68 stations in the Siwaliks; and v) 78 stations in the Terai. Monitoring station coverage of the four target glacierised basins includes: i) 20 stations for Thulagi; ii) 11 stations for Lumding Tsho; iii) six stations for Hongu; and iv) 13 stations for Lower Barun (Table 29).

Table 29. Monitoring station coverage of the four target glacierised basins[414].

Type of stations	Thulagi	Lumding Tsho	Hongu	Lower Barun
Aeronautical	-	-	-	-
Agrometeorology	2	1	-	1
Climatology	4	7	4	6
Precipitation	14	3	2	6
Synoptic	-	-	-	-
Total	20	11	6	13

[414] Shresta, M. Sharma, K. 2021. Identification of required optimum number of Hydrological and Meteorological Stations for proposed GCF funded project: “Protecting Livelihoods and Assets at Risk from Climate Change Induced Flooding in Glacierized River Basins of Nepal”

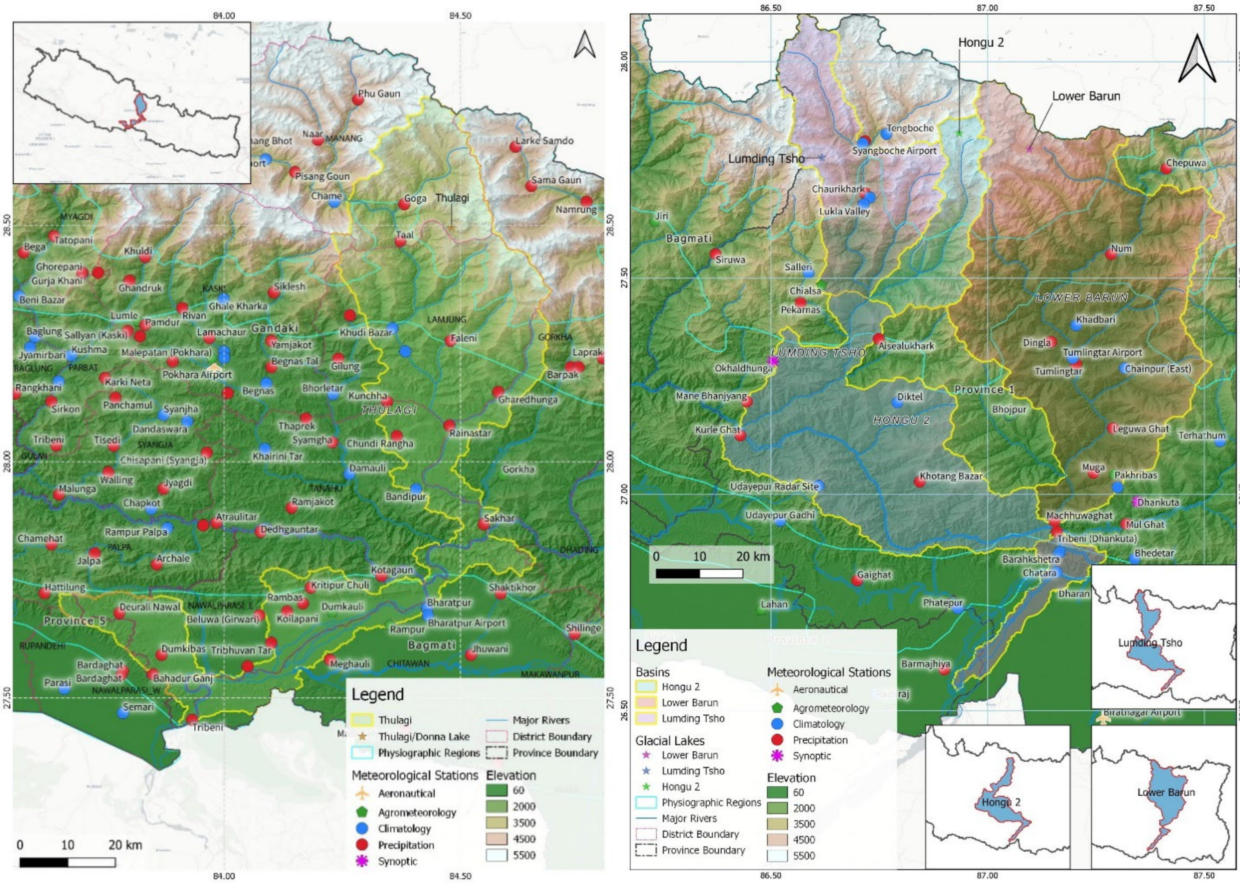

Figure 26. Spatial distribution of stations in the glacierized basins: (Left) Thulagi and (Right) Lumding Tsho, Hongu, and Lower Barun.

8.2.1. Synoptic Stations

Synoptic observations are disseminated at a regional scale, as well as at a global scale, to better forecast weather phenomena. Considering the threshold horizontal resolution of 100 km, the required number of stations in Nepal is 24. There are currently 16 synoptic stations in the country, none of which are located within the target basins. Because of the complex topography in Nepal, additional stations may be required to represent the spatial variability of the observed parameters. Stations are proposed considering the spatial homogeneity of stations, the different physiographic regions and in accordance with the WMO requirements of the Global Basic Observing Network (GBON) — the observational network as envisaged in WMO Integrated Global Observing System (WIGOS)[415].

8.2.2. Climate Stations

For climate application, there are a number of surface observations that WMO identify as mandatory[416], namely: i) atmospheric pressure; ii) pressure tendency and characteristics; iii) air temperature; iv) extreme temperatures; v) humidity; vi) surface wind/horizontal wind; vii) lightning; viii) extinction profile/cloud base; ix) visibility; x) precipitation amount; xi) state of the ground; xii) snow depth; xiii) soil temperature; xiv) soil moisture; xv) sunshine duration; xvi) solar radiation; and xvii) net solar radiation. There are 158 climate stations in Nepal (Figure 27), which normally take observations of temperature, humidity, and precipitation. As it is not currently possible to have climate stations in

[415] WMO (2019). Manual on the WMO Integrated Global Observing System, Annex VIII to the WMO Technical Regulations, WMO. No. 1160, Geneva, Switzerland
[416] WMO (2019). Manual on the WMO Integrated Global Observing System, Annex VIII to the WMO Technical Regulations, WMO. No. 1160, Geneva, Switzerland

Nepal that observe so many variables, it is recommended to assign a number of reference climate stations where such observations can be taken.

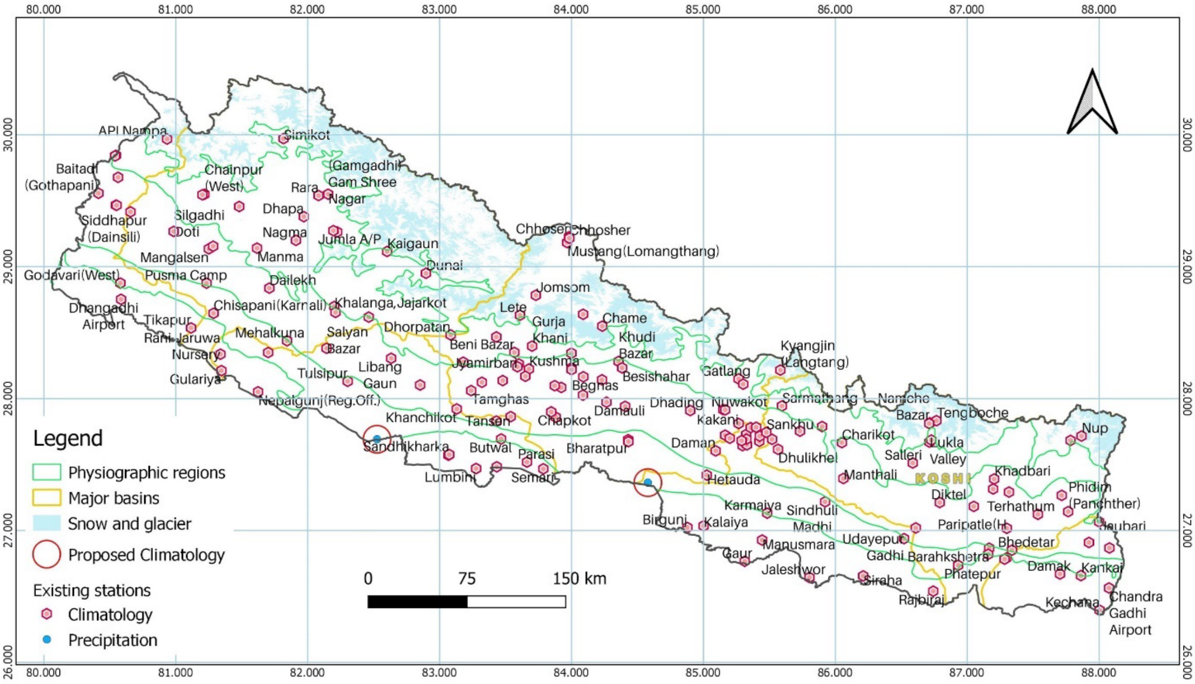

Figure 27. Network of existing climatological stations over Nepal.

8.2.3. <u>Agrometeorological</u>

As per the WMO guide to Agricultural Meteorological Practices, an agrometeorological station takes observation of the following meteorological variables[417]: i) atmospheric pressure; ii) air temperature; iii) surface wind; iv) humidity, including leaf wetness and dew; v) cloud cover; vi) precipitation; vii) evaporation and transpiration; viii) soil temperature and moisture, at depths 5, 10, 20, 50 and 100 cm; ix) sunshine duration x) solar radiation; and xi) visibility. In addition to these observations of the physical environment, observations of weather conditions causing direct damage to crops — such as frost, hail, drought, floods, strong winds and extremely hot and dry winds — are also observed and recorded. Agrometeorological stations are ideally located at agricultural research centres or at field sites. The existing extent of agrometeorological stations in Nepal is focused on the east of the country, with minimal coverage in the west.

8.2.4. <u>Aeronautical</u>

Aeronautical meteorological stations ensure safer aviation services and there are currently eight major airports in Nepal which offer these services, namely: i) Biratnagar; ii) Simara; iii) Pokhara; iv) Kathmandu; v) Surkhet; vi) Nepalgunj; vii) Bhairahawa; and viii) Talcha. These stations issue meteorological aviation reports (METAR) in an interval of one hour, or less, during the airport operation period. These stations also function as synoptic stations. With the development of tourism and economic activities, the frequencies of the operation of air services are expected to increase and, therefore, so will the demand for more aeronautical meteorological services. To expand aeronautical meteorological service, it is essential to have close collaboration with aviation authorities, following the guidelines of the International Civil Aviation Organization (ICAO) and WMO jointly.

[417] WMO (2012). Guide to Agricultural Meteorological Practices, 2012 edition. World Meteorological Organization, Geneva, Switzerland

8.2.5. <u>Precipitation</u>

DHM currently operates 281 stations for monitoring altitudinal variation of precipitation, with a further 75 stations that have been established but which are no longer operational (Figure 28). These stations are important for providing short interval data for early warning systems, as well as other hydrological designs that need frequency assessments. The majority of the precipitation stations are manual, which frequently results in difficulties in accurately measuring precipitation during adverse weather conditions — when accurate precipitation records are most needed. Furthermore, the existing precipitation stations do not record snow as a form of precipitation. The precipitation records of DHM show many gaps and inconsistencies in both the temporal and spatial domains.

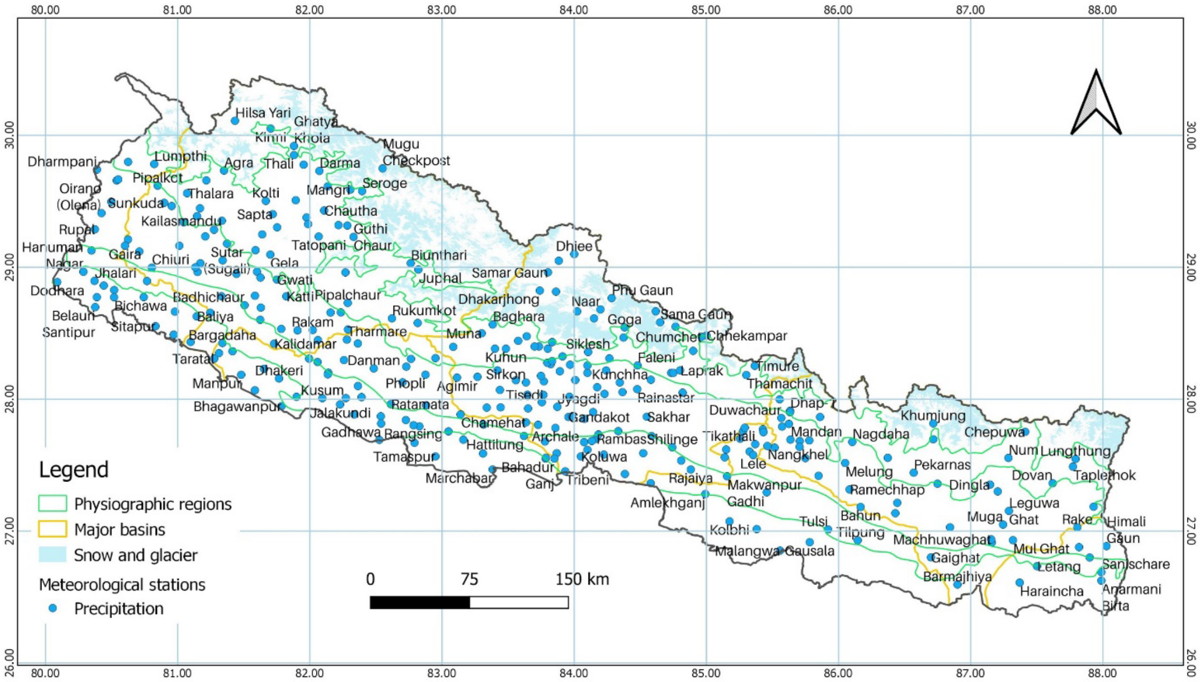

Figure 28. Network of existing stations measuring precipitation over Nepal.

8.3. Hydrological Network

Nepal's hydrological network was first established in 1960 and currently includes 200 hydrometric stations throughout the country (Figure 29). This network includes hydrological, sediment and water quality monitoring systems. Hydrological stations in Nepal are classified according to priority, namely:

- Low priority station (Priority III): Staff gauge with frequent discharge measurement. Discharge measurements that are inadequate for data processing and/or poor condition of station and/or poor quality of readings.
- Medium priority station (Priority II): Staff gauge with regular discharge measurement with the publication of daily discharge. Data quality compromised to some extent.
- High priority stations (Priority I): Staff gauge with regular discharge measurement. Most of the stations are equipped with recording systems. Some of the high priority stations include sediment sampling.

Further details on the existing hydrological network are presented in Section 4.2 of Annex 25.

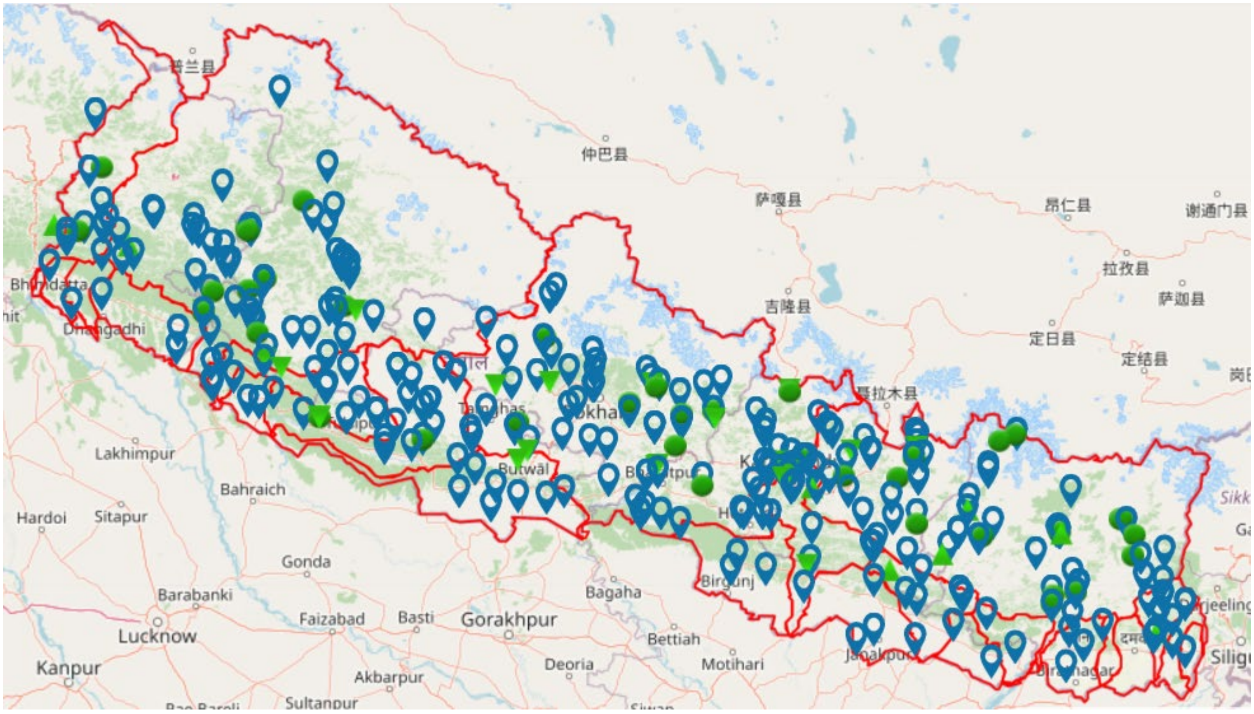

Figure 29. Hydrometeorological network in Nepal used for flood forecasting with telemetry[418]. Blue pins represent individual hydromet stations, and green dots represent realtime warning level (changing to yellow and red depending on level of danger)

8.4. Assessment of existing EWS

Existing EWS at DHM is based on threshold value water level and rainfall that are acquired online through telemetry. The existing mechanism of end-to-end Flood EWS in Nepal is shown in Figure 30. The existing EWS is based on flood inundation at warning level and danger level mapped with a hydraulic model. Water level alerts are divided into two stages, warning level and danger level, with an automatic online flood warning triggering when monitored water levels reach the warning level. These online systems are established at DHM, the national Disaster Risk Management Authority and several district headquarters. In addition, DHM has developed a system in partnership with telecom agencies whereby SMS alerts can be triggered and disseminated to vulnerable communities and responsible agencies. The reliability of warnings and alerts are, however, dependant on the resolution of Digital Elevation Model data and hydraulic modelling. Insufficient capacity for this monitoring and modelling currently limits the accuracy of these warnings.

[418] Available online at: hydrology.gov.np

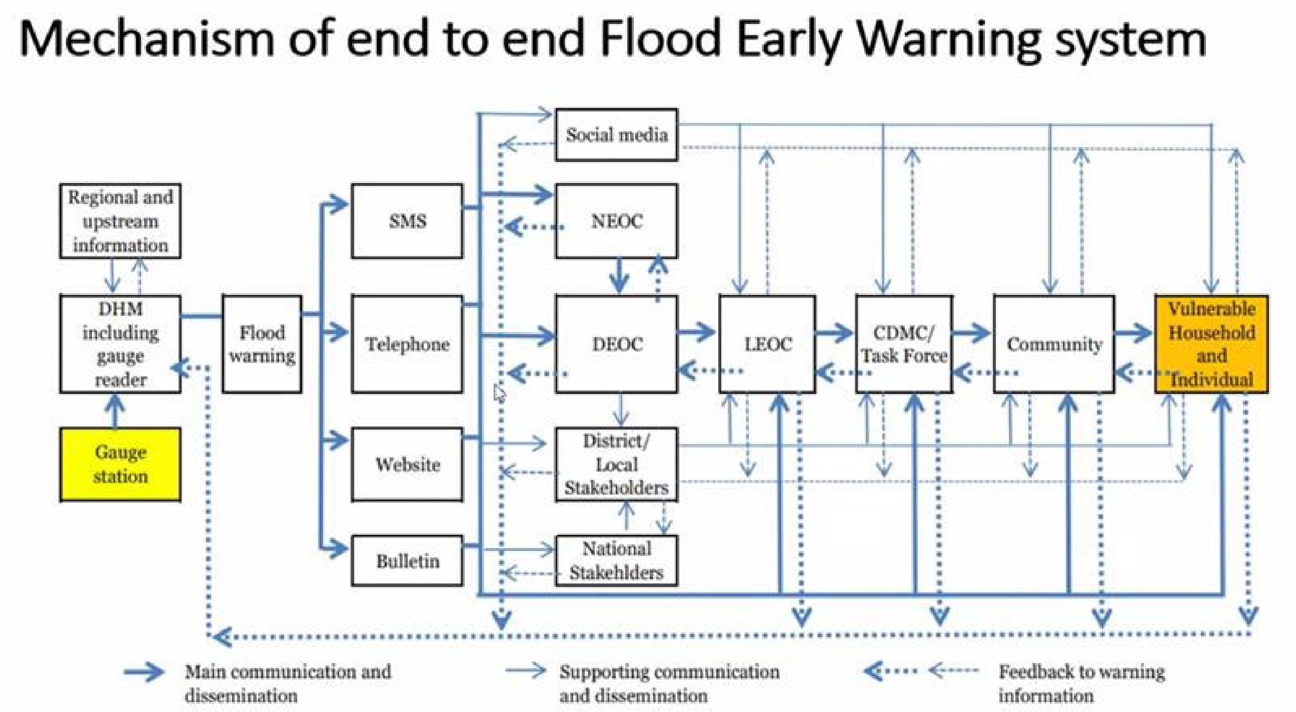

Figure 30. Mechanism of end-to-end Flood Early Warning System[419].

8.5. Existing challenges

8.5.1. <u>Capacity constraints</u>

Despite DHM ensuring that they are up to date with the development in technologies in the fields of hydrometeorology and telecommunication, the department does not have sufficient resources to adequately manage and operate the overall monitoring network. This lack of capacity is a result of human resources having decreased by more than 30% in the last 35 years. Furthermore, 35% of hydrometric stations and 20% of precipitation gauging stations have been discontinued during the last 40 years. Further shortcomings include:

- approximately 30% of the real time stations are not operational for data acquisition;
- poor hydrometeorological network coverage in high mountain areas; and
- inadequate infrastructure for the hydrological modelling required for early warnings in the most disaster-prone areas.

8.5.2. <u>Topographical challenges</u>

One of the major challenges in establishing hydrometeorological stations is Nepal's mountainous topography. Almost one-third of Nepal is occupied by high mountain areas, with elevations exceeding 3,000 m. High mountainous regions present challenges for establishing and maintaining hydrometeorological equipment as a result of their inaccessibility. It is therefore advisable to establish monitoring stations in areas with established settlements to ensure human inputs for security and station maintenance. There are only three settlements above 5,000 m (all in the Karnali basin) and 200 settlements above 4,000 m in Nepal[420]. The majority of the inhabitants of settlements above 3,000 m, however, move to lower elevation valleys during winter.

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[419] Received from UNDP Nepal Country Office in 2021.
[420] Chhabi L Chidi, C. L. (2009). Human Settlements in High Altitude Region Nepal. The Geographical Journal of Nepal, 1-6.

Trekking routes are some of the potential sites for the establishment of hydrometeorological stations. Such facilities, using the trekking route to the Everest base camp in the Koshi basin and the Machhapuchhre base camp in the Narayani basin, are already used by DHM for establishing hydrometeorological monitoring stations in high mountain-Himalayan areas. Special efforts are needed to install a station in areas above 5,000 m, which constitute 9% of the areas of Nepal[421].

Meteorological stations at high altitudes are generally remote and with harsh weather conditions, which means that instruments need to be appropriate to withstand harsh conditions without regular repair and maintenance. High altitude sites receive both solid and liquid precipitation. Therefore, tipping bucket rain gauges alone will not function effectively, especially during snowstorms. Pluviometers are needed to record precipitation in the form of both snow and rain. Similarly, these precipitation gauges should have Alter-shield to minimize wind under catch. Evaporation loss from these gauges is an important consideration and, therefore, evaporation suppressants in addition to antifreeze liquids are required while servicing and emptying the buckets in these precipitation gauges. Regular monitoring is not always possible in these stations; therefore, they need to be connected to remote communication systems (e.g., telemetry with GSM or satellite communications).

8.6. Optimum number of Stations

Methodology for the design of optimal precipitation network are based on the following assessments.
• Estimation of the altitudinal variation of precipitation
• Spatial and temporal variability of precipitation and
• Accessibility for the necessary maintenance of the stations.
DHM is the sole agency responsible for monitoring meteorology and hydrology in Nepal. Precipitation stations, maintained by DHM, are presented in Figure 12. Information on the existing networks has been compiled to assess the level of sufficiency for hydrometeorological monitoring and for disseminating early warnings.

Table 30. Coefficient of variation-based assessment of optimal network in the Karnali, Gandaki and Kosi basins.

	Long-term Annual Precipitation					
River Basin	Existing No. of Stations	Average (mm)	Minimum (mm)	Maximum (mm)	Standard Deviation	Anticipated Error (%)
Karnali	36	1426	591	2597	521	6.1
Gandaki	89	2089	146	5284	1040	5.3
Kosi	78	1752	824	4661	755	5
	Long-term Monsoon Precipitation					
River Basin	Existing No. of Stations	Average (mm)	Minimum (mm)	Maximum (mm)	Standard Deviation	Anticipated Error (%)
Karnali	36	1095	321	2126	491	5.1
Gandaki	89	1688	76	4493	886	5.9
Kosi	78	1370	599	3472	624	5.2

8.7. Adaptation needs to address existing challenges

The report commissioned by UNDP included expert consultations and field visits, which involved community consultations, as annexes. These consultations identified various needs in the target

[421] Sharma, K. P. (2014). Water: Statistics and information. Jalsrot Vikas Sanstha (JVS)/GWP, Kathmandu.

areas — in addition to the challenges detailed in Section 8.5. Existing Challenges. The expert consultations identified several operational and high-level needs including, *inter alia*, a need for: i) for multipurpose stations; ii) Common Alert Protocols to be initiated; iii) greater local government involvement; and iv) high altitude stations, as satellite-based/reanalysis data is not sufficiently accurate at high altitudes. The community consultations identified several societal and community level needs including, *inter alia*, a need for: i) community awareness raising on EWS; ii) awareness raising on forecast and alert alternatives to radio and television, such as the DHM website; and iii) training on proper community management of stations. Further details of these consultations can be found in the appended to Annex 25.

A primary outcome of these consultations was the confirmation that vulnerable communities require improved monitoring systems to enable them to manage flooding events more effectively. By improving the country's existing network in the target basins, vulnerable communities in these basins will be able to access decreased lead times for extreme events. To achieve this, the study of Nepal's existing hydrometeorological network proposed that an additional 66 meteorological stations be added to the network, along with 9 siren stations (Table 31, Figure 31). The 66 stations include six base stations, 24 automatic weather stations (AWS) stations, nine precipitation gauges (PCP) and 27 radar-based water level sensors (RLS), as determined by following WMO[422] and DHM standards, practices and criteria, scientific parameters, physical parameters and expert consultations.

Table 31. Proposed meteorological stations.

Basin/Sub-basin	AWS	PCP	RLS	Base Station	Siren
Marsyangdi Basin	7	2	11	2	4
Dudhkoshi Sub-basin	5	7	8	2	2
Barun/ Arun Sub-basin	12	0	8	2	3
Total	24	9	27	6	9
				Base station locations	Siren locations
				Pangboche	Rabuwa
				Jayaram Ghat — Middle Hill	Jayaram
				Tumlingtar (Turkighat)	Other locations to be added following site validations
				Chatara	
				Dharapani	
				Muglin	

[422] WMO (2018): Guide to Instruments and Methods of Observations, Volume I –Measurement of Meteorological Variables, WMO No.8

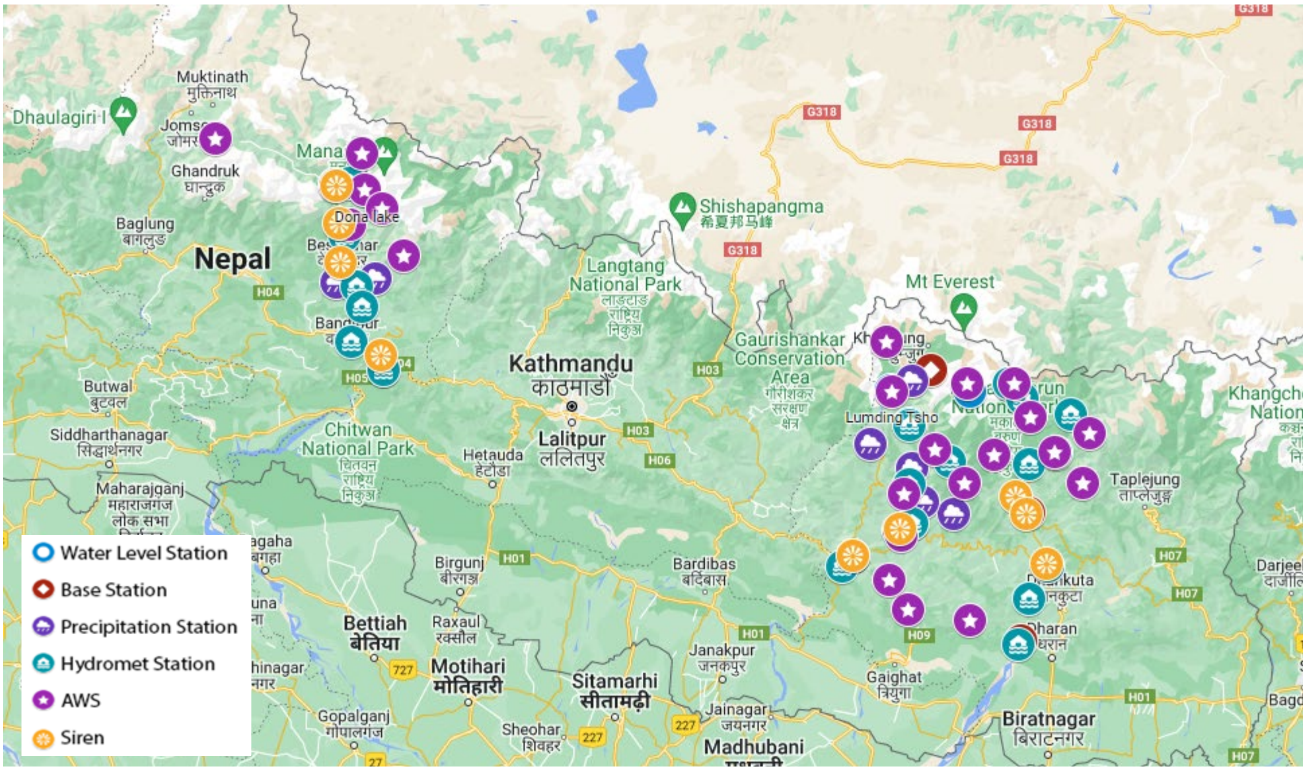

Figure 31: Locations of the proposed lake-level monitoring, hydrometry, precipitation and base stations in the Marsyangdi, Dudhkosi and Arun river basins.

9. Best practices and lessons learned

Completely reducing the risk of Glacial Lake Outburst Floods (GLOFs) in Nepal would require the relevant lakes to be drained, which is technically complex and requires an extremely large financial investment[423]. For most potentially hazardous glacial lakes, it is therefore not possible to eliminate the risk of GLOFs entirely. There are, however, a suite of risk reduction interventions that are suitable to reduce both the probability and impact of GLOFs, with the optimal solution being the implementation of an integrated approach comprising physical engineering and construction, nature-based solutions, and community-based disaster risk reduction (DRR). The following sections describe international and local best practices for addressing the impacts of GLOFs, as well as lessons learned from previous GLOF risk reduction efforts in Nepal and other similar contexts. These best practices and lessons have been used to inform the design of the proposed project, and they will also be referred to during the implementation phase to ensure the efficient and effective implementation of the project interventions.

9.1. Risk reduction for GLOFs

9.1.1. <u>Lowering water levels of glacial lakes</u>

The level of danger presented by GLOFs is determined by several characteristics of glacial lakes relating to the probability and impact of these floods. These characteristics include the: i) size, depth and volume of water in the lake; ii) speed at which the lake is expanding; iii) position of the lake relative

[423] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). Global Environment Facility and UNDP.

to the glacier; iv) size, structure and stability of the moraine dam; and v) proximity of hanging glaciers or potential for rocks or debris to fall or slide into the lake[424]. Lowering the level of a glacial lake decreases the likelihood of an outburst flood by reducing the hydrostatic pressure against the moraine dam and decreasing the likelihood of the lake overtopping the dam. It also reduces the volume of water in the event of an outburst flood, thereby reducing the potential impact of the GLOF. As a result, lowering lake levels is one of the most common and effective GLOF risk reduction measures.

Two high-risk glacial lakes have been successfully lowered in Nepal over the past three decades and similar initiatives have been implemented in Bhutan[425]. These projects experienced several challenges relating to the technical complexity of lowering glacial lakes in remote and extreme environments. In Nepal, most glaciers and glacial lakes lie more than 4,200 m above sea level (masl) and can only be accessed on foot or by helicopter[426]. Accordingly, the physical labour and transport of materials required for the excavation and construction work are particularly difficult. Indeed, for the GEF-funded *'Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP)'*, finding suitable contractors to undertake the construction work was a challenge as no bids were submitted in response to the tenders for this work[427]. The Nepalese Army was eventually contracted and employed their rigorous training and familiarity with extreme environments to complete the construction work for lowering Lake Imja[428]. This experience informed the CFGORRP project team that the highly specialised nature of the construction work should be considered in the procurement process, allowing extra time for the procurement of contractors. In addition, their experience in lake lowering and rigorous training makes the Nepalese Army valuable partners in the future lowering of glacial lakes in Nepal.

Several strategies for lowering glacial lakes have been employed in different parts of the world. As mentioned above, Thorthormi Lake in Bhutan was lowered by 5 m between 2009 and 2012 by excavating glacial materials from the lake[429]. In 1997, siphons were installed in the moraine dam of Tsho Rolpa, Nepal, in an attempt to lower the lake. However, this method was ineffective and did not lower the level of the lake sufficiently. In 2000, a channel was excavated in the terminal moraine to lower Tsho Rolpa by 3 m (Figure 32)[430]. This project was successful in temporarily reducing the risk of a GLOF from Tsho Rolpa, but the instability of the moraine is still a concern, particularly given that the region is prone to earthquakes[431,432]. The excavation of outlet channels has also been used to lower glacial lakes in Peru, Raphstreng Lake in Bhutan and Lake Imja in Nepal. Detailed planning of the excavation and construction in these cases has been necessary to ensure the success of the projects in extreme and dynamic environments.

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424 CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP
425 GEF. 2012. Reducing Climate Change-induced Risks from Glacial Lake Outburst Floods in Bhutan. Further information available at: https://www.adaptation-undp.org/projects/ldcf-glof-bhutan
426 Byers D. 2017. Imja Lake: A Story of Climate Adaptation in Nepal. Available at: https://www.youtube.com/watch?v=z7GKW-u-Gg4
427 Byers D. 2017. Imja Lake: A Story of Climate Adaptation in Nepal. Available at: https://www.youtube.com/watch?v=z7GKW-u-Gg4
428 Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). Global Environment Facility and UNDP.
429 CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP
430 CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP
431 Bajracharya SR. 2011. Glacial lake outburst floods risk reduction activities in Nepal. International Centre for Integrated Mountain Development (ICIMOD).
432 USAID. 2015. Post-Earthquake Assessment of Imja Tsho Rolpa and Thulagi glacial lakes in Nepal. Available at: https://www.climatelinks.org/file/1045/download?token=q57sgg8d

Figure 32. Outlet channel constructed to facilitate the lowering of Tsho Rolpa, Nepal. Image from CEPAD Hydro Consultants[433].

Given the potential instability of the moraine dams of glacial lakes, it is critical that lake lowering interventions are informed by detailed topographical and geological surveys. The lowering of Lake Imja under the CFGORRP project, for example, was designed based on detailed topographical mapping (Figure 33). In addition, ground penetrating radar (GPR)[434] and electrical resistivity tomography (ERT)[435] were used to map the sub-surface structure of the moraine dam[436]. These GPR and ERT surveys were particularly necessary for identifying potential channels for excavation. Moreover, important considerations for the design of the outlet channel included the volume of excavation required and the stability of the moraine dam. The GPR and ERT surveys were used to identify areas where buried ice was likely to compromise the stability of a constructed channel (Figure 34). For example, if water comes into contact with sub-surface ice during excavation, it may cause the ice to melt and destabilise the moraine dam. As a result, it is necessary to avoid excavating areas with dead ice where possible.

[433] CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP

[434] Ground-penetrating radar (GPR) is a geophysical method that uses radar pulses to image the subsurface. It is a non-intrusive method of surveying the sub-surface to investigate underground utilities such as concrete, asphalt, metals, pipes, cables or masonry.

[435] Electrical resistivity tomography (ERT) is a geophysical method used to image the subsurface using differences in measured electrical resistivity at the surface. These differences in resistivity can be tied to the porosity, fluid content, and degree of water content in the subsurface.

[436] CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP

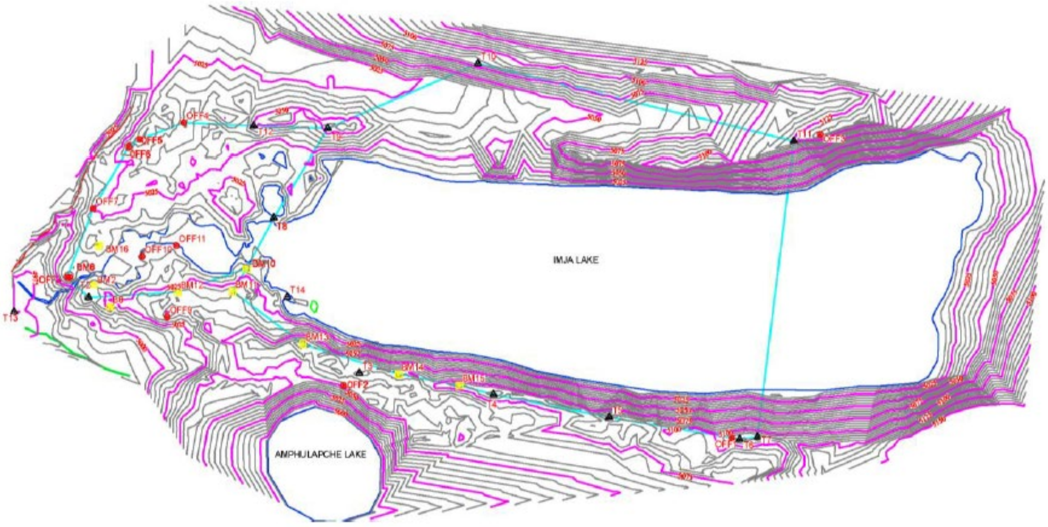

Figure 33. Topographical map to inform the lowering of Lake Imja[437].

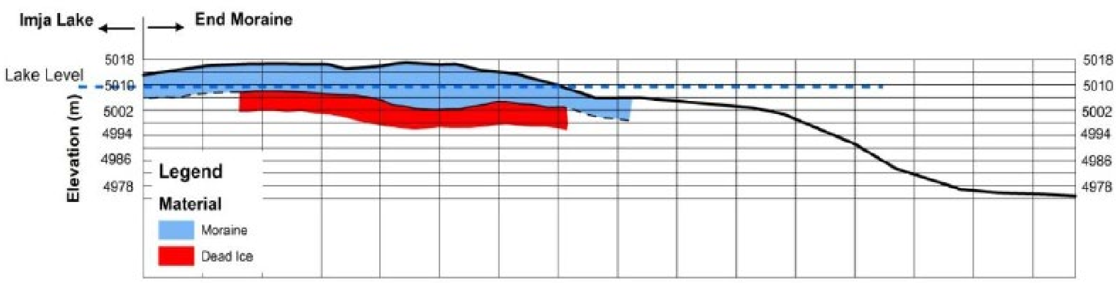

Figure 34. Buried or 'dead' ice identified using ERT for the moraine dam of Lake Imja[438].

For Lake Imja, the existing channel was excavated to lower the lake (Figure 35). This option was selected above excavating other areas of the moraine dam because: i) less excavation was required than for other wider parts of the moraine; and ii) this area was more geologically stable with less buried ice than the other areas surveyed[439]. The design of the channel considered the dynamic behaviour of the moraine, using a gabion mattress[440] as a flexible lining for the channel. A geomembrane[441] was used to line the bed of the channel to prevent seepage, while a steel gate with a reinforced cement concrete (RCC) base was constructed to regulate the flow. As far as possible, to minimise the costs of transporting materials, local materials were used.

[437] CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP
[438] CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP
[439] CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP
[440] Gabion mattresses are flat wire mesh containers filled with rock. They are widely used in river courses to prevent erosion.
[441] A geomembrane is a synthetic lining with low permeability which is used in construction to control or prevent the movement of fluids.

Figure 35. The excavated outlet channel of Lake Imja under construction (A) and complete (B)[442].

Careful planning of timelines and workforce capacity were important considerations in the lowering of Lake Imja. Seasonal fluctuations in temperature and rainfall contributed to time constraints on the construction work and influenced the working conditions. In addition, it was necessary for the project workers to be regularly rotated and transported to lower altitudes to prevent them from contracting Acute Mountain Sickness[443]. Navigating the technical and logistical complexity of lowering glacial lakes is therefore challenging, but this can be alleviated by using and developing institutional memory for these initiatives. Accordingly, it will be important for the Nepalese Army and DHM to be closely involved in the planning and implementation of further lake lowering activities for the four target lakes under the proposed project (Activity 3.1). This will be supported by detailed engineering designs to inform the lake lowering (Activity 3.1) as well as interventions to strengthen the policy, knowledge base and technical capacities of Nepalese institutions for improved GLOF management (Output 1).

9.1.2. Downstream flood risk reduction measures

While lowering the levels of glacial lakes is the only well-established method of reducing the likelihood of GLOFs occurring, several measures can be taken to reduce the downstream impact of GLOFs when they occur. The degradation of valley slopes and riverbanks increases the risk of flash floods

[442] Byers D. 2017. Imja Lake: A Story of Climate Adaptation in Nepal. Available at: https://www.youtube.com/watch?v=z7GKW-u-Gg4
[443] Byers D. 2017. Imja Lake: A Story of Climate Adaptation in Nepal. Available at: https://www.youtube.com/watch?v=z7GKW-u-Gg4

downstream of glacial lakes. The volume and force of the water released during a GLOF can directly cause extensive damage and additionally trigger landslides as well as other mass movements that compound the impacts of this hazard[444]. The construction of grey infrastructure downstream of potentially hazardous glacial lakes can be used to slow down and channel floodwaters as well as to protect land, assets and infrastructure from flood damage. Nature-based solutions, including the revegetation of slopes, have also been tested in GLOF risk reduction projects and can be used to stabilise slopes and reduce the risk of landslides. This combined approach of Integrated Watershed Management (IWM) is based on lessons learned and best practices in the design and implementation of physical downstream risk reduction measures, which are described below, and an overview of non-structural approaches to flood risk reduction is also provided. Importantly, while many of the flood risk reduction measures described below have been previously implemented in areas that are vulnerable to GLOFs, it is difficult to accurately determine their effectiveness without a GLOF occurring[445]. The development of these various Disaster Risk Reduction (DRR) measures align with Nepal's Second Nationally determined Contributions (NDC)[446] , in which DRR and management are highlighted as an adaptation priority to increase climate resilience in the country.

Flood check dams and detention dams

Flood check dams can be established by constructing a barrier across the entire width of the stream[447] (Figure 36) to reduce the energy and velocity of floodwaters through IWM. This strategy has been used to reduce flood risk in Nepal, including for seasonal and flash flooding (not related to glacial lakes) in the Churia region[448]. These flood check dams should be designed with reference to the specific conditions of the glacial lake and valley, including the expected peak flow and volume in the event of a GLOF, to ensure they are as effective as possible[449]. Flood check dams can be constructed from a variety of materials, including gabion material, masonry and vegetation or soil[450].

Based on similar principles, flood detention dams can be constructed across wide water channels to catch surface runoff and regulate water flow. Detention dams are a common mechanism used in flood prone areas to provide a buffer between high-risk water channels and vulnerable downstream communities. During flood periods, high volumes of water are detained in the dam and then gradually released at a controlled rate in accordance with the carrying capacity of the downstream channel later on. Detention dams are often constructed from concrete or masonry with a metal reinforcing substructure.

Similar to dams in general, the impacts of the structure on downstream communities and ecosystems should be considered in the design of any check or detention dam. In Nepal, glacial rivers are often used for irrigation, and it is important to consider the impacts of these measures on the livelihoods of local communities[451].

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[444] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[445] GCF. 2016. Funding Proposal: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. Available at: https://www.greenclimate.fund/document/scaling-glacial-lake-outburst-flood-glof-risk-reduction-northern-pakistan
[446] GoN. 2020. Second Nationally Determined Contribution (NDC). Available at: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Nepal%20Second/Second%20Nationally%20Determined%20Contribution%20(NDC)%20-%202020.pdf
[447] GCF. 2016. Funding Proposal: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. Available at: https://www.greenclimate.fund/document/scaling-glacial-lake-outburst-flood-glof-risk-reduction-northern-pakistan
[448] GCF. 2019. Funding Proposal: Building a resilient Churia Region in Nepal. Available at: https://www.greenclimate.fund/document/building-resilient-churia-region-nepal-brcrn
[449] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[450] GCF. 2016. Funding Proposal: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. Available at: https://www.greenclimate.fund/document/scaling-glacial-lake-outburst-flood-glof-risk-reduction-northern-pakistan
[451] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). GEF and UNDP.

Flood check and detention dams can be designed to allow the regular flow of the river to pass through, for example, through a gated sluice to prevent the disruption of downstream flow. In the event of a flood, the sluice will limit the amount of water flowing through and the flood water will gather behind the dam until it overtops the wall and moves through the spillways[452]. In this way, the dams slow the movement of floodwaters, increasing the response time for early warnings and enabling the evacuation of downstream flood zones. Designs including a gated sluice can also be used to store water during droughts or to regulate the flow of the river. These interventions, along with other flood risk reduction infrastructure, require a thorough assessment of their social and environmental impacts prior to construction as, despite the small scale, there may be adverse consequences for downstream communities and ecosystems if the river flow is disrupted[453].

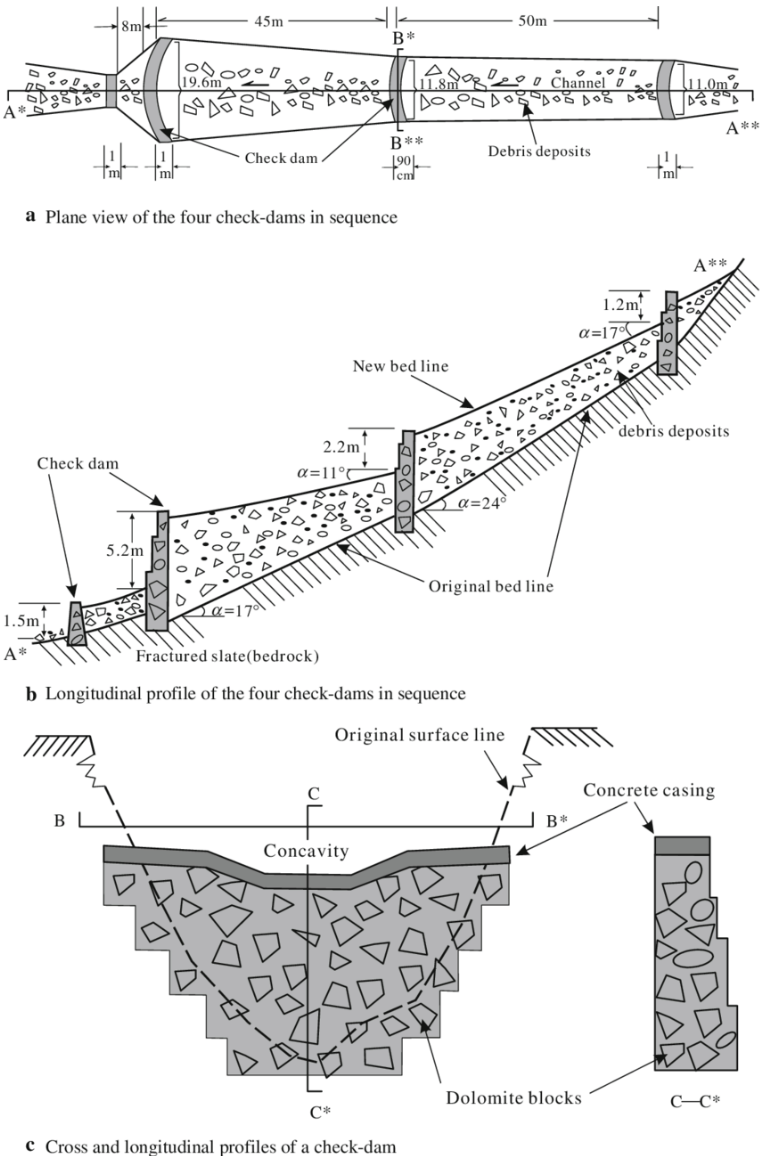

Figure 36. An example of a typical check dam design[454].

[452] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[453] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). GEF and UNDP.
[454] Zeng, Q.L., Yue, Z.Q., Yang, Z.F. and Zhang, X.J., 2009. A case study of long-term field performance of check-dams in mitigation of soil erosion in Jiangjia stream, China. Environmental Geology, 58(4), pp.897-911.

Gabion walls, spurs and protective structures

Both transverse — perpendicular to the flow of the river — and longitudinal — aligned with the riverbanks — structures can be used to protect infrastructure and landscapes from flood-related damage in IWM. Flood detention dams are transverse measures that require a wall to be constructed across the entire stream to slow floodwaters, while spurs can be constructed across part of a stream to redirect the channel away from vulnerable infrastructure and assets. Longitudinal structures, including gabion walls and revetments, can be used to protect infrastructure and assets from the floodwaters as well as to stabilise the riverbanks and reduce the risk of erosion (Figure 37)[455].

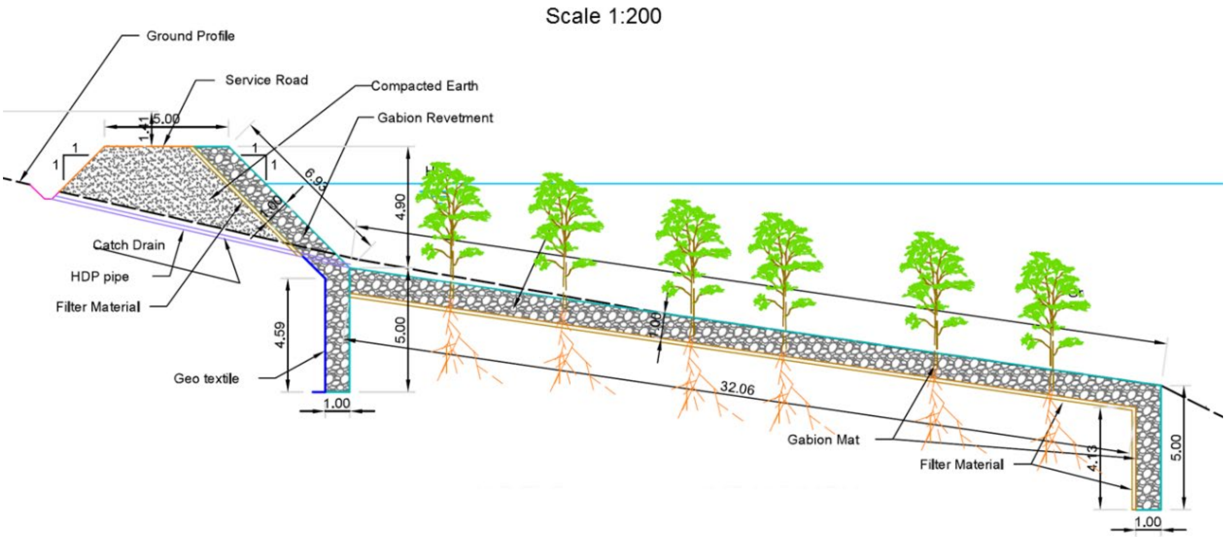

Figure 37. Example layout of structural measures to strengthen a riverbank for flood risk reduction.

Rivers located in the Himalayas are highly energetic and the undercutting of riverbanks, which leads to the collapse and erosion of these banks, is a common challenge in the region[456]. Under the Adaptation Fund project, entitled *'Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan'*, spurs to divert the river and gabion walls were constructed as GLOF risk reduction measures[457], which proved effective in protecting houses, agricultural land, livestock and orchards owned by 1,350 people in Chira village during a GLOF event in 2014[458]. However, in areas where the regular flow of the river is strong, protective structures may be gradually eroded and require frequent maintenance. In these areas, more robust measures such as the construction of flood detention dams or lowering of lakes may be required[459]. As mentioned above, in addition to considering the physical environment, the design of flood risk reduction structures should consider the requirements of affected local communities. Small-scale measures that can be maintained and upscaled by communities have been particularly beneficial in previous projects[460].

[455] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[456] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[457] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/TE_AF_Pakistan_Nov2015.pdf
[458] GCF. 2016. Funding Proposal: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. Available at: https://www.greenclimate.fund/document/scaling-glacial-lake-outburst-flood-glof-risk-reduction-northern-pakistan
[459] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/TE_AF_Pakistan_Nov2015.pdf
[460] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). GEF and UNDP.

Nature-based solutions (NbS)

Using NbS, including the revegetation of vulnerable slopes and hybrid grey and green structural designs, can increase the effectiveness of IWM-based GLOF risk reduction measures. Landslides, erosion and sedimentation linked to GLOFs present both immediate risks during the GLOF event and lead to longer-term damage. Vegetation can be used to contribute to risk reduction in several ways, including: i) reducing the velocity of floodwaters and dissipating energy[461]; ii) anchoring soils to prevent flood-induced erosion; and iii) stabilising slopes where there is a risk of landslides or slope failure being triggered by GLOFs[462]. Re-vegetating slopes can also reduce erosion from other causes, including monsoon rains and seasonal flooding, thereby increasing the resilience of the landscape to GLOFs and reducing the likelihood of GLOF-induced landslides. Similarly, using hybrid grey and green designs for flood risk reduction structures can increase their resilience to regular flow and seasonal flooding, ensuring their effectiveness in the event of a GLOF[463].

NbS have been used to reduce the risk of downstream flooding and sedimentation in the Churia Region in Nepal[464] as well as in GLOF risk reduction initiatives in Northern Pakistan[465]. While lessons can be drawn from these projects to inform the methods and plant species best suited to NbS for GLOF risk reduction in Nepal, local and Indigenous knowledge should also be considered. Local communities in some glacial lake valleys have implemented traditional flood risk reduction measures, for example, boulders and vegetation maintenance (Figure 38), and knowledge of the effectiveness of these measures can inform the design of further risk reduction efforts.

[461] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.

[462] Van Noord H and Shah BH. 2014. Mid-Term Evaluation: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP.

[463] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.

[464] GCF. 2019. Funding Proposal: Building a resilient Churia Region in Nepal. Available at: https://www.greenclimate.fund/document/building-resilient-churia-region-nepal-brcrn

[465] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/TE_AF_Pakistan_Nov2015.pdf

Figure 38. Photo showing traditional flood risk reduction measures including vegetation and boulders in Rabuwabazaar, Khotang District, Nepal[466].

NbS measures that involve the propagation of vegetation require the use of plants that are appropriate to the context. Indigenous species should be used as far as possible and, in some contexts, considering the commercial or livelihood value of the selected plants is necessary. Where communities depend on ecosystem services for their livelihoods — using *inter alia* fodder species for livestock and fuelwood species for fuel — is an important consideration of the NbS approach[467]. A detailed study of glacial river valleys in Nepal[468] suggests that different types of vegetation are likely to be most effective on different parts of the slopes. For example, grass species are usually fast growing and can provide ground coverage necessary to reduce the risk of shallow landslides. In addition, tree or shrub species with deeper and stronger roots can be used to strengthen riverbanks. For these purposes, restoration and revegetation can be undertaken by assisted natural regeneration, by propagating cuttings and rhizomes or by growing seedlings in a nursery and planting them once they are large enough to withstand environmental stressors in the target location[469].

- Non-structural approaches to climate change-related DRR
- An ecosystem-based approach to disaster risk reduction (Eco-DRR) and IWM is an integrated approach that includes the sustainable management, conservation and restoration of ecosystems[470]. Under this approach, the effective application of laws and regulations for development in floodplains forms an important component of effective flood risk reduction. In the glacial valleys of Nepal, housing and other buildings, as well as roads, trails and bridges, are

[466] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[467] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[468] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[469] GCF. 2019. Funding Proposal: Building a resilient Churia Region in Nepal. Available at: https://www.greenclimate.fund/document/building-resilient-churia-region-nepal-brcrn
[470] International Union for Conservation of Nature (IUCN). 2020. Disaster Risk Reduction. Available at: https://www.iucn.org/commissions/commission-ecosystem-management/our-work/cems-thematic-groups/disaster-risk-reduction

frequently located in flood-prone areas (Figure 39). While the steep slopes make construction above the floodplain difficult in some areas, planning for flood resilience has been successful in other places. In addition to land-use and development planning, watershed management and the sustainable use of ecosystems is an important component of Eco-DRR. In the Terminal Evaluation of the GEF-funded CFGORRP project, it was recommended that future GLOF risk reduction initiatives incorporate watershed management[471]. EWS and robust monitoring of glacial lakes is another critical component of GLOF risk reduction and is further discussed under Section 9.3 of this Feasibility Study.

Figure 39. Settlement and trail bridge in the floodplain of the Dudhkosi River (left) and a newly constructed trail bridge at higher elevation (right)[472].

Downstream risk reduction measures can play a key role in managing floods. Therefore the proposed project includes several downstream measures for increasing flood resilience, including the installation of check dams and other infrastructure for the diversion of GLOF and flash flood flow. Under Activity 3.2 check and detention dams will be constructed to manage high volumes of water in high flood risk areas by detaining the increased amount of water in the dams and gradually releasing it at a controlled rate. Further protective transverse and longitudinal structures will be installed to stabilise riverbanks and direct water away from high-risk communities, infrastructure and land, including the installation of: i) gabion spurs; ii) flood walls; iii) RCC revetments); iv) conservation ponds; and v) live check dams. In addition to the measures listed above, the proposed project includes EbA and non-structural ecosystem-based approaches to disaster risk reduction (Eco-DRR) to be applied to watershed management in flood-prone areas under Activity 3.3. The proposed project will facilitate an integrated, nature-based approach through: i) planting trees along vulnerable riverbanks and flood plains; ii) establishing vegetative gabion walls; iii) installing vegetative gabion revetments; iv) installing vegetative gabion check dams; v) installing vegetative stone rip-rap; vi) implementing bush layering; and vii) planting grass seedlings across 290,000 m^2.

9.1.3. Operations and maintenance

The long-term effectiveness of project based GLOF risk reduction efforts often depends on the ongoing operation and maintenance (O&M) of systems and equipment installed during the project. This includes the maintenance of physical infrastructure, EWS equipment and ecosystems that have been restored through project activities. For example, if flood protection structures are damaged by

[471] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). GEF and UNDP.
[472] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.

seasonal floods or monsoon rains, it is important that maintenance is done timeously to ensure that the structures are still effective in the event of a GLOF[473]. Increasing resilience to seasonal floods should also be considered in the design of these measures.

In previous projects, the long-term maintenance of project assets has been limited by budget constraints and limited local ownership of project outputs[474]. The most effective strategies for ongoing O&M in past projects have been systems that are embedded in the local community, where technical and financial capacity for O&M is developed at a community level. Under the Nepal Climate Change Support Programme[475], maintenance funds have been established and operated in many districts to support the sustainability of project outputs. In addition to the funding mechanism, developing technical skills for the maintenance of project outputs among community members has improved sustainability. Similarly, in the Adaptation Fund project entitled *'Reducing risks and vulnerabilities from glacial lake outburst floods in Northern Pakistan*[476], endowment funds were created for each project site to facilitate ongoing repair and maintenance of equipment and infrastructure. These endowments were linked to community leadership structures and accompanied by commitments from communities to contribute or raise small amounts of money to add to the fund. For long-term sustainability, it was necessary that the endowment was large enough for the costs of maintenance to be borne by the interest from the fund[477].

Effective O&M will be built into the proposed project via several mechanisms. Under Activity 1.1, methodology and standard operating procedures (SOPs) will be introduced for implementing integrated GLOF risk reduction in vulnerable watersheds, which will include O&M of systems and equipment. In addition, the project proposal includes a full O&M plan (Annex 21) that will cover details of all project activities with O&M aspects, primarily the maintenance of the: i) lakes lowered under Activity 3.1; ii) observation networks for hazard monitoring under Activity 2.1; iii) community-based early warning system under Activity 2.2; iv) nature-based solutions under Activity 3.2; and v) database for climate-induced hazards under Activity 1.2. Further, the project proposal includes an exit strategy and implementation arrangements plan to state forthcoming tasks for maintenance required, responsibility assigned and the long-term sustainability of the systems and infrastructure. These plans will be informed by the project's AE, EE, key stakeholders and experts to ensure critical aspects are covered.

9.2. GLOF risk assessments and monitoring

9.2.1. Technologies for monitoring glacial lakes

Remote sensing through the use of satellite data can be usefully applied to the monitoring of glacial lakes because it allows for data collection without the logistical challenges related to the remoteness of the lakes. However, remote sensing should be complemented with field-based data collection to inform effective early warning systems (EWS) and planning for GLOF risk reduction interventions[478]. In addition, because of the complexity of the physical conditions and information required for

[473] FEED (P) Ltd. 2020. Flood Risk Mitigation Measures Volume I. For the project: Protecting Livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal.
[474] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). GEF and UNDP.
[475] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme.
[476] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/TE_AF_Pakistan_Nov2015.pdf
[477] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/TE_AF_Pakistan_Nov2015.pdf
[478] Van Noord H and Shah BH. 2014. Mid-Term Evaluation: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP.

monitoring glacial lakes, the involvement of institutions with experience in using monitoring technologies is important. For example, the involvement of the Pakistan Meteorological Department in the installation and use of glacial lake monitoring equipment under the project entitled *"Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan"* helped to ensure the high technical standard of equipment installation and performance[479].

Remote sensing in the visible light and infrared spectrum, is frequently used to monitor glacial lakes. These images can be used to construct a time series of the lakes to understand interannual changes in lakes and glaciers. However, cloud cover often results in the images being difficult to analyse, particularly during monsoon season. One possible solution for this is to use microwave[480] remote sensing, which can penetrate clouds. Microwave remote sensing images are available from several sources and have been used, for example, by ICIMOD to monitor glacial lakes[481].

Real-time monitoring of glacial lakes and their geophysical environments is necessary for supporting GLOF EWS. Automatic weather stations (AWS), for example, provide high frequency and high accuracy data to inform glacial lake monitoring[482]. Hydrological monitoring systems, including river discharge sensors, glacial monitoring sensors and cameras to capture real-time images of glacial lakes, play an important role in these monitoring systems. Considering in detail the placement of equipment, for example of water-level sensors, can increase the lead time for flood warnings and prevent equipment from being damaged in the event of a GLOF or extreme weather events[483]. Under the Adaptation Fund project entitled *'Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan',* multiple instruments were installed for monitoring potentially dangerous glacial lakes, including: i) manual and automatic weather stations; ii) automatic rain gauges; iii) automated river discharge monitoring systems; and iv) sensors for monitoring glaciers and glacial lakes.

A detailed understanding of the geophysical context of glacial lakes is required for the planning of lake lowering and other physical interventions because the dynamic and unstable nature of glacial lakes makes these interventions potentially dangerous. One component of geophysical monitoring includes understanding the subsurface properties of moraine dams (further details are provided in Section 9.2.2 below). As mentioned above, ground penetrating radar (GPR) and electrical resistivity tomography (ETR) are two technologies that have been used for this purpose[484,485].

For these systems to be beneficial, it is important for the project to combine the installation of the equipment with capacity development for their effective maintenance and for necessary data analysis[486]. Under previous projects, the difficulty of ensuring adequate operation and maintenance

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479 Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/TE_AF_Pakistan_Nov2015.pdf

480 Microwave radiation has a lower frequency and longer wavelength than visible light and infrared radiation and is consequently not obstructed by cloud cover.

481 Bajracharya SR. 2011. Glacial lake outburst floods risk reduction activities in Nepal. International Centre for Integrated Mountain Development (ICIMOD).

482 GCF. 2016. Funding Proposal: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. Available at: https://www.greenclimate.fund/document/scaling-glacial-lake-outburst-flood-glof-risk-reduction-northern-pakistan

483 Van Noord H and Shah BH. 2014. Mid-Term Evaluation: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP.

484 CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. CFGORRP.

485 Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). Global Environment Facility and UNDP

486 Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/TE_AF_Pakistan_Nov2015.pdf

(O&M) of this equipment was resolved by integrating newly installed equipment into existing networks managed by existing institutions[487]. In addition, improving physical access to glacial lakes through the establishment of trails has been an important component of ensuring that monitoring equipment is well-maintained and effective[488]. Moreover, community monitoring of glacial lakes is necessary, in conjunction with scientific monitoring, to ensure the sustainability of EWS through the O&M of equipment installed for monitoring purposes. To further ensure the effective use of the data collected from this community-based monitoring, capacity development is necessary, along with standardised criteria for a hazard, risk and vulnerability analysis (HRVA), to ensure the application of a common language for improved efficiency[489].

Under Activity 2.1, the proposed project will support GLOF EWS through the installation of base stations, automatic weather stations, precipitation gauges and radar-based water level sensors at key locations in GLOF watersheds for hydrological and meteorological monitoring. The proposed project will also Integrate new and existing hydrology stations into a real-time data acquisition system to expand the reach and usability of monitoring systems in Nepal. In addition, the proposed project includes an O&M plan with details on the planned approach for the running and maintenance of monitoring technology. These monitoring technologies are underpinned by a geophysical understanding of the areas, which is required to install equipment safely and without disruption to the environment. The proposed project will utilise ground penetrating radar (GPR) and/or electrical resistivity tomography (ETR) and bathymetry of the glacial lakes to support safe and effective installation.

9.2.2. Risk mapping and assessment

The effective implementation of project interventions requires input from different assessments, including: i) glacial lake prioritisation — such as criteria and data sources used and existing classifications; ii) hazard mapping — detailed analyses, through field and remote sensing assessments as well as modelling, of a region to identify historical, currently active and potential future hazards to produce a map of hazards and their localities, along with the layers of complexity; iii) vulnerability mapping — identification of vulnerable households and assets, and their locations; and iv) risk mapping — combining the abovementioned hazard and vulnerability maps[490,491]. These assessments enable the identification of priority sites for monitoring and interventions.

Evaluation of glacial lakes to identify the potential for a GLOF includes assessment of the following characteristics: i) lake size (including depth, surface size and volume); ii) rate of expansion; iii) position with respect to the glacier; iv) size, height and structure of moraine dam; v) overtopping height; vi) hanging glaciers; and vii) potential rock falls and debris falls or slides. The ICIMOD report 'Glacial Lakes and Glacial Lake Outburst Floods in Nepal' separated glacial lakes into two broad categories[492]: i) lakes that form between the terminus of a steeply sloped retreating glacier and its end moraine; and ii) lakes that develop through growth and amalgamation of meltwater ponds on the lower, almost horizontal surface of a glacier tongue. In addition, the Final Report of the Detailed Topographical

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487 GCF. 2016. Funding Proposal: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. Available at: https://www.greenclimate.fund/document/scaling-glacial-lake-outburst-flood-glof-risk-reduction-northern-pakistan

488 Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/TE_AF_Pakistan_Nov2015.pdf

489 Rijal A and Ali J. 2015.Terminal evaluation report for the project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund. UNDP

490 van Noord H and Shah BH. 2014. Mid-Term Evaluation of the UNDP/AF Project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund

491 Zimmermann, M; Bichsel, M; Kienholz, H (1986) 'Mountain hazards mapping in the Khumbu Himal, Nepal, with prototype map, scale 1:50,000.' Mountain Research and Development 6(1): 29–40

492 ICIMOD (2011) Glacial lakes and glacial lake outburst floods in Nepal. Kathmandu: ICIMOD

Surveying and Structural Designing of Imja Lake Lowering for CFGORRP outlined this process and defined three categories for glacial lakes that resulted from this evaluation. These categories are: i) high priority lakes — requiring extensive and ongoing field investigation and mapping; ii) medium priority lakes — requiring continual monitoring and field surveys; and iii) low priority lakes — requiring periodic observation[493]. The application of these two methods of categorisation can strengthen the development of hazard maps by helping to identify potential hazards. By developing a database that contains the data collected from monitoring stations as well as an inventory and classification of glacial lakes, areas can be identified and ranked according to their risk and need for EWS. Regular updating of such a database would provide DHM with the ability to adaptively manage its EWS network and keep at-risk communities updated on the likelihood of a GLOF occurring[494].

In combination with these methods, 3D modelling of glacial river valleys can help to identify erosion hotspots and areas vulnerable to landslides for monitoring and potential project interventions. Hazard mapping and decision-making about DRR measures are based on characteristics such as expected flood height, the number of vulnerable households and assets/infrastructure, expected flood velocity[495]. The hazards presented by GLOFs include not only the direct impacts of flooding in valleys but also several indirect impacts. For example, they can exacerbate existing erosion cycles which, in turn, can lead to an increased risk of further landslides and floods. Additionally, large GLOFs could trigger instability in other glacial lakes, resulting in further GLOFs. There is, therefore, a need for modelling, monitoring, research and evaluation of GLOFs to develop comprehensive hazard maps for Nepal[496].

The establishment of monitoring stations enables the use of data from stations such as river discharge monitors and AWS for centralised hydrological modelling for DHM. Accordingly, these models can then be used to generate flooding scenarios and hazard maps of the areas that are at risk from GLOFs. Assessments can be used to develop vulnerability maps to identify the most vulnerable regions and communities. These hazard and vulnerability maps can then be combined to develop risk maps[497,498].

In order to effectively implement the proposed project, several assessments are required to gather necessary data to inform the design and execution of proposed interventions. Assessments have already taken place to identify the prioritised glacial lakes and sites. The proposed project's monitoring systems (Output 2), in combination with the strengthened technical and institutional capacity for GLOR risk management (Output 1), will enable ongoing hazard and vulnerability mapping that will inform the development of risk maps. Under Activity 1.1, the project will improve assessment through the: i) development of SOPs for inventory and spatial digital database (GIS) of glaciers and glacial lakes including geophysical investigation, as well as topographic and bathymetric surveys; ii) introduction of methods and tools for GLOF hazard prioritization, and mapping other extreme flood, landslide, mudflow and soil erosion hazards and risks, using a combination of remote-sensing and satellite data, as well as ground-truthing and socio-economic vulnerability assessments; and iii) establishment of methodology and standard operating procedures (SOPs) for implementing integrated GLOF risk reduction in vulnerable watersheds.

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493 CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP)

494 van Noord H and Shah BH. 2014. Mid-Term Evaluation of the UNDP/AF Project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund

495 Feed (P) Ltd. 2020. Protecting livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal

496 Bajracharya SR. 2011. Glacial lake outburst floods risk reduction activities in Nepal. ICIMOD

497 GCF FP 018: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. 2020

498 van Noord H and Shah BH. 2014. Mid-Term Evaluation of the UNDP/AF Project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund

9.3. Multi-hazard early warning systems

9.3.1. Incorporating local and traditional knowledge into EWS

Lessons learned under previous projects identify the necessity of integrating Indigenous and high-tech EWS, which are focused on community-based DRM to ensure the project's sustainability. This is because Indigenous EWS provides a strong basis for the integration of modern scientific methods into local communities. The combination of traditional and modern knowledge promotes a common understanding of how best to implement EWS for both local communities and project personnel[499,500]. the proposed project will leverage strong social networks and existing channels of community communication in rural communities through 'watch groups', to improve awareness of EWS and risk reduction procedures in these communities[501]

The incorporation of local and Indigenous knowledge into project design is important as it often demonstrates cost-effective and sustainable methods of DRR[502]. In particular, consultation with local communities is necessary to inform the design of flood mitigation measures, including placement and design, as local knowledge will contribute to the identification of the most vulnerable locations along a river or the ground truthing of risk and vulnerability modelling. Awareness raising on the risks of GLOFs and subsequent adaptation measures will, in addition to equipping communities with scientific equipment, help reduce potential risks, vulnerabilities and damages from GLOFs. Moreover, the incorporation of scientific knowledge into a community will strengthen their ability to enact precautionary measures or to act timeously in the event of a GLOF[503]. Scientific monitoring enables, *inter alia,* the following: i) hazard, vulnerability and risk maps to be accurately and frequently updated; ii) the establishment of safe emergency shelters; and iii) the early identification of GLOFs and, therefore, the timely warning of vulnerable communities[504]. The project design process will incorporate Indigenous knowledge and Indigenous and community groups to help institutionalise that knowledge, therefore ensuring it can be passed on to further generations and increasing the sustainability of project interventions[505]. Under Activity 2.2, a multi-hazard early warning system that combines centralised and community-based mechanisms, as well as focuses on Indigenous and local knowledge, will be established, supported by the development of community-based response mechanisms to increase the adaptive capacity of vulnerable communities to GLOFs and other extreme climate events.

9.3.2. Early warnings and disaster preparedness

Reducing the vulnerability of communities at risk of GLOFs requires awareness raising of the potential for these risks as well as subsequent appropriate responses to GLOFs. Technical capacity building, the introduction of scientific EWS and response mechanisms, as well as the development and

[499] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[500] van Noord H and Shah BH. 2014. Mid-Term Evaluation of the UNDP/AF Project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund
[501] GCF FP 018: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. 2020
[502] Feed (P) Ltd. 2020. Protecting livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal
[503] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[504] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[505] Feed (P) Ltd. 2020. Protecting livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal

implementation of GLOF drills are therefore necessary to ensure the early action and safety of these communities[506,507].

The dissemination of EWS is particularly important to ensure the safety of communities at risk of GLOFs. This can be achieved by using traditional media, social media or a combination of the two — by distributing alerts through either radio and mobile phone broadcasts (dynamic SMS alert system), sirens or across social media applications and sites. Specifically, under Activity 2.2, the project will install a low-cost tower with a free air satellite mode system and nine accompanying siren towers across the target GLOF watersheds. For events where the lead time is too short for media alerts to prove effective, sirens can be used to alert communities[508]. Additionally, the designation of a local individual to ensure system functionality by working with local community-based organisations — that have experience working on development projects in the area — will help ensure the dissemination of EWS to people living offline or disconnected from any media channels. The effectiveness of EWS and risk reduction procedures can be further increased by incorporating the strong offline social networks of the 'watch groups' of rural communities to assist with dissemination[509].

Target communities and intervention sites are often located in rural and remote areas. Access to the internet in rural areas is therefore important for both the transmission of data from lake monitoring stations and for communities to access information, which can be challenging. Increased connectivity can enable monitoring activities to occur in more remote areas by enhancing the ability for monitoring station data to be quickly and efficiently provided to decision-makers[510]. The proposed project will directly support the development of EWS by establishing a multi-hazard early warning system that integrated both centralised and community-based mechanisms to increase hazard alert and response systems (Activity 2.2). In addition, the project will develop and enhance dissemination mechanisms to deliver EWS to key Nepalese government agencies, including the DHM, as well as networks of critical sectors (Activity 2.2).

9.4. Governance across scales

9.4.1. Community participation and consultation

Community participation and consultation are important components of both project design and implementation to ensure project sustainability. Accordingly, project design that links institutions such as government agencies and local authorities with grassroots level institutions and local communities promotes local community participation. This community engagement in project design, implementation and maintenance will, furthermore, improve project effectiveness and sustainability. For example, the Mid-Term Evaluation for the 'Reducing Risks and Vulnerabilities from Glacier Lake Outburst Flood in Northern Pakistan' project determined that participatory community consultations enabled the identification of areas vulnerable to GLOFs as well as potential evacuation sites to be used for emergency shelters[511]. Sustained communication with the affected communities is therefore

[506] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[507] van Noord H and Shah BH. 2014. Mid-Term Evaluation of the UNDP/AF Project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund
[508] GCF FP 018: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. 2020
[509] GCF FP 018: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. 2020
[510] Bajracharya SR. 2011. Glacial lake outburst floods risk reduction activities in Nepal. ICIMOD
[511] van Noord H and Shah BH. 2014. Mid-Term Evaluation of the UNDP/AF Project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund

important to both build trust with the community and for their technical upskilling to ensure the sustainability and effectiveness of project interventions[512].

By involving community members in the construction and development of project interventions — such as physical infrastructure and EWS — the project will contribute to the development of the skills of local community members. This upskilling will enable community members to access jobs in surrounding areas, resulting in an indirect financial benefit for local community members[513]. The formation of Community Disaster Management Committees (CDMCs) — as part of the CFGORRP — was proven to help enable the training and performance of project-related tasks, as well as the coordination of local-level response measures. By creating community-run committees that are responsible for different aspects of project management, projects can strengthen a community's project involvement by fostering a sense of ownership over project activities[514]. Moreover, the Final Report on Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering for the CFGORRP also recognised the need for community involvement from project onset to ensure the sustainability of project interventions[515]. Additionally, the inclusion of communities in the project design and implementation enables the integration of Indigenous and scientific knowledge, which in turn can contribute to improving local preparedness and response capacities[516].

Although the inclusion of local communities in project management is necessary, it also requires financial support — in particular after project completion. Community-level funds to support ongoing maintenance of infrastructure and equipment are important for sustainability as they enable the community to maintain and manage project outputs beyond project implementation[517]. To ensure such sustainability, the UNDP project "*Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan*" established an endowment fund to support the local community with ongoing maintenance and management of project interventions[518].

Sufficient gender representation during project development and implementation is necessary to fully consider the impacts that the project intends to address. Women frequently account for 50% of a project or programme's beneficiaries, however as a result of cultural norms and barriers, they mostly remain at home, while men are more likely to be employed away from their villages — which makes women more vulnerable to GLOFs. Gender-biased attitudes, stereotypes and cultural norms can result in extended periods of recovery from a disaster for women[519]. The UNDP project *"Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan*" made efforts to include women in activities that were culturally sensitive, and which provided them with practical knowledge to safeguard them during GLOFs and other disasters, while the UNDP project "*Building a Resilient Churia Region in Nepal*" required a minimum of 30% women participants for all training

[512] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[513] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[514] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). Global Environment Facility and UNDP
[515] CEPAD Hydro Consultants. 2015. Final Report: Detailed Topographical Surveying and Structural Designing of Imja Lake Lowering. Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP)
[516] Shrestha, A.B., Shah, S.H. and Karim, R., 2008. Resource Manual on Flash Flood Risk Management Module 1: Community-based Management. ICIMOD, Kathmandu, Nepal
[517] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme
[518] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[519] Shrestha, A.B., Shah, S.H. and Karim, R., 2008. Resource Manual on Flash Flood Risk Management Module 1: Community-based Management. ICIMOD, Kathmandu, Nepal

events[520,521]. In addition to gender considerations, inclusivity and structures for representation should also apply to other excluded groups, including minority ethnic groups such as the Dalits, Tharus and Janajatis[522,523].

Feed (P) Ltd. acknowledged in their report on Flood Risk Mitigation Measures that community-based adaptation measures are proven to be effective in the implementation and management of project interventions, as they enable capacity development while integrating local knowledge into the design and implementation of these interventions. In addition, as previously mentioned, the involvement of local communities in the design of projects will ensure the sustainability of interventions that will be managed by those communities beyond project implementation[524]. Moreover, participatory community-based preparation activities ensure coordination and distribution of responsibilities during GLOFs — as opposed to individual household preparation, which results in greater losses during such events. Shifting risk management away from individuals and towards communities also enables the sharing of available resources and increases awareness of the risks posed by GLOFs[525].

Engagement of the community is necessary to ensure local participation and buy in, increase awareness and support the sustainability of the interventions beyond the project lifespan. Community participation will also increase the adaptive capacity of local communities. Accordingly, the project has been designed with the recognition that EWS relies on strong links with and ownership of local communities. Activity 2.2. will therefore establish a multi-hazard early warning system that uses both centralised and community-based mechanisms to support cross-level coordination, operation and maintenance.

9.4.2. <u>Coordination across scales (local, district, provincial and national)</u>

Working across multiple levels of governance (polycentric governance) provides support across these levels, contributing to: i) training people at all levels; ii) sharing knowledge within and across levels; iii) empowering local institutions; and iv) improving the efficiency and effectiveness of project implementation[526]. While small, local actions are beneficial for strengthening adaptation, it is also necessary for adaptation actions to match the scale of the climate change risks and disasters that the country is vulnerable to[527]. Effective coordination across local, district, provincial and national levels will ensure that project interventions are actionable at all levels and that neither local nor national needs are side-lined[528].

The UNDP project entitled "*Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan*" identified that coordination between agencies could be initiated as part of the project. This coordination enabled an integrated approach to risk reduction while also ensuring that the project drew on expertise from diverse fields[529]. The improvement of coordination between sub-

[520] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[521] GCF FP 118: Building a Resilient Churia Region in Nepal. FAO. 2019
[522] GCF FP 118: Building a Resilient Churia Region in Nepal. FAO. 2019
[523] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme
[524] Feed (P) Ltd. 2020. Protecting livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal
[525] Shrestha, A.B., Shah, S.H. and Karim, R., 2008. Resource Manual on Flash Flood Risk Management Module 1: Community-based Management. ICIMOD, Kathmandu, Nepal
[526] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[527] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme
[528] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme
[529] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf

national and local level institutions furthermore enables provincial-level capacity development and its integration into climate change action plans, with the potential to be strongly considered for development planning. This can be ensured by integrating the project structure into existing institutional arrangements[530,531].

The proposed project will support the Government of Nepal (GoN) to coordinate and mainstream institutional mechanisms into local planning processes, to ensure that — through planning, reviews and monitoring — the capacities of climate-vulnerable communities are increased and that project activities can effectively benefit these communities[532]. Mainstreaming coordination between national and local agencies can help ensure the sustainability of the project by engaging local communities in i) continued project activities; ii) regular monitoring; and iii) quality assurance in remote locations, which would otherwise be difficult for project staff to access[533]. The Nepal Climate Change Support Programme (2017) identified the institutionalisation of Coordination Committees at different levels as helping to enable the mainstreaming of climate change adaptation into local development plans[534].

Developing institutional knowledge related to GLOF adaptation requires sharing information and lessons learned with regional and international organisations to promote upscaling in other countries vulnerable to GLOFs[535]. In addition, interagency coordination — whether at government or community level or across levels — enables an integrated approach to addressing risks while also diversifying and expanding the field of expertise that can be utilised[536]. This type of collaboration among agencies and different information is important, while robust cooperation strategies are required to ensure the sustainability of such relationships[537]. In particular, interagency collaboration is necessary for effective flood risk management, as it requires input from fields such as hydrology, meteorology and disaster management[538].

9.4.3. Institutional arrangements

National Institution Context

The 2015 constitution of Nepal introduced federalism with three tiers of government – federal, provincial, and local – each with assigned exclusive powers and jurisdiction. Through substantial devolution of power by the constitution to the sub-national governments, the local governments are exclusively made responsible for taking necessary actions to protect the lives of the citizens from natural or manmade disasters with the support of provincial and federal governments. The federal and provincial governments, as per the provisions of the constitution for concurrent power, share the responsibility of reducing disaster risks with the local governments, and require working together towards ensuring an enabling environment and institutional capacities at the local level. With only four years of federalism experience, the local and provincial governments lack capacities in terms of

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[530] GCF FP 018: Scaling-up of Glacial Lake Outburst Flood risk reduction in Northern Pakistan. 2020
[531] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme
[532] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme
[533] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme
[534] UNDP. 2017. Annual Progress Report: Nepal Climate Change Support Programme
[535] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[536] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf
[537] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). Global Environment Facility and UNDP
[538] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). Global Environment Facility and UNDP

human resources, policies, budgets, regulations, systems, and mechanisms to become functional and capable enough to deliver as per the constitutional mandates. Disaster risk reduction and management is considered a cross-cutting issue in Nepal. Responding to glacial lake outbursts and flash flood risks requires building systemic knowledge about GLOF phenomena, technical capacities to map and respond to risks and a coherent policy for the three-tier governments to collaborate their efforts for risk reduction and preparedness on immediate, medium and long terms.

A series of consultations carried out with relevant national and sub-national government agencies at various levels and with other stakeholder groups including academic institutions, private sector and development partners, followed by an analysis of on-going and planned programs/projects of government, and close examination of institutional mandates, technical capabilities and policy environment, set the basis for defining the governance structure of the project.

Project Execution and Implementation

Accredited Entity: United Nations Development Programme (UNDP)

UNDP is accountable to the GCF for implementation of this project. UNDP provides oversight and quality assurance of project execution undertaken by the Implementing Partner through UNDP staff in the Country Office and at regional and headquarter levels. The quality assurance involves objective and independent project oversight and monitoring functions to ensure that project management and implementation follows UNDP and GCF policies and procedures and the standards and provisions outlined in the Delegation of Authority (DOA) letter for this project. The UNDP NCE Executive Coordinator, in consultation with UNDP Regional Bureau, UNDP CO and the Implementing Partner, retains the right to revoke the project DOA, suspend or cancel this GCF project. Being responsible for the Project Assurance, UNDP presents to the Project Board and Project Steering Committee and attends Project Board and Steering Committee meetings as a non-voting member. Being accountable to GCF funds, UNDP ensures quality of results, best value of money, fairness, integrity, and transparency throughout the implementation including fiduciary risk management and compliance to gender, environment, and social safeguards.

The UNDP Resident Representative assumes full responsibility and accountability for oversight and quality assurance of this Project and ensures its timely implementation in compliance with the GCF-specific requirements and UNDP's Programme and Operations Policies and Procedures (POPP), its Financial Regulations and Rules and Internal Control Framework. A representative of the UNDP Country Office will assume the assurance role and will present assurance findings to the Project Board and therefore attends Project Board meetings as a non-voting member.

UNDP CO support to NIM in project execution:

Based on the outcomes of capacity assessments conducted for the IP and RPs (HACT micro-assessments and PCAT) and the capacity gaps identified therein, the Implementing Partner has requested UNDP to provide support services which has been duly budgeted in the TBWP. The execution support services – whether financed from the project budget or other non-GCF sources - have been set out in detail and agreed between UNDP Country Office and the Implementing Partner in a Letter of Agreement (LOA). This LOA is attached as Annex 27 to this Project Document.

To ensure the strict independence required by the UNDP Internal Control Framework, these execution services will be delivered independent from the GCF-specific oversight and quality assurance services. A firewall will be maintained between the delivery of project oversight and quality assurance performed by UNDP and charged to the AE Fee and any support to project execution performed by

UNDP (as requested by and agreed to by both the Implementing Partner and GCF) and should be correctly budgeted in the TBWP agreed with the GCF.

Segregation of duties and firewalls vis-à-vis UNDP representation on the Project Board:

The segregation of functions and firewall provisions for UNDP's implementation oversight and quality assurance role in the project, will be assumed by UNDP Partnership and Quality Assurance Specialist, who will represent UNDP in the Board, together with UNDP's Portfolio Manager for Environment and Resilience, Programme Analyst – RBM and Programme Associate. To ensure project oversight and quality assurance including fiduciary risk management and compliance to environmental and social safeguards. To support the quality assurance functions, UNDP CO will further pull in in-house experts on gender and social exclusion, communication and partnership and hire additional staff to strengthen CO's capacities for technical oversight and quality assurance of civil engineering work related to lake lowering and flood mitigation, social and environmental safeguards, gender action plan and risk management. The cost of oversight and quality assurance will be covered under AE fees.

UNDP's execution support role in the project (as requested by the implementing partner and approved by the GCF) will be performed by a separate team of UNDP CO led by UNDP's ARR (Policy Advisor – Environment and Resilience) with the engagement of UNDP's Programme Analyst – Climate Change and Resilience. Following to the LOA signed with the IP for technical and operational support services, UNDP will set up an execution support team led by an International Chief Technical Advisor (CTA) supported by a number of thematic experts and support staff hired by UNDP to support the IP and RPs in the field of civil engineering, watershed management and livelihood, disaster risk reduction and climate change, coordination and communication, gender and social exclusion, finance and risk management and monitoring and reporting as well as operational and administrative services such as procurement, recruitment and finance management. The CTA will be hired by UNDP and will be responsible for timely and quality delivery of UNDP's support services to the IP and RPs. The CTA will report to UNDP through Assistant Resident Representative (ARR) responsible for Environment and Resilience. The cost of execution support services incurred by UNDP will be charged to GCF budget as agreed in project TBWP.

Implementing Partner (Executing Entity)

The Implementing Partner (IP) for this project is the Department of Hydrology and Meteorology (DHM) under Ministry of Energy, Water Resources and Irrigation (MoEWRI) of Nepal. The Implementing Partner is the entity to which the UNDP Administrator has entrusted the implementation of UNDP assistance specified in this signed project document along with the assumption of full responsibility and accountability for the effective use of UNDP resources and the delivery of outputs, as set forth in this document. The IP is accountable to UNDP for managing the project, including the monitoring and evaluation of project interventions, achieving project outcomes, and for the effective use of UNDP resources.

The Implementing Partner is responsible for executing this project. Specific tasks include:
- Project planning, coordination, management, monitoring, evaluation and reporting. This includes providing all required information and data necessary for timely, comprehensive and evidence-based project reporting, including results and financial data, as necessary. The Implementing Partner will strive to ensure project-level M&E is undertaken by national institutes and is aligned with national systems so that the data used and generated by the project supports national systems.
- Overseeing the management of project risks as included in this project document and new risks that may emerge during project implementation.
- Procurement of goods and services, including human resources.
- Financial management, including overseeing financial expenditures against project budgets.

- Approving and signing the multiyear workplan.
- Approving and signing the combined delivery report at the end of the year; and,
- Signing the financial report or the funding authorization and certificate of expenditures.

Responsible Parties (RPs):
The Implementing Partner (IP) will enter into agreements with the Responsible Parties (as listed below) to assist in successful delivery of project outcomes. The RPs are directly accountable to the IP, the Department of Hydrology and Meteorology (DHM) as outlined in the terms of their agreement:
- The Department of Forests and Soil Conservation (DoFSC) of Ministry of Forests and Environment (MoFE),
- The Department of National Parks and Wildlife Conservation (DNPWC) of Ministry of Forest and Environment (MoFE)
- National Disaster Risk Reduction and Management Authority of Nepal (NDRRMA), Ministry of Home Affairs

Specific Roles of IP and RPs in Implementation
1. The IP and the RPs will be responsible for implementation of the Activities set out in Table 6 below. The IP and RPs will follow prevailing government's budgetary and fund management system and procedures as defined by regulations to manage government funds reflected in the Red Book. The IP will set up a Project Management Unit (PMU) led by Department of Hydrology and Meteorology (DHM) to manage the project on day-to-day basis. Each RP will set up specific implementation arrangement to implement the project activities on the ground and ensure that results are produced on time and in cost-effective way and meet the quality standards. Based on the need, IP and RPs will set up field offices to ease smooth implementation of project activities on the ground. The cost of operation of field office will be covered by the IP and RPs.

Table 32. Activity-level distribution of implementation responsibilities

Output	Activity	Executing Entity	Responsible Parties/Executing Entity
Output 1: Institutional and technical capacity strengthened to develop and integrate climate risk and hazard information into planning and development.	1.1. Strengthen the knowledge base and technical capacities for improved climate research and risk reduction strategies.	MoEWRI/DHM	DHM
	1.2. Develop policy and financial mechanisms for sustainable GLOF and flood risk information services.		
Output 2: Improved hazard monitoring and the generation and dissemination of early warnings to local communities and important economic sectors.	2.1. Improve observation network density in GLOF watersheds to strengthen the technical capacity of DHM for the monitoring of climate hazard and risk.		DHM
	2.2. Improve early warning systems to strengthen adaptive capacity and response to GLOFs and other climate hazards.		NDRRMA
Output 3: GLOF and flash flood risk and impact reduction measures implemented in priority glacial lake watersheds.	3.1. Lower the levels of four of the highest risk glacial lakes.		DHM
	3.2. Install check dams and other infrastructure for the diversion of GLOF and flash flood flow.		DoFSC
	3.3. Implement eco-disaster risk reduction solutions to		DoFSC and DNPWC

	reduce the impact of GLOFs and flash floods.		

Project Steering Committee

The MoEWRI, the project Implementing Partner, will set up Project Steering Committee (PSC) chaired by the Secretary of MoEWRI responsible for Water Resources and Irrigation. The Project Steering Committee will be co-chaired by UNDP Resident Representative. Other members of the PSC will include Joint-Secretary level representatives from relevant federal and provincial ministries including National Planning Commission, UNDP, representatives of community organizations, indigenous people organization, academia, development partners and private sector as necessary. The main function of the PSC will be to provide strategic guidance and oversight and ensure inter-government coordination within and across various government ministries and agencies involved in project implementation. The PSC will review project's annual work plans and budget, project progress, and resolve project implementation issues. In addition, the PSC will approve the Project Implementation Manual (PIM) and Project Reporting Guidelines (PRG) as per GCF requirements during the inception phase and other project documents during implementation. The PSC meetings will be held at least once a year. The Secretary may designate a Joint Secretary level staff of MoEWRI to support PSC meetings. The Department of Hydrology and Metrology (DHM) will work as the Secretariate for the PSC and support the MoEWRI in organization of regular PSC meetings. The key functions of the DHM as secretariate to PSC will include a) consolidating project annual work plan, budget and financial reports for submission to PSC for approval, b) sharing the consolidated project annual work plan, budget and reports to UNDP before submission for PSC approval, c) setting agenda for PSC meetings tracking implementation of PSC decisions.

Technical Advisory Group

UNDP in consultation with the Chair of the PSC will set up a Technical Advisory Group (TAG) chaired by a senior national expert. The CTA of the project appointed by UNDP and senior technical specialists and experts of MoEWRI, DNPWC, DSCWM and NDRRMA will be the members of the TAG. Other members of TAG will include technical experts working in other government agencies, research institutions, development partner organizations and national and international organizations, with relevant experience in various thematic areas of the project, as decided by UNDP in consultation with the Chair of the PSC. The main function of the TAG will be to provide technical advice and inputs to the IP and RPs based on international best practice, regards to thematic assessments and technical studies conducted by the project. Including the Chair, the number of TAG members will be limited to a maximum of eleven. Meetings of the TAG will be organized up to twice a year, though it can meet on ad hoc basis as and when required.

Project stakeholders and target groups

The project is designed based on extensive stakeholder consultations organized at various levels, regards to GLOF risks and risk mitigation measures, climate adaptation priorities, flood risk and watershed management through enhanced green and grey infrastructure and climate-resilient agriculture-based livelihoods. The most relevant private sector including tourism and mountaineering association and individual power producer companies of Nepal were consulted about the importance of the project to their businesses and the way they can contribute to project sustainability. Likewise, the local youth, the indigenous people and women groups of the project area were consulted about impacts of the GLOF and flood risks to their livelihood and their potential role in mitigating those risks through project interventions. The project conducted a survey to explore feasibility of on-grant mechanism to promote social business and resilience building in close consultation with the local community, forest, water and watershed management groups, cooperatives, banking and financing institutions, development partner, NGOs and the local governments. Based on these consultations the project has developed an engagement plan with the various groups of stakeholders and following a multi-stakeholder approach, the project once under implementation will continue to engage with those groups at national and local levels. These include the implementing partner, the responsible parties, civil society organisations (CSOs), NGOs, private sector organizations, academia, local governments and other public entities. The roles and responsibilities of the various stakeholders are detailed in the Stakeholder Engagement Plan (see Annex 7 in FP).

Project Board

All UNDP projects must be governed by a multi-stakeholder board or committee established to review performance based on monitoring and evaluation, and implementation issues to ensure quality delivery of results. The Project Board is the most senior, dedicated oversight body for a project. The Project Board provides overall guidance and direction to the project, ensuring it remains within any specified constraints, and provides overall oversight of the project implementation. The Project Board review project performance based on monitoring, evaluation, and reporting, including progress reports, risk logs and the combined delivery report. The Project Board is responsible for making management decisions by consensus. Project Board decisions should be made in accordance with standards that shall ensure management for development results, best value money, fairness, integrity, transparency, and effective international competition. In case consensus cannot be reached within the Board, the UNDP representative on the board will mediate to find consensus and, if this cannot be found, will take the final decision to ensure project implementation is not unduly delayed. The Project Board will meet on quarterly basis in general but bi-annual meetings will be mandatory.

The two prominent (mandatory) roles of the project board are as follows:

- **High-level oversight of the execution of the project by the Implementing Partner** (as explained in the “Provide Oversight” section of the POPP). This is the primary function of the project board and includes annual (and as-needed) assessments of any major risks to the project, and decisions/agreements on any management actions or remedial measures to address them effectively. The Project Board reviews evidence of project performance based on monitoring, evaluation and reporting, including progress reports, evaluations, risk logs and the combined delivery report. The Project Board is the main body responsible for taking corrective action as needed to ensure the project achieves the desired results.
- **Approval of strategic project execution decisions of the Implementing Partner** (as explained in the “Manage Change” section of the POPP). The Project Board has an equally important, secondary role of approving, with the concurrence/approval of the GCF (where required by GCF policies and UNDP guidance on GCF programming), certain adjustments above provided tolerance levels, including substantive programmatic revisions (major/minor amendments), budget revisions, requests for suspension or extension and other major changes.

Requirements to serve on the Project Board:

- Agree to the Terms of Reference of the Board and the rules on protocols, quorum and minuting.
- Meet biannually at minimum.
- Disclose any conflict of interest in performing the functions of a Project Board member (if not avoidable) and take all measures to avoid any real or perceived conflicts of interest. This disclosure must be documented and kept on record by UNDP.
- Discharge the functions of the Project Board in accordance with UNDP policies and procedures.
- Ensure highest levels of transparency and ensure Project Board meeting minutes are recorded and shared with project stakeholders.

Responsibilities of the Project Board: Following are the key responsibilities of the Project Board:

Oversee project execution:

- Agree on project manager’s tolerances as required, within the parameters outlined in the project document, and provide direction and advice for exceptional situations when the project manager’s tolerances are exceeded.
- Appraise annual work plans prepared by the Implementing Partner and RPs for the Project; review combined delivery reports prior to certification by the implementing partner.

- Address any high-level project issues as raised by the project manager and project assurance and seek Inform PSC about issues and challenges faced by the project and seek timely guidance from PSC as required.
- Advise on major and minor amendments to the project within the parameters set by UNDP and the donor and refer such proposed major and minor amendments to the UNDP-BPPS/NCE Executive Coordinator (and the GCF Secretariat and/or GCF Board, as required by GCF policies).
- Provide guidance to the project management unit to ensure that the agreed deliverables are produced satisfactorily and according to plans.
- Track and monitor co-financed activities and realisation of co-financing amounts of this project.
- Approve the Inception Report, Baseline Report, GCF APRs, Interim Independent Evaluation and terminal evaluation reports, other reports that GCF may require.
- Ensure commitment of human resources to support project implementation, arbitrating any issues within the project.

Risk Management:
- Provide guidance on evolving or materialized project risks and agree on possible mitigation and management actions to address specific risks.
- Review and update the project risk register and associated management plans based on the information prepared by the Implementing Partner. This includes risks related that can be directly managed by this project, as well as contextual risks that may affect project delivery or continued UNDP compliance and reputation but are outside of the control of the project. For example, social and environmental risks associated with co-financed activities or activities taking place in the project's area of influence that have implications for the project.
- Address project-level grievances.

Coordination:
- Ensure coordination between various donor and government-funded projects and programmes.
- Ensure coordination with various government agencies and their participation in project activities.

<u>Other specific functions</u>:
- Approve project's annual and quarterly works plans and budgets and project reports (substantive and financial) and ensure execution support provided by UNDP are aligned to project priorities and work plan.
- Review project progress, milestones, targets, and implementation strategies and coordination structures.
- Review IP's and RP's project expenditure against activities and outcomes and approve readjustments in existing work plan and budget.
- Assess project performance, ensure efficiency and effectiveness of implementation and report to PSC.
- Ensure project budget is reflected into respective government ministry's LMBIS and Red Book and project co-financing is reflected into respective agencies' annual budget.
- Ensure compliance to fiduciary risk management, gender, environmental and social safeguard standards, in compliance with GCF guidelines.
- Support conducting project audits through Office of Auditor's General of Nepal (OAG)'s of Nepal while complying with GCF requirements.
- Ensure setting up project field offices & mechanism in place for handling grievances in fair & timely manner.
- Ensure timely fund disbursements from MoF to MoEWRI and from MoEWRI to the RPs and maintaining account of project co-financing.

Composition of the Project Board: The Project Board includes individuals assigned to the following three roles:

- *Project Executive:* This is an individual who represents ownership of the project and chairs the Project Board. The Executive usually is the senior national counterpart for nationally implemented project from the same entity as the IP. The Project Executive is the Director General of Department of Hydrology and Meteorology of MOEWRI as the IP of the project.

- *Beneficiary Representative(s):* Individuals or groups representing the interests of those groups of stakeholders who will ultimately benefit from the project. Their primary function within the board is to ensure the realization of project results from the perspective of project beneficiaries. Often representatives from beneficiary community, civil society organizations, local and provincial government entities benefiting from the project fulfil this role. This includes representatives Ministry of Finance, Ministry of Forest and Environment, Ministry of Home Affairs, National Planning Commission, Department of Forest and Soil Conservation, representatives from provincial governments, private sector, indigenous people and woman organizations and others as jointly decided by UNDP and MoEWRI.

- *Development Partners (Supplier):* Individuals or groups representing the interests of the parties concerned that provide funding, strategic guidance and/or technical expertise to the project. Resident Representative of UNDP Nepal will represent development partners in the PEB.

Project Assurance
Project assurance is the responsibility of each project board member; however, UNDP has a distinct assurance role for all UNDP projects in carrying out objective and independent project oversight and monitoring functions. UNDP performs quality assurance and supports the Project Board by carrying out objective and independent project oversight and monitoring functions, including applying and ensuring compliance with UNDP's risk management and social and environmental management systems. Project assurance is totally independent of project execution. The Project Board cannot delegate any of its quality assurance responsibilities to the PMU or National Project Manager. A designated representative of UNDP playing the project assurance role will attend all board meetings and support board processes as a non-voting representative and provide board members with the required documentation related to quality assurance. The Partnership and Quality Assurance Specialist of UNDP will mainly take the responsibility of assurance function with support from other staff.

Project Management
Execution of the Project: The National Project Manager (NPM) appointed by the IP will be Head of Programme Management Unit (PMU) and will work under the supervision of the Project Executive. The NPM will be responsible for overall and day-to-day management of the project on behalf of the Implementing Partner. The NPM is responsible for implementing the project work plan and budget including the mobilization of all project inputs, supervision of project staff, responsible parties, consultants and sub-contractors. The NPM presents key deliverables and documents to the board for review and approval, including progress reports, annual work plans, adjustments to tolerance levels and risk registers. The NPM will attend all board meetings and support board processes as a non-voting representative. The Project Board will meet at least twice a year and will approve the project quarterly work plans and budgets based on the project's annual work pan and budget.

Fund Flow and Approval of Proejct Work Plan and Budget
Upon approval of the project by the GCF Board, a Funded Activity Agreement (FAA) will be signed between the GCF and UNDP. Following FAA signing, the GCF proceed (grant) will be disbursed to UNDP. UNDP will transfer the GCF funds to the Ministry of Finance (MoF) of Nepal, from where the funds will be disbursed to the Implementing Partner (IP) and Responsible Parties (RPs). UNDP will retain necessary funds in line with the approved budget in the funding proposal to provide technical and operational support services to the IPs and RPs for implementation of project. Following the decisions of the PSC the funds will be transferred on annual basis from MoF to the IP and the RPs

(DoFSC, DNPWC and NDRRMA) through respective ministries of the government as per set procedures defined by Line Ministry Budgetary Information System (LMBIS).

The project IP will be directly responsible for overall implementation and reporting of project activities to UNDP as per approved project annual and quarterly work plans and budgets. The implementation of project activities by IP will follow the rules and regulations of the government set for project implementation. The IP will prepare consolidated annual and quarterly work plans and budgets with support of UNDP and submit to PMU for formal approval by PEB. The IP will also prepare consolidated annual and quarterly progress reports for both financial and physical progress for each of project targets, including those of Gender Action Plan, Indigenous Peoples Planning Framework and Environmental and Social safeguards with support of UNDP and submit to PMU for approval by PEB.

During the inception phase, the PMU with support of UNDP will develop detailed work plan and monitoring framework for the entire project duration and submit to PSC for approval. The CTA will provide inputs to the project work plan and budget. UNDP will prepare semi-annual financial report for GCF. Project expenditure made by the IP and the RPs will be audited annually as per the standard practice of the government for audit of government funds. All project reports, including audits, will be submitted to GCF by UNDP. The expenditures made by the project through IP will be verified by Financial Comptroller General Office (FCGO) of the Government of Nepal before submitting to PSC.

9.4.4. Using and developing institutional memory

GLOFs are a relatively under-researched extreme climate event, with the majority of work on the topic historically being project-based and discrete. Consequently, there is a need to develop capacity for GLOF monitoring, glacial lake mapping, DRR, EWS and watershed approaches. In addition, knowledge exchanges during project design, development and implementation are necessary to develop institutional knowledge across all levels of governance on GLOFs[539]. As GLOFs are not isolated to Nepal, regional knowledge exchanges with other GLOF initiatives would help ensure the sustainability and effectiveness of project interventions[540,541].

Working through existing government entities or parallel project structures, rather than creating new ones, will help develop the necessary capacity for the large-scale management of GLOFs. In turn, this will promote the long-term sustainability of project interventions. Working through established government structures could also simplify the process of engaging with institutions and structures in other countries that experience GLOFs[542]. Additionally, working within existing structures will also save time and resources that are required to establish a new initiative and will ensure that existing entities understand their roles and responsibilities, thus avoiding cross-sectoral conflicts about mandates.

The development of institutional memory in government structures enables the establishment of awareness-raising strategies and programmes for local communities to become more aware of the risks posed to them by climate change. For example, the Nepal Disaster Report 2019 identified how recent national DRR policies and the Strategic Plan of Action of the GoN focus on multi-stakeholder and inclusive approaches to DRR. To this end, the report acknowledged the role that children are able to play in DRR. By investing in the capacity and empowerment of children through community and school-based clubs, institutional knowledge on DRR can be developed and shared with family

[539] Bajracharya SR. 2011. Glacial lake outburst floods risk reduction activities in Nepal. ICIMOD
[540] van Noord H and Shah BH. 2014. Mid-Term Evaluation of the UNDP/AF Project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund
[541] Feed (P) Ltd. 2020. Protecting livelihoods and assets at risk from climate change induced flooding in glacial river basins of Nepal
[542] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf

and community members[543]. Additionally, by incorporating traditional knowledge into existing institutional memory and knowledge bases, project sustainability can be strengthened by reinforcing the importance of project interventions to local communities[544].

Along with the development of new institutional knowledge, existing institutional memory needs to be effectively managed and maintained to prevent delays in project design and implementation. The Mid-Term Evaluation of the UNDP and AF project 'Reducing Risks and Vulnerabilities from Glacier Lake Outburst Floods in Northern Pakistan' identified that losses of institutional knowledge, resulting from rapid staff turnover, led to administrative delays in project disbursement and formal decision-making[545]. Moreover, the Terminal Evaluation for the CFGORRP identified that, despite the DHM's experience managing GLOF risks at Tsho Rolpa, institutional knowledge was insufficient for managing the highly complex and site-specific nature of GLOFs at large scales, such as Lake Imja[546].

Institutional memory can significantly improve the management of and response to GLOF and flooding hazards. The proposed project will develop institutional memory in several ways, including establishing a system for recording and managing a climate-induced hazard event database (Activity 1.2.). in addition, the project will develop climate risk information products for key public and private sectors, including tourism, hydropower and irrigation to improve awareness, especially amongst government staff (Activity 1.2.). These efforts will support capacity development that will strengthen the long-term ability of Nepalese institutions to better manage DRR.

10. Barriers to the preferred solution

10.1. Barrier 1. Limited technical knowledge and institutional capacity for integrated GLOF DRR preparedness planning, including watershed-level approaches to GLOF risk reduction

At present, there is limited technical understanding within the GoN on how to develop a sustainable knowledge base focused on disaster risk reduction. There is also limited technical capacity across several departments involved in the planning and management of disasters for the development of comprehensive preparedness plans to facilitate proactive action and rapid response to an impending GLOF. This barrier is exacerbated by the reactive measures often employed to respond to GLOF risk, focussing on rescue and relief work, as opposed to developing proactive measures to mitigate the impacts of GLOFs. Limited guidelines for mainstreaming GLOF disaster risk reduction (DRR) combined with insufficient knowledge and training for decision-makers hinders effective GLOF DRR efforts. The effectiveness of these efforts is further reduced by the existing lack of mechanisms to ensure the coordination of DRR in Nepal. Disaster risk management (DRM) practitioners at the national and sub-national levels have limited detailed climate-risk information to inform probabilistic assessments of risks posed by climate-induced disasters to communities and their assets. This data could inform decisions to channel, albeit limited, financial resources into implementing adaptation interventions that are technically robust. Moreover, without these risk assessments, tailored measures for disaster and climate risk management cannot be developed. These barriers to generating understanding and integrating necessary GLOF knowledge contributes to the restricted ability of the public sector to take the preparatory actions required to ensure the protection of vulnerable communities.

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[543] Ministry of Home Affairs. (2019). Nepal Disaster Report, 2019, Kathmandu: Government of Nepal.

[544] Rijal A and Ali J. 2015. Report of the Terminal Evaluation Mission: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund and UNDP. Available at: https://www.adaptation-fund.org/wp-content/uploads/2011/06/464454AFPakistanTEreport.pdf

[545] van Noord H and Shah BH. 2014. Mid-Term Evaluation of the UNDP/AF Project: Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan. Adaptation Fund

[546] Fakhruddin B and Basnet G. 2018. Terminal Evaluation: Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP). Global Environment Facility and UNDP

Glacial watersheds are unique and complex systems that require tailored watershed-level responses to mitigate the contextual factors that influence or exacerbate the effects of GLOFs. While multiple legal and policy frameworks exist for Nepal relating to climate change adaptation (Section 6), they tend to focus on across-the-board approaches to GLOF risk reduction. Moreover, there is insufficient integration between policies and limited collaboration and coordination of government agencies which hinders the adoption of a watershed-level approach to address GLOF DRR. This is largely impacted by gaps in knowledge and limited capacity to develop and implement watershed-level management plans effectively. GLOFs and high mountain region watersheds are a relatively under-researched area, with the majority of work on GLOFs being generated from projects. Accordingly, there is a need to develop capacity for GLOF monitoring, glacial lake mapping, DRR and EWS to inform watershed approaches for DRR. Interventions for GLOF risk reduction in Nepal are more likely to be effective if the approach to the problem and solution cohesively considers ground and surface water flow within the hydrologically defined geographic area and the likely impacts of climate change.

10.2. Barrier 2. Limited technical capacity to access current, reliable and timely climate risk information for adequately disseminating early warnings

Both Nepal's Department of Hydrology and Meteorology (DHM) and the Department of Environment (DoE) currently have limited technical capacity to adequately gather, process and disseminate GLOF-relevant climate data to support early warnings and response to the onset of extreme climate events. This limited capacity is influenced by the fact that existing climate information servers are unable to process climate data in real time, leading to delays in the development and dissemination of early warning information products to decision-makers responsible for coordinating disaster response. Specifically, there is a lack of vulnerability maps, technical field surveys[547], hazard and risk information and comprehensive climate information necessary for the development of early warning action. In addition, research and monitoring are particularly constrained in remote areas of the Himalayan region because these areas are difficult to access. The International Centre for Integrated Mountain Development (ICIMOD) is the key organisation undertaking research on GLOF risk based on their own mandate, but their GLOF risk studies have not been updated since 2012. In addition, while some projects — such as the Pilot Project for Climate Resilience (PPCR) (Section 7.2.1) — are contributing to the rehabilitation of the hydrometric monitoring network in Nepal, there is no systematic observation and monitoring occurring to create a base for the monitoring of GLOF and other hazards, which hinders integrated watershed-level approaches for catchment management and DRR.

10.3. Barrier 3. Limited investment in, and investment planning for, long-term climate risk reduction to address GLOF and flood risk

Limited available funds and resources for interventions to reduce GLOF and flood DRR hinders Nepal's resilience ambitions. Undertaking risk reducing interventions for addressing GLOFs requires expensive infrastructure and materials, complex construction management, expert design and engineering skills, extensive labour, and in some cases, specialised transport. These necessary elements for GLOF and flood DRR projects have high associated costs and require significant investment, which is beyond the scope of the GoN's available budget. High project costs are compounded by the limited opportunities to generate income or recoup the abovementioned high costs associated with GLOF and flood risk reduction infrastructure, making it difficult to attract and secure necessary investment. In addition, the scope for private sector investment is limited by the inability to generate profit from GLOF and flood DRR infrastructure projects. Moreover, given the high cost of adaptation interventions, there are limited financial mechanisms to sustain risk reduction

[547] Including bathymetric mapping, hydro-meteorological observations, and geological, geophysical, and glaciological surveys to evaluate the condition and composition of the moraine material, the geological setting of the lake, glacier, moraine, and surrounding areas.

approaches or to support the mainstreaming of public investment initiatives or PPP for downstream flood management. Structural measures such as lake lowering can cost US$3 million per lake and to date have only been undertaken by donor-funded projects because of the GoN's limited financial resources for these projects, as well as insufficient capacity to identify and plan for such investments. In addition, there is a lack of sustained funding for research and monitoring activities for flood risk reduction, along with generally constrained funding for risk and damage assessment, which further hinders interest and investment in long-term climate risk reduction in Nepal. Because of Nepal's high vulnerability to extreme climate events and low global economic status, the GoN does not have the resources or institutional capacity necessary to break out of a reactive cycle to disasters. Consequently, the GoN has been unable to invest in necessary GLOF resilience interventions as a result of strained fiscal capacity leading to a disparity between the GoN's contribution to, and the required budget for, climate change adaptation and resilience building in the country. Year on year, the GoN has only been able to provide 24–45% of this budget, relying on grants and loans to make up the shortfall.

Another important factor hindering fiscal investment in DRR is the limited capacity and resources available for investment planning and blended finance. The GoN's capacity to systematically identify, plan for and programme financial investment requirements for risk reduction measures is limited. The national annual budget allocation for climate risk reduction, resilience and adaptation activities averages US$85 million while the average annual damages from climate-related hazards is US$270–360 million (or 1.5-2% of GDP) and this is expected to rise with increasing climate change risk. Collectively, these factors of fiscal constraints, high costs, low return on investments, and limited institutional capacity for effective DRR investment planning impede the development of an enabling environment for effective investment in GLOF and flood risk reduction interventions. Furthermore, legal frameworks in Nepal are not adequate to facilitate blended finance mechanisms to fund additional investment in DRR. This problem is exacerbated by the limited access to finance for Small and Medium Enterprises (SMEs), with only 39% of SMEs reporting to have access to finance[548].

10.4. Barrier 4. Limited community awareness and skills for GLOF disaster reduction actions

Knowledge and understanding of climate change and its related impacts — including GLOFs and rain-induced flooding — is limited among groups based in areas exposed to these events in Nepal. Compounding the impacts of limited knowledge is constrained adaptive capacity for vulnerable communities to manage extreme flooding events. A lack of investment and development of alternative livelihood options for communities in exposed areas further exacerbates this vulnerability. Limited community awareness and skills for GLOF disaster reduction actions impacts youth, women and marginalised Indigenous groups, who are most vulnerable to climate change-related shocks. While monsoon flooding is common in Nepal, the livelihoods and infrastructure of numerous exposed communities living in Nepal are not designed to withstand GLOFs. As a result, these communities are at risk of considerable damage to infrastructure, disruption of livelihoods — including agriculture and tourism, as well as potential injury and loss of life. Programmes aimed at building community resilience through early warning training and implementing emergency and evacuation measures have been undertaken in Nepal, however, significant potential to upscale and mainstream community resilience initiatives remains.

11. Project interventions to overcome barriers

The proposed project will contribute to GCF's paradigm shift objective of increased climate-resilient sustainable development by reducing the risk of Glacial Lake Outburst Floods (GLOFs) in Nepal. This

[548]http://southernvoice.org/wp-content/uploads/2019/04/Ocassional-Paper-Series-N48-final.pdf

shift will be achieved by implementing a transformative approach to the way in which the Government of Nepal (GoN) addresses GLOFs and rain-induced flooding. Specifically, direct investments from the GCF will be used to: i) reduce the impacts of a GLOF and its residual impacts on vulnerable communities; ii) promote the adoption of GLOF EWS measures among national- and local-level decision-makers to enhance rapid response to an impending GLOF; and iii) strengthen the technical and institutional capacity of the GoN and local communities to implement GLOF risk reduction measures through targeted training and awareness raising. The combined effect of project interventions will result in the adoption and implementation of a climate-resilient, integrated approach to GLOF risk reduction and flood management that can be readily scaled up and replicated nationally and across South Asia. The three main results that will be achieved by the project are described below, with further details on the associated activities and sub-activities presented in Section E.6 of the Funding Proposal.

Output 1. Institutional and technical capacity strengthened to develop and integrate climate risk and hazard information into planning and development.
Output 1 will improve DHM’s technical and institutional capacity to develop and disseminate tailored climate risk information and establishing public-private sector partnerships to encourage investment into GLOF risk reduction in Nepal. The strengthened regulatory frameworks, combined with capacity building and skills development in the disaster risk reduction sector, will create an enabling environment for the upscaling and replication of project interventions across the country. This upscaling potential will be achieved by: i) improving DHM’s capacity for hazard mapping and prioritising GLOF risk reduction strategies; ii) leveraging investment from the private sector into GLOF risk reduction beyond the conventional project-based approach; and iii) training the relevant staff from DHM on monitoring GLOFs, operating and maintaining existing risk databases and disseminating tailored, user-friendly climate risk information to major productive sectors in Nepal, including the tourism, hydropower and tourism sectors.

Output 2. Improved hazard monitoring and the generation of early warnings, including the dissemination of early warnings to local communities and important economic sectors.
Project interventions under Output 2 will strengthen Nepal’s GLOF early warning system (EWS) as well as the capacity of Nepal’s Department of Hydrology and Meteorology (DHM) to facilitate rapid information sharing and early action preceding a GLOF. At present, DHM has limited technical and institutional capacity to detect, monitor and respond to GLOFs and other extreme climate events. At present, EWS coverage in the Gandaki Basin, and Dudhkosi and Arun Sub-basins does not extend far enough to reach all downstream communities that will be affected should the Thulagi, Lower Barun, Lumding Tsho and Hongu 2 Lakes breach. This places these — mostly Indigenous — communities at increased risk of being impacted by a GLOF and the residual flooding. A study was recently commissioned by UNDP to address these constraints for the *“Identification of required optimum number of Hydrological and Meteorological Stations for the proposed GCF-funded project”*. This study identified gaps in the existing EWS network — in terms of the number of stations required — to detect and monitor hydrological and meteorological changes that contribute to GLOFs. In addition, the study identified limitations in the generation and dissemination of early warnings to downstream communities to enable them to respond timeously to impending GLOFs.

Output 2 of the project will fill these gaps in two ways. First, hydrological and meteorological stations will be installed across the prioritised GLOF watersheds to improve monitoring capacity and coverage in higher altitude areas. The type of stations and their locations are listed below.

- 6 base stations at Pangboche, Jayaram Ghat - Middle Hill, Tumlingtar (Turkighat), Chatara, Dharapani and Muglin (4 in the Marsyangdi Basin, 2 in the Dudhkosi Sub-basin and 3 in the Arun Sub-basin).
- 24 automatic weather stations (AWS) at key locations in GLOF watersheds (7 AWS in the Marsyangdi Basin, 5 in the Dudhkosi Sub-basin and 12 in the Arun Sub-basin).
- 9 Precipitation gauges (PCP) at key locations in GLOF watersheds (2 in the Marsyangdi Basin and 7 in the Dudhkosi Sub-basin).
- 27 radar-based water level sensors (RLS) at key locations in GLOF watersheds (11 in the Marsyangdi Basin, 8 in the Dudhkosi Sub-basin and 8 in the Arun Sub-basin).

The installation of these stations will be complemented by training workshops targeting DHM staff to strengthen their capacity to: i) collect, process and manage climate data from the new and existing stations; and ii) use the generated data to develop early warning information products, including easily interpretable infographics for local communities. This will enable DHM to reliably and timeously forecast GLOFs and other extreme climate events using data from the country's new and existing hydrological and meteorological stations. The data from these stations will be housed on DHM's existing servers. Second, the adaptive capacity and response among vulnerable communities in the target districts of Manang, Sankhuwasabha and Solukhumbu to GLOFs will be enhanced through a combination of capacity-building and awareness-raising interventions. This will include training communities on disaster risk management, first aid and search and rescue, as well as engagement workshops with relevant community leaders to ensure the establishment and uptake of knowledge and early warning processes at the national, local and community level.

The installation of stations and the training of government officials and communities will be supported through the development of multi-hazard-based risk assessments, which integrate traditional community knowledge and science-based assessments, and climate-responsive Municipal Disaster Preparedness and Response Plans and local-level Climate-resilient Action Plans. These plans will be developed in coordination between DHM, NDRRMA and communities. The integration of these plans with the training provided under this Output will ensure that communities are able to access and respond to early warnings more effectively and will increase community involvement in early warning processes.

Output 3. GLOF and flash flood risk and impact reduction measures implemented in priority glacial lake watersheds.

Output 3 will reduce the risk of GLOFs in the Gandaki Basin and Dudhkosi and Arun Sub-basins. A joint assessment was undertaken by UNDP and ICIMOD in 2020[549] of the glacial lakes in the Himalayas to identify Potentially Dangerous Glacial Lakes (PDGLs)[550]. From this, the glacial lakes were ranked based on their respective hazard levels, determined by the characteristics of the lakes and their dams, the activity of the source glacier and morphology of the surroundings. The critical lakes were classed under Rank 1, and these warrant the immediate implementation of potential measures for GLOF mitigation. Lakes classed under Ranks 2 and 3 require regular monitoring. Several Rank 1 glacial lakes were identified within Nepal, and while all pose a serious risk, 4 of the lakes at the highest risk of breaching have been selected for interventions under the proposed project

[549] Bajracharya, SR., Maharjan, SB., Shrestha, F., Sherpa, TC., Wagle, N. and Shrestha, AB. 2020. Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. *International Centre for Integrated Mountain Development (ICIMOD); United Nations Development Programme (UNDP).* Available at: https://lib.icimod.org/record/34905.

[550] ICIMOD. 2020. Research Report: Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India. Available at: https://lib.icimod.org/record/34905

to reduce the risk they pose to the population of Nepal. These are the Thulagi, Lower Barun, Lumding Tsho and Hongu 2 Lakes (Figure 40). Further details on the selection of these lakes for urgent intervention are provided in Section 3 of this Feasibility Study. The technical designs of these interventions are presented in Section 12 below.

The physical interventions developed under this Output will be further supported by the development of Integrated Watershed Management and National Park Management plans, to create the regulatory framework for sustainable land management and climate change adaptation, and training and capacity building interventions to ensure the effective implementation of these plans. capacity building interventions targeting the relevant groups will ensure the effective implementation of these plans. The capacity development of community members, CBOs, NGOs and relevant government officials will be delivered under thematic training modules and will promote engagement between these groups for the implementation of Multi-Hazard Risk Reduction Measures.

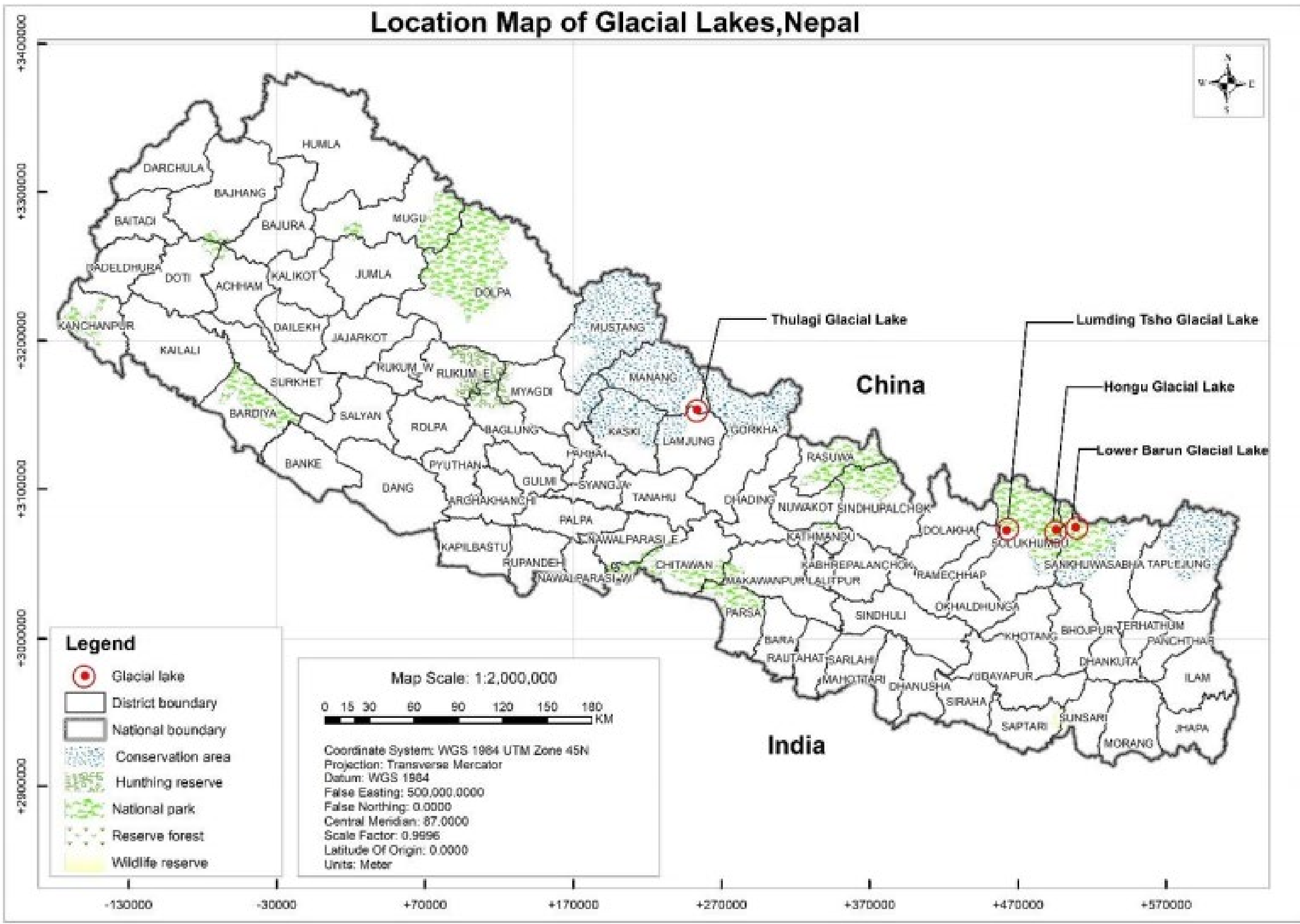

Figure 40. Locations of each of the target glacial lakes relative to one another and their respective districts.

Following the selection of the target lakes, an options analysis based on primary modelling, as well as international literature and proven successful lake lowering interventions (as described in Section B.1), was undertaken to determine the specific interventions required to sufficiently reduce the risk of GLOFs impacting nearby vulnerable communities. As a result of this analysis, an approach combining physical lake lowering and downstream adaptation interventions was selected for the proposed project. To reduce the primary risk of a GLOF, the water levels will be lowered at the four priority lakes (Thulagi, Lower Barun, Lumding Tsho and Hongu 2). Lowering the water level of the lakes will reduce the potential of triggering a GLOF and will also reduce the magnitude of a GLOF when one is triggered. In so doing, lake lowering will avoid US$ 45.1–86.9 million in potential damages and losses to vulnerable communities that are located within the potential flood-affected area. Furthermore, a combination of grey and green infrastructure interventions[551] will be implemented downstream of the lakes to reduce the residual impacts of a GLOF after lake lowering. These downstream interventions will include: i) check dams and other infrastructure to divert GLOF and flash flood flow; and ii) Eco-disaster Risk Reduction and Ecosystem-based Adaptation solutions. Implementing these downstream interventions will reduce the damages to agricultural land and other infrastructure, which was shown by the UNDP commissioned Residual Risk and Vulnerability Assessment, which included modelling for four different scenarios of GLOF impacts at the Lower Barun, Hongu 2 and Lumding Tsho Glacial Lakes. The models accounted for the GLOF impacts on the entire river basin downstream of each Glacial Lake, with the Lower Barun Glacial Lake affecting the Arun River Sub-basin and impacts in the Dudhkosi River Sub-basin being divided into subsets with the Hongu 2 Glacial Lake affecting the Hongu-Dudhkosi River Basin subset and the Lumding Tsho Glacial Lake affecting the Lumding-Dudhkosi subset. The four modelled scenarios were: i) Scenario 1 (S1) — GLOF at the Glacial Lake without any interventions with a complete breach; ii) Scenario 2 (S2) — GLOF at the Glacial Lake after lowering the recommended depth with complete breach of moraine dam; ii) Scenario 3 (S3) GLOF at the Glacial Lake with a partial breach[552] after lowering by the prescribed amount of 3 m for Lower Barun and Lumding Tsho and by 1 m for Hongu 2; and iii) Scenario 4 (S4) — GLOF at the Glacial Lake with a partial breach[553] after lowering by the prescribed amount and with downstream adaptation interventions. The GLOF impacts on agricultural land and infrastructure were projected for all four scenarios and are summarised in Table 33. There is a reduction in impacts between S1 and S2, which shows the effectiveness of lowering the Glacial Lakes by the prescribed amount to reduce damages and losses. Further reductions in the impacts are shown between S3 and S4, which indicates the importance of downstream adaptation measures to further offset the impacts of a GLOF at any of the three Glacial Lakes. These results show that the most effective solution with the greatest reduction of losses is the combination of lake lowering with downstream grey and green infrastructure interventions.

Table 33. Modelled impacts of GLOF events at the Hongu 2, Lower Barun and Lumding Tsho Glacial Lakes under different intervention scenarios.

River Basin	Expected direct damage											
	Agricultural land (ha)				Household (No.)				Road (km)			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Arun	1, 271	674	236	20	272	267	173	10	7	7	7	1.9
Hongu-Dudhkosi	256	256	115	5	124	123	83	4	6	6	6	1.6
Lumding-Dudhkosi	104	104	71	7	99	97	65	2	6	6	6	1.6
River Basin	Expected direct damage											
	Trail bridge (No.)				Motorable bridge (No.)				Trail (km)			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4

[551] "Green infrastructure refers to the interconnected set of natural and man-made ecological systems, green spaces, and other landscape features. It includes planted and indigenous trees, wetlands, parks, green open spaces and original grassland and woodlands, as well as possible building and street-level design interventions that incorporate vegetation, such as green roofs. Together these assets form an infrastructure network providing a wide range of services and strategic functions in the same way as traditional hard infrastructure" — State of Green Infrastructure in the Gauteng City-Region (GCRO 2013). Available at: http://www.gcro.ac.za/media/redactor_files/Green%20Infrastructure%20Citylab%20information.pdf.
[552]Partial breach depth - 5 m for Hongu 2 and Lower Barun, and 3 m for Lumding Tsho.
[553]Partial breach depth - 5 m for Hongu 2 and Lower Barun, and 3 m for Lumding Tsho.

Arun	32	32	26	4	2	2	1	1	9	9	9	2.8
Hongu-Dudhkosi	17	17	13	1	3	3	2	1	2	2	2	1.5
Lumding-Dudhkosi	21	21	13	0	1	2	2	1	2	2	2	1.5

12. Proposed technical designs for lake lowering

12.1. Glacial Lake Lowering

As described in Section 3, the selection of Thulagi, Lumding Tsho, Lower Barun and Hongu 2 was based on the ICIMOD inventory of glacial lakes, which identified them as Rank 1 Glacial Lakes, which had previously been identified as potentially dangerous glacial lakes (PGDL)[554].

The proposed technical designs for lowering the level of the target glacial lakes were informed by technical studies of the target glacial lakes as well as case studies from within Nepal as well as from outside of Nepal. The selection process used to identify the target lakes is detailed in Section 3. The technical studies of the target glacial lakes were commissioned by UNDP, specifically for the proposed project, and included reviews of existing technical data — such as electrical resistivity tomography, bathymetry and ground penetrating radar — as well as aerial site observation and visual assessments. The in-country case studies assessed included the lake lowering projects at Tsho Rolpa and Imja Glacial Lake, while the international case studies assessed included South Lhonak glacial lake in India, Thorthomi Lake in Bhutan and Palcacocha and Huaraz Lakes in Peru. Based on these studies, the design team determined a fixed safe lowering depth of 3 m for Thulagi, Lumding Tsho and Lower Barun and 1 m for Hongu 2. The lake lowering depth limit of 3 m was recommended because of the presence of dead ice zones, which, if reached, could lead to foundations being destabilised, therefore, resulting in the failure of interventions. The depth of 1 m for Hongu 2 was recommended as it will enable the safe release of discharge from the lake, which will reduce the hydrodynamic wave pressure on the end moraine.

Several engineering design options were identified as possibilities for the lowering of the target lakes, with the option of structural interventions finally determined as the most appropriate measure (see Annex 22: Technical Lake Lowering Design Report for details).

12.1.1. Conceptual design chosen

The structural interventions identified for Thulagi, Lower Barun and Lumding Tsho include a combination of a: i) cofferdam, which is designed to block water for the construction of downstream works; ii) diversion channel, which is designed for draining the normal flow of the river during the construction work in the mainstream; iii) central channel, which is designed for leading the mainstream flow from the vertical sluice gate; iv) race floor, which is designed to reduce the velocity or turbulence of the flow; and v) vertical sluice gate which is designed to control the flow and pass the required flow downstream. In contrast, only a main channel was deemed necessary for Hongu 2.

For Thulagi, Lumding Tsho and Lower Barun, the outlet channel at the end of their moraines will be blocked by a cofferdam, while a diversion channel will be built to divert the flow of each lake. Materials such as geomembranes and geotextiles with a sand base will be used to provide seepage control for

[554] Bajracharya, S.R., Maharjan, S.B., Shrestha, F., Sherpa, T.C., Wagle, N., Shrestha, A.B. (2020). Inventory of glacial lakes and identification of potentially dangerous glacial lakes in the Koshi, Gandaki, and Karnali River Basins of Nepal, the Tibet Autonomous Region of China, and India. Research Report. ICIMOD and UNDP.

the cofferdam. The outflow from the diversion channels will then be discharged approximately 165 m, 70 m and 55 m downstream of the proposed structures, respectively.

A trapezoidal main channel will be built 70 m, 25 m and 40 m downstream of the Thulagi, Lower Barun and Lumding Tsho cofferdams. The banks of these channels will be strengthened with boulder impact gabion walls to protect them against erosion once the cofferdam is removed and the main channel is the primary discharge outlet for the lake.

The vertical sluice gate will enable control of discharge from the target lakes. Despite the ease of fabrication and the short time needed to erect them, vertical sluice gates require the construction of an abutment to ensure their stability. The walls of this abutment will guide water from the lake into the channel, just before the outlet gate.

For Hongu 2, as only a main channel is proposed and there is no outlet discharge from the lake, the end moraine will be used as the sluice gate. Once this main channel has been completed, the end moraine will be excavated to lower the level of the lake through controlled discharge via the main channel. The moraine at Hongu 2 will be reinforced with a combination of gabion mattresses, geotextiles, sand and geomembranes to ensure that, as with the cofferdams at the other three target glacial lakes, seepage is minimised during construction. The specific details on the proposed structural interventions for each site are outlined in Annex 22: Technical Lake Lowering Design Report, with brief outlines in the following sections.

12.1.2. Thulagi Glacial Lake

- The specific dimensions of the proposed structural interventions for lake lowering at Thulagi are presented in Table 34 below. Additionally, the designs for these structures are presented in this section (Figure 41, Figure 42, Figure 43, Figure 44, Figure 45 and Figure 46 below). The stability of the cofferdam was determined through a seepage analysis, with the Thulagi cofferdam predicted to be 198 $l.s^{-1}$.

Table 34. Thulagi Structural Intervention Dimensions.

Structure	Main Channel	Cofferdam	Diversion Channel	Sluice Gate
Length (m)	50	32.5	102.82	-
Top width (m)	12.48	1.8	5.36	3
Bottom width (m)	3	11.8	2	3
Water depth (m)	1.67	4	0.82	-
Freeboard[555]	0.7	-	0.3	-
Slope	2:1	-	1.5:1	-
Weight (tons)	-	-	-	2.2
Proposed chainage[556]	-	-	-	0+049

[555] The freeboard is the vertical distance between the crest of the embankment and the reservoir water surface.
[556] Chainage is the horizontal distance (in feet) as measured along a combination of curves and straight lines between two points.

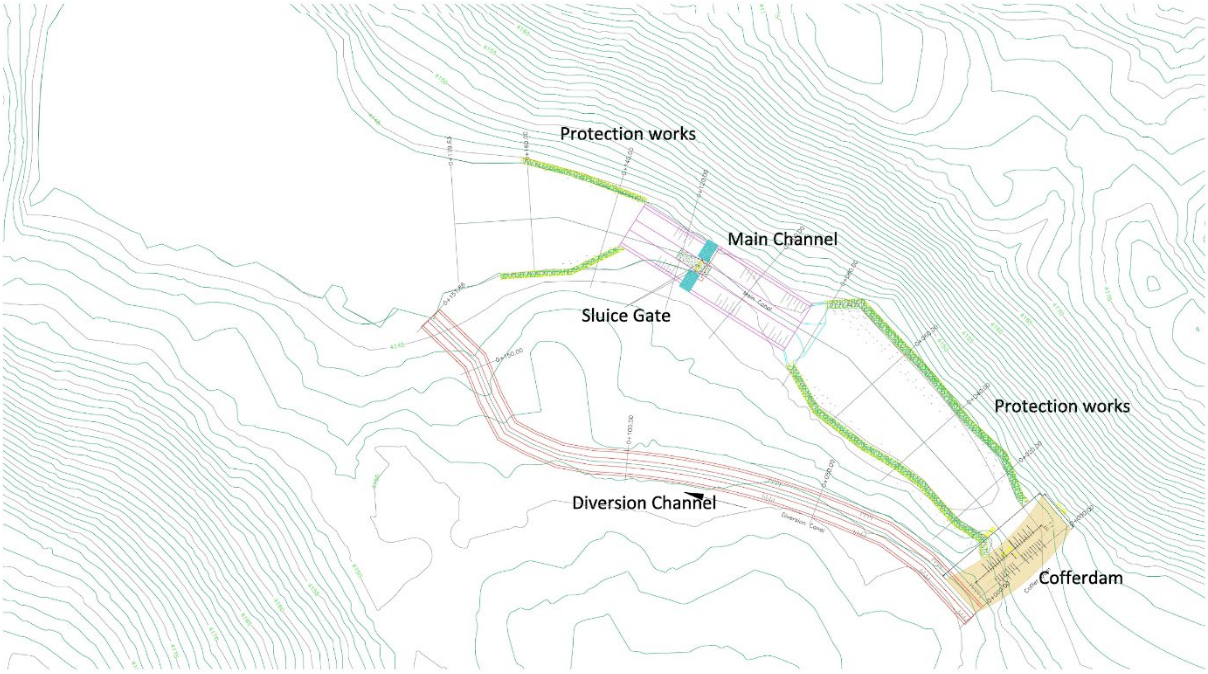

Figure 41. Thulagi Glacial Lake.

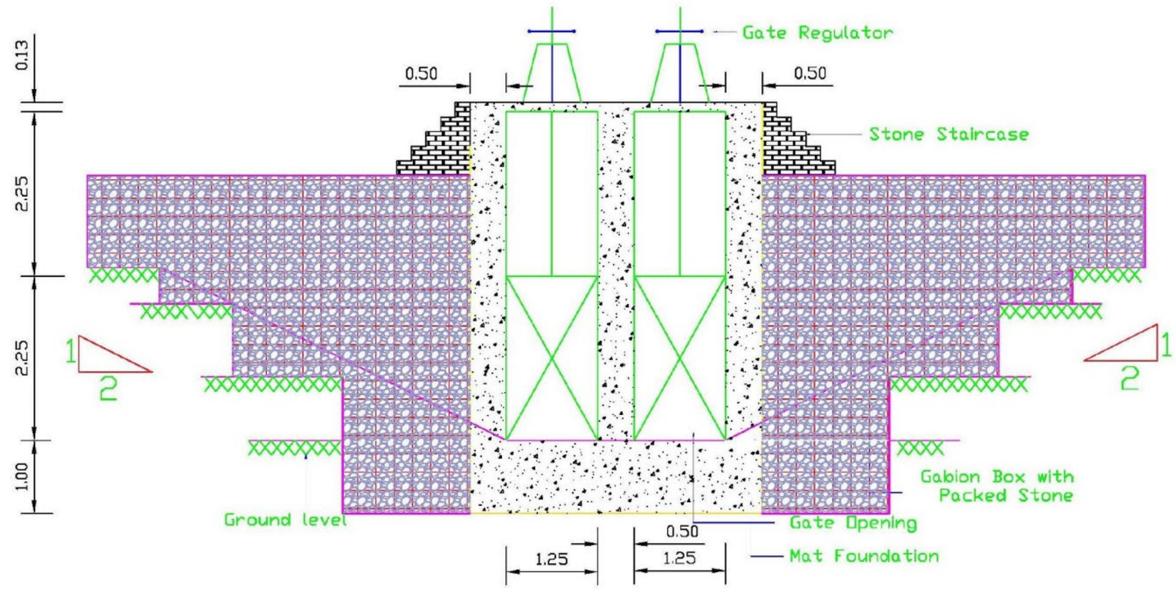

Figure 42. Thulagi vertical sluice gate.

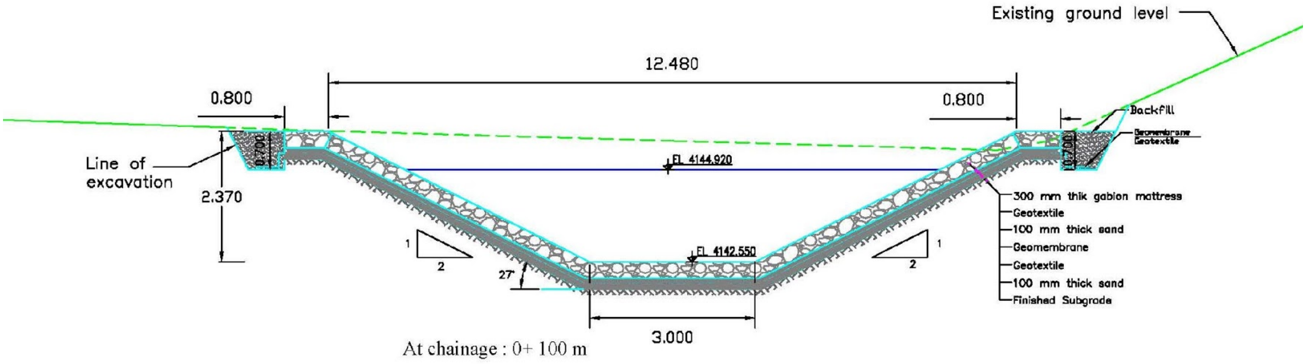

Figure 43. Thulagi main channel cross section.

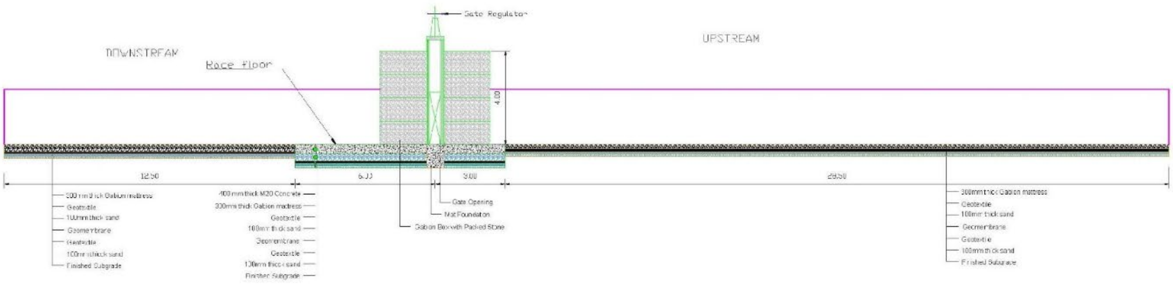

Figure 44. Thulagi main channel profile with gated structure.

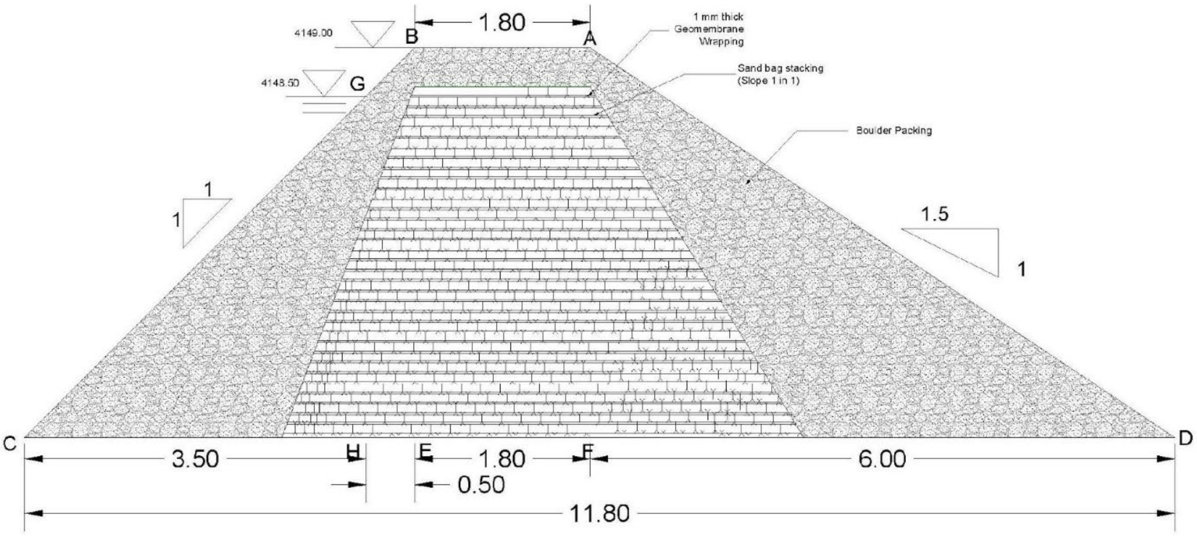

Figure 45. Thulagi cofferdam.

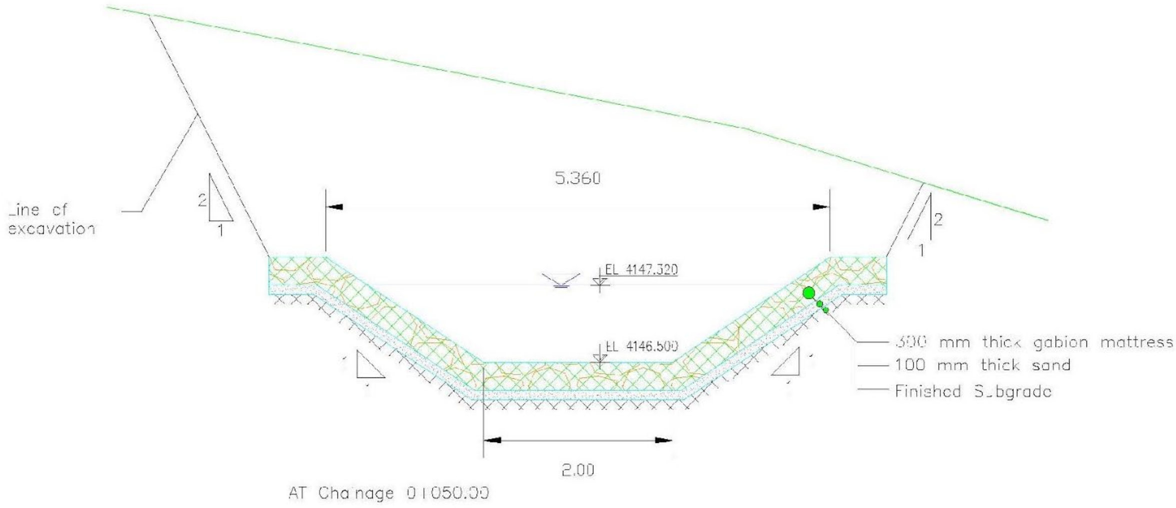

Figure 46. Thulagi diversion channel cross section.

12.1.3. Lumding Tsho Glacial Lake

- The specific dimensions of the proposed structural interventions for lake lowering at Lumding Tsho are presented in Table 35 below. Additionally, the designs for these structures are presented in this section (Figure 47, Figure 48, Figure 49, Figure 50, Figure 51 and Figure 52 below). The stability of the cofferdam was determined through a seepage analysis, with the Lumding Tsho cofferdam predicted to be 5.22 $l.s^{-1}$.
- Unlike Thulagi and Lower Barun, Lumding Tsho has a wide opening at the end moraine. An approach channel has been proposed for this glacial lake to compensate for this.

Table 35. Lumding Tsho Structural Intervention Dimensions.

Structure	Main Channel	Cofferdam	Diversion Channel	Sluice Gate
Length (m)	80	74	100	-
Top width (m)	11.8	1.8	4.7	2.6
Bottom width (m)	3	10.05	2	2.6
Water depth (m)	1	4	0.4	-
Freeboard	0.75	-	0.5	-
Slope	2:1	-	1.5:1	-
Weight (tons)	-	-	-	2.2
Proposed chainage	-	-	-	0+080

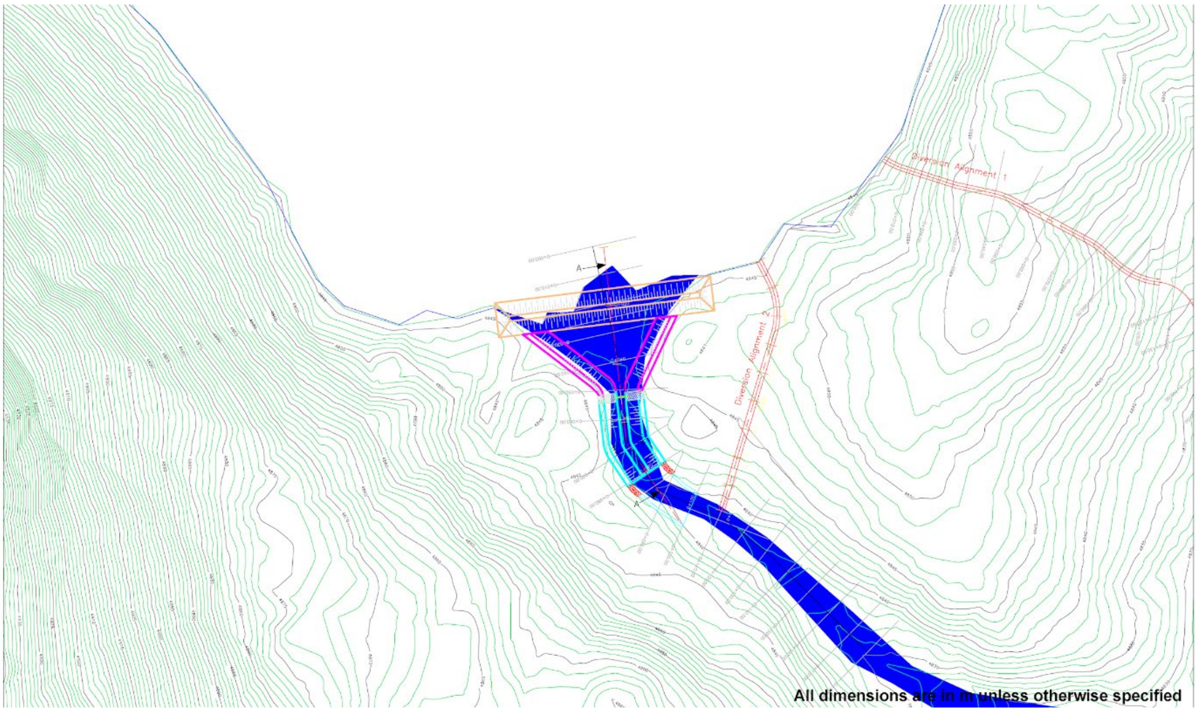

Figure 47. Lumding Tsho Glacial Lake.

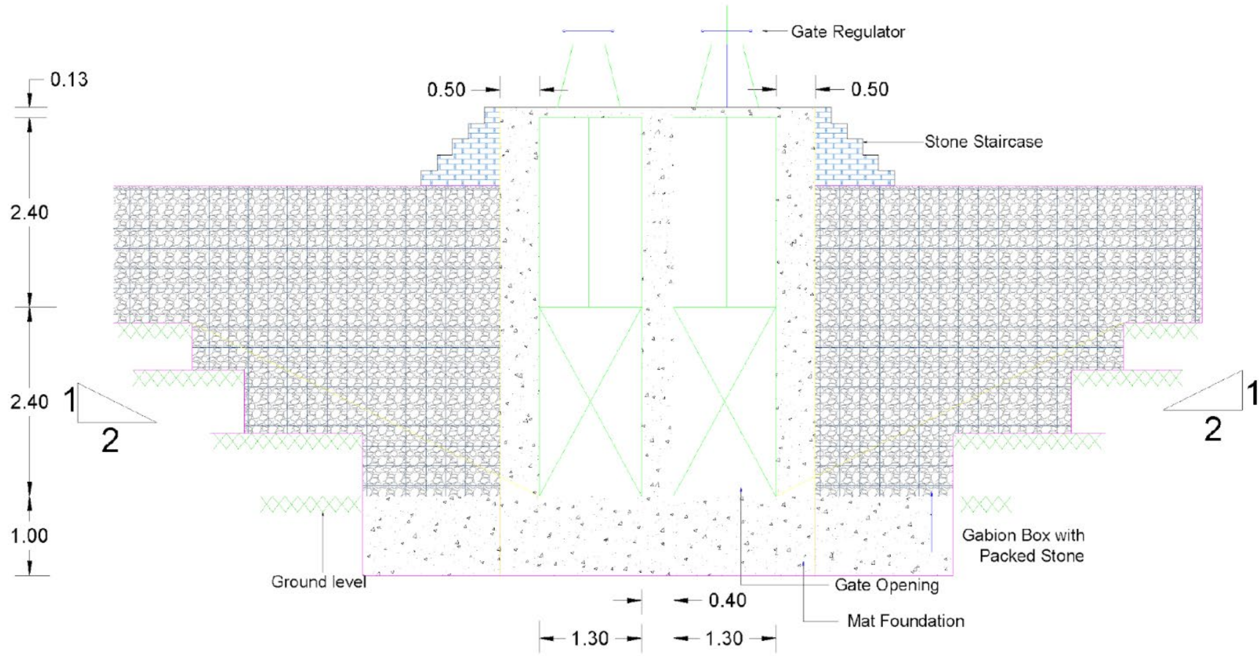

Figure 48. Lumding Tsho vertical sluice gate.

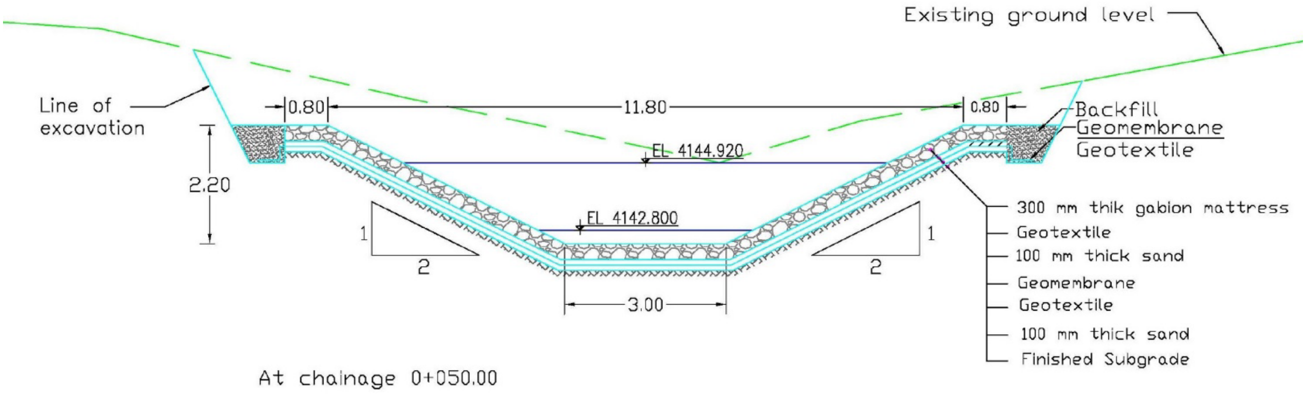

Figure 49. Lumding Tsho main channel cross section.

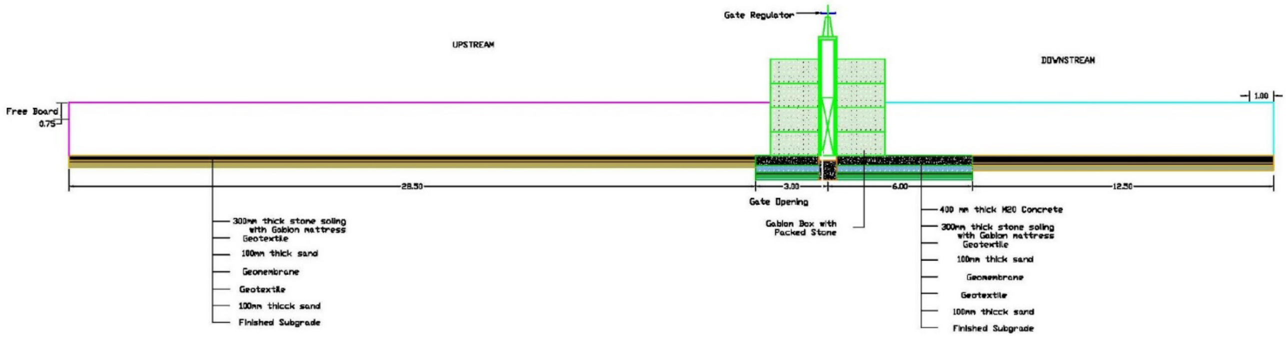

Figure 50. Lumding Tsho main channel profile with gated structure.

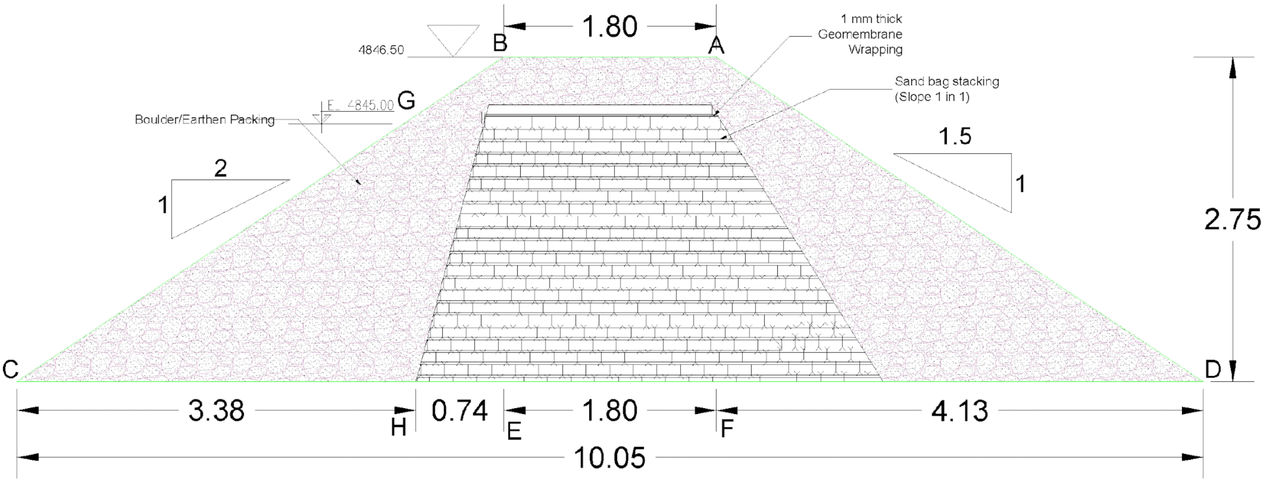

Figure 51. Lumding Tsho cofferdam.

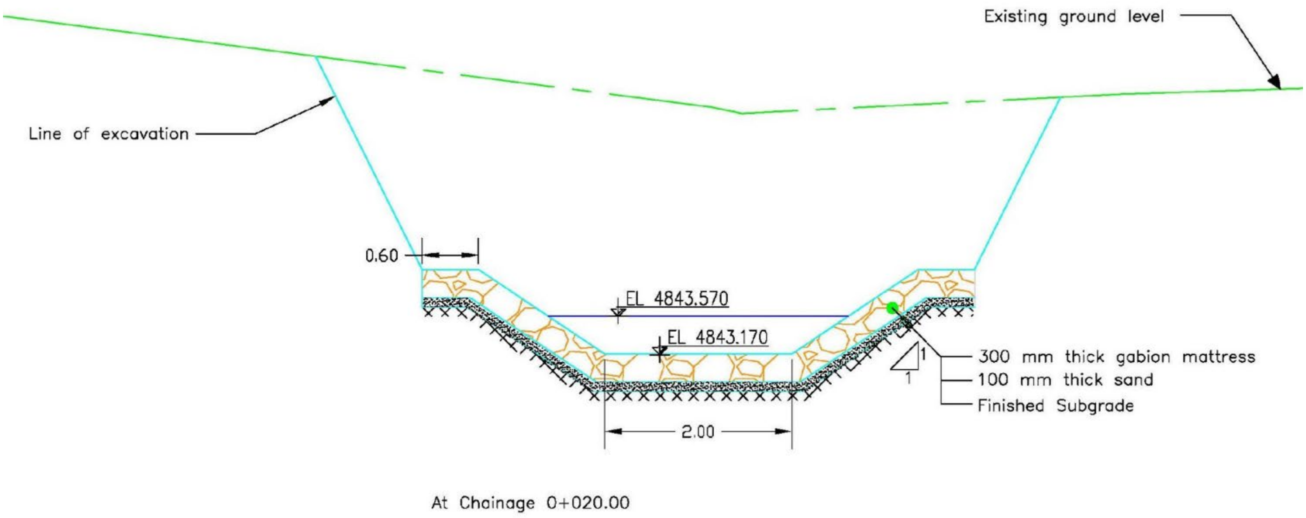

Figure 52. Lumding Tsho diversion channel cross section.

12.1.4. Lower Barun Glacial Lake

- The specific dimensions of the proposed structural interventions for lake lowering at Lower Barun are presented in Table 36 below. Additionally, the designs for these structures are presented in this section (Figure 53, Figure 54, Figure 55, Figure 56, Figure 57 and Figure 58 below). The stability of the cofferdam was determined through a seepage analysis, with the Lower Barun cofferdam discharge predicted to be 21.5 $l.s^{-1}$.

Table 36. Lower Barun Structural Intervention Dimensions.

Structure	Main Channel	Cofferdam	Diversion Channel	Sluice Gate
Length (m)	80	40	180	-
Top width (m)	15.8	1.8	4.85	4.5
Bottom width (m)	5	15.80	2	4.5
Water depth (m)	2	4	0.45	-
Freeboard	0.75	-	0.5	-
Slope	2:1	-	1.5:1	-
Weight (tons)	-	-	-	4.77
Proposed chainage	-	-	-	0+050

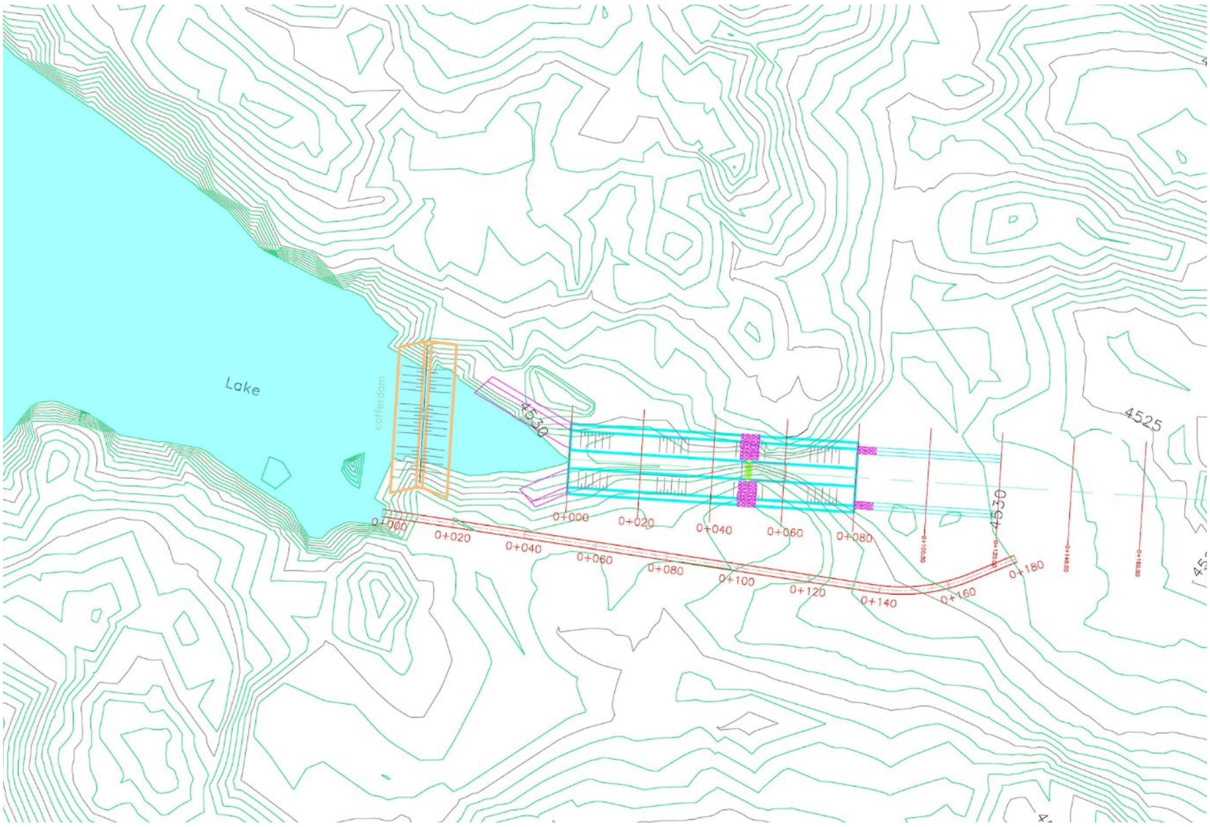

Figure 53. Lower Barun Glacial Lake.

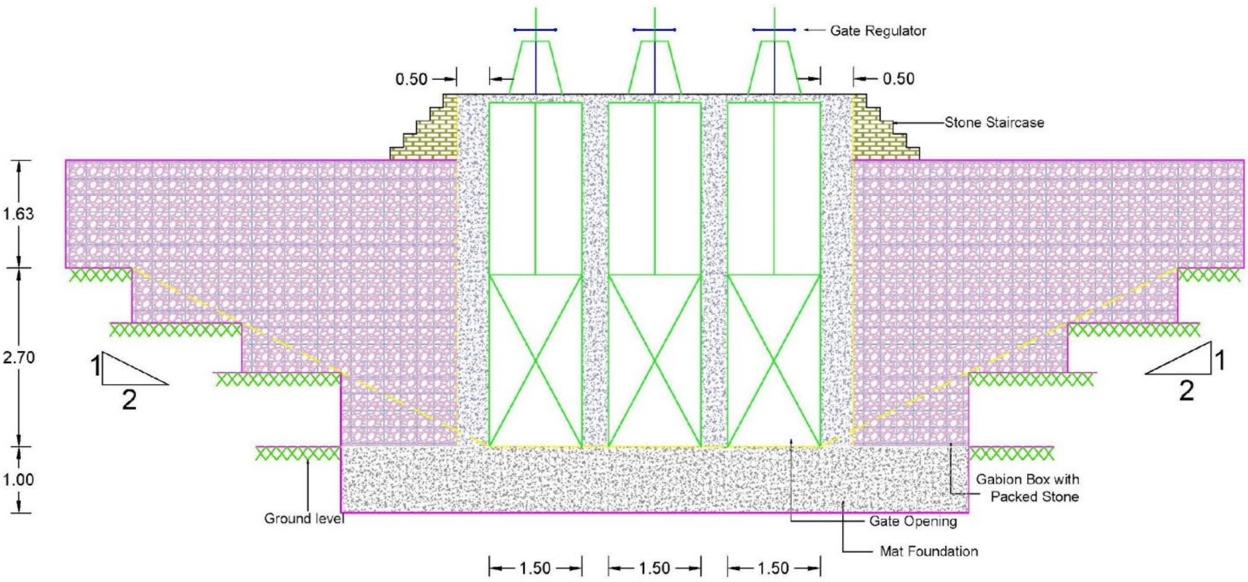

Figure 54. Lower Barun vertical sluice gate.

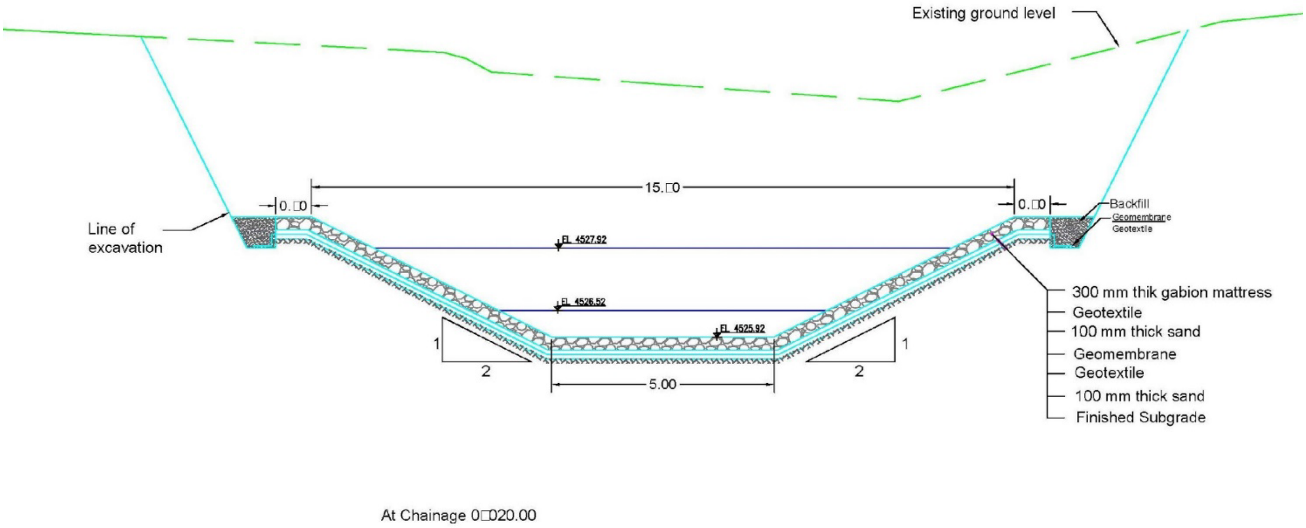

Figure 55. Lower Barun main channel cross section.

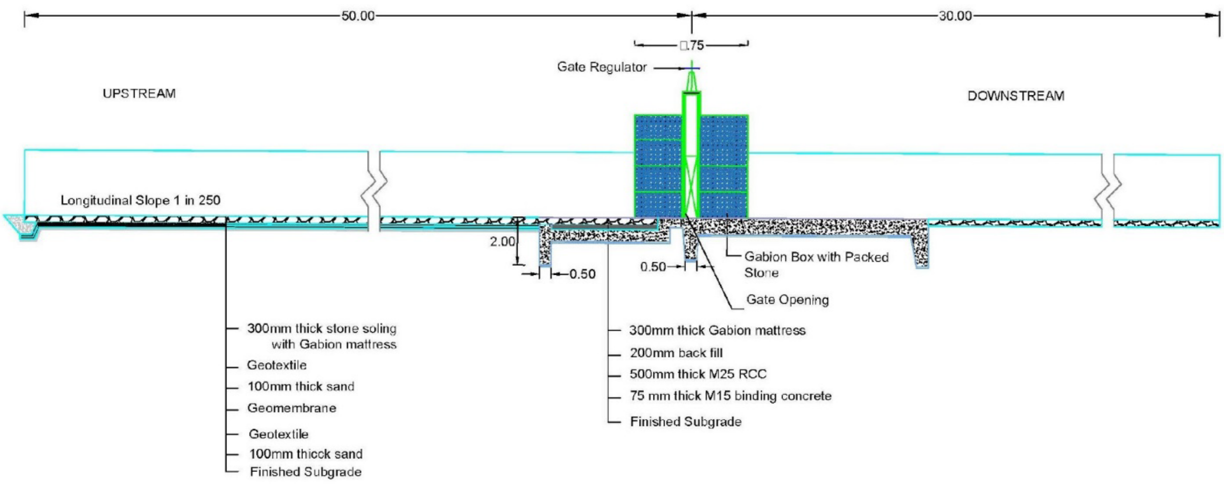

Figure 56. Lower Barun main channel profile with gated structure.

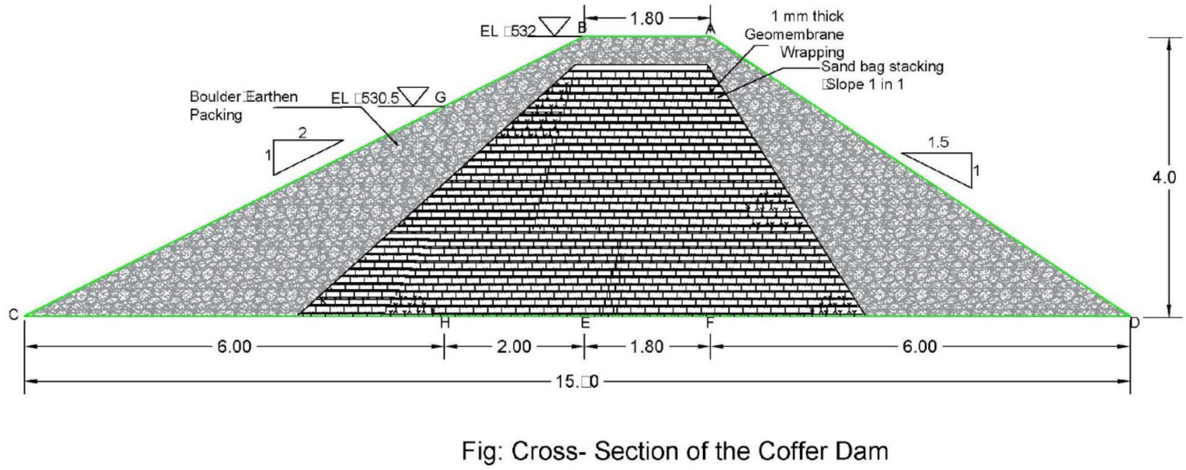

Figure 57. Lower Barun cofferdam.

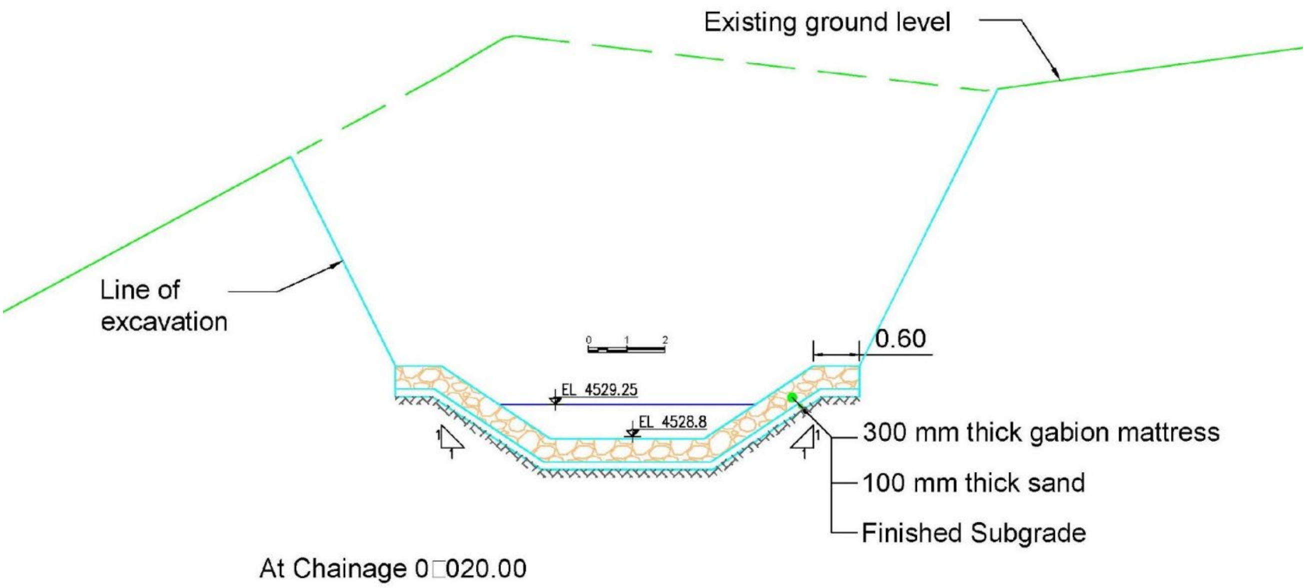

Figure 58. Lower Barun diversion channel.

12.1.5. <u>Hongu 2 Glacial Lake</u>

The structural interventions proposed for Hongu 2 are based on the fact that it is not increasing in size, with the primary threat being avalanches or rockfalls leading to the generation of impulse waves high enough to breach the moraine and resulting in a GLOF event. Based on models conducted under the technical study, the proposed lowering depth of 1m is projected to be sufficient to prevent waves overtopping the moraine under even the most extreme scenario modelled. The specific dimensions of the proposed structural interventions for lake lowering at Hongu 2 are presented in Table 37 below. Additionally, the designs for these structures are presented in this section (Figure 59, Figure 60 and Figure 61 below).

Table 37. Hongu 2 Structural Intervention Dimensions.

Structure	Main Channel
Length (m)	70
Top width (m)	9.8
Bottom width (m)	3
Water depth (m)	1
Freeboard	0.75
Slope	2:1

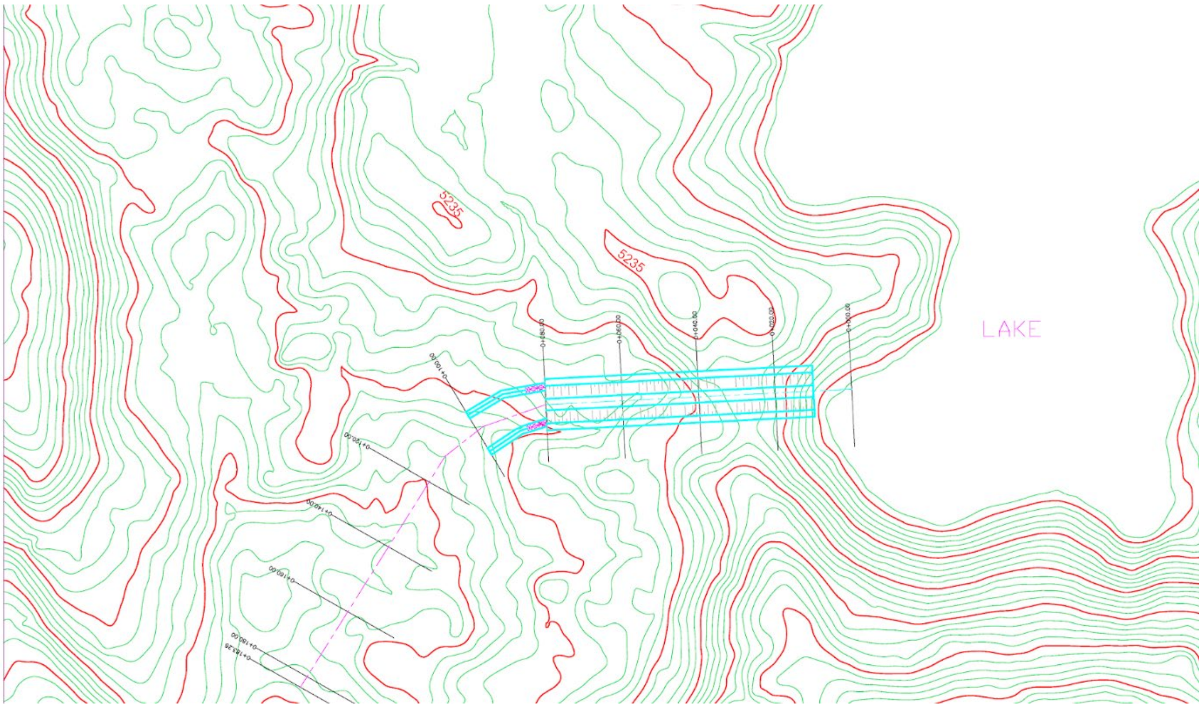

Figure 59. Hongu 2 Glacial Lake.

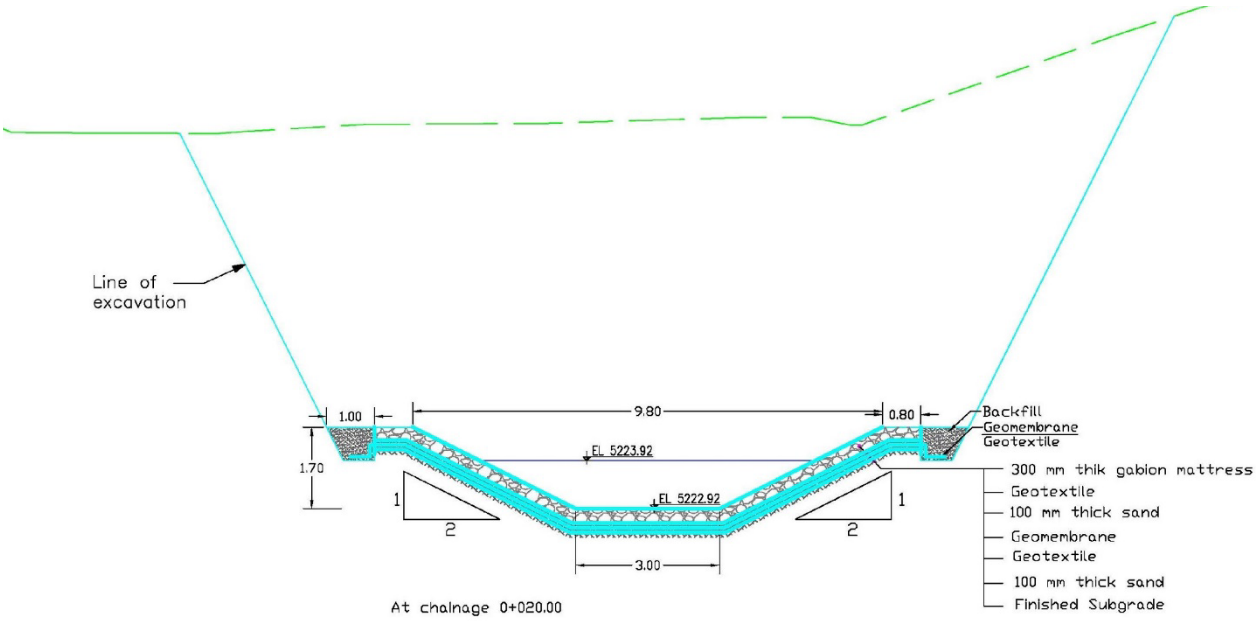

Figure 60. Hongu 2 main channel cross section.

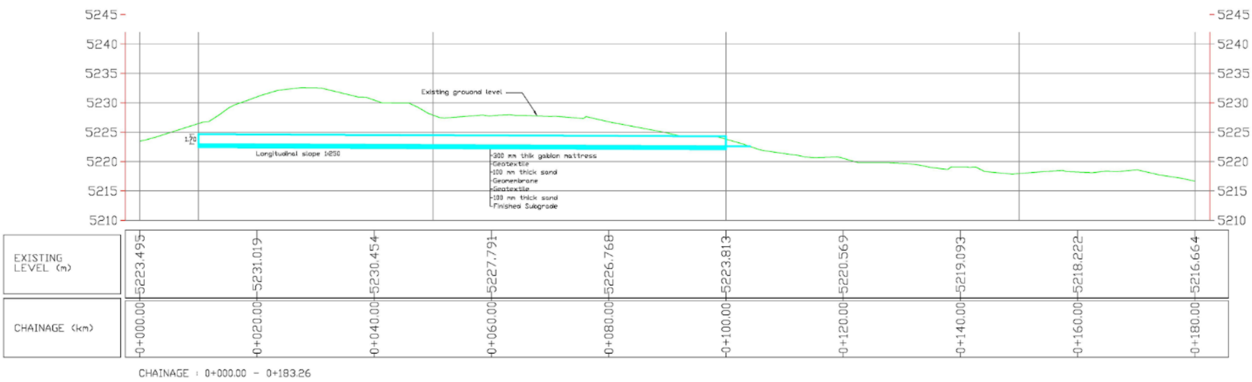

Figure 61. Profile of proposed structure for the Hongu 2 Lake.

12.2. Considerations

12.2.1. General Considerations

Several general considerations regarding the target lake locations and the identification of where to implement interventions were made by the team undertaking the technical studies of the four target glacial lakes, including:

- The site for the structure was chosen based on the contour where the freeboard is minimum, and the excavation volume is the least possible. The natural depression was considered the possible site for the channel where it first overflows from that point when the lake is filled.
- The discharge from the respective glacial lake outlet was calculated or estimated with the glacio-hydrological model. The design discharge for the structural intervention was calculated with a factor of three of the estimated full release for the main channel and maximum monsoon flow for the diversion channel.

- Flexibility and ductility are important aspects to prevent the structure from earthquakes. The major components used in channel sections are the gabion mattresses built from surrounding moraines to consider seismic effect. Only the abutments of the gate and race floor are concrete structures. So, the overall structure at each glacial lake is flexible enough to attenuate the seismic effect.
- The study areas are located in the same geological zones (Higher Himalayan Zone) and between the locations having Seismic Zoning Factor, Z, equal to 0.9 and 1 according to the Nepal National Building Code (NBC 105: 1994) and within 200–300 gal acceleration of seismic hazard according to Nepal Seismological centre, Department of Mines and Geology. From a seismic point of view, all glacier lake sites lie under seismic-prone areas according to the seismic epicentre map published by the Department of Mines and Geology (DMG). The map indicates that M 4.0 to 5.0 on the Richter scale are more frequent than the major earthquakes except for the 2015 Gorkha and Dolakha earthquakes and the 1934 Udaypur earthquake.
- The geological sub-divisions of the Nepal Himalayas arranged longitudinally from south to north are provided below. All lakes fall in the same geological region.
- There are four stages in the planning phase of engineering study, viz—preliminary, pre-feasibility, feasibility, and detail study. The preliminary estimation is done with fewer data and resources. The cost variation is above 25–30%. The pre-feasibility studies are allowed to run between 20 and 30%, whereas the feasibility studies should offer estimates that are within 10 to 20% accuracy. The detailed study accuracy ranges from 5–10%. Since this is a preliminary design study, the estimate's accuracy should lie within 25–30%. Therefore, it is strongly recommended to consider increasing the project's cost by this percentage during the fund application. Bearing the past project implementation experience in Nepal, the cost variation due to time extension because of various factors other than engineering must be considered.

12.2.2. Geological Considerations

Based on geological observations from the technical studies, several considerations should be considered prior to the construction of interventions:

- The stability of the terminal moraines will need to be monitored as — despite being comparatively stable because of the thickness of the moraine and the extension of debris with a moderate slope towards the downstream — the piping effect and splashing from glacier ice breakage could lead to increased instability.
- The presumed Safe Bearing Capacity of the terminal moraine soil for the proposed locations is considered to be greater than or equal to 150 KN/m^2.
- The angle of the existing slope of the outlet is less than the angle of friction which represents that the area is safe from mass movements.
- The target areas are located near the Main Central Thrust of the Himalayas. Project interventions, therefore, need to consider the likelihood of earthquakes and earthquake-triggered events in their implementation.

12.2.3. Technical considerations before lake lowering

The proposed technical designs were developed based on a rapid technical assessment of the target glacial lakes by a technical team with experience from the lowering of Lake Imja. The technical assessments below were not performed under the initial technical studies and are proposed to be implemented by the project prior to construction (Activity 3.1), as this will ensure that the designs take into account the most up-to-date characteristics of each lake their surrounding geography. This will also allow for the technical studies to be integrated into the projects Monitoring and Evaluation framework and the broader knowledge base developed under the project.

- Topographical surveys of each site and moraine dam are needed for detailed analyses and to inform the precise design of proposed interventions.
- Bathymetric surveys to determine the most recent volume, depth, topography, lake extension and changes to end moraines for each lake.
- Hydrometeorological surveys using the tracer method are required to provide more detailed information on the current discharge of glacier outlets.
- Geophysical surveys — including the use of GPR and electric resistivity tomography — of the sites are required to determine the stability of the moraine dams and the intensity of the geophysical environment.

13. Justification for project beneficiaries

Project beneficiaries were assessed based on the areas of the Arun, Dudhkosi and Marsyangdi River Basins, where glacial lake lowering and GLOF risk reduction and mitigation measures will take place under the proposed interventions. Proposed project activities will also include the restoration of degraded ecosystems in the Arun and Dudkhosi Basins. Flood risk reduction and mitigation measures are designed based on GLOF and flash flood hydrological models that consider the vulnerability of the sites and the human activities which occur in the area. Similarly, the proposed ecosystem restoration measures are based on the degree of environmental vulnerability of the basins. It is expected that the ecosystem restoration measures will trigger benefits for the populations living in the basins by improving ecosystem health.

Communities living in the basins will benefit directly or indirectly from the risk reduction measures implemented by the project. Administrative boundaries were overlaid on a Digital Elevation Model (DEM) of the area to determine direct or indirect beneficiaries. The geospatial analysis also included a local drainage network map, contour map and settlement map. This analysis was undertaken using Geographic Information Systems (GIS), with shapefiles[557] that were obtained from OpenStreetMap (OSM)[558]. The following assumptions were made to delineate direct and indirect impact areas:

- in the areas where flood risk reduction and mitigation measures are proposed, the populations and surrounding environment will directly benefit;
- in the areas where ecosystem restoration measures are proposed, the populations and surrounding populations will directly benefit; and
- communities that are situated immediately adjacent to the areas where flood risk reduction and mitigation measures or ecosystem restoration measures are proposed will indirectly benefit.
-

The area of the basins has been divided — to define the impact areas clearly in order to estimate direct beneficiary populations accurately — into: i) the main river basin area where flood risk reduction and mitigation measures and ecosystem restoration measures are proposed; and ii) downstream areas of the main river channel where early warning systems (EWS) are proposed. Any areas adjacent to these areas are considered indirect beneficiary impact areas.

A total of 385,956 direct beneficiaries and 1,912,347 indirect beneficiaries are estimated based on the populations of the impact areas (Table 38). The estimated direct impact areas of Arun and Dudhkosi Basins are 5,115 km^2 and 4,063 km^2, respectively (Figure 62). The downstream impact areas of these basins are 856 km^2 and 1917 km^2, respectively (Figure 63 and Figure 64). The impact area of the Marshyandgi Basin is 1917 km^2 (Figure 65). There are 29 municipalities in the direct

[557] A shapefile is a format for storing the geometric location and attribute information of geographic features.
[558] OpenStreetMap (OSM) is a collaborative, project to create a free editable geographic database of the world. More information available at: www.openstreetmap.org.

impact area of the Arun Basin, and 16 and 19 in the Dudkhosi and Thulagi Basins, respectively (Table 39).

Table 38. Number of direct and indirect beneficiaries by basin and disaggregated by sex.

Basin	Direct beneficiary population (female)	Direct beneficiary population (male)	Direct beneficiary population (total)	Indirect beneficiary population (female)	Indirect beneficiary population (male)	Indirect beneficiary population (total)
Arun	11,866	10,865	22,731	194,222	177,850	372,072
Dudkhosi	28,759	26,435	55,194	164,237	150,393	314,630
Arun/Dudkhosi common downstream	65,925	61,783	127,708	253,067	241,388	494,455
Arun/Dudkhosi in between	N/A	N/A	N/A	38,959	35,675	74,634
Thulagi	94,679	85,645	180,324	386,173	345,016	731,189
Total	201,228	184,728	385,956	997,699	914,648	1,912,347

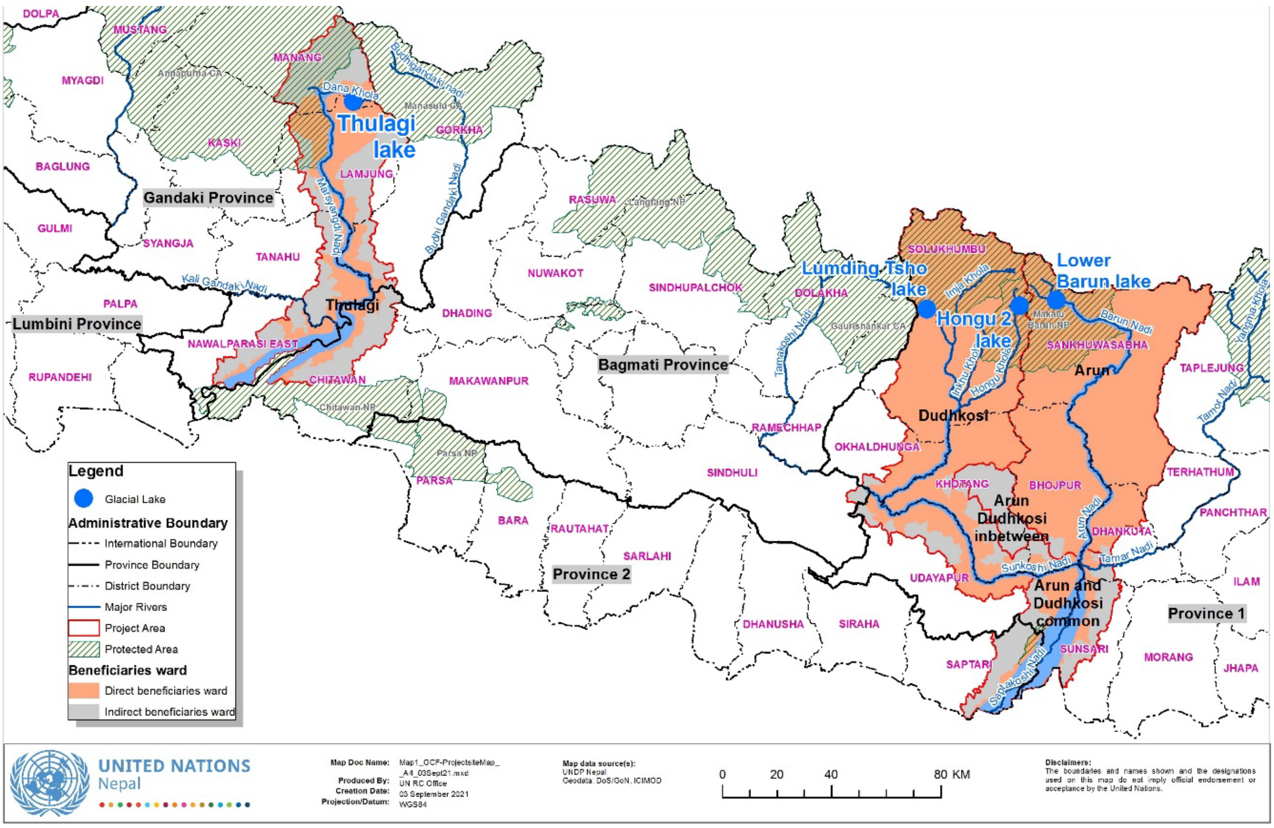

Figure 62. Overall map of the project sites and the delineated direct and indirect beneficiary areas.

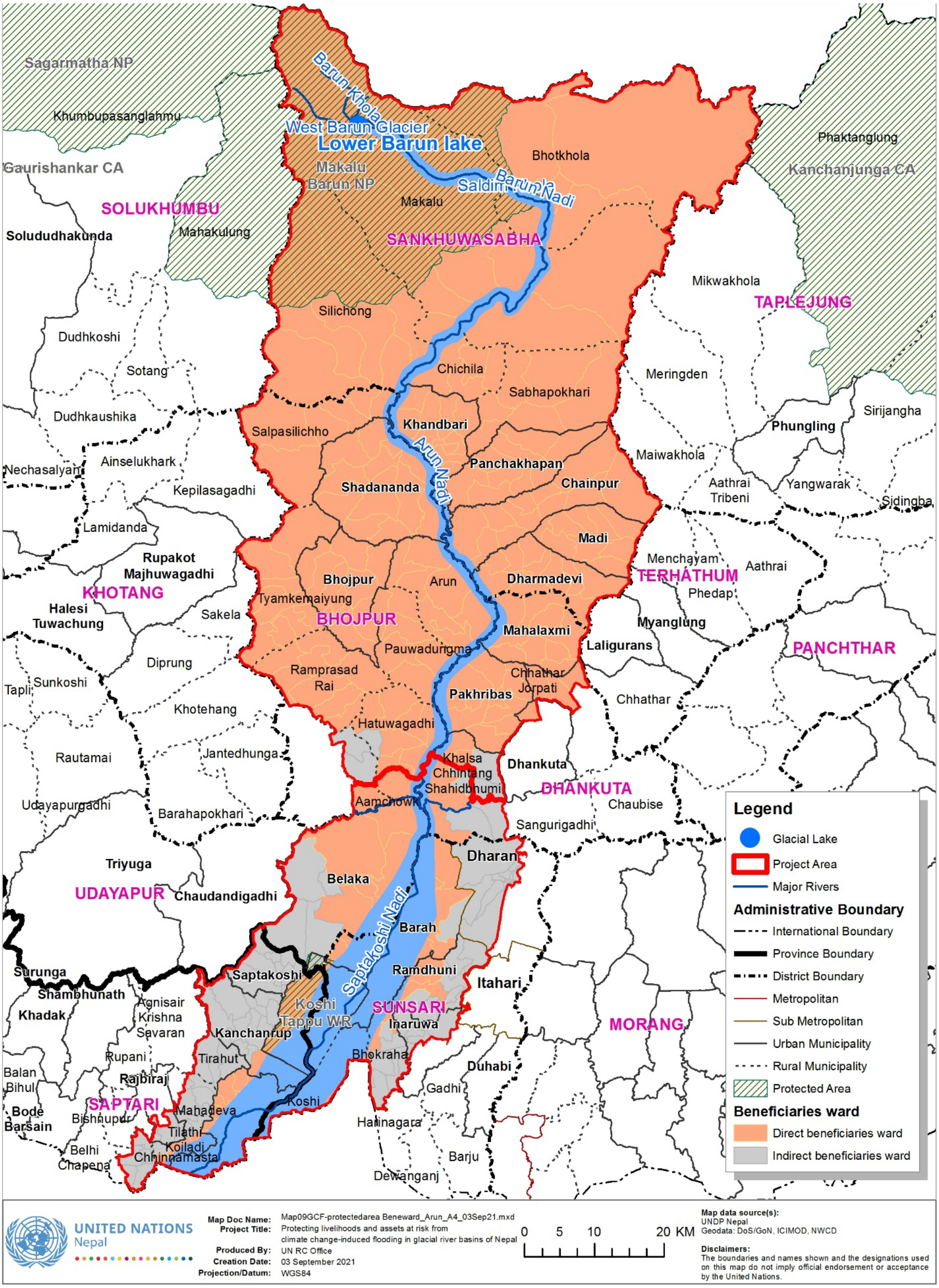

Figure 63. Map of delineated direct and indirect beneficiary areas in Arun Basin.

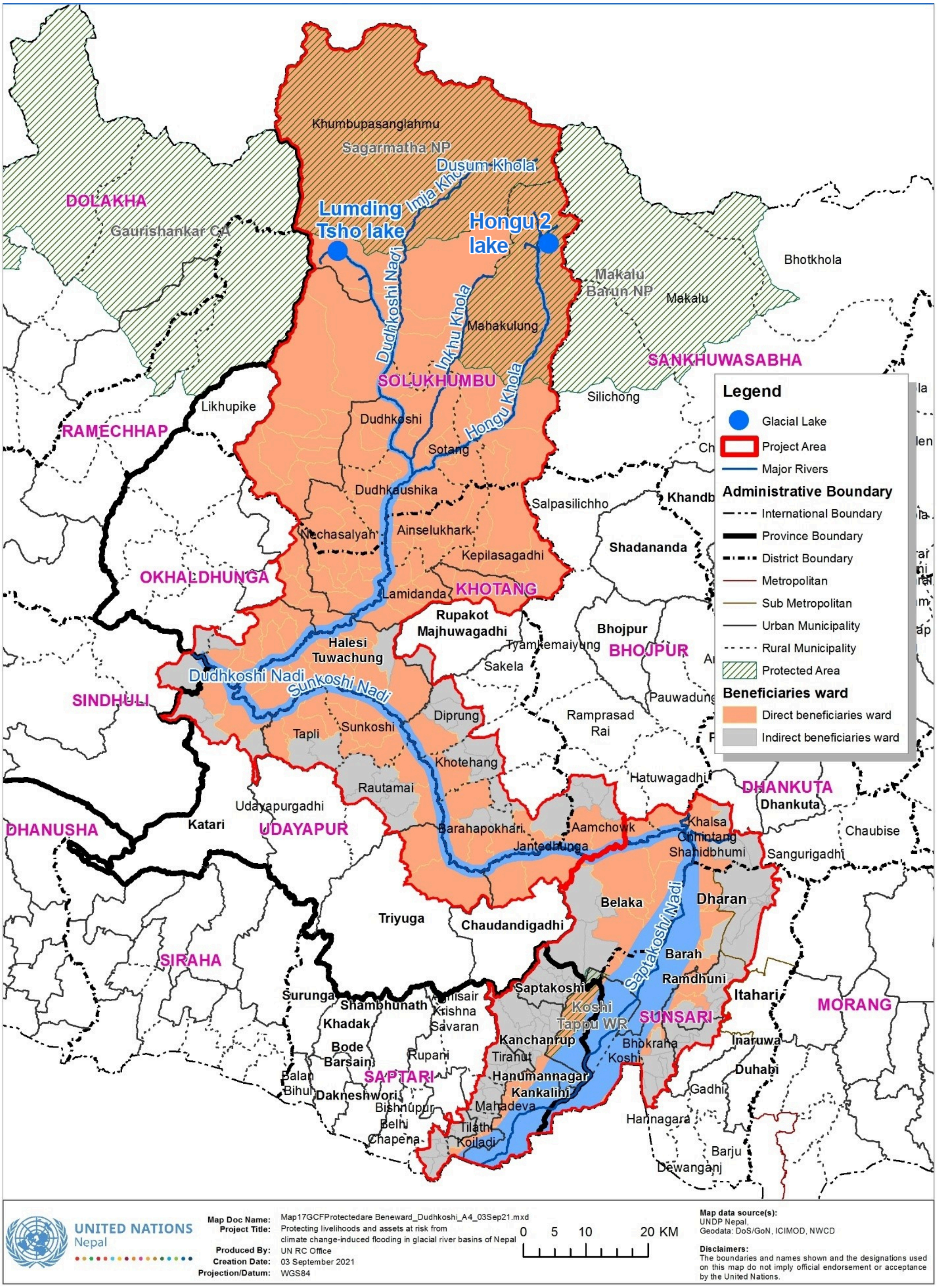

Figure 64. Map of delineated direct and indirect beneficiary areas in Dudhkosi Basin.

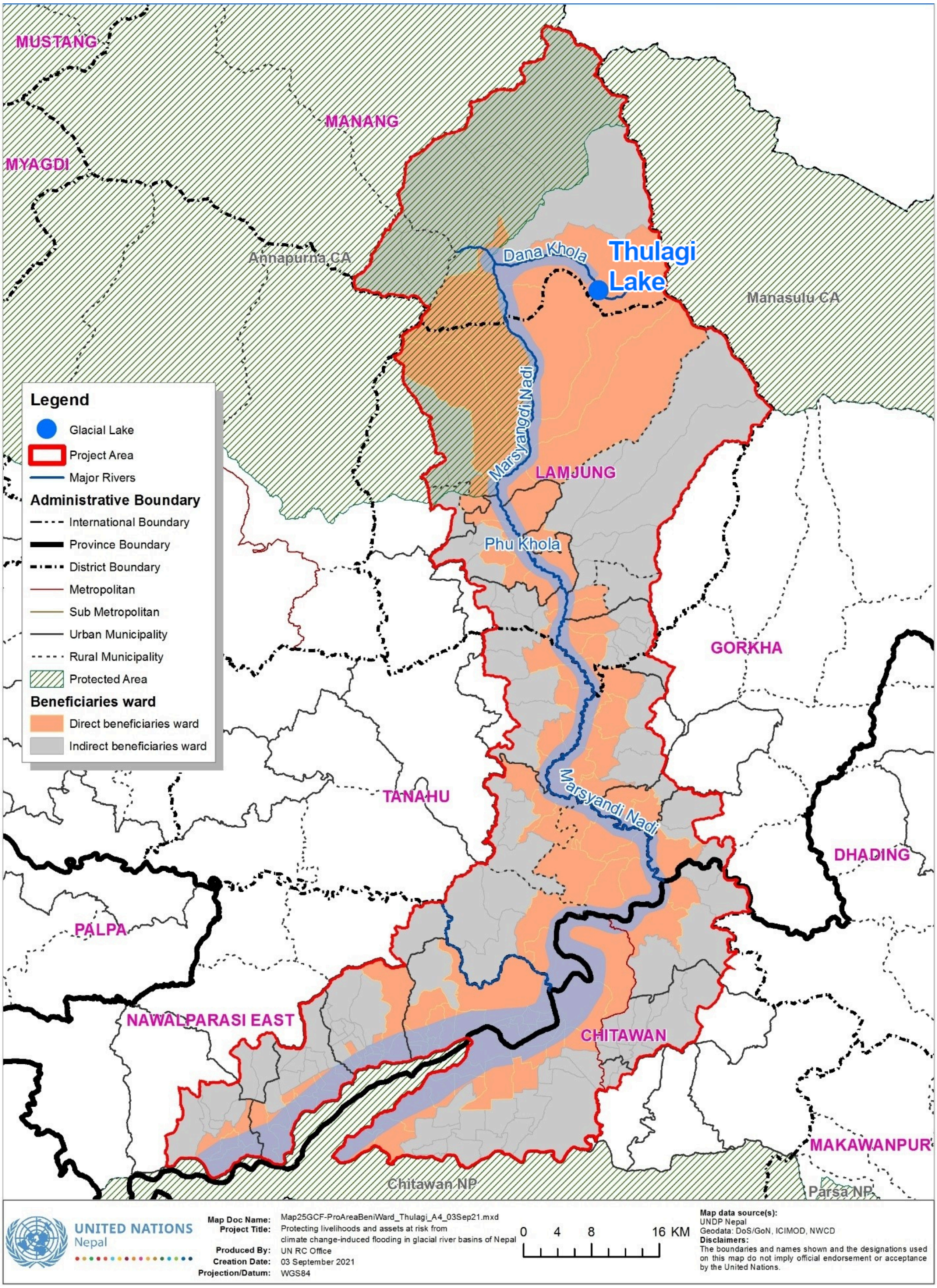

Figure 65. Map of delineated direct and indirect beneficiary areas in Thulagi Basin.

Table 39. Municipalities in the direct beneficiary impact areas by District.

District	Municipality
Bhojpur	Aamchowk
	Arun
	Bhojpur
	Hatuwagadhi
	Pauwadungma
	Ramprasad Rai
	Salpasilichho
	Shadananda
	Tyamkemaiyung
Chitawan	Bharatpur
	Ichchhyakamana
	Kalika
	Ratnanagar
Dhankuta	Chhathar Jorpati
	Dhankuta
	Khalsa Chhintang Shahidbhumi
	Mahalaxmi
	Pakhribas
	Sangurigadhi
Gorkha	Gorkha
	Palungtar
	Sahid Lakhan
	Siranchok
Sankhuwasabha	Bhotkhola
	Chainpur
	Chichila
	Dharmadevi
	Panchakhapan
	Khandbari
	Sabhapokhari
	Silichong
	Madi
	Makalu
Khotang	Ainselukhark
	Halesi Tuwachung
	Kepilasagadhi
	Lamidanda
	Rupakot Majhuwagadhi
	Barahapokhari
	Diprung
	Halesi Tuwachung
	Sakela
	Jantedhunga
	Khotehang
Okhaldhunga	Chisankhugadhi
	Siddhicharan
	Sunkoshi
	Manebhanjyang

Solukhumbu	Dudhkaushika
	Dudhkoshi
	Khumbupasanglahmu
	Mahakulung
	Nechasalyan
	Solududhakunda
	Sotang
Udayapur	Chaudandigadhi
	Katari
	Rautamai
	Sunkoshi
	Tapli
	Triyuga
	Katari
	Belaka
Sunsari	Barah
	Bhokraha
	Dharan
	Inaruwa
	Koshi
	Ramdhuni
Lamjung	Besishahar
	Dordi
	Marsyangdi
	Rainas
	Dudhpokhari
	Kwholasothar
	Sundarbazar
Manang	Nashong
	Chame
Nawalparasi	Devchuli
	Bulingtar
	Gaidakot
	Hupsekot
	Kawasoti
	Madhyabindu
Saptari	Hanumannagar Kankalini
	Chhinnamasta
	Kanchanrup
	Mahadeva
	Rajbiraj
	Saptakoshi
	Koshi Tappu
	Tilathi Koiladi
	Tirahut
Sindhuli	Phikkal
Tanahu	Anbukhaireni
	Bandipur
	Bhanu
	Devghat