ASSESSMENT OF CLIMATE RISKS ON WATER RESOURCES FOR NATIONAL ADAPTATION PLAN (NAP) FOR BHUTAN

Priority Risks and Recommendations for Adaptation

OCTOBER 2023

DEPARTMENT OF WATER

Executive summary

This report presents the final results of the assessment of climate risks on water resources for the National Adaptation Plan (NAP) in Bhutan. It identifies the main priorities for adaptation for drinking water and irrigation water supply, hydropower and disaster risk management.

Water being cross-sectoral in nature and realizing its criticality, the current NAP Project for Bhutan provides prime focus on the water sector. Water is one of the major resources for Bhutan through hydropower and agriculture activities across the country, which are critical for Bhutan. However, with the changing climate, the water sources are dwindling and drying up, with experiences of wetter summer months and drier winter months and increased melting of glaciers. Such a situation has multiple effects on various sectors, in particular those sectors that are primarily dependent on water, such as drinking and sanitation, agriculture, hydropower, disasters and others. As water is a cross cutting sector as well as climate sensitive, it has been selected as a key area for the NAP in Bhutan.

Therefore, the study, “Assessment of climate risks on water resources for the NAP" has been undertaken. In this study the potential impacts of climate change on water resources in Bhutan are explored to prioritize and formulate actions for the NAP. Therefore, a climate vulnerability and impact analysis has been performed on which these priorities for actions can be based. The aim of a climate vulnerability analysis is to identify those climate conditions that lead to the most severe impacts within the boundaries of both historic climate variability and future climate uncertainties. More specifically, the climate change impacts on water resources are assessed for drinking water supply and sanitation, irrigation water supply, hydropower and water related disasters from the national to local level.

Approach of the project

The prime objective of this assessment is to identify priorities and hotspots for adaptation and corresponding appropriate actions for the short and longer term. Therefore, it is necessary to know:

- Where climate variability and change are already leading to water issues?
- How are these issues likely to increase on the short and long term?
- What is the best adaptation strategy to tackle these issues?

Thus, a bottom up (regional consultation) and top down approach (climate and hydrology analysis) are combined in which:

- The consultation (at dzongkhag and thromde) provides information on what are specific issues experienced, when, where (gewog/location) and what are the perceived causes (climate or other) as well as the capacity building requirements and identification of vulnerable groups.

- The climate and hydrology analysis shows how water availability and hazards have evolved historically, and how is it likely to evolve in the future.

- The main impacts are approached by dry spell and flood indicators/metrics that are calculated based on the climate and hydrology analysis. The outcome of the indicator analysis called “risk characterization” serves as a proxy for the likelihood of future occurrence of identified water issues.

Depending on the issue, the main causes are identified, the top down assessment of impact indicators and the confidence in the analysis of the impacts, and adaptation options are recommended.

Table Issues and metrics (indicators) applied to approximate the impacts

Issue	Proxy variable	Specific metric/statistic
Droughts/ water shortages	Daily stream flow at sub-catchment level Daily groundwater recharge at Gewog level	Changes in the duration, frequency, and severity of dry spells. Dry spell threshold set to Q10 of daily 7MA of flow/recharge.
Extreme precipitation/ flooding	Daily precipitation at Gewog level Daily stream flow at sub-catchment level	Changes in the frequency of extreme rainfall and flow events (at 10 and 30 years return intervals)
Landslides	Proxy variables: Daily precipitation at Gewog level	Changes in the 7-day accumulated precipitation amounts during the Monsoon season (JJASO)
GLOF	Daily temperatures	Change of area with permafrost
Hydropower	Proxy variables: Daily river flow at hydropower plant locations	Changes in annual, as well as dry and wet season means.

Risks of **local dry spells** at Gewog level are expected to increase under climate change for large parts in the country enhancing the drying of water sources that are already clearly visible to date. This will increase the challenge to keep up the speed in supplying the growing water demand for drinking, industrial and irrigation water.

Increase of **frequency and duration of low flows** in main rivers are assessed as an uncertain risk for Bhutan, as projections of periods of low flows are both showing decrease and increases in dry spells depending on global emission scenarios and time horizon. For RCP4.5 (current emission trajectory) periods of low flows for the short term are rather decreasing than increasing. For the long term the opposite is true. However, given the large uncertainty in the current analysis it is important to continue monitoring the trend in low flows and improve the understanding of the hydrological processes involved, especially for those streams that are key for water supply.

The **risks of increased floods**, both pluvial and riverine are assessed as rather high. There are already many serious reports on these issues and at the same time the projected changes especially for the second half of the century seem substantial.

Projections in 7-day consecutive rainfall events, potentially triggering **landslides**, point towards a clear increase especially for the longer term. There are already many reports on serious impacts of landslides as well. For a higher confidence assessment, all contributing factors to landslides including local geomorphological (slope, soil and land use characteristics) conditions should be combined in one analysis.

Melting of glaciers is already occurring under the current warming and will continue to occur in the future under clearly increasing temperature trends that are stronger at higher altitudes. Historically, **GLOFs** are a known phenomenon in glacial areas in Bhutan. Most risky sites have been identified and are being monitored. Under projected temperature trends the risks on GLOF events will increase. Projected extreme precipitation increases may also add to increasing risks.

Although the above-mentioned issues are occurring throughout the whole of Bhutan, it is evident that not all dzongkhags and gewogs will experience them with the same level of impact. Therefore, the study has also presented results per dzongkhag and gewog illustrating the local issues and future projections and its uncertainty.

Based on this assessment the main direction for adaptation is a flexible strategy that starts with low-regret actions that improve the resilience and robustness of the water sector in Bhutan over time.

Recommendations for adaptation

Based on the above analysis, seven strategic directions (objectives) for adaptation (and underlying actions for the short and long term) are recommend for inclusion in the NAP:

1) Strengthening ecosystems

Improve the natural capacity for infiltration and water buffering – Key for this is to improve the existing system for watershed protection and management. Actions include ecosystem restoration, and reforestation. A healthy good functioning ecosystem is the basis for a *resilient* water system.

Prevent fast runoff and erosion by maximizing infiltration and buffering in ecosystems by preventing overgrazing, applying agriculture practices minimizing erosion, wetland restoration, afforestation.

2) ***Improved flood risk management and planning***

Maximize the discharge capacity of river and streams by instituting no build zones, remove unnecessary bottlenecks and if needed, build emergency storage and bypasses to assist in controlled release from glacial lakes. To create more *robust river systems,* implement at a larger scale, flood risk management plans.

3) ***Protect critical infrastructures and settlements*** against floods and landslides by applying flood mitigation structures, slope stabilization, improved drainage systems in urban areas.

4) ***Develop more resilient infrastructure*** on different levels: better planning of roads and settlements to avoid risky places, design of roads, supply & sanitation infrastructures, build back better (replacement) and operation and maintenance of infrastructure (aimed at fast recovery).

5) ***Improve early warning and response & recovery capacity*** **–** expand and improve existing early warning systems for GLOFs and other types of flash floods**.** Make sure that relief funds (and other mechanisms e.g. insurance) for fast repair and recovery of properties and infrastructures and to compensate for damages are in place.

6) ***Increase robustness of sectoral water supply and demand*** for drinking and irrigation water; where needed, generate additional water buffers to overcome periods of drought – low regret actions that can be started at the short-term are the restoration of existing sources, study the options for household level rain water harvesting or create additional storage capacity at community level (e.g. in GW aquifers). The fast development of Bhutan at some locations (e.g. larger towns, agricultural or tourism centers) may also require a step-change in water supply systems. For the short term, further study could be started on how larger scale multi-purpose reservoirs, larger water supply schemes or sustainable use of ground water can add extra robustness on the longer term. To reduce exposure and vulnerability to dry spells a low regret short term action is to continue and intensify the improvement of the water use efficiency in domestic and agricultural supply and demand by applying new irrigation techniques, reduction of water losses in supply network and irrigation channels and modernized sanitation systems.

7) ***Increase the climate resilience of the Hydropower sector*** through existing and newly built hydropower facilities to cope with more erratic flow patterns and increase of disaster risks. Actions include upstream watershed management and downstream disaster risk management as well as exploration of new technologies.

In addition to the above actions, ***enabling actions*** are identified:

Training and capacity building of planners and operators. *Awareness raising* of citizens to ensure that they are capable of responding in an appropriate manner in case of a disaster. For water supply, WUAs could be further capacitated as they have a key role and are responsible for regular monitoring and maintenance of water sources, the appointment of a water caretaker and contribution of a monthly budget.

Research & capacity building among local experts. To increase the confidence in future analysis on impact and adaptation, additional studies need to be done, for example on the contribution of groundwater and the cryosphere to seasonal water availability under different climate scenarios, on more detailed exposure scenarios (e.g. on future land use and water demand) and at potential and feasibility of specific adaptation strategies such as rainwater harvesting, land use changes, nature-based solutions and possible multi-purpose reservoirs. Capacity building among local experts from NCHM, policy makers, water, ecosystem and disaster risk managers should go hand in hand with new knowledge acquired. A start has been made to learn to work with the climate and hydrology and impact data acquired during the current project. Follow up capacity building can encourage a more structural use of the models and data by the institutions in Bhutan.

Monitoring is a key activity, that should have a central role in the NAP as it is the most important way to get a better understanding on climate, hydrology and impacts on the water sector. Monitoring can also support the progress of implementation of actions and their effects. To that end it is a necessary means to increase confidence in future analyses.
It is recommended to choose a comprehensive, yet feasible set of indicators that capture the most important aspects of the causes (climate and other), interventions (in line with NAP) and impacts (hydrology, sectoral). Indicators could be similar to the ones used in the Bhutan water security index (BWSI) system as earlier applied in Bhutan (NECS, 2016). A follow up definition study for a monitoring framework is recommend as a short-term low regret action. Based upon the findings in the current study, an improved monitoring system should further include: watershed and source quality and quantity monitoring, improve hazard reporting (incl. consequences) and improve monitoring of exposure and vulnerability (e.g. of critical infrastructures).

To prepare for further implementation, responsible institutions should prioritize locations for investments, identify funding arrangements and build capacity and issue follow up research that can support better targeted investments.

Contents

Acronyms and Abbreviations

BHU	Basic Health Unit
BU	Bottom-up
CMIP5	Coupled Model Inter-comparison Project Phase 5
CMIP6	Coupled Model Inter-comparison Project Phase 6
CNRM	Centre National de Recherches Meteorologique
CRU	Climate Research Unit
DES	Department of Engineering Service
DGPC	Druk Green Power Corporation
DHPS	Department of Hydropower and Power systems
DJF	December, January and February
DR	Disaster Risk
DT	Dzongkhag Tshogdu
EbA	Ecosystem-based adaptation
ECMWF	European Centre for Medium Range Weather Forecast
ERA5	ECMWF Reanalysis Archive version 5
FEMD	Flood Engineering and Management Division
GCM	General Circulation Model
GHG	Green House Gases
GLOF	Glacier Lake Outburst Flood
GNHCS	Gross National Happiness Commission
GT	Gewog Tshogchhung
GWP	Global Water Partnership
HDPE	High-density polyethylene
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institute Pierre-Simon Laplace
IWRM	Integrated Water Resources Management
JJAS	June, July, August and September
LAP	Local Area Plan
LG	Local Government
MAM	March, April and May
MIROC	Model for Interdisciplinary Research on Climate
MoAF	Ministry of Agriculture and Forestry
MoEA	Ministry of Economic Affairs
MoH	Ministry of Housing
MoHCA	Ministry of Home and Cultural Affairs
MoWHS	Ministry of Works and Human Settlement
MPI-ESM	Max Planck Institute for Meteorology Earth System Model
MRI	Meteorological Research Institute
NAP	National Adaptation Plan
NASA	National Aeronautics and Space Administration
NCHM	National Center for Hydrology and Meteorology
NEC	National Environment Commission

NEX GDDP	NASA Earth Exchange Global Daily Downscaled Projections
NSB	National Statistics Bureau
PES	Payment for Environment Services
PHCB	Population and Housing Census of Bhutan
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RGoB	Royal Government of Bhutan
RIMES	Regional Integrated Multi-Hazard Early Warning System
RSPN	Royal Society for Protection of Nature
RUB	Royal University Bhutan
RWSS	Rural Water Supply Scheme
SSP	Shared Socio-economic Pathway
TD	Top-down
UNDP	United Nations Development Programme
WTP	Water Treatment Plant
WUA	Water User Association

Glossary

Adaptation The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC).

Actions, measures Both terms are used interchangeably as neutral terms devoted to all adaptation responses. Most commonly they are responses (e.g. infrastructure, spatial planning, capacity building) taken to decrease climate risks. Actions and measures may also be instrumental or policy steps necessary to make certain measures possible or to stimulate others to respond.

Low regret actions would generate net social and/or economic benefits under current climate and a range of future climate change scenarios (IPCC).

Robust actions perform acceptable over many futures.

Flexible actions can be expanded, adapted or complemented when direction and size of climate change is changing.

Resilient actions help to cope better with climatic shocks.

Dzongkha terminologies

Chhuzhing	Wetland (Paddy)
Chiwog	A group of villages under a gewog with a Tshogpa
Demkhong	A constituency in urban area/ thromde with an elected representative
Dzongkhag	District
Dzongdag	District administrator
Gewog	Block/County with a group of chiwogs
Gup	Elected head of the gewog/ block
Kamzhing	Dry land
Mangiap	Asst. blockhead
Tshogpa	Village headmen
Thromde	Urban Center/ town
Thrompon	Mayor, elected head of a thromde
Thuemi	Elected representative of a demkhong/ constituency in an urban area
Soelkha	Offering to local deities

1 Introduction

1.1 Rationale

The NAP process for Bhutan was launched in 2015 with a prime focus on the water sector. It aims to build on Bhutan's Nationally Determined Contribution by accelerating the NDC's vision to scale up adaptation in the medium to long term and by focusing on priority sectors in the NDC, such as water resources. The expected outcomes of the projects are; i) enhanced coordination, learning, and knowledge management for an iterative NAP process, ii) technical capacity enhanced for the generation of climate scenarios and impact assessment, iii) vulnerability assessments undertaken and adaptation options appraised and prioritized, and iv) NAP formulated and capacity for implementation and monitoring established.

Water being cross-sectoral in nature and realizing its criticality, the current NAP Project for Bhutan provides prime focus on the water sector. Water is one of the major resources for Bhutan through hydropower and agriculture activities across the country, which are critical for Bhutan. However, with the changing climate, the water sources are dwindling and drying up, with experiences of wetter summer months and drier winter months and increased melting of glaciers. Such a situation has multiples effects on various sectors, in particular those sectors that are primarily dependent on water, such as drinking and sanitation, agriculture, hydropower, disasters and others. As water is a cross cutting sector as well as climate sensitive, it has been selected as a key area for the NAP in Bhutan.

Therefore, under outcome iii) of the NAP project, "Assessment of climate risks on water resources for the NAP" is undertaken. In this study, further referred to as NAP water study, the potential impacts of climate change on water resources in Bhutan are explored to prioritize and formulate actions for the NAP. A climate vulnerability and impact analysis has been performed on which these priorities for actions can be based. The aim of a climate vulnerability analysis is to identify those climate conditions that lead to the most severe impacts within the boundaries of both historic climate variability and future climate uncertainties. More specifically, the climate change impacts on water resources are assessed for drinking water supply and sanitation, irrigation water supply, hydropower and water related disasters from the national to a local level.

1.2 Water resources in Bhutan

There are around 3182 rivers and rivulets within Bhutan representing 4741km of total river length. Precipitation is predominantly concentrated in the monsoon season (88% of the total precipiation) which contributes to a major portion of the water volume (ADB, 2016).

Bhutan has five main river basins namely Amochhu, Wangchhu, Punatsangchhu, Mangdechhu and Drangmechhu as shown in figure 1.1 below. The largest basin is Punatsangchhu basin with an area of 9,645 km² which is around 25% of the country's total area (table 1.1). There are also five smaller river basins namely Jaldakha, Aiechhu, Nyera Amari, Jomori and Merak-Saktengchhu.

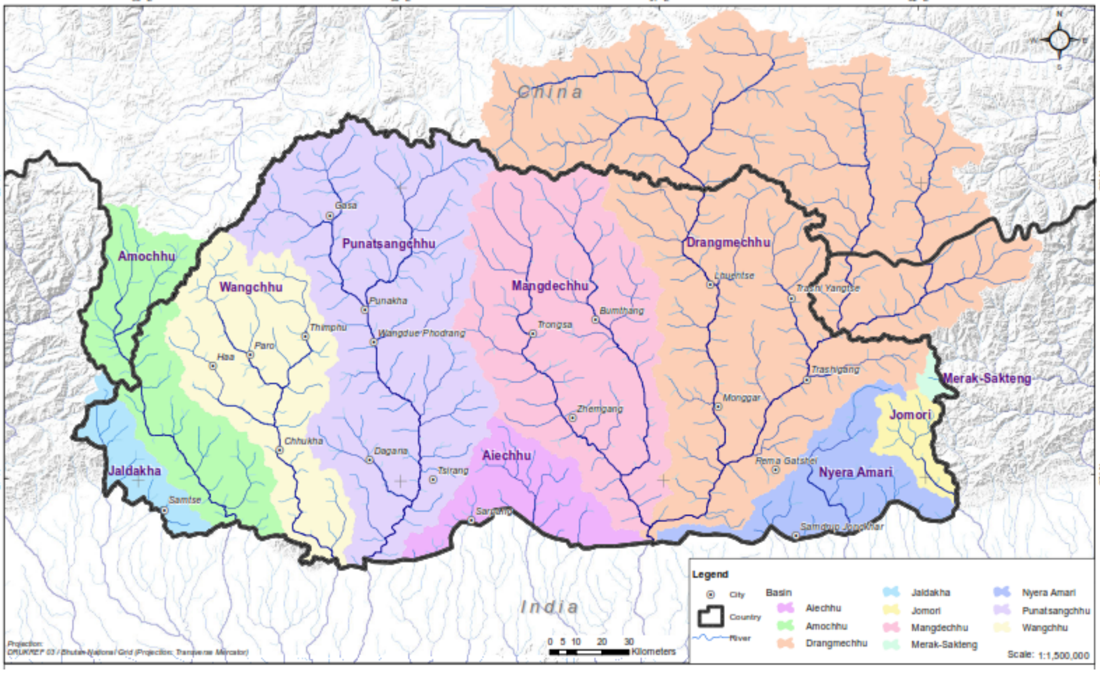

Figure 1.1 River Basins of Bhutan.

Table 1.1 River basin flows of Bhutan (NIWRMP, 2016).

Management Basin	Area (km²)	River Basins	Area (km²)	Annual flow (MCM)
Amochhu	3,252	Jaldakha	942	2,715.64
		Amochhu	2,310	6,659.36
Wangchhu	4,596	Wangchhu	4,596	5,209.06
Punatsangchhu	11,582	Punatsangchhu	9,645	19,129.79
		Aiechhu	1,937	6,989.14
Mangdechhu	7,380	Mangdechhu	7,380	11,797.24
Drangmechhu	11,584	Drangmechhu	8,457	13,569.14
		Nyera Amari	2,348	3,383.89
		Jomori	642	925.24
		Merak - Sakteng	137	197.44
Total	38,394	Total	38,394	70,576.01
		Flow		2,238.0 m^3/s

There are a total of 3027 high-altitude wetlands above 3000 m.a.s.l covering about 0.26% of the country's total land area (Wangdi et al. 2010). This includes supra-snow lakes, glacial lakes and supra-glacial lakes and marshes. As per the recently released Bhutan Glacier Inventory, 2019 by the National Center for Hydrology & Meteorology (NCHM), Bhutan has a total of 700 glaciers covering an area of about 630km² or 1.64% of the country's total land area. The largest glacier was found at the base of Gangkar Phuensum in the Mangdechhu sub-basin, which is almost 16km long.

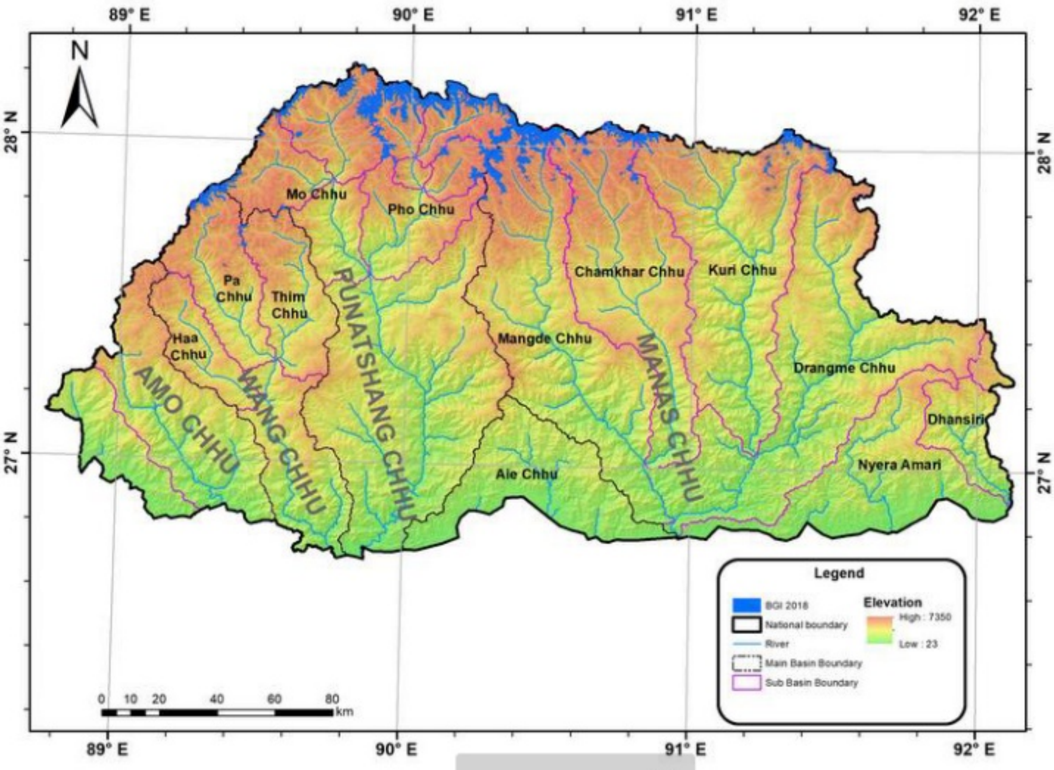

Figure 1.2 Physical map and glaciers of Bhutan (NCHM, 2019).

Most of the main rivers in Bhutan provide water for hydropower use, tourism/recreation, industry, ecological needs, and irrigation. The tributaries of these main rivers and streams provide water sources for all water uses in Bhutan such as irrigation, domestic water supply, smaller industries and for mini/micro hydropower plants.

With an average flow of 2,238 m^3/s, Bhutan generates 70,572 million cubic meters per annum, i.e. 94,500 m^3/person per year, the highest in the region (NIWRMP, 2016). Despite a high per capita water availability in Bhutan, accessibility remains a major issue, causing seasonal localized shortages. Geographically, human settlements and farmlands in the country are mostly located on hilltops and the upper slopes of mountains. The water resources, on the other hand, flow through streams and rivers at the bottom of the valleys, making it physically difficult for residents to access the resources easily.

Specifically, access to clean drinking water is a challenge for about 1.4% (2,231) of households, mostly in the rural parts of the country, that still depend on rainwater for both drinking and irrigation. In addition to accessibility issues, the water sector in Bhutan also faces problems in terms of water distribution (NIWRMP, 2016).

The 2017 Royal Audit Authority (RAA) report for the Thimphu area accounts for a loss of about 34 percent of water resources alongside the distribution networks due to illegal tapping, water connection bypassing water meter, approval of water connection from transmission lines, and diversion of water supply.

As per Population and Housing census of Bhutan (PHCB) 2017, about one-fifth (29.973) of the total households lack reliable water supply across Bhutan, which meant that these households did not have adequate access to water during the critical hours of the day.

Other new issues in the water sector are lack of data or hydrogeological knowledge regarding alternative water sources like groundwater and springs. With climate change drastically affecting glacial regions like the Himalayas, Glacial Lake Outburst Floods (GLOFs) is another threat to Bhutan's water sector as well as its economy.

Furthermore, as the impacts of climate change intensify over the years, the available water sources and their distribution could likely get hampered, leading to more shortages, floods, and extreme events.

1.3 Objectives

The aim of this study is to assess the impact of climate change on water resources in Bhutan and to identify and prioritize adaptation actions and subsequent proposed implementation in the NAP process. In the inception phase, through an early stocktaking exercise the following challenges and more specific objectives where identified:

- Gain better insights in the spatial and seasonal trends in precipitation.
- Develop a hydrological modelling approach that captures well the spatially and regionally varying hydrological phenomena observed and that will subsequently be used for climate change projections.
- Incorporate increased water demands in future projections of water shortages, confronting demand and availability at gewog level.
- Assess whether climate change is a potential major contributor to the drying up of water resources.
- Assess how changes in hydrology may affect future performance.
- Assess where and to what extent climate change may enhance drinking & irrigation water shortages or disaster risks to agricultural land and infrastructure, and
- Connect known flood vulnerable areas (from the MoWHS assessments and hotspot analysis) with hydrological modelling of historical and future return periods.

1.4 Study and report outline

To tackle these objectives, a mixed approach of top down and bottom up methods has been developed in undertaking the assessment for the NAP as shown in Figure 1.3 (also see Inception report, Deltares 2021a). This approach consists of:

- A top down quantitative analysis of climate (see climate data report, Deltares 2021b) and hydrology at the highest possible resolution and that has informed seasonal water availability and peak flow frequencies (see hydrology report, Deltares 2021c),

- A bottom-up qualitative structured consultation using Focus Group (FG) discussion at district levels and subsequent validation of local vulnerabilities to water and climate.

The outcomes of both tracks have been combined into an indicator-based analysis of climate impacts on water supply and sanitation, irrigation water supply, hydropower and water related disasters from the national to local level, all key dimensions for water-security in Bhutan. The climate impacts on water security are used to inform the priorities for adaptation for which appropriate adaptation options are identified and prioritized to provide recommendations for the NAP.

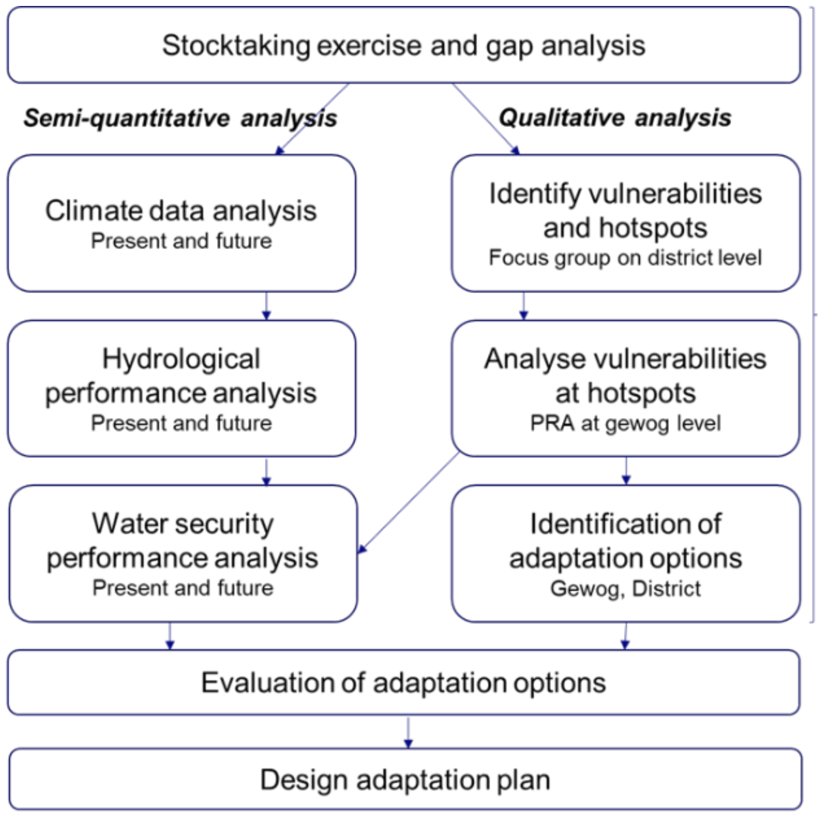

Figure 1.3 Project approach showing the parallel top down (semi-quantitative analysis) and bottom up (qualitative consultations) analysis tracks of the project. Note that in the ultimate execution of the project the further analysis of vulnerabilities at hotspot gewogs was replaced by validation meetings of already collected information.

The rest of the report is structured as follows:

In chapter 2, the methodology on how to analyse the impacts of climate on water security and how to formulate appropriate adaptation responses for the NAP is described in more detail.

In chapter 3, a structured summary is given of the outcomes of the bottom up consultation among the different dzongkhags and an overview is presented of the priority gewogs (hot-spots) identified.

In chapter 4, a summary is provided of the climate and hydrological analyses that has served as an input to the impact analysis. More details on these analyses can be found in two background reports (Deltares, 2021b and c). A more detailed presentation can be found in the background report on the Bottom-up consultations (Deltares, 2021d).

In chapter 5, the results are presented at a national level of the impacts of climate change on the different indicators for water security, what the consequences are for the water issues identified in the hot-spots and what the appropriate adaptation responses can be.

In chapter 6, it is demonstrated for selected dzongkhags how a similar analysis of impacts and adaptation can be repeated at a more regional level.

In chapter 7, recommendations on the adaptation for the NAP on water are given.

2 Approach and methodology

2.1 Overview

The aim of this assessment is to identify priorities and hotspots for adaptation and corresponding appropriate actions for the short and longer term. Therefore, it is necessary to know:

- Where climate variability and change are already leading to water issues?
- How are these issues likely to increase on the short and long term?
- What is the best adaptation strategy to tackle these issues?

A bottom-up (regional consultation) and top-down approach (climate and hydrology analysis) are combined in which:

- The consultation (at dzongkhag and thromde) provides information on specific water related issues experienced, when, where (gewog/location) and what are the perceived causes (climate or other) as well as the capacity building requirements and identification of vulnerable groups.

- The climate and hydrology analysis showing how water availability and hazards have evolved historically, and how is it likely to evolve in the future.

- The main impacts are approached by drought and flood indicators that are calculated based on the climate and hydrology analysis. The outcome of the indicator analysis called “risk characterization” serves as a proxy for the likelihood of future occurrence of identified water issues.

Depending on the issue, the main causes (related to exposure and vulnerability), the urgency and confidence of the impacts, adaptation options are recommended. The more detailed method on how these indicators are formulated and used to approximate the impacts and how adaptation responses are formulated are described below.

Textbox 2.1 Decision making under uncertainty (DMU)

Principles of DMU are applied throughout the NAP water study and can be summarized as follows:

- Consider multiple plausible futures, not one single future, in the planning. Choose these futures to stress test the water resources management system. What performance outcomes are acceptable and which of them are not?
- Seek **robust** and **resilient** actions that perform acceptably over many futures and can cope with unavoidable climatic shocks, not optimal plans designed for a single, best-estimate future.
- Make the plans **flexible** and adaptive where possible to be able to increase effort and or change course.

In the analyses done for the NAP water study these principles are implemented in a practical way. For the water ***impact analysis*** multiple projections are used and performance indicators are formulated across all of them representing wetter and dryer conditions. If different projections for the same period are contradictory this information is presented in a measure of agreement. Agreement serves as a proxy for the confidence in the results (see also textbox 2.2).

Resilient actions help to cope better with climatic shocks;

- vulnerability is reduced by *diversification* of resources and means.
- *Recovery* capacity
- *Buffering*: Essential capacities are over-dimensioned such that critical thresholds in capacities are less likely to be crossed **(Robust**).
- *Redundancy*: overlapping functions; if one fails, others can take over.

For the identifying and selecting appropriate adaptation responses, the confidence in the assessment is taken into account for choosing flexible, robust/resilient and low regret options

2.2 Impact Analysis and Risk Characterization

A climate risk characterization and impact assessment approach has been developed by combining bottom-up regional consultations and the top-down model-based analysis. In the following sections, we first give a short review of basic risk concepts and then present the details of this approach.

2.2.1 Risk concepts and definitions

For this work, we conceptualize disaster risk based on the earlier definitions by the Intergovernmental Panel on Climate Change (IPCC, 2012) and The United Nations Office for Disaster Risk Reduction UNDRR (2016). *Disaster risk* is defined as “the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time” (UNDRR, 2016). Disaster risk is expressed through three concepts, namely hazard, vulnerability, and exposure (Figure 2.1):

- *Hazard* refers to a natural or human-triggered event that may cause adverse impacts such as loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation. Examples include droughts, floods, tropical cyclones and earthquakes.
- *Vulnerability* refers to the characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard. Various cultural or institutional factors can play a role in the vulnerability of a water system, for example, poor design of infrastructure, poverty, or lack of public awareness.

- *Exposure* refers to people, property, systems, or other elements present in the geographic area of hazards. These can include the number of people or types of assets within hazard zones that are subject to potential losses.

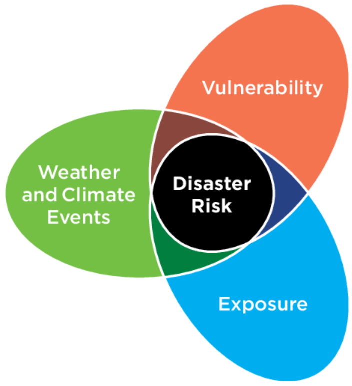

Figure 2.1. Disaster risk components (adopted from IPCC, 2012).

2.2.2 Risk characterization framework for water security analysis

Water-related impacts and disasters are quite broad in nature and because of complex interactions in the ocean atmosphere-land processes, highly depend on the geography and context. Floods, landslides, tsunamis, storms, heat waves, cold spells, droughts and waterborne disease outbreaks are some examples of typical water-related disasters.

Earlier in the project, a stocktaking and comprehensive literature review was completed (see Deltares 2021a and d) to screen main types of water-related disasters across different dzongkhags. With this information in mind, we present a four-step risk characterization process by first identifying the main types of water-related problems or disasters to focus on; second, defining the main hazard, exposure, and vulnerability indicators for each type of problem; third, carrying out a model-based analysis to quantify hazards at the gewog and sub-catchment level, and finally summarizing the findings on risk through series of hazard maps and risk tables. This four-step process is illustrated in Figure 2.2.

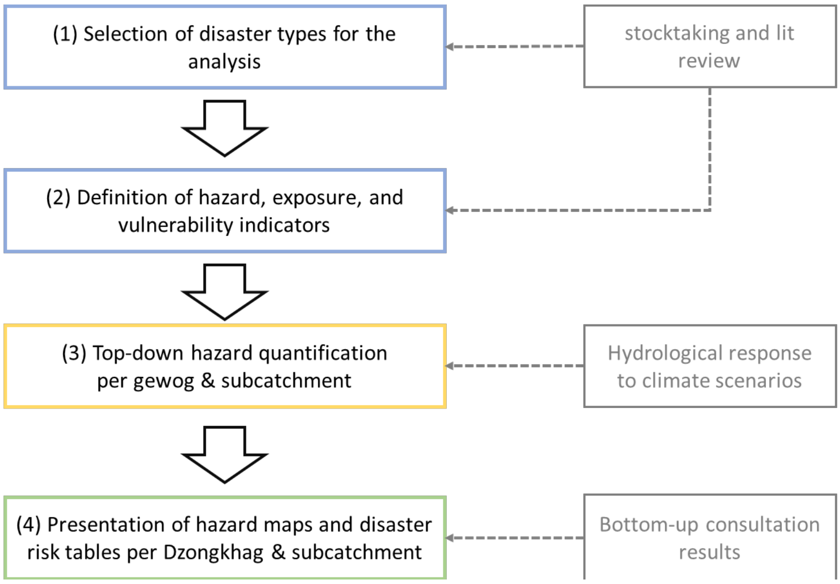

Figure 2.2. Main steps in the top-down risk characterization and presentation process. Dashed arrows indicate information flow to each step.

As illustrated in Figure 2.2, the risk characterization process requires various types of information and effort. The initial stocktaking exercise and literature review helps to understand local problems and relating them to hazards, exposures, and vulnerabilities in steps 1 and 2. Climate scenarios and hydrological responses to those scenarios help to quantify future hazards at the local level and how they are expected to change in Step 3. Finally, the results from the bottom-up regional consultations are integrated and evaluated together with the top-down hazard assessment results in the final step.

2.2.3 Water-related disasters and problems

In this work, we evaluate water-related issues through two main types of disaster events:

- Droughts linked to water supply shortages for both domestic and irrigation uses
- Extreme precipitation events linked to flooding and landslides
- Declining hydropower production

Hydrological droughts manifest themselves through long, continuous periods of low precipitation and lower levels of groundwater recharges and river flows, resulting in drying of springs and eventually the depletion of both groundwater and surface water resources. Depletion of groundwater and surface water resources means less water availability for domestic and irrigation uses. In this work, we use a number of hydrological drought indicators as a proxy for water availability/shortage-related problems.

Extreme precipitation events result in direct damage to livelihoods and infrastructure through flooding and landslides. We use indicators to assess the damage from both fluvial (river) flooding, based on extreme river discharges, and also pluvial (surface) flooding, where heavy rainfall creates a flood event independent of an overflowing water body (described in the following section).

In addition, however more qualitatively, we characterize the risks of increasing landslides and GLOFS. According to a recent NASA study for the Himalayas in China and Nepal[1] (the first quantitative study of the link between precipitation and landslides in the region) more frequent and intense rainfall events due to climate change could cause more landslides in the region. It is found that in the summer months in the years 2061-2100, thanks to increasingly frequent and intense monsoon rainfall events steep mountainsides can further destabilize, triggering landslides.

The border region of China and Nepal could see a 30-70% increase in landslide activity compared to the historic climate. More landslides are especially expected in areas that are currently covered by glaciers and glacial lakes and where the warming climate may not only trigger GLOFS but also exposes, once frozen and covered, slopes to excessive rainfall. These processes luckily happen remotely from the populated areas. In the more populated areas in the valleys, risks are expected to increase with 20%. The method used by NASA assesses the hazard by evaluating information about roadways, the presence or absence of nearby tectonic faults, the types of bedrock, change in tree cover and the steepness of slopes and precipitation data[2].

As Bhutan has a similar geography and therefore similar high susceptibility to landslides as has been experienced in the past and shown in Figure 2.3 landslide risks under climate change are approached in a similar way as in the NASA study.

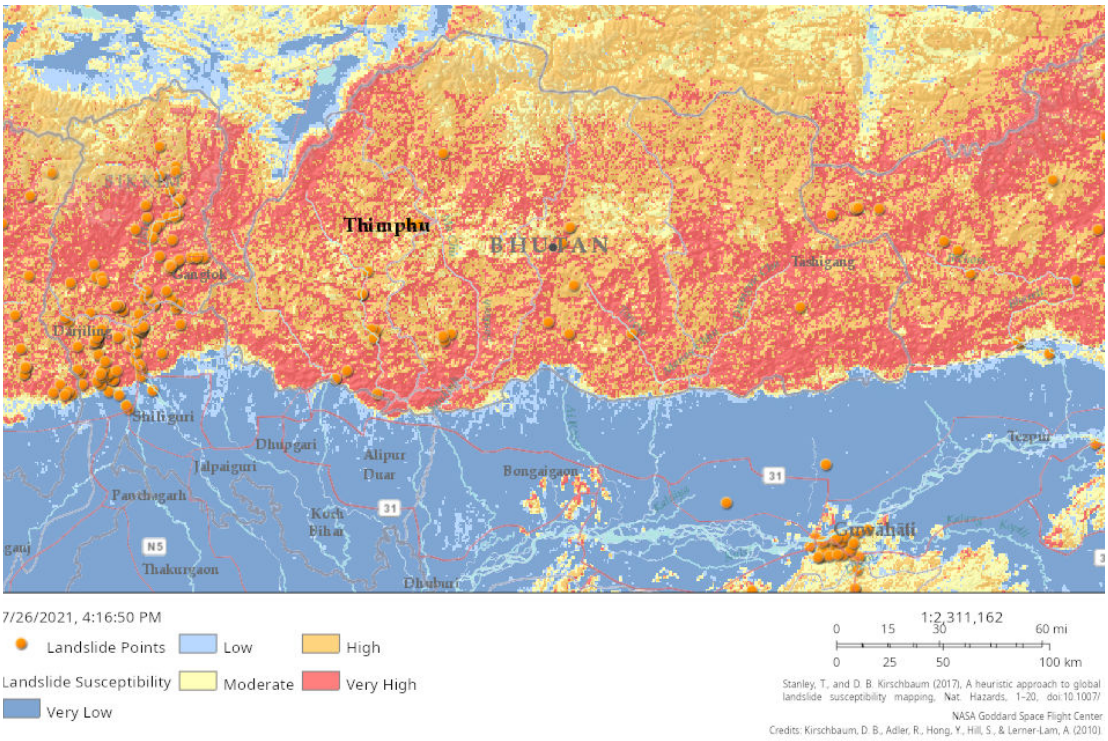

Figure 2.3 Landslide susceptibility downloaded from the NASA landslide viewer. Dots indicate historic occurrence of landslides based on news reports. Colours indicate the susceptibility to landslides estimated based on a combination of data on slope, faults, geology, forest loss, and road networks (Stanley and Kirschbaum, 2017).

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[1] https://www.nasa.gov/feature/goddard/2020/climate-change-could-trigger-more-landslides-in-high-mountain-asia

[2] If the amount of precipitation in the preceding seven days is abnormally high for that area, then the potential occurrence of landslides increases.

2.2.4 Hazard, exposure, and Vulnerability indicators

Next, we define a set of simple hazard, exposure, and vulnerability indicators to express the impacts from droughts, extreme precipitation/flooding events, disasters (landslides) and hydropower generation.

- For droughts, we use simulated daily surface flow series at sub-catchment level, considering a drought threshold set to be the 10^{th} quantile of the record. Since the river flow locations evaluated do not necessarily coincide with the gewog coordinates, we use daily groundwater recharge series to assess drought conditions at the gewog level. The drought impacts are evaluated using three quantitative metrics of drought duration, frequency, and severity.

- For extreme rainfall and flooding, we carry out a statistical analysis on 7-day moving average of daily precipitation and amounts river flow and evaluate the changes in the 10-year and 30-year events on two spatial scales, e.g., at sub-catchment (flow) and gewog levels (precipitation).

- For landslides, we carried out a similar analysis as for extreme rainfall, but this time focusing on 7-day accumulated precipitation to represent multi-day severe storm events.

- Finally, for hydropower, we focused on the proxy variable of daily flow and evaluated annual and dry and wet season means of at hydropower plant locations. Further information on hazard indicators is given in Table 2.1.

Table 2.1 List of hazard indicators used in the study

Issue	Proxy variable	Specific metric/statistic
Droughts/ dry spells	Daily stream flow at sub-catchment level Daily groundwater recharge at gewog level	Changes in the duration, frequency, and severity of drought events. Drought threshold set to Q10 of daily 7MA of flow/recharge.
Extreme precipitation/ flooding	Daily precipitation at gewog level Daily stream flow at sub-catchment level	Changes in the frequency of extreme rainfall and flow events (at 10 and 30 years return intervals)
Landslides	Proxy variables: Daily precipitation at gewog level	Changes in the 7-day accumulated precipitation amounts during the Monsoon season (JJASO)
GLOF	Daily temperatures	Change of area with permafrost
Hydropower	Proxy variables: Daily river flow at hydropower plant locations	Changes in annual, as well as dry and wet season means.

For exposure and vulnerability, the bottom-up consultations provide a basis for a qualitative evaluation, however, a more detailed analysis using quantifiable metrics (such as for the hazards) was not possible due to lack of local data. Some exceptions are the projected changes in population at sub-catchment level, which can be used as a proxy indicator of exposure indicator to hazards (Figure 2.4) and water demand projections from NIWRM (2016) for different water uses until 2030 (see table 2.2-2.4). Note that, the population growth in table 2.2. does not match the NSB projections in figure 2.4.

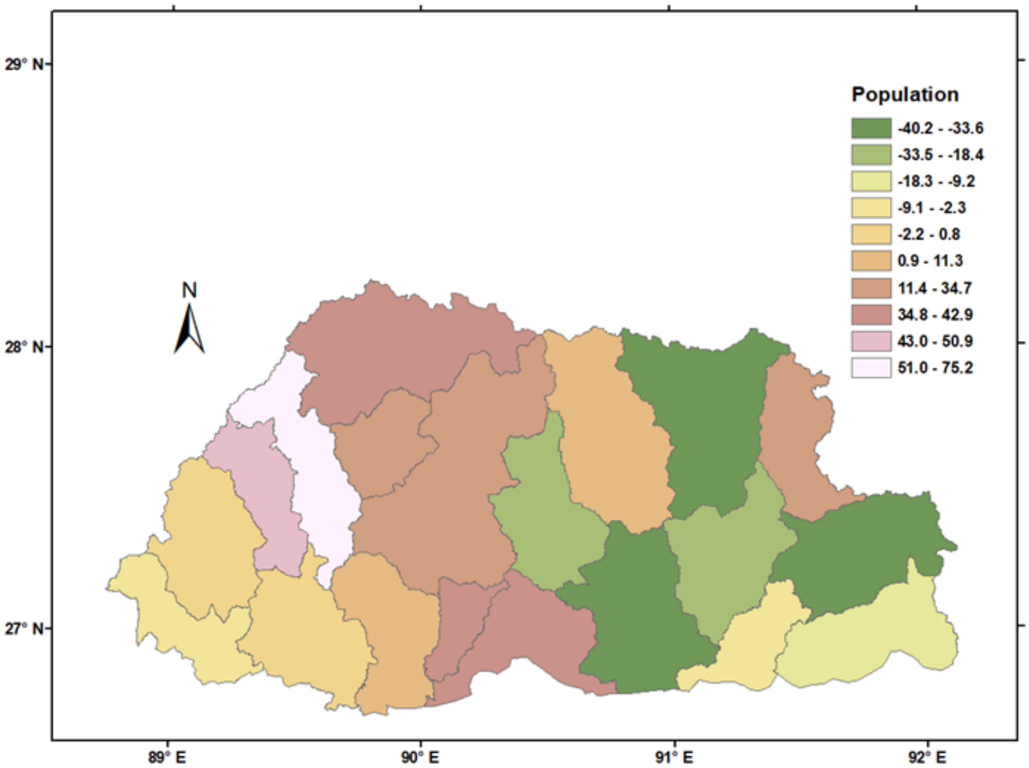


Figure 2.4 Projection of population change in 2042 (%) NSB.

Table 2.2 Current and future household water demand (NIWRMP, 2016).

Dzongkhag, Gewog/Town	Population in 2015	Water Required 2015 (MCM/Yr)	Water Required (MCM/Month)	Population in 2030	Water Required (MCM/Yr)	Water Required (MCM/Month)
Bumthang	18,695	0.82	0.07	22,562	2.06	0.17
Chhukha	88,342	4.37	0.36	104,555	7.61	0.63
Dagana	26,597	1.16	0.10	31,290	2.86	0.24
Gasa	3,615	0.16	0.01	4,362	0.40	0.03
Lhuentse	17,396	0.76	0.06	21,553	1.97	0.16
Monggar	43,371	1.90	0.16	51,897	4.74	0.39
Haa	13,501	0.45	0.04	17,843	1.01	0.08
Paro	43,168	1.09	0.09	49,364	2.43	0.20
Pemagatshel	24,961	1.09	0.09	31,202	2.85	0.24
Punakha	27,451	1.20	0.10	32,847	3.00	0.25
Samdrup Jongkhar	39,989	1.75	0.15	47,445	4.33	0.36
Samtse	68,443	3.00	0.25	82,604	7.54	0.63
Sarpang	44,659	1.96	0.16	52,102	4.75	0.40
Thimphu	116,012	8.89	0.74	131,743	13.05	1.09
Trashigang	55,125	2.41	0.20	68,296	6.23	0.52
Trashiyangtse	20,578	0.90	0.08	24,836	2.27	0.19
Trongsa	15,612	0.68	0.06	20,338	1.86	0.15
Tsirang	21,467	0.94	0.08	26,134	2.38	0.20
Wangdue	36,722	1.61	0.13	43,568	3.98	0.33
Zhemgang	21,245	0.93	0.08	26,090	2.38	0.20
Total	**746.949**	**36.09**	**3.01**	**890.631**	**77.68**	**6.47**

Table 2.3 Current and future industry and other water demand (NIWRMP, 2016).

Industry and other Demands (M.m3/Yr)			
District	**Basin**	**2015**	**2030**
Bumthang	Mangdechhu	3.31	10.37
Chhukha	Wangchhu	4.45	9.04
Chukha	Amochhu	6.11	12.40
Dagana	Punatsangchhu	1.98	7.63
Gasa	Punatsangchhu	1.42	4.69
Haa	Amochhu	1.08	3.82
Haa	Wangchhu	1.34	4.77
Lhuentse	Drangmechhu	2.02	7.61
Mongar	Drangmechhu	4.13	14.32
Paro	Wangchhu	5.67	13.53
Pema Gatshel	Aiechhu	1.15	2.69
Pema Gatshel	Drangmechhu	1.59	3.73
Punakha	Punatsangchhu	2.89	8.28
Samdrup Jongkhar	Nyera Amari	4.72	11.80
Samtse	Amochhu	6.76	20.03
Sarpang	Aiechhu	3.93	11.10
Thimphu	Wangchhu	4.87	11.56
Thimphu	Punatsangchhu	1.33	3.17
Trashigang	Drangmechhu	3.39	12.90
Trashigang	Nyera Amari	2.44	9.30
Trashi Yangtse	Drangmechhu	1.57	5.98
Trongsa	Mangdechhu	1.53	5.49
Tsirang	Punatsangchhu	1.40	5.51
Wangduephodrang	Mangdechhu	1.02	3.52
Wangduephodrang	Punatsangchhu	2.91	10.02
Zhemgang	Aiechhu	0.18	0.65
Zhemgang	Mangdechhu	1.20	4.44
Total		**74.39**	**218.35**

Table 2.4 Current and future irrigation water demand (NIWRMP, 2016).

Districts	**Basin**	**Irrigated Area (Ha)**		**Crop Water Requirement**	**Irrigation Water Requirement (MCM /Yr)**	
		2015	**2030**	**M3/Yr/Ha**	**2015**	**2030**
Bumthang	Mangdechhu	75.11	188.66	2,444.2	0.18	0.46
Chhukha	Wangchhu	377.45	533.37	24,469.0	9.24	13.05
Chukha	Amochhu	517.87	731.81	24,469.0	12.67	17.91
Dagana	Punatsangchhu	1,779.91	2,642.46	27,391.6	48.75	72.38
Gasa	Punatsangchhu	49.21	59.01	1,517.6	0.07	0.09
Haa	Amochhu	50.56	64.40	2,393.7	0.12	0.15
Haa	Wangchhu	63.09	80.36	2,393.7	0.15	0.19
Lhuentse	Drangmechhu	1,489.28	1,936.18	38,856.6	57.87	75.23
Mongar	Drangmechhu	546.74	905.24	31,913.3	17.45	28.89
Paro	Wangchhu	1,536.14	1,931.21	32,408.1	49.78	62.59
Pema Gatshel	Aiechhu	67.98	76.95	19,682.7	1.34	1.51
Pema Gatshel	Drangmechhu	94.27	106.70	19,682.7	1.86	2.10
Punakha	Punatsangchhu	3,247.61	3,872.50	38,077.8	123.66	147.46
Samdrup Jongkhar	Nyera Amari	833.03	1,419.69	7,087.6	5.90	10.06
Samtse	Amochhu	1,800.64	4,256.36	11,647.3	20.97	49.58
Sarpang	Aiechhu	4,018.18	5,719.50	14,292.6	57.43	81.75
Thimphu	Wangchhu	208.28	423.18	33,803.4	7.04	14.30
Thimphu	Punatsangchhu	57.05	115.90	33,803.4	1.93	3.92
Trashigang	Drangmechhu	868.40	1,140.03	24,900.0	21.62	28.39
Trashigang	Nyera Amari	626.27	822.16	24,900.0	15.59	20.47
Trashi Yangtse	Drangmechhu	992.15	1,246.26	27,280.1	27.07	34.00
Trongsa	Mangdechhu	1,006.32	1,277.75	24,618.1	24.77	31.46
Tsirang	Punatsangchhu	1,428.73	1,968.30	25,848.6	36.93	50.88
Wangdi	Mangdechhu	728.97	931.41	40,248.4	29.34	37.49
Wangdi	Punatsangchhu	2,075.20	2,651.49	40,248.4	83.52	106.72
Zhemgang	Aiechhu	60.48	108.12	24,607.0	1.49	2.66
Zhemgang	Mangdechhu	412.04	736.55	24,607.0	10.14	18.12
Total					**666.90**	**911.80**

2.2.5 Top-down quantification of the hazard indicators

We carried out a top-down analysis of climate scenarios and hydrological responses to those scenarios to understand how the drought and flood-related water hazards may change over the future.

The analysis consists of five climate models (CNRM-CM5, IPSL-CM5A-LR, MIROC5, MPI-ESM-MR, and MRI-CGCM3), two emission scenarios (RCP 4.5 and 8.5), and two future periods (near future 2035 and far future 2085), altogether resulting in a combination of 20 scenarios. Medium term was not considered.

For assessing issues over the historical period, gridded ERA5-land dataset (1979-2019 period) has been used (see also Deltares, 2021a and b).

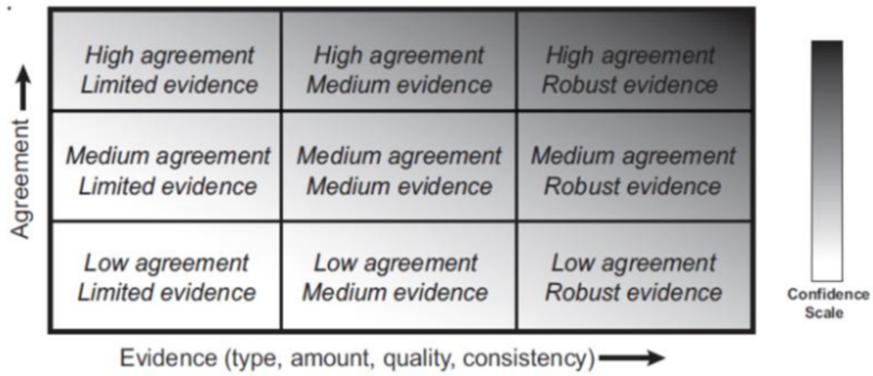
For each hazard type, using the variables and specific metrics shown in Table 2.1, the following steps were undertaken:

1. Calculate the drought/flood statistic over the historical period $M_{Historical}$.
2. Calculate the drought/flood statistic over each of the 20 climate scenarios M_{Future}.
3. Calculate percent change in each future scenario relative to the historical period: $100 * (M_{Future} - M_{\mathrm{Historical}})/M_{\mathrm{Historical}}$ or calculate the change factor as $M_{Future}/M_{\mathrm{Historical}}$.
4. For each emission scenario and future period, find the median change (%) across all climate model results (the 3rd results when sorted out of 5 model runs).
5. For each median change, identify the number of climate models that agree with respect to the direction of change (out of a total of five models). For further description of model agreement and confidence, see textbox 2.2.

The five-step calculation procedure explained above is applied for all drought and extreme precipitation and flow metrics (metric calculations are provided in the following section).

Textbox 2.2 Confidence and agreement

The figure below explains the concept of confidence as it has been applied by IPCC authors in writing the 5th assessment report (Mastrandrea et al., 2010). For example, if multiple high-quality measurements, e.g. both ground based and satellite based, show a clear trend in a certain climate variable and this is confirmed by multiple climate model projections (multiple sources of evidence showing high agreement), the confidence is high.



Scales of confidence used by the IPCC to communicate uncertainty. Confidence is defined as: the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement.

Confidence can be considered as the inverse of uncertainty. High confidence corresponds to low uncertainty.

In the NAP water study, the same principles have been applied and the level of confidence has been assessed for each of the impacts considered. This is done in two ways:

- top-down indicators calculated from the ensemble of climate model and hydrological model runs are scored for their **agreement** in the **direction of change,** e.g. when all models agree about an increase
- in the overall risk characterization per dzongkhag a qualitative assessment of the confidence and the agreement between i) perceived impacts from the bottom-up analysis, ii) observed trends and iii) projected changes is given.

2.2.5.1 Dry spell/drought metrics

Future risks of dry spells are quantified with the metrics of average dry spell duration, occurrence frequency, and average severity. By focusing on different aspects, these three metrics provide a fuller characterization of drought or dry spell risks. Calculation procedures for these metrics are as follows:

1. *Define a critical drought threshold based on daily series:* the critical drought threshold is set at the 10^{th} quantile, e.g., the value that is ranked at 10% of the daily series. This is done using the data from the historical period and for each gewog or sub-catchment.

2. *Calculate 7-day moving average (7MA) of daily series:* the simulated daily series of river flow or groundwater recharge is "smoothed" by calculating the 7-day moving averages.

3. *Detect drought events over the simulation period:* a drought event is defined when the calculated 7MA value of daily river flow or recharge falls below the identified drought threshold.

4. *Calculate drought occurrence frequency over the simulation period:* the drought occurrence frequency is simply calculated by counting the number of independent (non-continuous) drought events occurring over the simulation period.

5. *Calculate average drought duration (days) over the simulation period:* average drought duration is calculated by averaging the durations of all drought events identified in step 3.

6. *Calculate average severity of drought events over the simulation period:* average drought severity is calculated by averaging the maximum deficits (minimum value) from all drought events.

7. Calculate the relative change in each metric using the procedure described previously in section 2.4.1.

   These 7 steps are both applied to ground water recharge at gewog level and river flow at sub-catchment level.

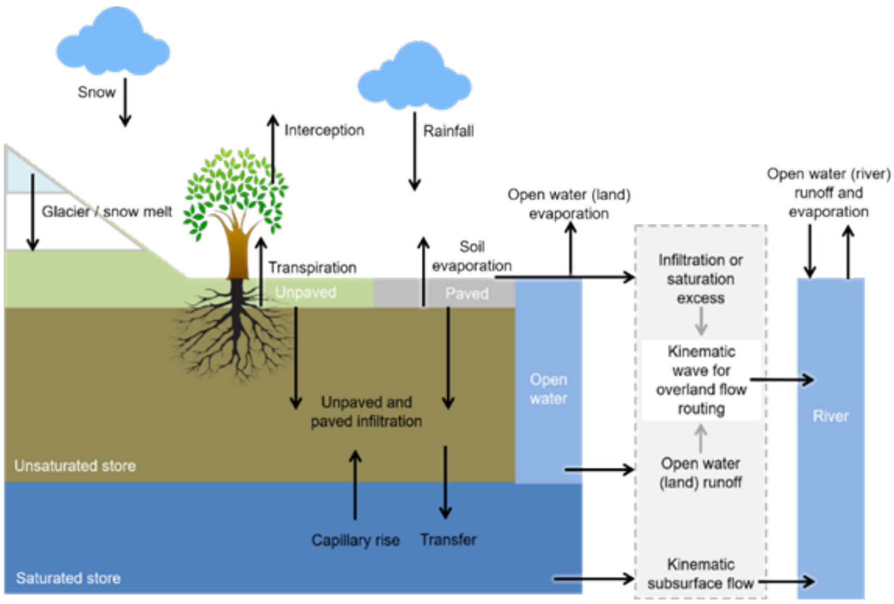


Figure 2.5 Hydrological processes included in the wflow model used for this study.

Note that ground water recharge and river flow represent dry spells and underlying processes (see Figure 2.5) at different scales. Ground water recharge, in this study, is seen as a proxy for water available from shallow groundwater fed local springs and sources. The recharge flux is determined by rainfall/snow, runoff, and evaporation. The river flow, in this study seen as proxy for water available from streams and rivers, is determined by upstream catchment scale processes of rainfall and snow, surface and sub-surface runoff, evaporation and glacial melt. Because of these differences, the gewog level groundwater recharge based dry spell metric does not necessarily show the same response to climate change than the river flow-based metric.

2.2.5.2 Flooding metrics

Potential impacts from future extreme precipitation are calculated using a simplified flood-frequency analysis approach based on annual daily maxima of precipitation and by focusing on the future occurrences of 10-year and 30-year historical extreme precipitation events. The calculation procedures are as follows:

1. Calculate annual daily maximum values from daily precipitation series: for each sub-catchment/gewog, find daily maximums over the historical period.
2. Calculate extreme precipitation events with a return period of 10 and 30 years: for each sub-catchment/gewog, first, fit the annual maximum values to an extreme value distribution, i.e., GEV[3], and calculate events with 10 and 30-year return intervals (for an example, see Figure 2.6).
3. Calculate the frequency of 10-year and 30-year precipitation events over the future period.
4. Calculate the relative change in each metric using the procedure described previously in section 2.4.1.

The same procedure is applied for river flow data at primary and secondary station locations.

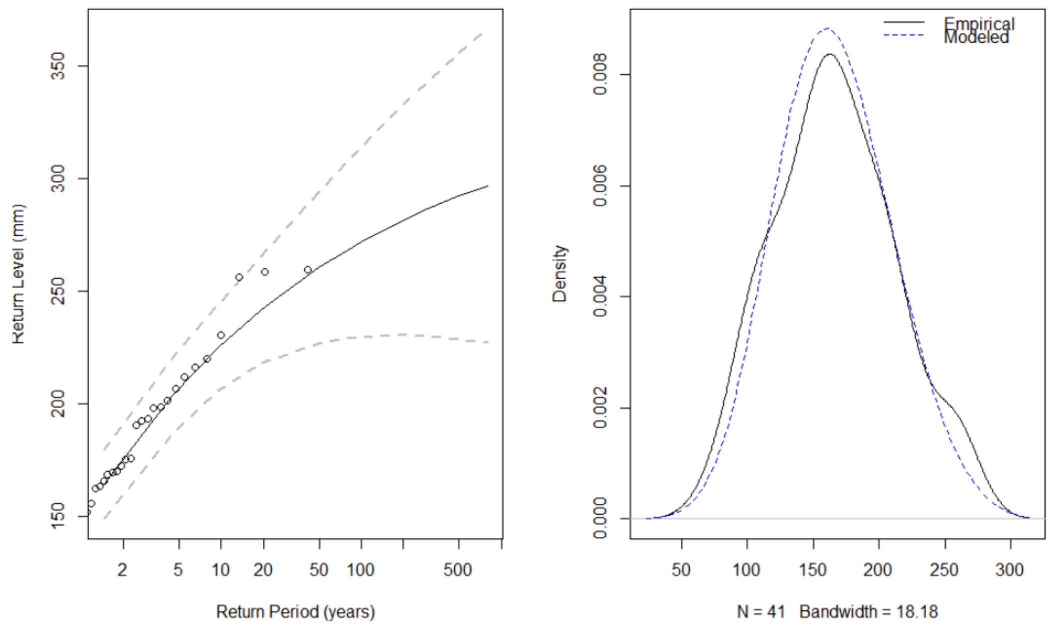


Figure 2.6. GEV distribution fitted to daily precipitation data from a selected gewog (in this example, Norgaygang). Model fit is illustrated with a return level plot (left) and a density plot (right). On the left plot, the return period of precipitation events is shown in the x-axis and corresponding return levels (mm) on y-axis. The line shows the fitted GEV, whereas the dashed grey lines shows the statistical significance range. Each dot shows the empirical return levels calculated from the

[3] Generalized Extreme Value (GEV) distribution: The GEV distribution is a family of continuous probability distributions developed within extreme value theory. It offers the possibilities to use mathematical function to mimic the observations of extremes and extend statistic beyond the observed values.

underlying data. On the right plot, the black line shows the empirical density function, and the blue dashed line shows the fitted GEV density function. A closer match between the two indicates a higher degree of match.

2.2.5.3 Landslide metrics

Landslide hazard impacts at gewog-level are calculated through a simple procedure, using 7-day accumulated precipitation as a proxy metric. Calculation steps are as follows:

1. Obtain daily precipitation time-series for each gewog over the historical analysis period
2. Calculate 7-day accumulated precipitation time-series for each gewog, by recording the precipitation for each day in the record and summing the precipitation amount from the six previous days.
3. Find the 95th quantile (Q95) values from the calculated 7-day accumulated precipitation series for each gewog (Q95 is the value in the data that 95% of all values fall below).
4. Calculate the count of 7-day accumulated precipitation values exceeding the Q95 in the historical period.
5. Calculate the count of 7-day accumulated precipitation values exceeding the Q95 in each future period (all scenarios and reporting years).
6. Find the relative change in the count of 7-day accumulated precipitations in each future period relative to the historical period (as a percentage).

Note that this rainfall-based metric only represents the triggering event for landslides. Whether this leads to a real landslide occurrence also depends on the susceptibility (based on geological and land cover characteristics) of the area to landslides. This susceptibility has not been specifically calculated in this study. However, Figure 2.3 shows that there is no dzongkhag within Bhutan that is without locations of high susceptibility to landslides. So, on a dzongkhag level, and probably also on a gewog level this is not the most discerning factor.

2.2.5.4 Hydropower metrics

Hazards from reduced energy output from the hydropower sector is calculated using simple metrics of streamflow. At each hydropower plant location (i.e. Basochhu, Kurichhu, Mangdechhu, Punatsangchhu and Tala), annual mean flows as well as dry season (DJF)[4] and monsoon season (JJAS) means are calculated over the historical and future analysis periods.

[4] It is noted that in the hydropower sector the lean season is defined from November to April. However, as all hydrological analyses in this national and multisectoral study have been done for DJF as the lean season this has been applied to hydropower as well.

2.3 Adaptation analysis

2.3.1 Approach

There are many policy documents that describe concrete plans and actions for making improvements to the water sector. There are sector wide plans such as the 2016 NIWRM plan, the Strategic Programme for Climate Resilience (2017) and the 2019 12th five-year plan with the National Key Result Area 17 for sustainable water. In addition, there are sectoral plans for irrigation development (Irrigation master plan), hydropower (Hydropower System Master Plan, JICA, 2019), watershed management and drinking water (Flagship programme).

As input to the adaptation analysis, an exercise to stocktake the main actions from these existing plans and programmes and a country wide consultation has been carried out. This has led to long lists of potential actions to take.

The adaptation analysis of this NAP water study consists of two steps:

- Identify appropriate adaptation options to respond to the impacts and risks assessed. Note that this also involves decision making under uncertainty.
- Next, evaluate those options based on a set of criteria to be able to prioritize actions for the NAP.

The steps are applied to the long-list of options obtained from the consultations. The adaptation options collected during the consultations are presented in chapter 3. The final recommendations on adaptation are presented in chapter 7.

Note that, there is not a simple formula for determining the best adaptation options. Definition of policy actions for adaptation is a very much local context driven process, in which not only the outcomes of a risk analysis play a role but also different stakes and priorities across multiple policy domains as well as preferences and capacities of stakeholders. Therefore, in this study and in this section a method is provided that can only structure this process. Based on the outcomes, recommendations can be given. The ultimate decisions for the NAP need to be taken by the decision makers and stakeholders in Bhutan.

2.3.2 Identify appropriate response to risks characterised

There are many ways to categorize adaptation options. For the NAP water study, it is considered most important that the adaptation options are chosen in first instance based on the main components of risk. In other words, the adaption options should respond to the main causes of the impacts identified. The components of hazard, exposure and vulnerability therefore offer a useful framework for this next to commonly used categories in water resources management and in disaster risk management (see also Figure 2.7 and Figure 2.8).

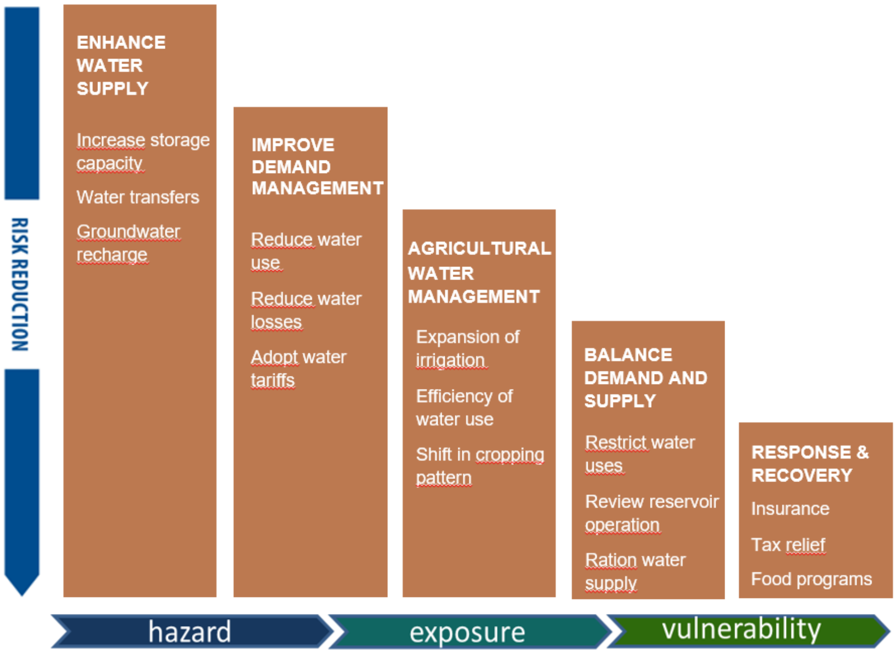


Figure 2.7 Categories of options for water resources management under climate stress (GCF/Deltares 2021, under publication).

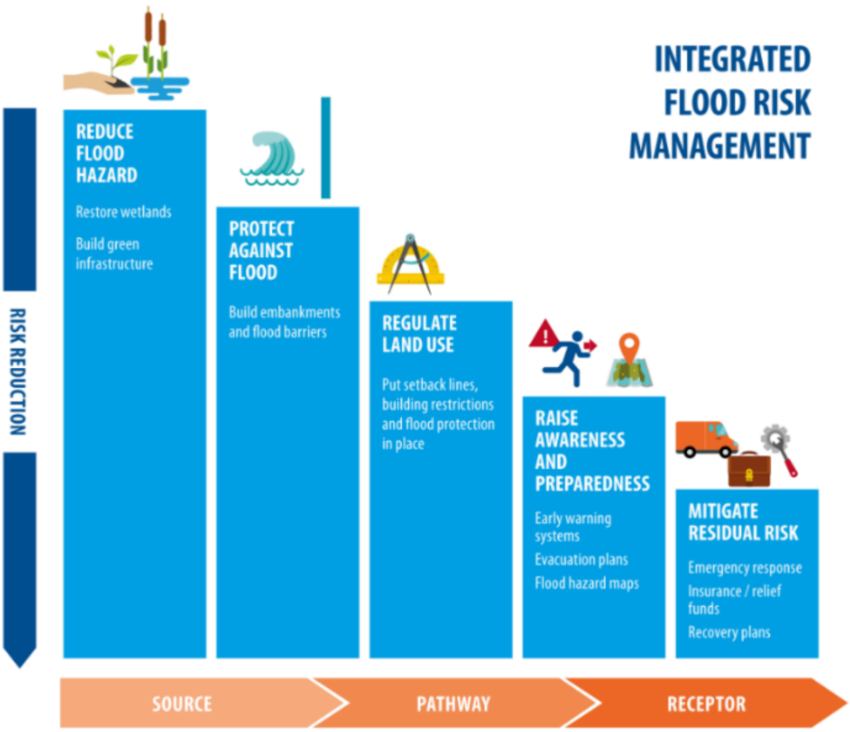


Figure 2.8 Categories of options for flood risk management under climate stress (GCF/Deltares 2021, under publication)

The bottom-up consultations (see chapter 3) are instrumental to identify the main water issues and its main causes. As a climate sensitive sector, climate variability and change (whether it is current or future) is always a key factor for **hazards** to occur. The top-down analysis as outlined under 2.2 is providing an assessment whether these hazards (drought, flood, landslide) are likely to increase or decrease under climate change. Adaptation options to reduce the climate/water itself therefore are always part of an adaptation plan. In addition, in a developing country like Bhutan socio-economic development is another key determinant for risk and impact. As more people and economic activities demand more water and it will be subject to hazards. It is therefore key to include adaptation options that allow to manage this water demand and **exposure** of people and assets to disasters.

A climate resilient water sector and society is less **vulnerable** when exposed to hazards as it is i) well informed, prepared and aware, ii) its assets and its infrastructure are to some extend hazard-proof and can be quickly recovered after a disaster to resume services and iii) vulnerable groups and people are supported and compensated. These vulnerability-reducing measures often are non-structural measures and therefore have lower associated costs. Often, they are low regret.

Table 2.5 gives an overview of generic adaptation options under these three categories for the water issues in the NAP water study.

Table 2.5 Example adaptation options for the most common issues identified in the NAP water study.

Issues	**Insufficient water**	**Floods**	**Landslides**	**Insufficient hydropower**
Hazard minimization	Create more / larger and more sustainable water sources. Protect the ecosystems sustaining them. Create temporary storages.	Minimize runoff / maximize infiltration. Provide sufficient space to the rivers.	Stabilize slopes, Forest and ecosystem management. Engineering structures such as nailing and anchoring along with bioengineering and dry-stone wall terracing.	Reservoirs to overcome lean season / flood/erosion protection of infrastructure
Exposure reduction	Manage water demand and use efficiency, Improve reliability of infrastructure.	Protect populated places and critical infrastructure. Institute no-build zones. Risk informed spatial planning.	Protect populated places and critical infrastructure. Institute no-build zones. Risk informed spatial planning.	Flexible delivery contracts that allow for temporary lower firm yield.
Vulnerability reduction	Integrated Watershed management, Provide alternate emergency supply, crop / income loss insurance / relief fund.	Early warning systems, Awareness raising, Flood-proof infrastructure and buildings Insurance.	Early warning systems. Awareness raising. Quick recovery and repair capacity Insurance.	Alternate power supply sources that reduce dependence on hydropower.

Implementation: Depending on the actual size and size of change in hazard and exposure and character of vulnerability different options will be proposed.

2.3.3 Choosing right response under uncertainty

Adaptation responses are also strongly dependent on the uncertainty characteristics (or confidence) of the risks identified. In general, it can be said that risks associated with low confidence require a more flexible risk mitigation plan compared to risks associated with a high confidence, which can be addressed in a more straightforward manner. If there is no or only low climate change risk associated with high confidence, there is no direct need to deviate from the norm (see Figure 2.9). In addition, a higher expected impact requires that the robustness and resilience of a sector is increased (see textbox 2.1).

A **flexible** plan has the characteristic that it can be adapted over time to respond to changing insights. A **robust plan** has the characteristic that it performs well under multiple future conditions. A **resilient plan** has the characteristic that it can deal and recover well from shocks associated with disasters and in this way reduces the vulnerability.

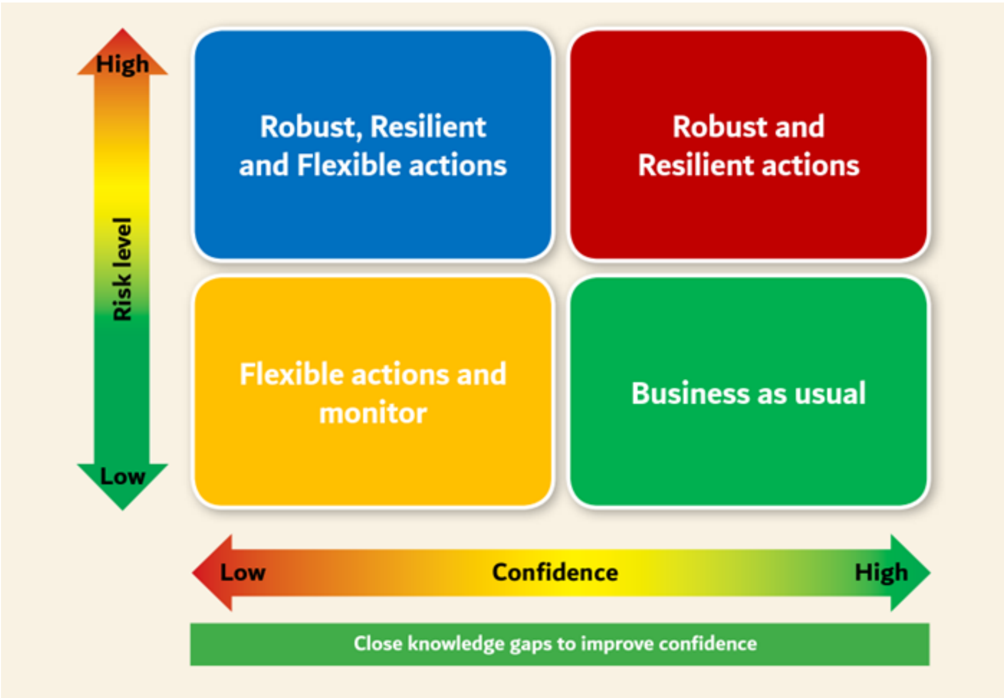


Figure 2.9 Strategic directions for adaptation depending on risk and confidence levels[i].

Basically, four combinations of low and high risk and near- and longer-term occurrence are possible. Priority actions will usually be justified when there is a high level of short-term risk or if there are longer term risks which require adaptations with long lifetimes or lead times. Long-term risks in principle allow for postponing any action and monitor the situation, especially if risks are assessed as relatively low. However, it is advisable to bring adaptation forward if there are early robust benefits and opportunities for low regret implementation of a measure at an earlier stage.

Implementation: Dependent on the outcomes of the risk assessment in terms of the size of the risks and level of confidence in the assessment; flexible, resilient, robust and low-regret adaptation options have been proposed. This has been done in a workshop with main stakeholders based on a long list of adaptation options per sector. See chapter 7 for the results.

2.3.4 Evaluating and prioritizing adaptation options

Once appropriate response options to risk and uncertainty have been identified, it is key to further prioritize the actions for the NAP. This is usually done based on an evaluation of the expected costs and impacts of the proposed actions and often complemented by an implementation analysis. Basically, two questions have to be answered: which adaptation options perform best and how can they be best implemented?

The evaluation of the adaptation options collected is done based on the following criteria:

- **Effectiveness** - actions to be taken are those which solve the most serious problems and have the highest impact on the objectives. In this case, the objective of the NAP is to reduce climate risks for the water sector. This means that actions should ranked based upon their effectiveness in reducing those risks to acceptable levels.

- **Costs** – actions are preferred that are effective against the lowest cost.

- **Co-benefits** – actions that have wider benefits than reducing the specific water risk are preferred. Example: introducing green spaces in urban areas can improve drainage capacity and at the same time contribute to a cooler environment and offer space for recreation.

- **Trade off** - actions that have the risk to lead to negative effects on other domains (other societal objectives, upstream or downstream effects). Examples: using pumps for water supply may negatively influence CO_2 reduction targets. Downstream dams may increase upstream flood risks.

Once prioritized the actions should be complemented with arrangements for the NAP. Such a plan for action typically contains the following elements (Mendoza et al. 2018):

1. A preferred strategy, including both short- and long-term actions.
2. Organizational, financial, and legal directives to implement the actions.
3. A monitoring plan to keep track of implemented actions and to trigger future action.
4. An implementation agenda, including budget, lead actors, and preparation times.
5. An assignment of institutional responsibilities for implementing the components of the plan as well as scheduled updates.

Implementation: Per sector appropriate adaptation options have been ranked using the above criteria for a qualitive evaluation based on expert knowledge. Lead organization, implementation partners and financing options have been identified for the priority actions. Actions have been separated in short- and longer-term action. This has been done in a workshop with main stakeholders. See chapter 7 for the results.

2.4 Limitations of the study

Here we present a list of the main limitations of the study:

General/Overview

The analysis is intended to provide a complete picture of climate change impacts on water resources for Bhutan. Therefore, climate data sets and a hydrological modelling system have been set up that covers all river basins and the whole geography of Bhutan with a resolution of 1 by 1 kilometre and is providing outcomes for every part of the country. This top-down approach has been combined with bottom-up consultations among the dzongkhags and water sector stakeholders in Bhutan. This approach to inform the NAP on water is suited to analyse the big picture and show change over time and a diverse set of impacts across the country. The analysis is not suited to draw too strong conclusions at a more local gewog level.

Top down assessment

The climate data analysis and hydrological modelling provided the basis of the TD impact assessment. The limitations of the TD approach are:

- Hydrological modelling
    - The model has been calibrated globally with a standardized procedure (see chapter 4). It has not been validated or calibrated in all details.
    - There are biases in the input climate data (especially rainfall) that are being transferred to the hydrological output. This reduces the overall confidence in the model outcomes. The results cannot be used as absolute changes but only as relative changes compared to historic values.
    - For assessment of local solutions (e.g. larger reservoirs, land-use changes) a more localized and validated hydrological model would be needed.
    - Impacts are not quantified but approximated by a set of indicators. This still leaves room for interpretations on causes and impacts. In addition, the thresholds used for critical dry spells, flows and rainfall events are based on expert judgement translated to statistical extremes (percentiles) but are not verified by local hazard information.
    - Quantitative data on future exposure and vulnerability data were referred to in the analysis but not integrated in the quantitative assessment. Beyond 2030 these data are not available. The climate-hydrology projections only project changes in hazard and not in exposure and vulnerability. This makes it difficult to assess the role of climate change in comparison to other causes of water issues.

Bottom up assessment

Little quantitative historic hazard information (e.g. on when, what consequences, how long, often etc.) could be retrieved from reports and the bottom-up consultations. This makes it difficult to relate future climate change to experienced hazards in the past (to combine the TD and BU analysis)
The bottom-up consultation did not prioritize issues for the whole of Bhutan but per gewog.

Adaptation analysis

The analysis has been qualitative, and expert based. Ground truthing and further assessment of effectiveness of adaptation options is required towards further implementation.

Nevertheless, the results that are presented in next chapters do give clear directions to the NAP on water priorities for adaptation. The underlying climate and hydrological evidence together with the bottom-up assessment is sufficient to support a national level plan such as the NAP. To support more localized decision making that can support concrete adaptation designs and improve confidence in the assessments, recommendations on strengthening the evidence base and knowledge structure will be provided.

3 Bottom-up consultations

3.1 Approach and Methodology

The bottom-up approach and assessments are participatory approaches involving people from the local areas to provide information and views. These assessments focus on the major water issues and causes of the issues at the ground level. Bottom-up assessments rely on information collected in that location provided largely (though not exclusively) by the people concerned. In this case, we involved local stakeholders from dzongkhags, thromdes and gewogs to provide their experiences, views and desires about the water sector and its various sub-dimensions of drinking water, irrigation, disaster and hydropower.

The main reasons for using the bottom-up approach were the fact that accurate local-level information could be acquired, involvement of local stakeholders in the identification of problems and solutions that are realistic and also to improve the collaboration between the national agencies and local governments.

Such assessments involving the local governments such as dzongkhags, thromdes and gewogs also provides a more holistic view and facilitate better buy-in from the local governments when the NAP is developed later as part of the project.

The first step here is a stakeholder consultation for identification of the issues and characterization of these issues and causes with the historical and past adaptation activities that were carried out in each dzongkhags, thromdes and gewogs.

In addition to the consultation with the stakeholders, a review of the literature of the past studies was also carried out. Drinking water and sanitation at dzongkhag as well as gewogs were extracted from the National Statistics Bureau (2017) and the Water Flagship Program implemented by the Department of Engineering Services, MoWHS (2020). This was complemented by the consultations from the gewogs which provided the issues, causes of the issues, adaptation options and community engagement including vulnerable groups.

For the bottom-up approach, the participants at the dzongkhag and thromde level were mainly Dzongkhag Environment Officer, Dzongkhag Engineer, Dzongkhag Planning Officer, Thromde Engineer, Statistical Officer, Disaster Management focal person and Thromde Environment Officers. In some dzongkhags, other officials from the dzongkhag also supported the assessment. They were consulted to provide information on the details of key water-related issues due to impacts of climate change and identifying the hotspots in their respective dzongkhags and gewogs.

The questionnaires based on the water resources and climate change for the three sectors; drinking water and sanitation, irrigation and water-related hazards were explained to the respective dzongkhag and thromde officials. The questionnaires (see Annex A.3) were prepared with the objective to identify the issues and the causes, vulnerable groups and the adaptation options of these three sectors.

To commensurate the in-depth assessment, the compiled information was then validated virtually with the respective dzongkhags and thromdes. Some of the changes that were made during the validation workshop were mainly for the hotspots identification and the adaptation options that were further noted and integrated into the report (Deltares 2021d).

For the hotspots identified at dzongkhag level, 3 for the sector from each administrative unit, a further in-depth assessment was carried out at gewog level with virtual consultations with the local leaders, water caretaker and also site visits to some of the hotspots for identification of main issues and causes of the issues and the vulnerable groups in specific gewogs.

For the hydropower sector, only the key stakeholders such as the Department of Hydropower and Power systems (DHPS), Department of Renewable Energy (DRE), Bhutan Power Corporation Limited (BPCL), Druk Green Power Corporation Limited (DGPCL), and Bhutan Electric Authority (BEA) were consulted for the risk assessment and identification of the adaptation options. Plant related information was collected from the hydropower plants directly through the DGPCL head office. Table 3.1 shows the step-by-step approach for the bottom-up approach.

Table 3.1 Approach and Methodology for Bottom-Up Approach

Steps	Date	Method	Activities/Objectives	Remark
Step 1	30 December 2020	Focus Group Discussion with Hydropower sector	Adaptation plans for the hydropower sector based on the issues and causes of issues related to climate change	Virtual mode
Step 2	4 February 2021	Focus Group Discussion with Samdrup Jongkhar thromde, Samdrup Jongkhar dzongkhag, Samtse dzongkhag and Sarpang dzongkhag	Questionnaires explanation for in-depth assessment to be done by dzongkhags and thromde officials	First phase trial with virtual mode
Step 3	15 and 16 March, 2021	Focus Group Discussion with all other dzongkhags and thromdes	Questionnaires explanation for in-depth assessment to be done by dzongkhags and thromde officials	Second phase virtual mode
Step 4	27 May 2021 and 31 May, 2021	Validation of the information received from the dzongkhags and thromdes	Finalization of identification of hotpots at gewog level and adaptation options	Validation (virtual mode)
Step 5	June-July 2021	Validation of findings with the gewogs and thromde Demkhongs	In-depth assessment of the hotspots on issues, causes of the issues and options at gewog / Demkhong levels	Site visits and mostly virtual consultation

3.2 Summary of results

3.2.1 Drinking water

With the highest per capita availability of water in the world, Bhutan still faces drinking water shortages. About 99.5% of Bhutan's population has access to improved water sources but only 63% has 24-hour access to drinking water[5]. Hence, the consultations were conducted with dzongkhag and thromde officials to gather information on drinking water issues. They identified three hotspots (gewogs and demkhongs) that are susceptible to drinking water issues from each dzongkhag and thromde (Figure 3.1).

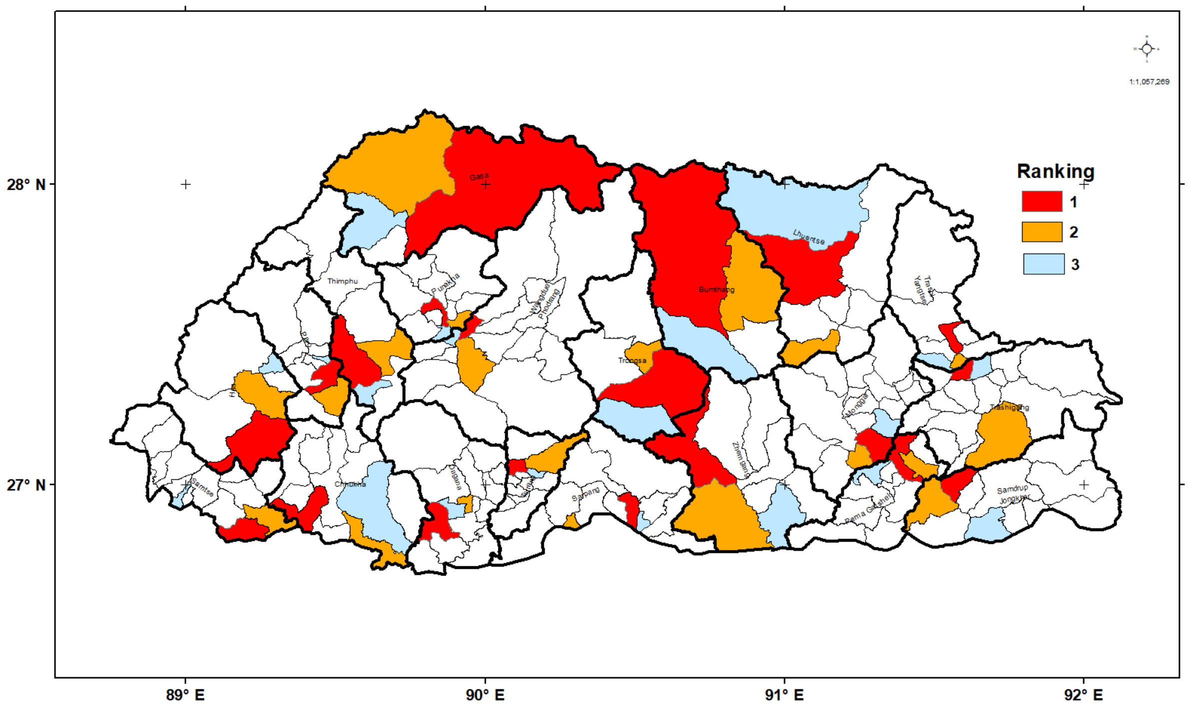


Figure 3.1: Drinking water issue ranking of top three gewogs of individual dzongkhag and four demkhongs of individual thromde.

Table 3.2 Summary of drinking water issues, causes, adaptation measures, capacity building and training and vulnerable groups of dzongkhags.

Drinking water issues reported	• Insufficient water; poor water quality during the monsoon season; • Accessibility; • Poor management of water sources; • Lack of proper water source; • Lack of technical skills for water supply schemes; • Damage and deterioration of pipelines and water-related conflicts
Causes of these issues	• Rise in water consumption for different purposes with increasing settlements /population; • Deforestation; • Drying of water sources/scarce water sources in the community; • Location of water sources on the fragile landscape;

[5] Kubota, A. (2020). *Water and climate change: UNDP*. Retrieved from https://www.bt.undp.org/content/bhutan/en/home/stories/water-and-climate-change.html

	• Lack of ownership; • Lack of training and incentives to water caretaker. • Management issues of the water distribution system; • Poor maintenance of the RWSS and the water sources; • Both water sources and alternative water sources are located far from the settlements; • No proper watershed or spring shed management; • Climate change (increasing temperature, erratic rainfall and decreasing precipitation leading to reduction of recharge rate); • Water pollution during heavy monsoon leading to murky water; • Human-wildlife conflict (e.g., destruction of water pipeline by elephants in southern Bhutan);
Adaptation measures proposed	• Explore and study the feasibility of new or alternative water sources; • Joint planning for watershed management with relevant central agencies; • Maintenance of Rural Water Supply Scheme; • Afforestation to protect a water source; • Strengthen and formation of WUAs; • Awareness of water-related laws and policies (IWRM); • Ensure periodic water quality testing; • Construct reservoir tanks and explore water harvesting technologies; • Water treatment during monsoon seasons to supply clean drinking water; • Replace damaged water pipelines; • Construction of modern tanks with high capacity, proper distribution lines and supply of good quality pipes; • Training in hydrological modelling of water sources and impacts on the catchment area.
Specific capacity and training required	• Upgrading the technical capacity of engineers; • Identification of water experts to provide timely intervention; • Providing plumbing skills; • Training and periodic refresher courses for water caretaker; • Capacity building to users on proper management of water supply including minor maintenance; • Training on water conservation; • Sustainable management; • Water harvesting techniques and strategies; and • Awareness to the community on water protection and management.
Vulnerable groups identified	• New settlers in the community; • Differently-abled people; • Households with single parents; • Nomads; • Low-income families; • People with a medical condition; • Senior citizens; • Hoteliers; • Women and children.

3.2.2 Irrigation water

Bhutan's irrigation development began with farmer's initiative and venture in the construction and management of irrigation systems in 1967 during the second five-year plan. Irrigation systems are categorized into community-managed irrigation systems (CMIS) and agency-built community managed irrigation systems.

The contribution of irrigation systems to the growth of the national economy, agriculture (increase food production and self-sufficiency of country), and as the primary source of livelihood for the rural communities are significant. However, irrigation systems face numerous challenges whereby this affects the agriculture sector. The consultations with dzongkhag officials were conducted to gather information on irrigation systems and related problems. From each dzongkhag three hotspots (gewogs) were identified which are more susceptible to irrigation-related issues, as shown in Figure 3.2.

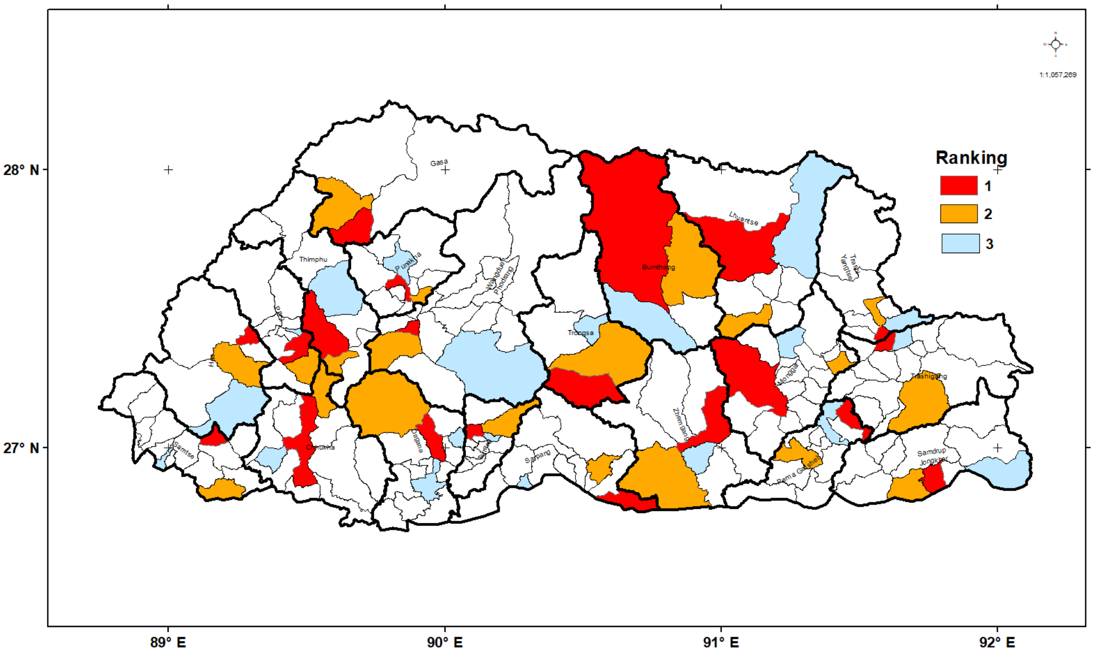


Figure 3.2: Irrigation-related issues ranking of top three gewogs of each dzongkhag.

Table 3.3 Summary of irrigation water issues, causes, adaptation, capacity building and training and vulnerable groups of dzongkhags.

Irrigation issues reported	• Monsoon dependent; • Drying of water sources; • Inefficient use of water; • Irrigation water-related conflicts; • Damage of the earthen channels; • Disruption of the source and irrigation channel due flood and landslides, and • Blockages of irrigation channel and pipe during summer.
Causes of these issues	• Use of the open unlined channels; • Sources are located far away; • Lack of sources in some gewogs; • Technical failure of water supply schemes; • Irrigation channels located on the fragile landscape; • No proper planning of storm water drains along the newly constructed farm roads; • Conversion of wetland irrigation water source into rural water supply scheme; • Poor management of irrigation water; • Poor quality of channels or pipes; • Lack of awareness; • Increasing population; • Falling boulders and trees; • Increase in agriculture activities; • Seepage of water from channels; • No proper management of WUA; • Degradation of watershed; • Erratic rainfall and heavy monsoon; • Deforestation.

Adaptation measures proposed	• Awareness on the impacts of climate change; • Involvement of multi-stakeholders in irrigation systems management; • Renovation of existing irrigation systems; • Adequate financial assistance for repair and maintenance; • Water source protection and awareness; • Adopt climate smart irrigation systems such as water harvesting and micro-irrigation technology (pond irrigation, sprinkler irrigation, drip irrigation, rain water harvesting etc); • Frame proper management rules and regulation of water usages; • Allow paddy cultivation on government land with sufficient water source on lease; • Construction of lined irrigation channel or closed channel with HDPE pipes to reduce water loss; • Protection and management of watershed; • Fodder seed plantation in landslide prone areas; • Formation and proper management of WUAs; • Advocate beneficiary households on the importance of WUA; • Diversification of water sources; • Ensure quality construction of irrigation channel; • Sourcing of reliable and sustainable water source from stream/river; • Explore crops which consume less water; • Strengthen the weather and hydrological monitoring and forecasting capacity; • Revival of ritual culture to conserve water and appease deities • Revival of abandoned ponds, and • Study the potential for groundwater utilization.
Specific capacity and training required	• Enhancing skills of WUAs; • Improve technical capacity building for water-related infrastructure engineering; • Set up a separate technical team to work on irrigation and drinking water-related supply systems; • Training in maintenance of drains; • Training on construction of irrigation water supply, comprehensive training on water pump system for RWSS technicians; • Masonry training to the user group; • Technical training to engineers, local leaders, caretakers and agriculture extension supervisors about various irrigation systems; • Training on rainwater harvesting strategies; • Mass awareness on preservation of traditional plants and cereal; and • General awareness on the impact of developmental activities on drying up of water sources are also necessary to address the issues.
Vulnerable groups identified	• Differently-abled people, • Unemployed youth, • Women-headed households, • Old-age groups, and • Leased-in (lessee) individuals. **The reason for listing them as vulnerable:** • No alternative water source; • Located far away from the source/mono-water source for irrigation, • Individual are not mobile enough to get to the source, • Economically dependent

3.2.3 Disaster risk management

Climate change causing erratic rainfall patterns with the heavy shower during monsoon and rapid retreating of glaciers has enhanced the probability of flash floods and GLOF in the river catchments areas. Examples of such disasters are, GLOF in Punakha (1994), and floods in Gelephu because of the rise in Mao Chhu with heavy rainfall (2020). Bhutan has faced over 21 GLOF and frequent occurrences of floods and landslides every year. These disasters have damaged agricultural land, public properties, institutions and took many lives[6].

The consultations were conducted with dzongkhag and thromde officials to gather information on water-related disasters. They identified three hotspots (gewogs and demkhongs) that are susceptible to water-related disasters from each dzongkhag and thromde (Figure 3.3). The major water-related hazards are flash floods, landslides, rainstorms, hailstorms, soil erosion, and river flood.

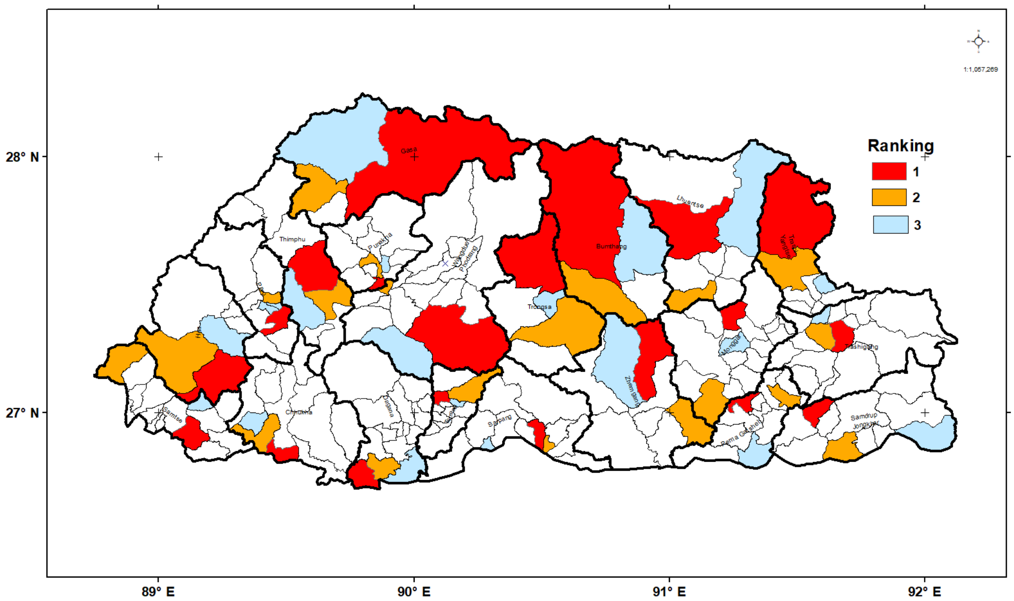


Figure 3.3: Water-related disasters ranking of the top three gewogs and demkhongs of individual dzongkhag and thromde.

Table 3.4 Summary of water-related disasters issues, causes, adaptation, capacity building and training and vulnerable groups of dzongkhags.

Water-related disaster issues reported	• Loss of lives; • Destruction of agricultural land and products; • Obliteration of transportation infrastructure (roads and bridges); • Destruction of protection walls; • Loss of topsoil and nutrients; • Landslides along the roads; • Disruption of water sources, drinking and irrigation water supply; • Damage to public properties such as schools, offices, and airlines

[6] National Centre for Hydrology and Meteorology (n.d.). *Compendium of climate and hydrological extremes in Bhutan since 1968 from Kunsel*.

Causes of these issues	• Glacier lake outburst flood; • Flash flood due to cloud bursting; • Flooding due to erratic rainfall patterns attributed to climate change; • Lack of proper drainage systems; • Altering river base and course; • Existing flood protection and mitigation works are not sufficient; • Sudden heavy downpour during monsoon season increases the river volume; • Change in the weather pattern; • Blockages of irrigation channels during heavy rainfall; • Divergence of river and stream
Adaptation measures proposed	• Awareness about water-related hazards (GLOF, floods); • Permanent diversion of some rivers; • River dredging and other flood mitigation works along the river beds; • Digging the channels that pass via the valleys to widen the river course; • Training on disaster management; • Construction of slide gabion, retaining walls and flood mitigation structures at the slide and flood-prone areas; • Resettlements of the public living near the landslide-prone area; • Basic study on water-related hazard management in the local area; • Installation of permanent rainfall stations providing hourly data to represent the spatial rainfall pattern over the entire catchment for future studies on proper flood hazard assessment and management; and • Maintain proper causeway and drainage along the farm road.
Specific capacity and training required	• Formation of disaster preparation plan for vulnerable chiwogs; • Training on disaster management to various vulnerable groups (elderly, disabled, students and women); • Search and rescue training to key personnel at the gewogs; • Conduct training on water-related hazard mitigation measures; • Involve communities during planning and execution of mitigation measures; • Practical training and periodic mock drills with preparedness plans to face the disaster; • Training people (especially those dwelling in hazard-prone areas) on the usage of PPE (personal protective equipment); and • Advocacy programs on species that help prevent landslides like Napier grass.
Vulnerable groups identified	• Impoverished, • Differently-abled, • Elderly, • Women and children, • People settling in landslide-prone areas.

3.2.4 Hydropower

Hydropower generation is the energy source that is most likely to be impacted by climate change. Changes in river flow, timing and pattern of precipitation have a direct impact on hydropower generation. Bhutan is rich in hydropower resources and it is deemed as an important resource for the socio-economic development in the country. It has driven economic growth and greatly boosted progress in meeting many of the country's social-economic development objectives.

However, hydropower generation is at risk due to the adverse effects of climate change and it is a climate-sensitive sector with complete reliance on flows in the rivers, which is variable depending on good monsoon and lean season flows. As a result, years with good monsoons and high-water levels result in higher electricity sales and greater revenue, while poor monsoons have a negative impact on revenues and the economy.

According to past studies and reports, there will be temporal and spatial variation in flow with high flows during monsoon and very low flows during the lean season making the management of hydropower system challenging (NEC, 2020). This will notably affect electricity production affecting domestic supply as well as exports due to disruption of average flows for optimum hydropower generation.

The other major issue is the formation of supra-glacial lakes due to increasing temperatures. Several flash floods and landslides have occurred in the country since 2002 (NEC, 2020). Glaciers retreating with high chances of GLOFs and erratic rainfall patterns affect the ability of catchment areas to retain water, leading to increased runoffs affecting flow regimes of the rivers thereby causing spillovers. Decreasing flows during the dry season further decreases hydropower energy generation during the winter which puts further stress on the lean season energy security. When facing power shortages during the lean months (November–March) due to reduced flow, the country runs short of electricity. According to PSMP (2040), in February and March which are the lean months and are the times when electricity demand is the highest, the capacity is insufficient for the domestic supply and is compensated for by power imports from India which would be further accelerated by climate change.

As the energy production in hydropower is directly dependent on the quantity of water available in a given stream, the changing climate conditions are posing a threat to the hydropower resource potential. It has become a high priority that the climate change factor has to be considered for designing future hydropower projects in the country which is currently not being taken into account.[7]

As per the consultation with the main stakeholders, the main impacts of climate change on the hydropower plants are reduced flow during the lean season affecting power generation when the demand is high. The other impacts are sedimentation and wear and tear of the power plants due to floods. The compounding impacts as per the stakeholders are a decreased revenue, higher operation and maintenance costs, impact on energy security, low e-flow and unreliable power generation.

Through the consultation, it was reported that some of the adaptation measures are already being carried out. The past adaptation measures for different hydropower plants that are in operation in the country are:

- Hard Coating of Turbine runners
- Diversion of Lubichhu & Tichhalumchhu diversion for Chhukha HPP
- Diversion of Tsibjalumchhu for Tala HP
- Funding conservation in the catchment for Wangchhu
- Dredging works
- Regular maintenance for mini and micro hydropower plants
- Bunakha Reservoir is planned to cascade and support THP and CHP

Based on the consultation from the 20 dzongkhags and the Technical Working Group/Focus Group (TWG/FG the adaptation options are:

- More study and investment to study reservoir storage plants,

[7] Focus Group Discussion with hydropower sectors, December 2020

- Upstream check dams,
- High altitude reservoirs,
- Hydro-peaking is possible, but not done (there is the possibility of using it as an adaptation for winter domestic needs
- Study of groundwater in detail,
- Understand snow and glacier contribution better,
- In-depth assessment of flow regime changes in the smaller stream due to natural changes and higher consumptive uses,
- Pumped- storage hydropower plants, and
- Watershed protection

4 Climate and Hydrology analysis

4.1 Methodology

To evaluate the impact of climate change on the water resources of Bhutan, a hydrological model was applied, using a new set of historical and future climate data as an input. The aim of this analysis was to present a representative and high-resolution analysis for the country that can also capture some key climatic variability that could enhance the risk for the water sector. Before applying the climate data for the hydrological modelling the climate data itself were extensively analysed on trends, variability and biases and compared to previous studies such as the NCHM (2019) study.

The wflow_sbm model, which is developed by Deltares, was used for the hydrological analysis. The model is a fully gridded model, meaning that output of all relevant hydrological state and flux variables is generated at any point in the model domain for each time step. The model parameters describe physical catchment characteristics and are estimated using global datasets of land use and soil characteristics. Dominant hydrological processes, including glaciers, snow, interception, transpiration, soil evaporation, capillary rise, groundwater recharge, are included in the model schematization (see also Figure 2.5).

The model is forced with precipitation, temperature and potential evaporation. For the historical data, 40 years of ERA5 reanalysis data with a resolution of .25^{o} was used. Reanalysis data provide the most complete picture currently possible of past weather and climate. They are a blend of observations and past short-range weather forecasts rerun with modern weather forecasting models. The analysis of the data for Bhutan shows that spatial and temporal patterns are well captured but that there also seems to be a strong bias in precipitation (ERA5 overestimates precipitation in comparison to observations from NCHM), especially at higher altitude stations. For the future climate, down-scaled projections from a set of 5 GCMs from the NASA GEX-NDDP dataset were taken, which was also used by NCHM in 2019 and has a resolution of 25x25 km (for more information on the climate data see Deltares, 2021a).

The hydrological model performance for historical conditions is evaluated at the primary and secondary streamflow stations of Bhutan. Overall the model reproduces observed streamflow relatively well. However, it was found that the input data likely overestimate precipitation in several areas, leading to an overestimation of simulated peak flows.

The model is subsequently run for 20 climate change projections, which include projected climate data from 5 global circulation models (GCMs), 2 Representative Concentration Pathways (RCP4.5 and 8.5) for the near future (2021-2050) and the far future (2071-2100). For each climate change projection, a delta change approach was applied which aims to transform the historical data to represent future changes derived from the projected climate data. This implies that first the monthly deltas have been calculated that describe the difference between the historical and future GCM data. These monthly gridded deltas are then applied to the historical ERA5 time series to represent future climatic conditions. This enables the comparison of the relative changes in simulated streamflow between climate change projections and the historical conditions.

4.2 Results

From the 40 year of ERA5, historical climate data trends for precipitation at each dzongkhag in Bhutan were calculated. A clear and significant increasing trend in temperature could be derived for all regions, which was strongest in higher altitude dzongkhags. For total precipitation, an increasing trend was calculated for almost all dzongkhags, however statistically not significant in most places. For the dry season, most of the calculated trends show a decrease in precipitation over the past 40 years, though for most regions statistically not significant (for more information see Deltares 2021).

Based on the future climate data analysis, averaged over the country of Bhutan, mean annual precipitation and temperature are both projected to increase for each climate projection, as shown in figure 4.1. However, where all models show an increase in precipitation for the wet summer period (June until September JJAS), the models show both an increase and a decrease for precipitation during the dry winter period (December until February, DJF), as shown in figure 4.1. The annual increase in precipitation over the climate projections has a mean of +23% (with 5th and 95th percentiles of +6% and 54%), which is similar to values found in literature (Almazroui et al. 2020). All studied climate models project an increase in mean summer precipitation, with a mean of +25%. However, both an increase and a decrease in mean winter precipitation is projected, ranging from -38% to +57%.

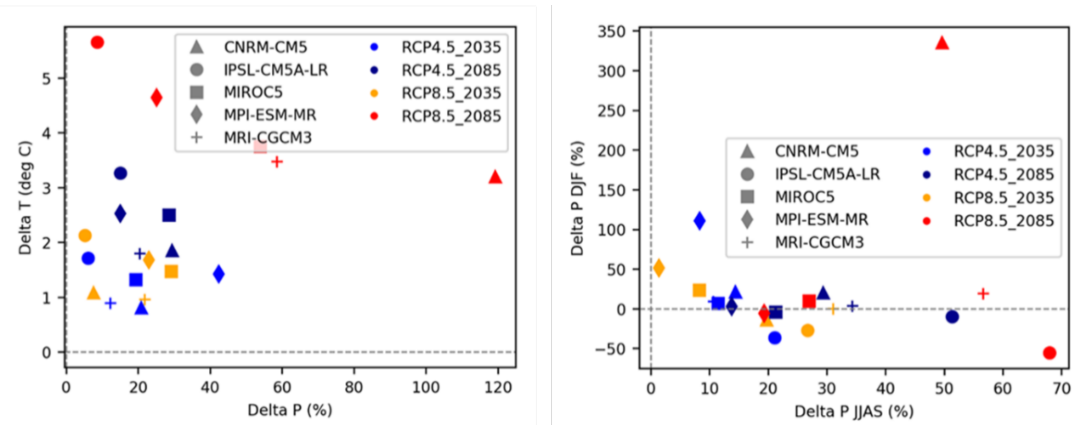


Figure 4.1 Left: Mean annual deltas for temperature T (in °C) as a function of mean annual deltas for precipitation P (%) for each of the 20 climate projections (5 GCMS, 2 RCPs, near future 2035 and far future 2085) spatially averaged over Bhutan. Right: Mean annual deltas for precipitation P during the dry winter period of December until February DJF (in %) as a function of mean annual deltas for precipitation P during the wet summer period of June until September JJAS (in %) for each of the 20 climate projections (5 GCMS, 2 RCPs, near future 2035 and far future 2085) spatially averaged over Bhutan.

Next, the impact of climate change on the water resources of Bhutan were assessed for each of the 20 climate projections in terms of:

- Change in annual, winter and summer precipitation and groundwater recharge at dzongkhag and gewog level (e.g. *Figure 4.2* for the change in winter groundwater recharge at the gewog level, we refer to the technical report for all other results).

- Change in aridity index for the catchments upstream of the primary monitoring stations.

- Change in annual, summer and winter precipitation and streamflow over the 40 years period in comparison to historical conditions (to account for natural variability) for the catchments upstream of the primary monitoring stations.

- Change in annual, winter, summer, 90th percentile streamflow across the primary stations, secondary stations and main hydropower locations (e.g. Figure 4.3 for the primary stations, see the technical report for detailed results).

- Change in mean annual snow storage compared to historical conditions.

The results indicate that, overall (detailed results in the technical report, Deltares 2021b):

- Mean annual groundwater recharge is projected to increase with approximately 16%. The increase applies for almost all climate projections.

- Mean annual, summer and 90th percentile streamflow is projected to increase with approximately 20%.

- During winter, there is more disagreement amongst climate projections on the sign of change of recharge and streamflow, but median values still indicate an increase. *Figure 4.2* for example shows that there is large disagreement in net DJF groundwater recharge between the 5 climate models.

- A substantial median decrease of -35% in snow storage for the catchment of Mutkirap is projected across the climate change projections as a result of the rising temperatures. No other basins have been analysed for snow storage.

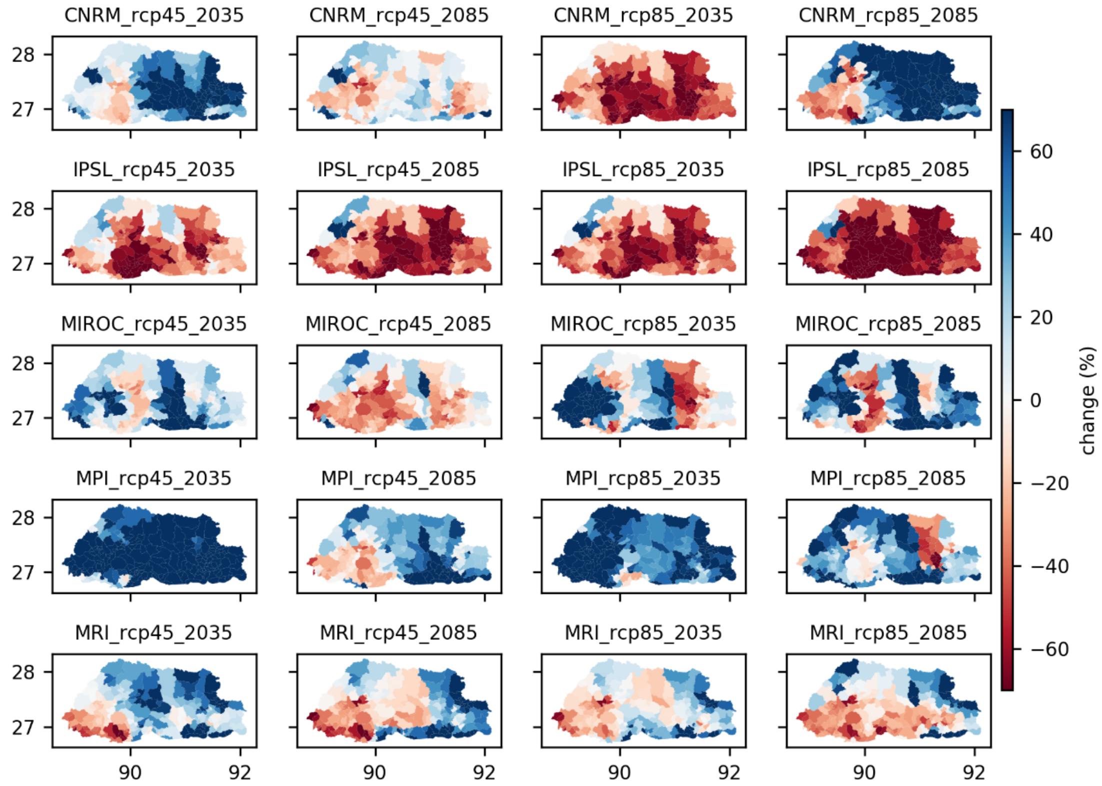


Figure 4.2 Percentage change in winter groundwater recharge for each GCM and projection period compared to historical conditions over the gewogs.

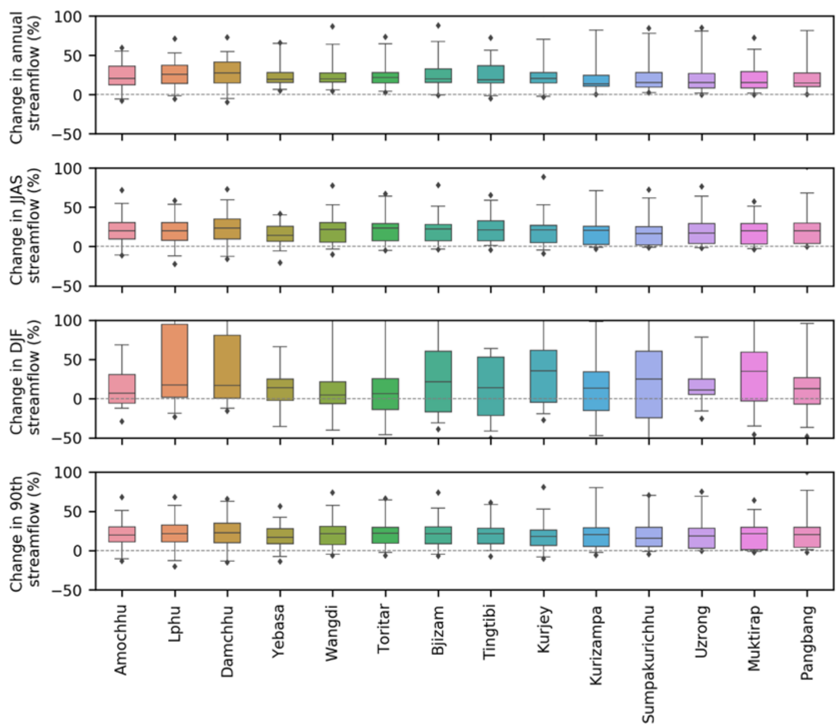


Figure 4.3 Percentage change in mean annual streamflow, mean wet season (JJAS) streamflow, mean dry season streamflow (DJF) and 90th percentile streamflow over the 20 projections for each of the primary stations. The boxplot represents the variability across the 20 climate change projections.

5 National level impacts

In this chapter, the results of the risk characterization method, as explained in chapter 2, are presented.

5.1 Droughts and water supply risks

5.1.1 Top down analysis of reduced groundwater recharge at gewog level

In Figure 5.1, an analysis of drought indicator based on groundwater recharge is presented.

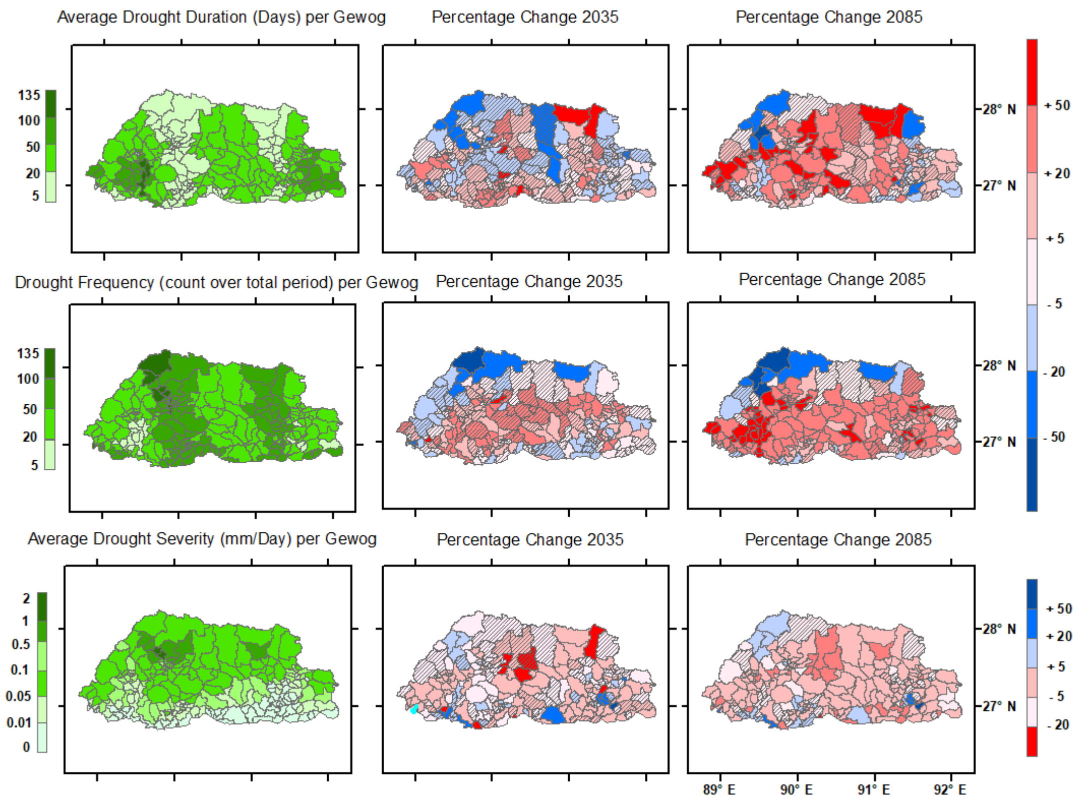


Figure 5.1 Dry spells (defined here as groundwater recharge < 10 percentile duration, frequency and intensity under historic climate (left column) and future climate (2035 and 2085) for RCP4.5. Hatched areas indicate gewogs where no more than 3 GCMs project the same direction of change. See annex B for RCP8.5.

It can be seen that:

- Frequency and duration are correlated under the current climate. Patterns that can be distinguished are: the Punatsangchhu and Drangmechhu basins with shorter drought periods (5-20 days) but higher frequencies (1-3 times per year), the lower Wangchhu basin and the upper Nyera Amari and Jomori basins with longer durations (up to over 100 days) but lower frequencies (~once every 2 years).

- In absolute values, 10th percentile groundwater recharge under the current climate is lowest in the southern part of the country where temperatures as well as evaporation are highest during dry spell events.

- Under a changing climate frequency, duration and intensity of dry spells are increasing for the largest parts of the country, especially towards the end of the century. There are some exceptions: for some of the high-altitude northern gewogs drought frequency is decreasing. The most robust decrease is seen over the north-western part of the country.

- For 2035, agreement between the different projections is still low. Agreement between projections is increasing towards 2085 and from RCP4.5 to 8.5 (see Appendix B, Figure B.1).

- *Figure 5.2* confirms the overall trend towards higher frequencies and longer droughts under future climate change with some exceptions for gewogs 50 (Laya, Gasa), 51 (Lunana, Gasa), 23 (Soe, Thimphu) and 24 (Lingshi, Thimphu).

- Most of the changes are between 0 and 100% for frequency and duration for 2085 and between -25 and 50% for 2035. This implies that current droughts may become up to 1.5 to 2 times longer and more frequent.

- These results illustrate that while the median values on a seasonal basis may point towards on average wetter conditions (see 4.2), the extreme values, in this case dry spells, can increase at the same time in frequency and duration. This confirms the common scientific understanding that with climate change, extremes both on the wet and dry side of the spectrum are expected to increase.

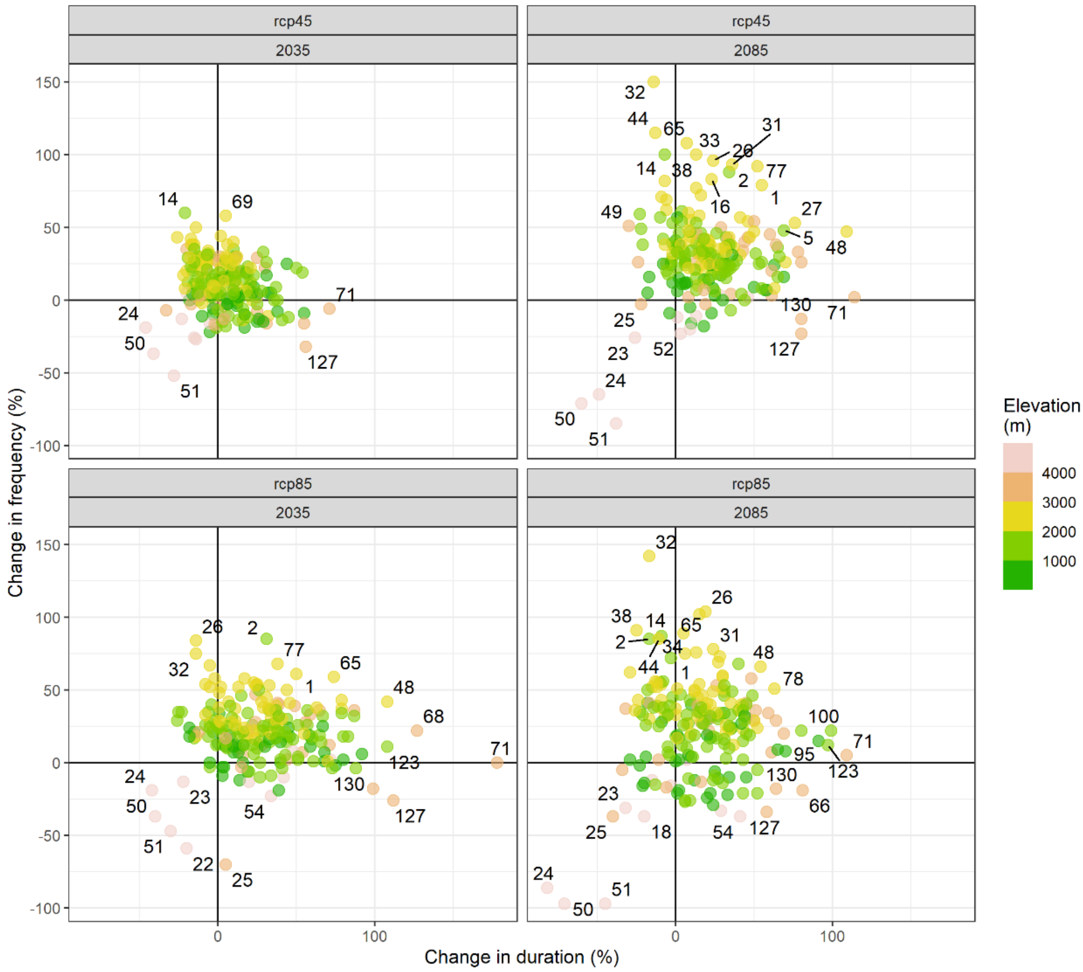


Figure 5.2 Scatter plot of change in dry spells (defined here as groundwater recharge < 10 percentile) frequency versus duration for all gewogs (ID's included) under RCP4.5, 8.5 and 2035 and 2085. Every point in the figure represents one of the 205 Gewogs. The numbers indicate ids of selected gewogs.

5.1.2 Top down analysis of reduced river flows

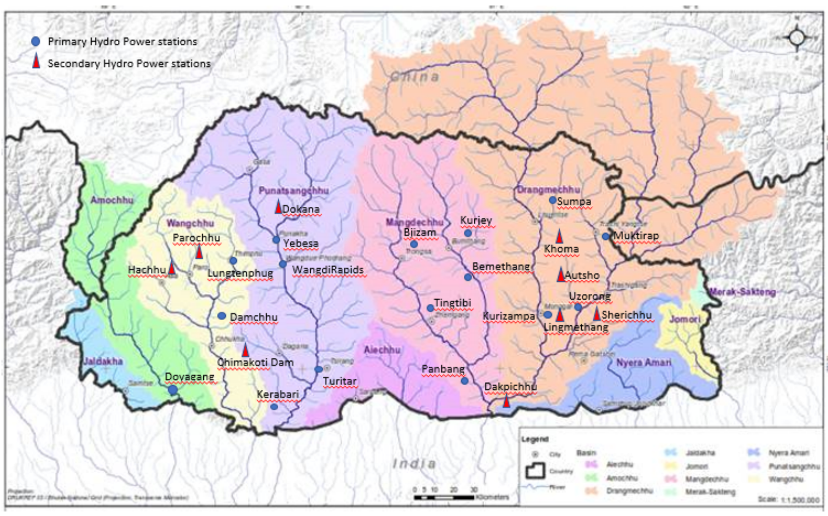


Figure 5.3 Locations of flow calculations in table 5.1 and 5.3. Note that there are no outputs for the Jaldakha, Aiechhu, Nyera Amari and Jomori basins.

Error! Not a valid bookmark self-reference. Table 5.1 shows the results of the dry spell indicators based on river flow for the locations shown in figure 5.3.

Table 5.1 Indicators for dry spells (defined here as river flow < 10th percentile) at river station locations representing the sub-catchments as shown in

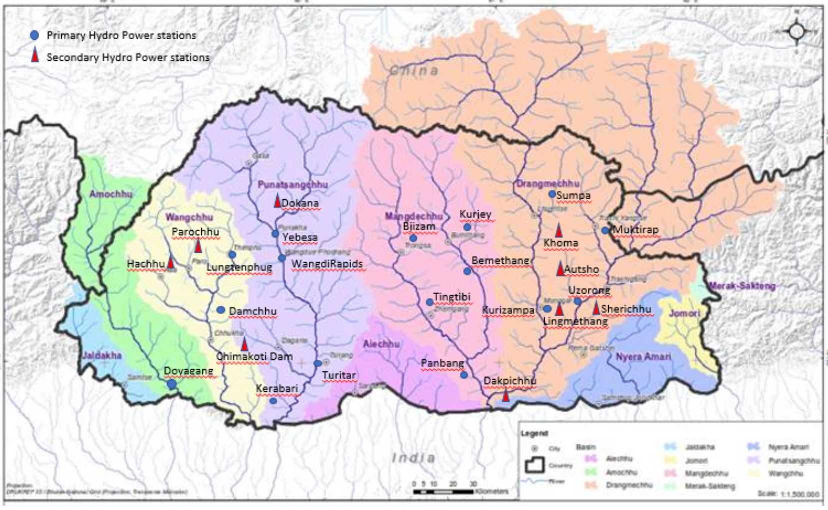


Figure 5.3. Results are shown as percentage change compared to historic flows for 2035 and 2085 for RCP4.5 and RCP8.5. Agreement (Ag) between the 5 GCM projections is classified as low (L, on average 3,5 or less models agree on sign for duration and frequency), medium (M, between 3, 5 and 4,5) and high (H, all models agree for both indicators).

					RCP4.5						RCP8.5					
ID	Sub-catchment	Historical Dry Spells			2035 Relative Change (%			2085 Relative Change (%			2035 Relative Change (%			2085 Relative Change (%		
		Q10 of fL (cms)	Duration (days)	Frequency (count)	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag
Amochhu																
1	Doyagang	14,6	35	43	-16	-12	M	5	2	L	20	-7	M	-23	-21	M
Wangchhu																
2	Lungtenphug	2,8	42	35	-31	14	M	-14	31	M	8	20	L	-33	11	M
15	Haa	0,8	41	36	0	-6	M	46	11	M	19	11	M	48	3	M
3	Damchhu	8,5	40	37	-44	-54	M	-12	14	M	-7	16	L	-16	8	M
21	Chimakoti Dam	11,1	40	37	-38	-30	M	-1	16	M	-4	19	M	-13	16	M
Punatsangchhu																
4	Yebasa	29,3	24	60	-16	-15	M	1	12	L	45	-13	M	15	-18	M
16	Samdingkha	21,9	24	61	6	-10	M	16	8	M	75	-5	M	44	-18	M
5	Wangdi	75,0	29	50	-11	-2	L	4	6	L	50	8	M	16	-2	L
6	Turitar	128,2	35	42	-26	-12	M	-5	19	M	43	12	L	-2	10	M
Mangdechhu																
7	Bjizam	3,6	41	36	-17	14	M	21	14	M	36	14	M	-14	11	M
17	Tingtibi_on_Dakpaich	0,5	45	33	-7	-9	M	1	24	H	23	24	L	-3	24	M
8	Tingtibi	13,7	48	31	-28	26	M	2	26	M	20	32	M	-16	35	M
Chamkharchhu																
9	Kurjey	2,7	37	40	-34	-28	M	17	0	M	35	2	M	-5	-8	M
Kurichhu																
18	Sumpa_On_Khomachh	6,4	32	46	6	-9	M	32	-9	M	63	-7	M	26	-9	M
11	Sumpakurichhu	5,8	31	47	8	-11	M	36	-13	M	66	-9	M	27	-11	M
19	Autsho	68,2	35	42	-7	-2	M	4	0	M	64	2	M	13	-2	M
10	Kurizampa	73,2	35	42	-8	-2	M	9	0	L	64	0	L	14	-2	M
Drangmechhu																
13	Muktirap	2,6	43	34	-20	3	M	-10	9	M	0	21	M	-38	-6	M
20	Sherichhu	5,2	42	35	4	11	M	0	14	M	24	14	M	-2	17	M
12	Uzrong	27,2	39	38	-15	-13	M	-8	5	M	14	8	M	-29	-5	M
Drangmechhu+Kurichhu																
14	Pangbang	132,3	32	46	8	-7	M	9	-4	M	73	-9	M	25	-11	L

What can be concluded from table 5.1 is:

- Historic dry spell durations (i.e. duration of flow below 10th percentile) are in the order of magnitude of 1-2 months with a frequency of occurrence of once to twice every year.

- In contrast with the results for recharge, the low flow durations and frequencies are projected to decrease (low to medium level of agreement) for RCP4.5 short and to some extent also for RCP8.5 long term. On average this decrease is between 0 and 30-40%. There are only a few exceptions, such as the small catchment of Sherichhu where both duration and frequency are slightly increasing.

- On the other hand, for RCP8.5 on the short term for almost all sub-catchment low flow duration and frequency is increasing. Changes in duration may amount to over 50%. To a lesser extend this is also true for RCP4.5 on the long term (2085).

- These variable patterns over time and RCP can only be explained by the hydrological processes taking place such as:

    - Snow and ice melt increasing under all timeframes and RCPs as temperature is increasing as well under all of them especially at higher altitudes (see Deltares, 2021a). The low flows are mainly sustained by these sources. The highest temperatures (under RCP8.5) would therefore lead to the highest amounts of melting water. During the dry winter season, when the most serious dry-spells occur, this is probably not a big factor.

    - Precipitation increasing all year round in the sub-catchments and on average also in the dry season leading on average to slight increased flows (see also Deltares 2021b).

    - In the higher temperature projections, a larger share of precipitation will appear as rain instead of snow, leading to faster run-off. In theory, this will lead to higher frequencies of both floods and dry spells.

    - More water will evaporate under higher temperature projections before it can add to runoff and flows. This will increase the frequency and duration of low flows.

  The balance between these four processes will ultimately determine the trends in projected low flows.

- Given the variable and even contrasting trends in low flow duration and frequency among RCP scenarios and short and long term, it is advised to consider a possible increase of low flow duration and frequency when preparing adaptation options. Especially for the short term, low flow duration and frequency may increase under a high emission, like RCP8.5.

- Of all larger catchments the Punatsangchhu (Toritar, Yebesa, Wangdi), Mangdechhu (Bjizam, Tingtibi, Kurjey) have the highest likelihood of increased duration and frequency low flows. And to a lesser extend parts of Drangmechhu (Kurizampa, Kumparichhu, Pangbang) and Wangchhu (Haa).

5.1.3 Impacts on drinking and irrigation water supply: top down and bottom-up analysis combined

Note that the direction and relative size of change may have been quite robustly demonstrated in previous paragraphs. However, this is not directly an indication for the criticality of the impacts. After all, the threshold value for dry spells (10 percentile of 40-year daily recharge and flow data) was chosen arbitrary independent of associated impacts. That is why the top-down analysis needs to be combined with findings from the bottom-up consultations.

In summary, the main issues around water supply for drinking water and irrigation identified from the bottom up consultations are:

1) There is an increasing lack of adequate good quality water resources due to:

   a. Sources of springs and streams drying during the dry season; groundwater recharge is reduced due to climate change and erratic rainfall.
   b. Sources and the watersheds they belong to are sometimes not well managed and protected
   c. The infrastructure for water supply and irrigation is sometimes insufficient, poorly managed and therefore malfunctioning.
   d. New sources seem to be difficult to find within reasonable distance.

2) The demand for water is increasing because of development and climate change:

   a. Growth of population
   b. Growth of welfare, sanitation facilities and associated water demand
   c. Growth of irrigated agricultural areas
   d. Crop water demand is increasing because of increasing evapotranspiration under higher temperatures
   e. Growth of other economic activities such as tourism and associated water demanding facilities.

3) As a result, there is growing competition over the available water. The most vulnerable people and groups have least access to the water.

Table 5.2 Current and future water demand for the water sectors in Bhutan (National Environment Commission, 2016)

Sectors	**Population/total irrigated area (Ha)**	**Drinking water demand**	**Water required 2017 (MCM/Yr)**	**Population in 2050**	**Water Demand LPCD**	**Water Required 2030/2050 (MCM/Yr)**
Drinking water	727,145	150	39.81	1,039,090	300	113.78
Industry & others	-	-	74.39	-	-	218.35
Irrigation water	25011	-	666.9	-	-	911.8

In a nutshell, this shows that climate change, with reports on increasingly erratic rainfall patterns, higher temperatures and longer drought periods, is a serious stress factor during the winter season. Adding to existing problems with infrastructure and watershed management and in a country with a growing population that is developing its agriculture, economy and improving its living standards.

These reports are confirmed by observed trends in decreasing rainfall (medium confidence) and increasing temperatures (high confidence) (see Deltares 2021a and b). The top down dry spell analysis shows that especially periods of reduced groundwater recharge are likely to increase in length and frequency. This will put more stress to water availability from local rainfed springs and wells. The only region that may escape this additional stress is the north-western part of the country.

These longer and more frequent periods of droughts will also put extra stress to watershed ecosystems that are key to maintain provision of clean water.

With further increasing temperatures and evaporation the water demand from crops, trees, ecosystems will further increase in this way putting extra pressure on available water sources.

Where water for consumption and irrigation is supplied by larger rivers and tributary streams, potentially water availability is reduced as well. However, the increase of this risk is uncertain and therefore very much dependent on the future climate scenario. With a climate development according to RCP4.5 (more or less the current trajectory) for the short term the dry spells are more likely to become shorter and less frequent.

5.2 Floods and landslide risks

5.2.1 Top down analysis of extreme precipitation events

The analysis of historical and future extreme precipitation events at the 10 and 30-year frequencies are shown in Figure 5.4.

The results show that:

- Historically, gewogs in the east of Bhutan (in Drangmechhu and Nyera Amari basins) show higher frequency of 10-year precipitation events. In contrast, the more extreme 30-year precipitation events occur most frequently in the south of Bhutan, in gewogs within Aiechhu basin.

- Overall, the historical risk from extreme precipitation events is lower in the north of Bhutan (the upstream parts of the Punatsangchhu and Mangdechhu basins) compared to the other regions.

- Under the projected climate changes in 2035 (RCP 4.5), there is a clear pattern of increasing risk from extreme precipitation events, as both 10 and 30-year precipitation events can increase from 1 to 5 times of its historical value.

- No clear spatial pattern is observed for the projected changes at 2035, across different basins in Bhutan. Although few gewogs show large changes in extreme precipitation, i.e., up to 10 or even 20 times of the historical values, they are distributed across different basins.

- Under the projected climate changes in 2085 (RCP 4.5), the existing pattern in increasing and extreme precipitation risk continues. The frequency of 10-year events increases on average 2 to 10 times over the country, whereas more concerning 30-year events increase, on average up to 5 to 20 times.

- Increases in extreme precipitation events for the year 2085 show profound differences from one region to another. 10-year precipitation events increase mostly in the gewogs located in central Bhutan across the Punatsangehhu and Mangdechhu basins, and to a lesser extent in the east of the Drangmechhu basin. For the 30-year events, the gewogs that face greatest risk increase (i.e., increases of 20 to 50x) are those located in the east of Drangmecchu basin and on the south in Aiecchu basin.

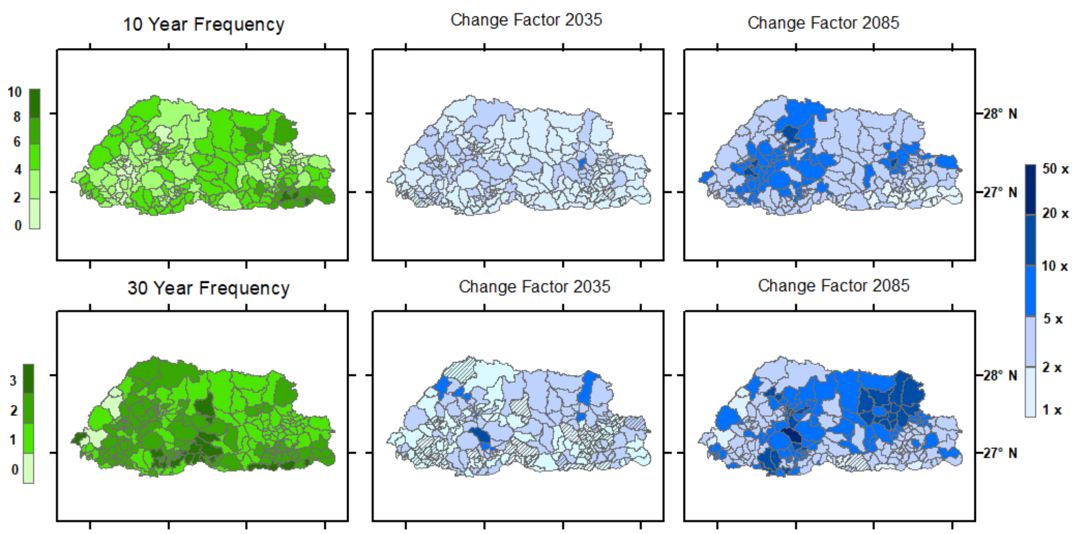


Figure 5.4 The summary of extreme precipitation event occurrences (i.e., 10-year and 30-year events) at the gewog level. Left panes show the historical frequencies of 10-year and 30-year precipitation events. The middle and right columns show the ratio of future extreme event frequencies to historical frequencies for the years 2035 and 2085 respectively for RCP4.5 (upper) and RCP8.5 (lower panels). Hatched areas indicate gewogs where no more than 3 GCMs project the same direction of change.

Figure 5.5 provides a quick overview of projected changes in both flooding metrics (10-year and 30-year events) at gewog-level, also in relation to elevation (meters). Results show that most gewogs with lower level of increase in flooding are located at lower elevations (< 3000 m). More extreme, and in some cases, unrealistic increases are detected for gewogs at higher elevations (> 3000 m). While this is an interesting finding, we note that both the historical climate dataset and GCM projections are less reliable at higher altitudes.

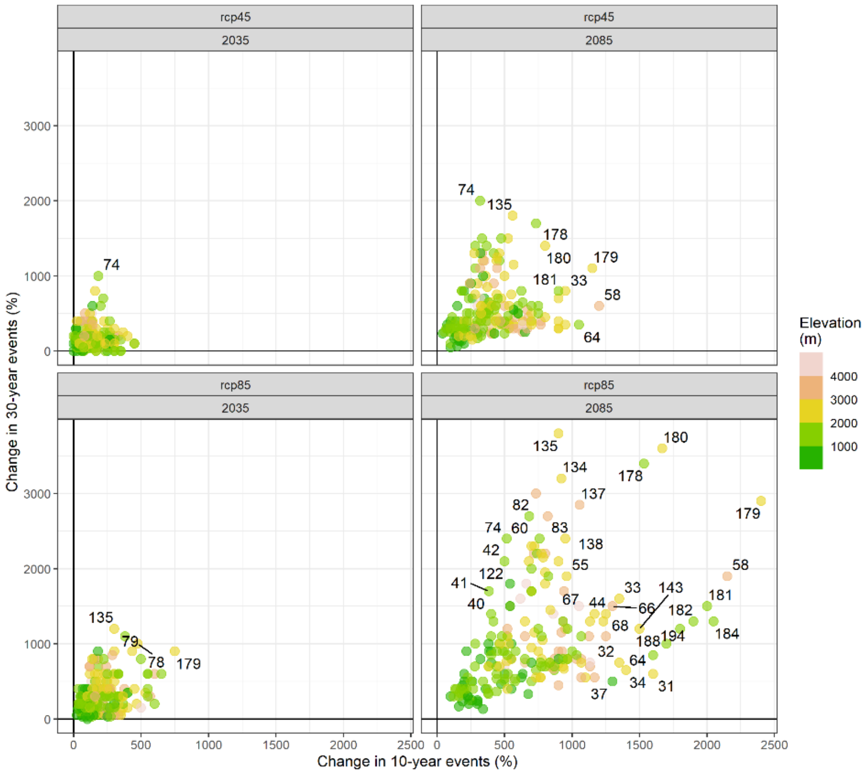


Figure 5.5. Scatter plot of change in 1/10 versus 1/30 rainfall event for all gewogs (ID's included) under RCP4.5, 8.5 and 2035 and 2085.

Finally, table 5.3 shows the same 10-year and 30-year precipitation events metrics averaged over the sub-catchment levels for both RCP4.5 and 8.5 respectively. The basin level results agree with the spatial variances depicted in Figure 5.4 at gewog level and indicates highest increase in flooding risk in the subcatchments of Muktirap, Haa, Samdingkha, and Toritar.

Table 5.3 Summary of historical occurrences and future projected changes in I0-year and 30-year peak flow events (m3/s) in Bhutan basins for RCP4.5 and RCP 8.5 scenario. Agreement (Ag) between the 5 GCM projections is classified as low (L, on average 3,5 or less models agree on sign for duration and frequency), medium (M, between 3,5 and 4,5) and high (H, all models agree for both indicators).

						RCP4.5						RCP8.5					
		Historical levels (m^3/s)		listorical frequenc		2035 Change Factor			2085 Change Factor			2035 Change Factor			2085 Change Factor		
ID	Catchment	10 years	30 years	1/10 yrs	1/30 year	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag
Amochhu																	
1	Doyagang	3998	4816	5	2	1	2	M	3	6	H	1	2	M	7	11	H
Wangchhu																	
2	Lungtenphu	312	387	7	3	2	1	M	6	5	M	3	2	M	13	13	M
15	Haa	210	255	9	1	1	4	M	4	19	H	1	6	M	9	43	H
3	Damchhu	1378	1712	7	2	1	2	M	4	6	H	2	3	M	10	14	H
21	Chimakoti Dam	2409	3006	7	2	1	2	M	3	5	H	1	2	M	8	11	H
Punatsangchhu																	
4	Yebasa	668	826	11	1	2	6	H	6	22	M	4	14	M	16	66	H
16	Samdingkha	708	836	8	4	2	1	L	9	5	H	7	4	M	21	17	H
5	Wangdi	1979	2280	8	2	2	4	H	8	16	H	5	9	M	22	48	H
6	Turitar	5263	5736	3	3	4	1	H	13	9	H	9	4	H	37	24	H
Mangdechhu																	
7	Bjizam	602	676	7	4	2	1	H	9	9	H	5	3	H	26	28	H
17	Tingtibi_on_Dakpaich	241	275	6	3	1	1	H	3	2	H	2	2	H	6	7	H
8	Tingtibi	3368	3816	4	2	1	2	H	5	7	H	4	3	H	16	21	H
Chamkharchhu																	
9	Kurjey	526	605	9	3	1	2	H	7	9	H	3	6	H	20	34	H
Kurichhu																	
18	Sumpa_On_Khomachl	418	461	5	2	2	1	H	12	17	H	5	6	H	43	66	H
11	Sumpakurichhu	400	441	5	2	2	2	H	11	16	H	4	7	H	43	66	H
19	Autsho	2741	3099	5	3	2	1	H	11	8	H	7	4	H	35	39	H
10	Kurizampa	3215	3648	5	3	2	1	L	9	7	H	6	4	H	31	36	H
Drangmechhu																	
13	Muktirap	613	727	12	1	1	7	M	3	21	H	1	16	M	8	47	H
20	Sherichhu	707	858	4	1	2	2	L	4	9	H	3	6	H	11	19	H
12	Uzrong	4337	5790	9	1	0	3	M	2	9	M	1	7	H	8	22	H
Drangmechhu+Kurichhu																	
14	Pangbang	11971	14665	8	1	1	4	H	2	11	H	1	11	H	12	44	H

5.2.2 Top down analysis of landslide risk

The historical and future projected risks of landslides are evaluated using the 7-day accumulated precipitation metric as previously defined in section 2 at gewog-level. The results are depicted through Figure 5.6 to Figure 5.8.

Figure 5.6 depicts the range of critical threshold values for each gewog set based on the 95th quantile (Q95) value of the historical 7-day accumulated precipitation. Results show a large spatial variation, ranging from 91mm at Laya (Gasa dzongkhag) to 616mm at Samtenling (Sarpang dzongkhag).

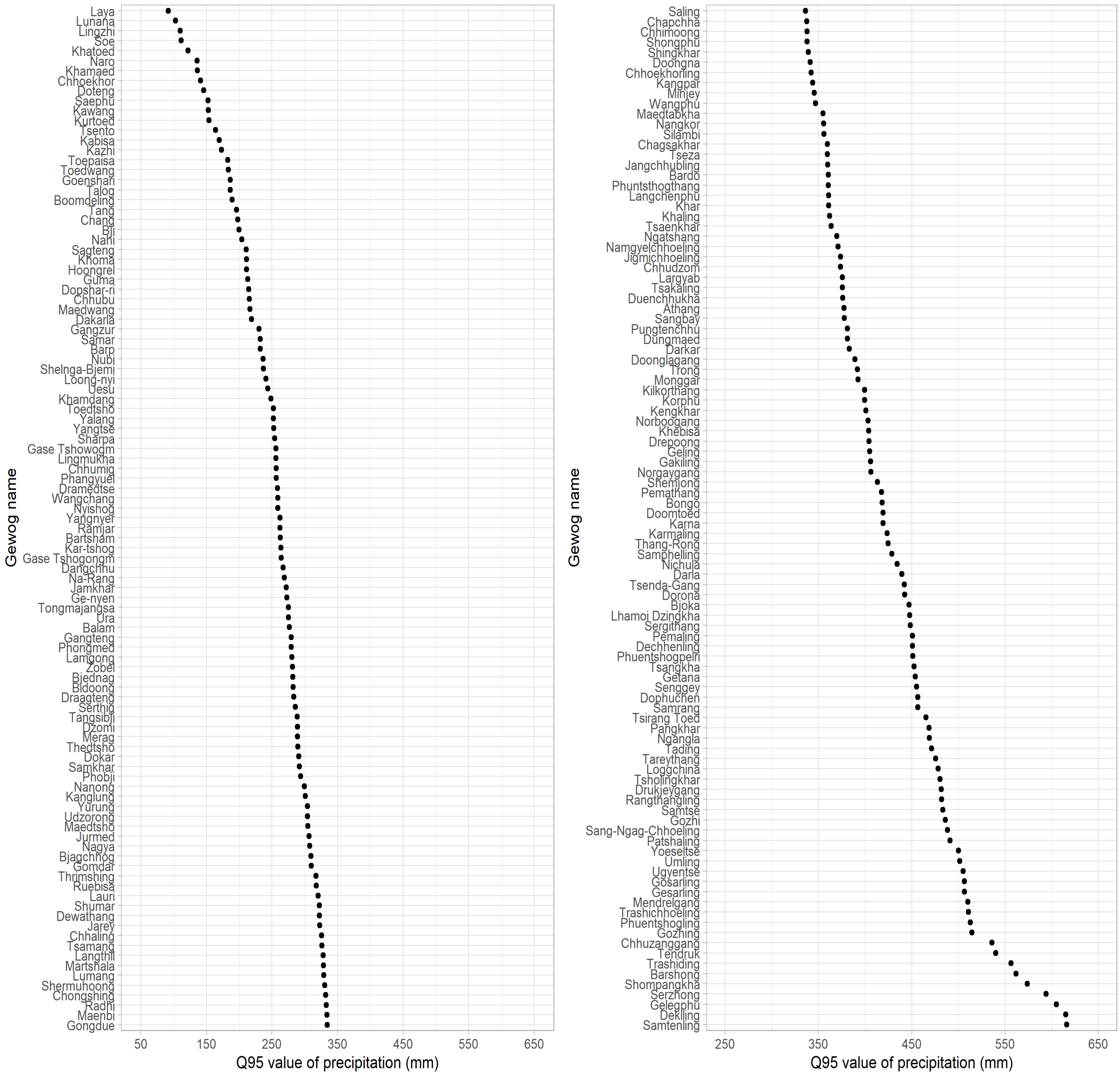


Figure 5.6. The 95th Quantile (Q95) values of 7-day accumulated precipitation (mm) values calculated for each gewog. Calculations are based on the historical analysis period.

Figure 5.7 shows the historical frequencies (same in each gewog, as it calculated directly from the empirical Q95 values) and projected changes in the frequency of continuous high precipitation events that can trigger landslides. The results show that:

- There is a general trend in the increase of landslide risk in the north part of Bhutan, especially in the north-west, i.e., upstream region of Punatsangchhu basin. This is in line with increase of precipitation in this region.

- In RCP 4.5, the projected increases in risk is moderate (up to x2) in the near term (2035), and more severe (up to x4) near the end of the century (2085), when the effects of climate change are more pronounced. The increases are mostly limited to the upstream parts of Punatsangchhu and Drangmechhu basins in the near term.

- In RCP 8.5, the projected increases in landslide risk is higher both in the near term and near the end of the century. For the year 2035, increases in risk are up to 2x but this time, over a larger geographic area (including central Bhutan). For the year 2085, a clear increase in the landslide risk (2x is more) is seen over the entire country, but more severe increases are in the north. Highest increases in risk is found for the upstream of Punatsangchhu (5x to 6x), and the upstream of Drangmechhu (5x), followed by the increases in the upstream part of Mangdechhu and other remaining areas (up to 4x).

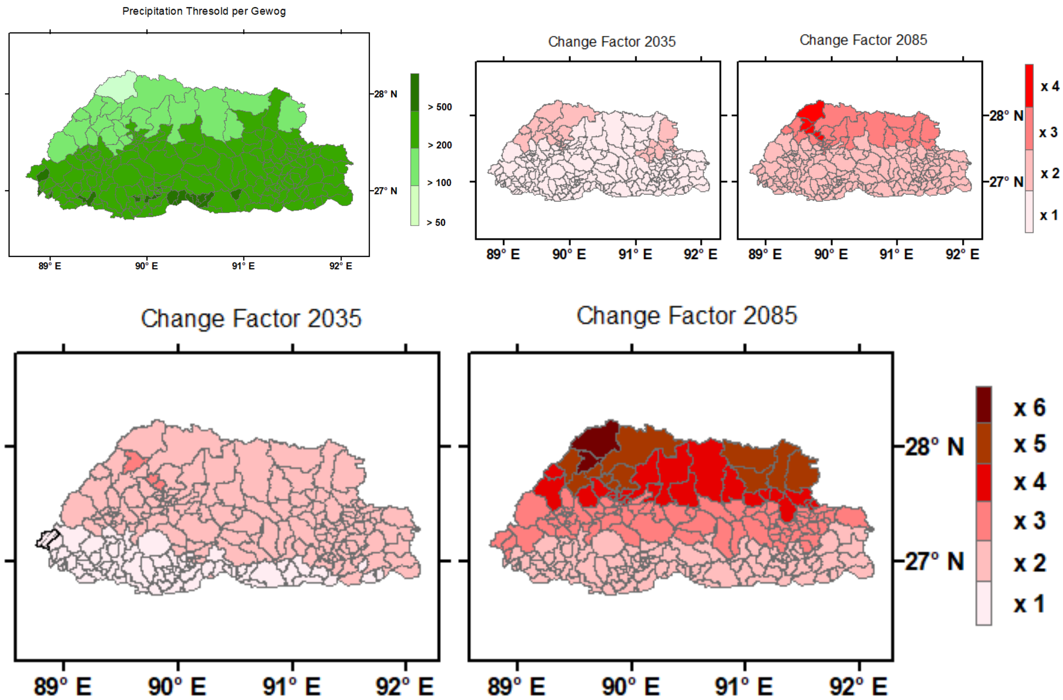


Figure 5.7. Changes in the 7-day accumulated precipitation occurrences above the Q95 threshold at the gewog level. The upper left map shows in mm the Q95 values per gewog. The other maps show the ratio of changes from the historical frequencies for the years 2035 and 2085 respectively for RCP4.5 (upper) and RCP8.5 (lower). Hatched areas indicate gewogs where no more than 3 GCMs project the same direction of change.

Figure 5.8 summarizes the findings by combining the results Figure 5.6 and Figure 5.7 to better show how the relative risk changes with respect to the magnitude of landslide-triggering precipitation amounts. The figure shows that the gewogs with the highest level of change, especially in the year 2085 are those having lower Q95 values (hence also lower mean precipitation). Results also show the clear relationship between gewog elevation (m) and relative change in landslide risk, such that highest increases in risk are at the highest elevations.

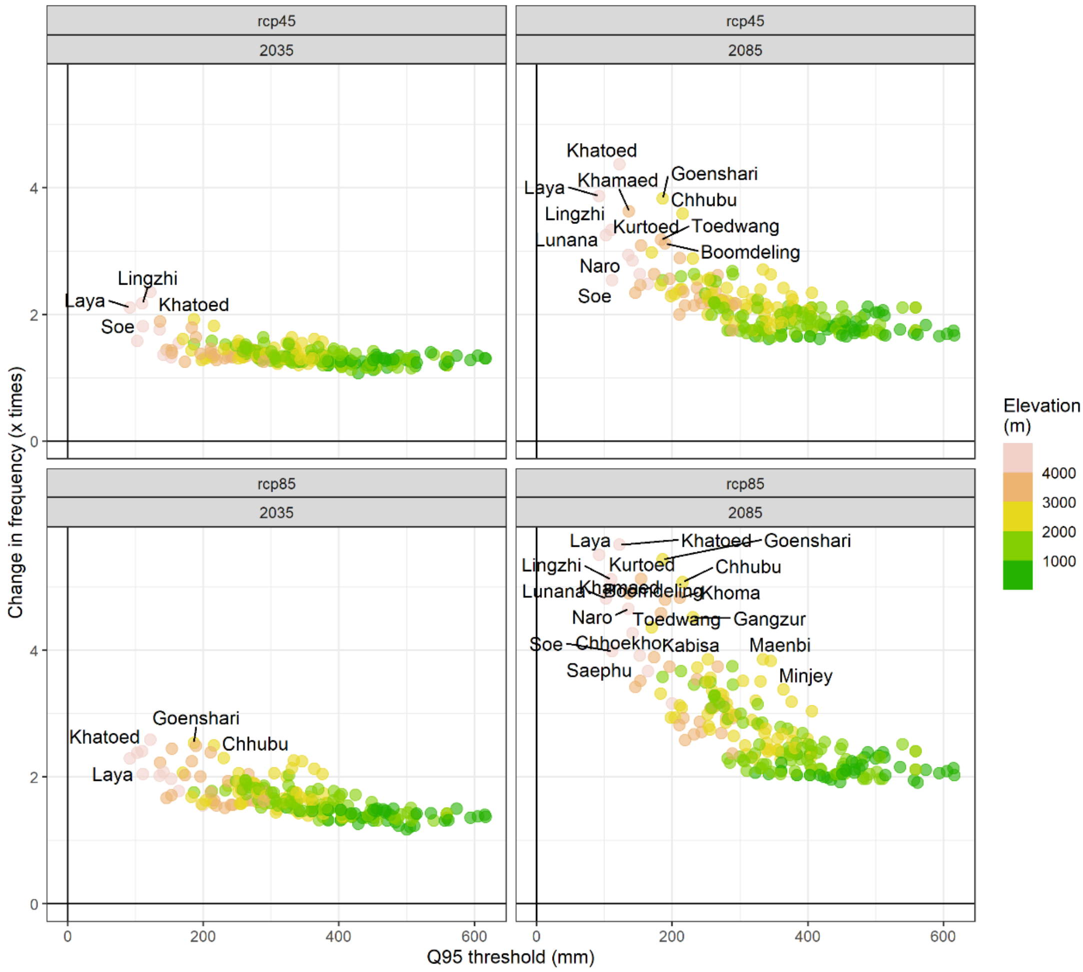


Figure 5.8 . Scatter plot Q95 threshold of 7-day total precipitation (mm) per gewog and changes in the landslide risk frequency (y-axis) under RCP4.5, 8.5 and 2035 and 2085. The colour scale shows the average elevation (m) of each gewog.

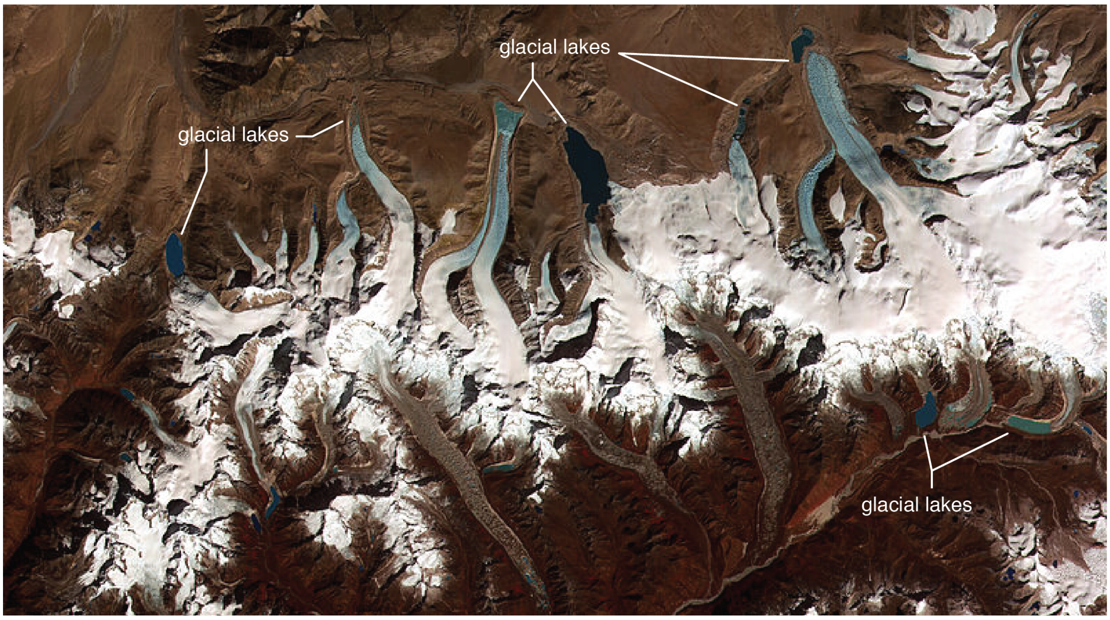
Overall, the national-level analysis shows an increasing risk from landslide events in Bhutan in the future, especially for the gewogs located in the north. Note that this is relative compared to historic accumulated precipitation amounts, whose absolute values are highest at lower altitudes. These findings largely agree with the previous findings on increasing risk of extreme precipitation and flooding, since landslides are largely triggered and closely related with such extremes. However, the change factors for the 7-day total precipitation (the landslide trigger) is much smaller than for the 1/10 and 1/30 extreme daily precipitation event (the local flood trigger).

5.2.3 Glacier lake outburst floods (GLOF)

The risk from GLOFs are expected to increase under increasing temperatures from climate change (Khanal et al. 2014; Richardson and Reynolds, 2000). However, there are significant gaps in our knowledge on the specific impacts of climate change on glacial lakes, for example, the dynamical responses of glacial lakes over time and possible change in magnitude, timing, and frequency of glacial-related hazards (Harrison et al., 2018). Over the Himalayan region, rising temperatures[8] can result in

[8] Raising temperature trends lead to increased retreat and melting of glaciers. Under certain geographical conditions (e.g. existence of moraine dams) new lakes may form. For existing lakes, the volume will increase. Raising temperatures will signify a shift from snow to rainfall. Heavy rainfall events can also lead to more rapid filling up of lakes.

formation of new glacial lakes as well as enlargement of the existing ones, resulting in an overall increase of destabilization and outbursts (Rosenzweig et al.,2007).



Photograph 5.1 Glacial lakes in Bhutan Himalaya. See for different failure mechanisms leading to GLOFs http://www.antarcticglaciers.org/glacier-processes/glacial-lakes/glacial-lake-outburst-floods/

Our qualitative analysis on GLOFs agrees with the existing research, especially in the Himalayan region indicating higher risk in the future (figure 5.1). Average temperatures are expected to increase in Bhutan, in the order of 2 to 2.5°C in the near term (2021-2050), and 3.5-4 °C in the longer term (2070-2099) relative to historical means. Northern Bhutan region, where glacial lakes are located, can see even higher temperature increases of up to 3°C in the near term and 5.5°C in the long-term (see climate data report figure 4.8). Thus, it is a safe assumption to expect increasing risk from glacial-related hazards over Bhutan, especially as more frequent and severe GLOFs.

5.2.4 Impacts on water related disasters: top down and bottom-up analysis combined

The top-down analysis on extreme precipitation and landslide events show a clear long-term increasing trend for both hazards. The factor of change for single precipitation events and peak flows events (as triggers for floods) is much larger than for the 7-day accumulated precipitation (as a trigger for landslides). However, the magnitude of projected changes in both type of hazards is highly uncertain and should be regarded with care.

Moreover, similar to the drought hazard analysis presented in section 5.1, the critical thresholds for extreme precipitation was set as 1/10 and 1/30 year events and for the case of landslides, a Q95 value in the absence of more precise information at the local level. While these thresholds provide a general basis for the assessment and comparison of hazards at the national scale, it should be noted that these thresholds may not be representative of the actual hazards at the local level.

The bottom-up consultations regrading flooding and landslides align with the general findings from the top-down analysis, indicated large risk of extreme precipitation events and related disasters. There is a general and observable increase in extreme precipitation events, which can be attributed to climate change.

Extreme precipitation events and related disasters generally manifested as increased probability of flash floods due to two main factors:

 - More severe rain during monsoon season,
 - Rapid retreating of glaciers due to increasing temperatures

- Hazard events such as extreme precipitation, landslides and GLOFs have resulted large damage over the past years (for example in 1994), causing damage to agricultural land and public properties. Besides environmental/climate related factors, these were also resulting from:

  - Lack of adequate infrastructure, including proper drainage systems.
  - Improper alterations of the river bases and their courses.
  - Lack of proper flood protection and mitigation measures.
  - Blockages of irrigation channels during the times of heavy rainfall.

- Possible adaptation measures to adapt to extreme precipitation and related disasters are identified as:

  - Implementing flood adaptation works along the river beds, including dredging and diversions.
  - Resettlement of the public from high risk to low risk areas.
  - Better monitoring and analysis of rainfall and streamflow data at a high resolution (hourly level), especially at high-risk locations.
  - Improved capacity to cope with flooding, which would include training of practitioners on flood risk management and improving public awareness.

5.3 Hydropower

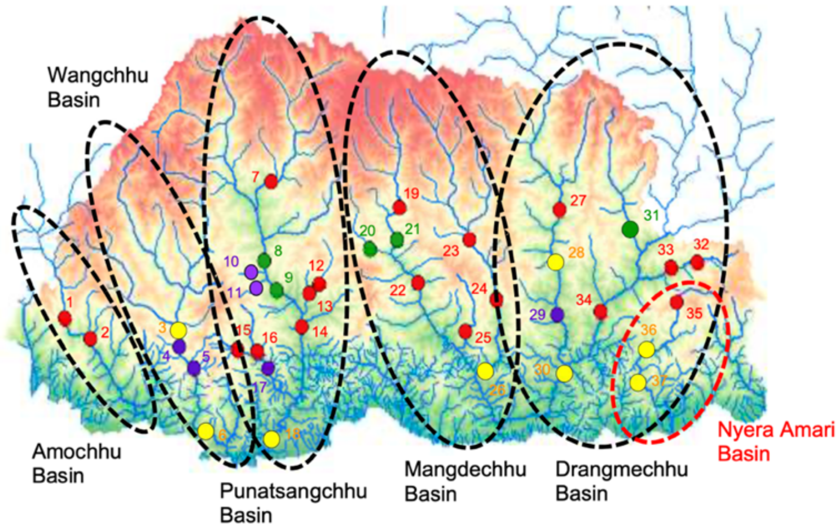
5.3.1 Sector description

Due to its major contribution to the national economy (18%- 23% of GDP), hydropower is deemed as an important resource for the socio-economic development in the country (JICA,2019). The development of hydropower has not only helped the domestic sectors with improved livelihoods, but the industrial sector has been thriving rapidly. It has driven economic growth and greatly boosted progress in meeting many of the country's social-economic development objectives; as close to 80% of electricity generated is exported.

Currently, power generation in the country is mostly dependent on run-of-river (RoR) type hydropower plants. As these RoR plants depend on the flow, they are more susceptible to variation in rainfall patterns and the impacts of climate change. As a result, years with good monsoons and high-water levels result in higher electricity sales and greater revenue, while poor monsoons have a negative impact on revenues and the economy.

Therefore, through the National Adaptation Plan, it is expected that the gaps and issues would be assessed and addressed through the integration of the appropriate adaptation measures in the national development plan and implemented coherently.

There are 6 hydropower plants that are under operation, 5 are under construction and 8 planned projects with high potential in different basins. The locations of these hydropower plants are shown on the map of Bhutan in Figure 5.9. Basically, all the northern districts of Bhutan are important in terms of catchment protection and water resources conservation. The projects are located in the middle Himalayas and the southern part.



Amochhu Basin			Punatsangchhu Basin			Mangdechhu Basin			Drangmechhu Basin		
1	A-5	Tingma	7	P-17	Tseykha	19	M-6	Jongthang	27	K-13	Minjey
2	A-8	Dorokha	8	U. C.	punatsangchhu-I	20	U. C.	Nikachhu	28	Planning	Dorjilung
Wangchhu Basin			9	U. C.	punatsangchhu-II	21	U. C.	Mangdechhu	29	Existing	Kurichhu
3	Planning	Bunakha	10	Existing	Basochhu-I	22	M-11	Wangdigang	30	Planning	Kuri-Gongri
4	Existing	Chhukha	11	Existing	Basochhu-II	23	M-17	Buli	31	U. C.	Kholongchhu
5	Existing	Tala	12	P-29	Kago	24	C-7	Chamkharchhu-IV	32	G-10	Gamrichhu-2
6	Planning	Wangchhu	13	P-30	Pinsa	25	C-10	Chamkharchhu-II	33	G-11	Gamrichhu-1
			14	P-26	Thasa	26	Planning	Chamkharchhu-I	34	G-14	Uzorong
			15	P-34	Darachhu	U. C. : Under Construction			Nyera Amari Basin		
			16	P-35	Dagachhu-II				35	N-1	N.A. Kangpara (G)
			17	Existing	Dagachhu				36	Planning	Nyera Amari-I
			18	Planning	Sankosh				37	Planning	Nyera Amari-II

(Source: JICA Survey Team)

Figure 5.9 Distribution and basins of 18 sites to be constructed through the master plans and existing dams (including those under construction)

According to a desktop study carried out by the Department of Renewable Energy, 148 Small Hydropower Project sites were identified and listed in the Renewable Energy Master Plan (REMP 2017-2032). The 148 projects total 1553.5 MW spread across all parts of the country ranging from 1.1 MW to 44 MW all of which are located on east-west tributaries and the majority being in the south. Further studies and analysis are being carried out to rank and plan the small hydropower projects. The detailed identified locations are shown in Figure 5.10 below.

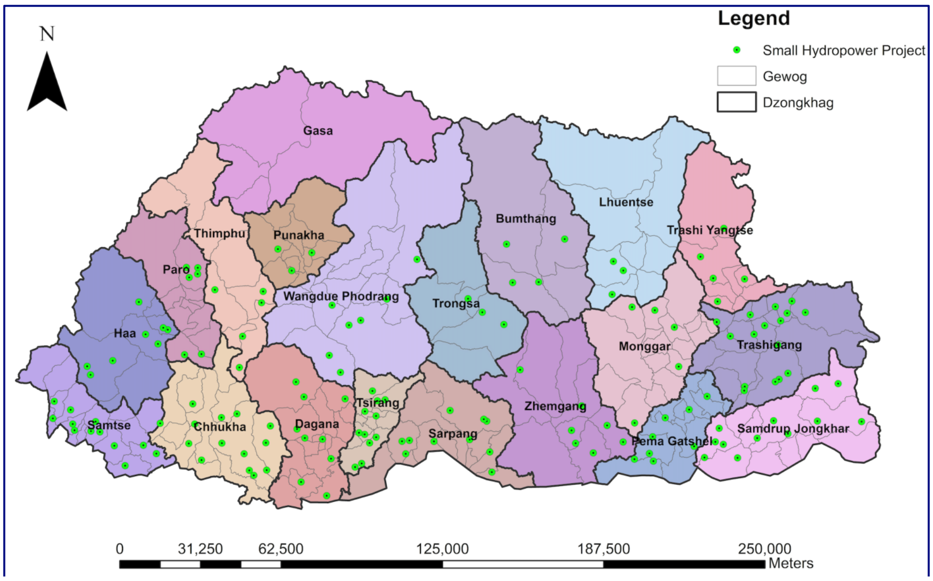


Figure 5.10 Potential of Small Hydropower projects in Bhutan by Gewogs

5.3.2 Top down analysis of flow at hydropower plant locations

Table 5.4 below shows mean annual flows of five catchments feeding the hydropower plants of Basochhu, Kurichhu, Mangduechhu, Punatshangchhu, and Tala for two different RCPs (RCP 4.5 and RCP 8.5) and two time slices of 2035 and 2085 which are compared to their respective historical flows.

For both RCP 4.5 and 8.5 at different time scales of 2035 and 2085, the mean annual flows at all 5 hydropower plants are increasing. The increase is 11-20 % for 2035 and 20-30% in 2085 for RCP 4.5. The highest increase is for RCP 8.5 in 2085 in the range of 44–54 %, while it is 12-21 % for 2035. The confidence of models (5 GCMs used) are medium or high.

Table 5.4 Mean Annual Streamflow projections of five hydropower plants derived from the hydrological model calculations under RCP4.5 and 8.5 and 5GCM projections. Agreement between the 5 GCM projections is classified as low (on average 3,5 or less models agree on sign of change), medium (between 3,5 and 4,5) and high (all models agree).

RCP 4.5				
Catchment Name	**Historical (m^3/s)**	**2035 Change (%)**	**2085 Change (%)**	**Agreement**
Basochhu	4	16	28	MEDIUM
Kurichhu	470	11	20	HIGH
Mangdechhu	142	14	29	HIGH
Punatsangchu	397	18	25	HIGH
Tala	199	20	30	MEDIUM
RCP 8.5				
Catchment Name	**Historical (m^3/s)**	**2035 Change**	**2085 Change**	**Agreement**

Basochhu	4	22	47	MEDIUM
Kurichhu	470	12	50	MEDIUM
Mangdechhu	142	18	44	MEDIUM
Punatsangchhu	397	16	54	HIGH
Tala	199	21	48	MEDIUM

Flows were also computed for the dry season (DJF) and wet season flows (JJAS). The results of which are shown Table 5.5 below.

Under RCP 4.5 the flows for both dry and wet season will increase in 2035 with more increase in dry season than wet season. However, in 2085, the dry season flows for Basochhu and Punatsangchhu are projected to decrease, while an increase is projected for the others. The wet season flows for all plants are increasing.

The wet season flows under RCP 8.5 for 2035 are all projected to increase, whereas it is decreasing from -7% to –33% for dry season except for Tala. In 2085 under RCP 8.5 the dry season flow for Basochhu is going to decrease, but increase for all plants for both dry and wet seasons.

The hydropower sector should consider the possibility of low winter flows especially under RCP8.5 Scenario. This is further confirmed by the low flow dry spell indicators that show an increase of low flow duration and frequency under RCP8.5 on the short term but also for RCP8.5 on the long term, though the agreement between the different projections is only low to medium (3-4 out of 5 models agree on the sign). On the other hand, the hydropower potential on an annual basis is further increased by the projected changes in hydrology (medium to high agreement between projections). This is in line with the Third National Communication (NEC, 2019), in which, based on an earlier hydrological modelling study for the Wangchhu, Punatsangchhu and Manaschhu, it was determined that the total annual flow in all these basins would increase in future times for both RCP 4.5 and RCP 8.5 scenario.

Table 5.5 Changes (%) in winter and summer flow at hydropower locations. Agreement between the 5 GCM projections is classified as low (on average 3,5 or less models agree on sign of change), medium (between 3,5 and 4,5) and high (all models agree).

RCP 4.5

Catchment Name	Historical		2035 Change		Agreement	2085 Change		Agreement
	DJF (m3/s)	JJAS (m3/s)	DJF	JJAS		DJF	JJAS	
Basochhu	1	9	21	12	MEDIUM	-23	32	HIGH
Kurichhu	94	966	33	6	MEDIUM	8	24	MEDIUM
Mangdechhu	12	331	37	9	HIGH	5	28	MEDIUM
Punatsangchu	121	795	17	11	MEDIUM	-4	23	MEDIUM
Tala	19	486	41	17	MEDIUM	14	29	MEDIUM

RCP 8.5

Catchment Name	Historical		2035 Change		Agreement	2085 Change		Agreement
	DJF (m3/s)	JJAS (m3/s)	DJF	JJAS		DJF	JJAS	
Basochhu	1	9	-33	18	MEDIUM	-15	47	MEDIUM
Kurichhu	94	966	-13	22	MEDIUM	23	38	MEDIUM
Mangdechhu	12	331	-28	20	MEDIUM	50	56	MEDIUM
Punatsangchu	121	795	-7	24	MEDIUM	18	47	MEDIUM
Tala	19	486	6	15	MEDIUM	1	48	MEDIUM

Table 5.6 Changes (%) in duration and frequency of reduced flows (<10 percentile) at HP locations. Agreement between the 5 GCM projections is classified as low (on average 3,5 or less models agree on sign of change), medium (between 3,5 and 4,5) and high (all models agree).

RCP 4.5

Catchment Name	Historical		2035 Change		Agreement	2085 Change		Agreement
	Drought Duration (Days)	Drought frequency (count over total period)	Drought Duration	Drought frequency		Drought Duration	Drought frequency	
Basochhu	34	44	13	-14	LOW	48	36	HIGH
Kurichhu	36	41	-10	0	LOW	3	5	MEDIUM
Mangdechhu	45	33	-18	21	MEDIUM	18	21	MEDIUM
Punatsangchu	32	45	-24	-11	MEDIUM	-2	11	MEDIUM
Tala	41	36	-41	-25	MEDIUM	-1	19	MEDIUM

RCP 8.5

Catchment Name	Historical		2035 Change		Agreement	2085 Change		Agreement
	Drought Duration (Days)	Drought frequency (count over total period)	Drought Duration	Drought frequency		Drought Duration	Drought frequency	
Basochhu	34	44	54	9	LOW	30	30	MEDIUM
Kurichhu	36	41	59	2	MEDIUM	11	0	LOW
Mangdechhu	45	33	43	24	MEDIUM	-8	21	MEDIUM
Punatsangchu	32	45	31	13	LOW	-10	0	LOW
Tala	41	36	-2	17	LOW	-18	14	MEDIUM

5.3.3 Impacts on hydropower production: top down and bottom-up analysis combined

To get in-depth information at the hydropower plant level on the issues and impacts within the hydropower sectors, focus group discussion was conducted with the participants from Druk Green Power Corporation, Department of Renewable Energy, Department of Hydropower and Power Systems, MoEA, Bhutan Electricity Authority (BEA) and Bhutan Power Corporation (BPC).

The details of the consultation and its findings are in the bottom-up approach report (Deltares 2021d). The key findings from the FGD are described below.

- The most visible impacts in Bhutan, is the faster rate of glacier retreat causing accelerated melting of glaciers leading to increased river flows and flooding in the short term and a decrease in glacial runoff and river flows in the long term, affecting the water supply for hydropower plants in the long run. There would be positive impacts for the glacial melt for the short term with more flow available for hydropower. However, this would be only for the short term as there would be no water available for the long term for hydropower as the glacier stock would eventually disappear.
    - The top-down analysis is partially confirming this worry. According to the modelling exercise done, the balance between changes in precipitation, evaporation and glacial melt is leading to the largest increase in low flow duration and frequency on the short-term under the RCP8.5 scenario followed by RCP4.5 for the long term. If this is due to limitations of the glacier stock or erratic precipitation during the lean season is difficult to tell.
- Secondly, erratic rainfall and heavy rainfall would cause floods that would affect the water quality which would increase siltation and sedimentation increasing the operation and maintenance cost of the hydropower plants including the durability

of the turbines and also leading to dam bursts. During the lean season, there would be less flow and low generation in winter when the demand is high.

  - From the TD results on peak flows (see section 5.2) there is ample confirmation that these risks will increase. Both the 1/10 and 1/30 peak flow events are projected to occur more often in the future especially under an RCP 8.5 scenario. This increase is higher for the peak flows than for the average flows and higher for 1/30 year flood than the 1/10 year flood pointing indeed to a more erratic flow regime.

- Thirdly, in case of low flow and the events of dry spell, there would be difficulty in maintaining environmental flows which are necessary to maintain the health and biodiversity of the river basins.

  - This is confirmed partially (see first bullet) and a potential development that should be carefully monitored.

- Finally, due to the vulnerability and increased sensitivity of the hydropower sector, there would be uncertainty in funding, leading to decreased investment in the hydropower projects.

  - Indeed, the future flow situation becomes more uncertain. However, this would be similar for the whole region and overall there still is a great potential available that is likely to increase.

- The overall impacts of all the effects of climate change would be decreased revenue, higher cost in operation and maintenance, low energy security, unreliable power, fewer job opportunities and lower regional development.

  - This is questionable given the hydrological analysis presented

6 Dzongkhag level results

6.1 Introduction

This chapter is a demonstration of how the top-down and bottom-up analysis results can be used together at the level of a dzongkhag.

The vast amount of information collected through the bottom-up consultations in tables on priority locations (gewogs), issues, causes, proposed adaptations and capacity building needs (see Deltares, 2021d) provide a valuable data set of the experienced water issues on the ground within the dzongkhags. Not all the issues mentioned have a direct relationship with climate (i.e. the cause is not climate related) but for a good functioning water sector all issues should be solved together in an integrated manner. However, newly analysed top-down data, are focussed on climate change and resulting hazards alone.

The data-set of top-down indicators for dry spells (groundwater recharge and low river flows), floods (peak rainfall and peak river flows) and landslides (7 day accumulated rainfall) can be used at a dzongkhag level to assess whether the climate related issues identified on the ground are likely going to get worse.

Figure 6.1 Dzongkhags chosen to demonstrate the use of TD and BU data.

To this end, four dzongkhags were selected to represent a diverse set of water issues. A three-step analysis is proposed to demonstrate how priorities for adaptation can be established:

1. Describe the issues from the BU analysis that have a clear climatic cause or that are clearly sensitive to the impacts of climate change.

2. Describe based on the TD results:

    a. what is the direction of change,
    b. approximate size of change (small, big),
    c. the evolution of change from short (2035) to long term (2085), from a mild climate development (RCP4.5) to extreme climate development (RCP8.5) scenarios,

   d. What is the confidence in the analysis based on:
      i. Agreement between the GCM projection on the sign of change
      ii. Confirmation by other sources. E.g. is the current trend and/or are other studies using other data pointing in the same direction?

3. How is the exposure and vulnerability to the hazards likely to change and how will this affect the risk?

   a. Will there be more people living, working in the area? How many?
   b. Is the water demand going to increase? By how much?

To support the analysis for each dzongkhag tables summarizing the results have been produced that show ranked gewogs based on reported drinking- and irrigation water issues and water related disasters. In addition, the change under climate change and associated agreement between GCM projections for 2035 and 2085 is shown. Additional information on population and change (NBS figures), which gewogs (IDs) belong to which river basin and on the historic precipitation trend are presented. These tables, and a brief climate risk analysis, for all dzongkhags not included in this chapter can be found in Annex C.

NOTE: The data presented in the following paragraphs are the result of climate model and hydrological model projections that are subject to many uncertainties. This means that the size of changes presented can only be interpreted as being small, medium or large. The numbers cannot be used for design of adaptation measures. In addition, the results are sensitive to the choice of indicator definitions and percentile thresholds chosen. These are by no means verified by experiences on the ground. With right knowledge on what defines critical conditions these indicators can be easily redefined and recalculated for specific basins or locations.

How to read the tables in this chapter and in Annex C:

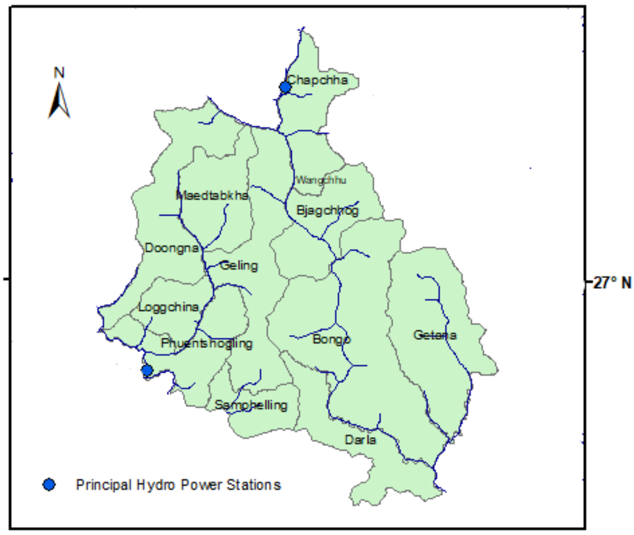
- The BU ranking is presented for drinking water (D-water) and irrigation water (I-water) and disasters.
- Changes for dry spell indicators are expressed as percentage change compared to historic values. For flood indicators a change factor compared to historic values is presented.
- Colours blue and red are used to show shift towards wetter and dryer conditions respectively. An increase in dry spell duration and frequency is marked red and an increase in flood frequencies in blue.
- Agreement (Ag) between the 5 GCM projections is classified as low (L, on average 3,5 or less models agree on sign for duration and frequency), medium (M, between 3,5 and 4,5) and high (H, all models agree for both indicators).
- See legends below.

Legend	
Confidence	
3	L
3.5-4.5	M
5	H
Percentage Change	
(red)	>50
(light red)	>20
(pink)	>5
(pale pink)	>-5
(light blue)	>-20
(blue)	>-50
(dark blue)	<-50

Legend	
Confidence	
3	L
3.5-4.5	M
5	H
Change Factor	
	50x-75x
	21x-50x
	11x-20x
	6x -10x
	3x-5x
	0-2x

6.2 Chhukha

6.2.1 Map and statistics



Administrative map of Chhukha (Principal Hydro Power station location = location of existing hydropower facility)

Dzonkhag: Chhukha				Dry spells in ground water recharge													
Population 2017:		68966		River basin:		Amochhu (34, 36, 37,39,44)						DJF precipitation trend			Non- Significant		
Population change 2042 (%):			1			Wangchhu (35, 38, 40, 41, 42, 43)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
37	Phuentshogling	1		28	46	11	30	M	0	41	M	10	7	L	21	30	M
40	Darla	2		54	26	10	35	M	17	38	H	9	31	M	14	35	M
41	Bongo	3		38	37	14	19	M	32	43	M	1	24	M	49	46	M
36	Loggchina		3	71	20	1	15	M	0	35	M	-25	35	M	-10	55	H
38	Chapchha		1	135	11	-7	27	M	-7	82	M	-14	18	M	-25	91	H
44	Geling		2	114	13	-16	38	M	-13	115	H	-8	54	M	-11	85	M
Other gewogs (not ranked)																	
34	Doongna			78	19	4	16	M	15	58	H	7	42	L	5	89	M
35	Maedtabkha			97	15	-10	27	M	8	60	H	-5	27	M	0	33	M
39	Samphelling			28	46	8	17	M	1	57	M	0	13	L	-18	41	M
42	Getana			35	39	19	8	L	16	46	M	-6	18	M	31	46	M
43	Bjagchhog			61	24	-7	25	M	-6	62	M	1	38	L	-9	54	M

Table 6.1 Combination of top-down and bottom-up results for Chhukha dzongkhag. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM

projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

					RCP4.5						RCP8.5					
ID	Sub-catchment	Historical Dry Spells			2035 Relative Change (%			2085 Relative Change (%			2035 Relative Change (%			2085 Relative Change (%		
		Q10 of fL (cms)	Duration (days)	Frequency (count)	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag
3	Damchhu	8,5	40	37	-44	-54	L	-12	14	M	-7	16	L	-16	8	L
21	Chimakoti Dam	11,1	40	37	-38	-30	M	-1	16	L	-4	19	L	-13	16	L
1	Doyagang	14,6	35	43	-16	-12	L	5	2	L	20	-7	L	-23	-21	M

Table 6.2 Changes in low-flow dry spells (duration and frequency) under future scenarios at the nearest hydrological stations in Chhukha for the Wangchhu (3,21) and Ammochhu (1).

Dzonkhag: Chhukha			Extreme Rainfall Events													
Population 2017:	68966		River basin:		Amochhu (34, 36, 37,39,44)						Annual precipitation trend			Non - significant		
Population change 2042	1				Wangchhu (35, 38, 40, 41, 42, 43)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
36	Loggchina	3	4	2	2	1	L	4	4	H	2	2	M	7	6	M
37	Phuentshogling	2	2	2	4	1	M	8	4	H	3	2	M	14	6	M
39	Samphelling	1	5	2	1	1	M	4	6	M	2	2	M	5	9	M
Other gewogs (not ranked)																
34	Doongna		2	2	4	2	M	10	4	M	3	2	M	15	8	M
35	Maedtabkha		3	2	2	2	M	6	5	H	2	2	M	10	8	M
38	Chapchha		3	2	2	2	M	6	4	M	2	2	M	9	7	M
40	Darla		6	1	1	3	M	4	15	M	2	4	M	5	15	M
41	Bongo		6	1	1	4	M	4	12	M	1	5	M	5	18	M
42	Getana		6	1	2	5	M	4	16	H	2	5	M	6	22	H
43	Bjagchhog		3	2	2	2	M	6	5	H	2	2	M	11	9	M
44	Geling		2	1	3	3	H	10	8	H	3	4	M	14	15	H

Table 6.3 Combination of top-down and bottom-up results for Chhukha dzongkhag. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

						RCP4.5						RCP8.5					
ID	Catchment	Historical levels (m^3/s)		Historical frequenc		2035 Change Factor			2085 Change Factor			2035 Change Factor			2085 Change Factor		
		10 years	30 years	1/10 yrs	1/30 year	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag
3	Damchhu	1378	1712	7	2	1	2	M	4	6	H	2	3	M	10	14	H
21	Chimakoti Dam	2409	3006	7	2	1	2	M	3	5	H	1	2	M	8	11	H
1	Doyagang	3998	4816	5	2	1	2	M	3	6	H	1	2	M	7	11	H

Table 6.4 Changes in peak flows (1/10 and 1/30 year) under future scenarios at the nearest hydrological stations in Chhukha for the Wangchhu (3,21) and Ammochhu (1).

6.2.2 What are the issues identified during the BU consultation?

From the bottom up surveys 6 gewogs (Phuentshogling, Darla, Bongo, Loggchina, Chapccha, Geling) were ranked high based on reported issues on drinking and irrigation water (see table 6.1). The major water sources are springs, streams, rainwater and river. These gewogs suffer from insufficient water availability, damage of pipes located on the slopes and pipe leakages. The sources used for irrigation are qualified as not proper and unreliable. They have no alternative sources available. Available water is used inefficiently. As irrigation is faulty, it is becoming too dependent on the rainfall during monsoon season.

Climate is not explicitly mentioned as a cause of these issues. It is noted that water sources are drying and that this could be due to a changing climate. However, it is also mentioned that there is an increased number of users of the water and that there are all sorts of inefficiencies in the construction of channels (open, earthen), the maintenance of the source and infrastructure, technical failure of the schemes, that lead to extra water loss. Landslides during the monsoon are mentioned as one of the causes of infrastructure malfunctioning. Connected to these technical issues there is a reluctance in participating in the WUA.

Flood Hazard

Assessment for Chhukha dzongkhag (FEMD, DES, MoWHS) reported that the critical flood-prone area identified was the low-lying area along with river systems such as Wangchhu river in Bjagchhog and Bongo gewog, Damchu River in Chapchha gewog, Chimti Khola (river) in Loggchina gewog, road infrastructure along Barsa River in Samphelling gewog. In Phuentsholing thromde, Amochu (Toorsa river), Om chhu, Barsa chhu, Balujora chhu, and Singye chhu pose a risk to public infrastructure, industries and human livelihood. In accordance with the consultations with officials of Chhukha dzongkhag, the three hotspots for disaster are Sampheling, Phuentsholing and Loggchina. The trend of these disasters is said to be increasing causing damage of agricultural land, crop and private property, loss of lives and livelihoods, frequent damage of farm roads. Besides climate change, the increase in developmental activities, deforestation and overgrazing are mentioned as causes for increasing risks.

6.2.3 What are the TD results indicating?

In all ranked gewogs, **dry spells** frequency is increasing both on the short and long term. For duration there is a mixed signal. For gewogs ranked on irrigation water issues, dry spell duration is decreasing slightly. For example, for Geling (the gewog with the highest relative change) the average dry spell duration is projected to drop from 113 days to about 100 days (>3 months) in the future and the average dry spell frequency now ~ once every 3 years (13x per 40 years) is projected to change to once every 1.5 years. Changes in dry spell frequency are around 10-50% on the short term, increasing to 50-100% on the long term for RCP8.5. For example, for Chapccha gewog this could mean that for the second half of the century it could face a dry period of 100 days every second year. Agreement on the sign of change in duration and frequency is medium to high. This is in line with observed trends in precipitation for this dzongkhag.
For the non-ranked gewogs, calculated dry spell duration and frequency are of similar magnitude both in their historic values and future changes.

The Wangchhu and Amochhu are the major river basins in this dzongkhag. The duration and frequency of low flows (<10^{th} percentile) of these rivers (now around 30-40 days almost every year) are projected to decrease on the short term under RCP4.5 (see Table 6.2) but frequency may increase a bit on the long term. Agreement on the sign of these changes between the different models is low to medium.

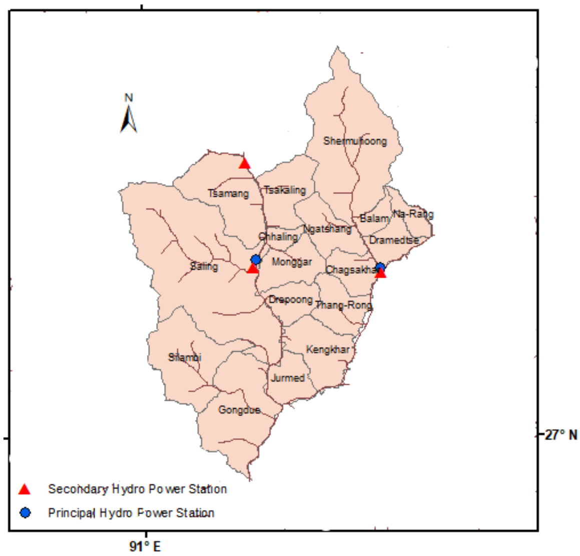
As a proxy of **flood-risks,** the number of peak rain and flow events is likely to increase especially for the long term (medium to high agreement). This is the case for all gewogs not only the ranked ones. For the short-term projected rainfall changes are relatively mild (~factor 2-3 in frequency) and uncertain (low to medium agreement). For flow (see Table 6.4) this is similar, but agreement is higher. For the long term, especially under RCP 8.5 projected changes are quite substantial both for rainfall and flow with changes in frequency of the 1/30 years events over a factor 10. This could imply that a 1/30 year flood event could occur 1/3 years in the second half of the century (for the short term more likely a 1/30 year event to happen every 10-15 years and a 1/10 event happening every 4-5 years. For landslides, the risks may increase slightly with a factor 2 towards 2085 (see Figure 5.7)

6.2.4 Is climate change a serious enhancing factor for the water issues?

- Given that spring and small stream sources are drying up already the above described potential climate developments both on the short and long term will further complicate water supply for drinking water and irrigation during periods of dry spell.
- Water provision from the main river system is not likely going to be further compromised due to climate change.
- Note however that the per capita water demand is likely going to increase with a factor 2 and that new users in the area are reported (though population change is only projected to be +1%).
- The risks of flooding seem to be seriously enhanced by the projected changes in peak flows. These floods will enhance impacts on people, community and infrastructure (including that for irrigation and piped drinking water supply).
- The risks of rainfall induced landslides is only slightly enhanced putting both challenges for protection of people and infrastructure (including that for irrigation and piped drinking water supply).
- More frequent peak flows may also increase the sediment content of the water which will make it less useable for water intake and treatment.

6.3 Monggar

6.3.1 Map and statistics



Administrative map of Monggar

Dzonkhag: Monggar				Dry spells in ground water recharge													
Population 2017:		37150		River basin:		Drangmechhu						DJF precipitation trend (historic):			Significant Decreasing		
Population change 2042 (%):		-18															
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
177	Saling		1	26	51	12	10	L	21	25	M	34	20	M	10	20	M
175	Jurmed	2		26	49	36	0	M	55	8	M	73	-4	M	43	2	M
187	Na-Rang		2	37	37	-4	14	M	34	24	H	38	22	M	22	32	M
179	Tsakaling		3	17	71	11	27	M	15	32	M	29	38	M	26	34	M
189	Kengkhar	1		22	56	10	4	M	12	21	H	27	0	M	11	4	L
190	Thang-Rong	3		18	66	28	6	M	32	15	H	51	2	M	52	-5	M
Other gewogs (not ranked)																	
174	Gongdue	9	14	25	52	45	-12	M	42	4	M	51	4	M	43	-21	M
180	Shermuhoong	16	13	21	63	21	22	M	32	33	M	37	29	M	22	40	M
181	Chhaling	5	7	15	72	7	-11	M	44	0	M	88	-4	M	52	-21	M
182	Monggar	4	10	16	70	16	-6	M	17	34	H	37	17	M	20	11	M
183	Drepoong	13	11	12	90	25	-3	M	25	6	M	61	1	M	25	-9	M
184	Ngatshang	6	5	19	63	11	13	M	29	25	H	39	32	M	31	16	M
185	Balam	14	6	34	38	-19	29	M	-1	37	M	-1	26	M	-4	39	M
186	Dramedtse	7	8	38	35	-11	9	M	2	46	M	20	-6	M	-5	11	M
178	Tsamang	15	4	18	69	15	20	M	18	32	M	32	26	M	34	25	M
188	Chagsakhar	10	9	21	59	10	7	M	31	19	H	43	5	M	34	10	M
176	Silambi	11		36	38	4	13	M	27	24	H	33	37	M	19	37	M

Table 6.5 Combination of top-down and bottom-up results for Monggar dzongkhag. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

					RCP4.5						RCP8.5					
ID	Sub-catchment	Historical Dry Spells			2035 Relative Change (%			2085 Relative Change (%			2035 Relative Change (%			2085 Relative Change (%		
		Q10 of fL (cms)	Duration (days)	Frequency (count)	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag
10	Kurizampa	73,2	35	42	-8	-2	M	9	0	L	64	0	M	14	-2	L

Table 6.6 Changes in low-flow dry spells (duration and frequency) under future scenarios at the nearest hydrological stations in Monggar for the Kurichhu (10).

Dzonkhag: Monggar			Extreme Rainfall Events													
Population 2017:		37150	River basin:		Drangmechhu						Annual precipitation trend (historic):			Non - significant Increasing		
Population change 2042		-18														
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
174	Gongdue	2	7	2	1	2	M	2	5	H	2	3	H	2	5	H
179	Tsakaling	1	2	1	6	2	M	12	18	H	9	10	H	25	30	H
182	Monggar	3	2	1	5	1	M	8	7	H	7	7	H	20	14	H
Other gewogs (not ranked)																
175	Jurmed		6	2	2	2	M	3	5	H	2	3	H	3	5	H
176	Silambi		5	1	2	3	M	3	5	H	2	5	H	5	8	H
177	Saling		3	1	3	1	M	5	7	H	4	6	H	13	14	H
178	Tsamang		3	1	4	5	H	8	12	H	6	9	H	16	35	H
180	Shermuhoong		3	1	4	4	M	9	15	H	5	10	H	18	37	H
181	Chhaling		2	1	6	2	M	10	9	H	8	7	H	21	16	H
183	Drepoong		3	1	3	1	M	5	6	H	4	7	H	10	9	H
184	Ngatshang		2	1	5	1	M	8	7	H	7	7	H	22	14	H
185	Balam		4	1	2	3	M	4	5	H	3	4	H	9	13	H
186	Dramedtse		5	1	2	3	M	3	5	H	2	4	H	6	12	H
187	Na-Rang		3	1	3	2	M	6	5	H	4	4	H	11	13	H
188	Chagsakhar		2	1	4	1	M	6	5	H	7	4	H	18	11	H
189	Kengkhar		3	1	3	2	M	5	5	H	4	4	H	9	8	H
190	Thang-Rong		3	1	3	1	M	4	5	M	4	7	H	10	8	H

Table 6.7 Combination of top-down and bottom-up results for Monggar dzongkhag. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

						RCP4.5						RCP8.5					
		Historical levels (m^3/s)		Historical frequenc		2035 Change Factor			2085 Change Factor			2035 Change Factor			2085 Change Factor		
ID	Catchment	10 years	30 years	1/10 yrs	1/30 year	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag
10	Kurizampa	3215	3648	5	3	2	1	L	9	7	H	6	4	H	31	36	H

Table 6.8 Changes in peak flows (1/10 and 1/30 year) under future scenarios at the nearest hydrological stations in Monggar for the Kurichhu (10) in Drangmechhu basin.

6.3.2 What are the issues identified during the BU consultation?

From the bottom up surveys 6 gewogs were ranked high based on reported issues on drinking and irrigation water (see Table 6.5). The major drinking water sources are springs, streams and rainwater. A lack of proper clean water sources which also in terms of quantity cannot supply sufficient drinking water are reported (hotspots are Jurmed, Kenkhar and Thangrong). Drying sources, deforestation and increasing settlements, sometimes above the sources are mentioned as the causes of these problems. In addition, there is a lack of technical skills to properly manage the water supply system.

NSB (2017) data for gewogs reported that Drametsi gewog has the highest cultivated areas (chuzhing) with 158.3.41 acres followed by Shermuhoong gewog with 151.113 acres. The highest numbers of irrigation schemes are located in Saling gewog with 12 schemes and a length of 24.8 km followed by Shermuhoong gewog with 11 schemes and 25km of length.
Saling, Narang and Tsakaling gewogs are classified as a hotspot of irrigation related issues during consultations with relevant dzongkhag officials. The irrigation water sources are mainly streams, rivers, rainwater and spring. The trend observed is of these sources decreasing. A decrease in the availability of irrigation water due to drying of water source, leading to insufficient water to meet the crops water demand year-round is reported. Climate change could be an enhancing factor as temperature increases and rainfall is perceived as more erratic. But also increasing population and deforestation are mentioned as possible causes. Landslides in the monsoon season cause blockages of irrigation channels.

Drylands of Jadung and Bakaphay villages, a wetland of Sheri village in Balam gewog, along Durdari river and Morabri stream in Chagsakhar gewog, dry land surrounding Zhunglen Tsho in Drepoong gewog, Thridangbi village in Saling gewog, along Sherichhu river in Shermuhoong gewog and Lungkangchhu river in Tsakaling gewog are flood-prone areas according to Flood Hazard Assessment for Monggar dzongkhag (FEMD, DES, MoWHS). Out of all the preceding flood-prone areas Tshangkhu chu along with Thridangbi village in Saling gewog and Sheri chu along the crematorium in Shermuhoong gewog are the critical areas that requires flood mitigation works (FEMD, MoWHS, 2019). Moreover, the rainfall-runoff during the monsoon season imposes flooding risk to 24 automobile workshops and footpaths in the municipal area by Rawangyoe seasonal stream. The scouring at the left bank of Kurichhu happens every time during the cleaning schedule of the hydropower plant and this imposes flooding risk to Gyalpozhing town.

As per the consultations with officials of Monggar dzongkhag, three hotspots for water-related hazards, both landslides and river floods, are Tsakaling gewog, Gongdue gewog and Monggar town. Reported issues are damage to crops and agricultural land and properties, soil erosion, damage of water source and roadblocks and obstruction of the PNH way. Causes mentioned are the increase in the water level of rivers and streams during the rainy season, the fact that these gewogs have larger marshy areas with lower drainage capacity and colluvium soils susceptible to landslides. Climate change is not explicitly mentioned as a cause.

6.3.3 What are the TD results indicating?

In most of the ranked (and unranked) gewogs, dry spell frequency and duration is increasing both on the short and long term under both RCP4.5 and RCP8.5. Duration will relatively increase more (going from around 4 weeks to max 6 weeks) than frequency (remaining around once per year). Agreement on the sign of change in duration and frequency is medium to high. This is in line with observed trends in precipitation for this dzongkhag.

The Drangmechhu (Kurichhu) is the major river basin in this dzongkhag. The duration and frequency of low flows (<10th percentile) of these rivers (now around 30-40 days about every year) are projected to remain the same on the short term under RCP4.5 but duration may increase a bit on the long term (10-40%) under this RCP. For RCP8.5 on the short term there may be a substantial increase in low flow duration with 40-70% which is reduced again on the long-term. Agreement on the sign of these changes between the different climate model projections is medium (at least 4 out of 5 models agree).

As a proxy of flood risks, the number of peak rain and flow events is likely to increase especially for the long term (high agreement, this is also in agreement with observed trend in the annual precipitation). This is the case for all gewogs not only the ranked ones. For the short-term projected rainfall changes are relatively mild (~factor 2-5 in frequency) and uncertain (low to medium agreement). For flow (see section 5.2) this is similar (all projections agree on the sign). For the long term especially under RCP 8.5, projected changes are quite substantial both for rainfall and flow with changes in frequency of the 1/30 years events over a factor 10. This could imply that a 1/30-year flood event could occur 1/3 years in the second half of the century (for the short term more likely a 1/30-year event to happen every 10-15 years and a 1/10-event happening every 4-5 years). For landslides the number of critical 7 day accumulated rainfall events may increase slightly with a factor 2-3 on the short term and possibly more on the long term (see Figure 5.7).

6.3.4 Is climate change a serious enhancing factor for the water issues?

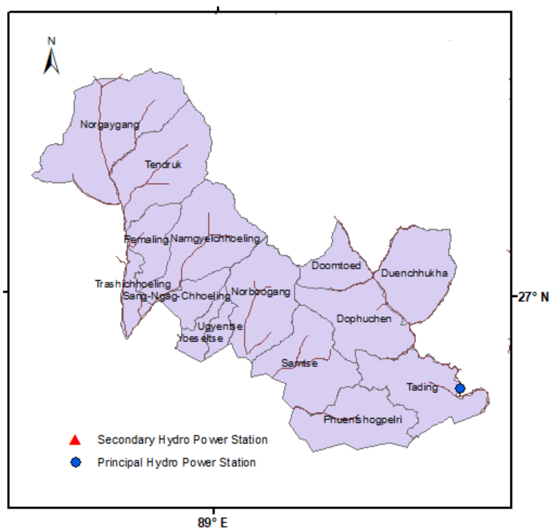
- Given that spring and small stream sources are drying up already the above described potential climate developments both on the short and long term will further complicate water supply for drinking water and irrigation during periods of dry spell.

  Water provision from the main river system may be further compromised due to climate change but the amounts needed versus the amounts available should be studied further.

- Note however that the per capita water demand is likely going to increase with a factor 2 and that new settlements in the priority gewogs are reported (though population change for the whole dzongkhag is projected to decrease, with -18%).
- The risks of flooding seem to be seriously enhanced by the projected changes in peak flows. These floods will enhance impacts on people, community and infrastructure (including that for irrigation and piped drinking water supply).
- The risks of rainfall induced landslides is also enhanced putting both challenges for protection of people and infrastructure (including that for irrigation and piped drinking water supply).
- More frequent peak flows may also increase the sediment content of the water which will make it less useable for water intake and treatment.

6.4 Samtse

6.4.1 Map and statistics



Administrative map Samtse

Dzonkhag:Samtse				Dry spells in ground water recharge													
Population 2017:		62590		River basin:		Jaldakha (0 - 10)						DJF precipitation trend			Non-significant		
Population change 2042 (%):		-2				Amochhu (11- 14)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
11	Phuentshogpelri	1	2	19	62	25	-15	M	10	-16	L	4	-3	M	25	-6	M
12	Tading	2		24	54	12	-4	M	-3	24	M	-18	24	M	22	17	M
7	Yoeseltse	3	3	19	63	-3	-10	M	6	11	M	-3	21	M	10	40	L
14	Doomtoed		1	97	15	-21	60	M	-7	100	H	-4	40	M	-9	87	M
Other gewogs (not ranked)																	
5	Namgyelchhoeling			44	33	7	12	L	69	48	H	44	30	L	43	39	M
6	Sang-Ngag-Chhoeling			24	55	-5	-22	M	63	24	M	45	24	L	36	24	M
3	Pemaling			49	29	-12	0	L	24	31	M	44	14	L	-5	7	L
8	Ugyentse			15	70	-18	0	L	29	17	M	-15	21	M	-5	33	M
9	Norboogang			34	42	-1	-19	M	35	38	M	22	26	L	26	17	M
10	Samtse			19	67	11	0	L	31	25	L	1	34	M	31	34	M
1	Norgaygang			52	28	-15	29	L	55	79	M	50	61	M	6	75	M
2	Tendruk			56	26	-19	12	L	34	88	M	31	85	M	-17	85	M
13	Dophuchen			42	33	-11	6	L	-8	42	M	-5	-3	L	0	18	L
4	Trashichhoeling			7	106	17	-19	M	57	7	M	14	-12	M	27	-11	M
15	Duenchhukha			82	18	-10	28	L	4	61	M	-15	17	M	-12	39	M

Table 6.9 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related issues. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

					RCP4.5						RCP8.5					
ID	Sub-catchment	Historical Dry Spells			2035 Relative Change (%			2085 Relative Change (%			2035 Relative Change (%			2085 Relative Change (%		
		Q10 of fL (cms)	Duration (days)	Frequency (count)	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag
1	Doyagang	14,6	35	43	-16	-12	L	5	2	L	20	-7	L	-23	-21	M

Table 6.10 Changes in Low-flow dry spells (duration and frequency) under future scenarios at the nearest hydrological stations in Samtse for the Amochhu (1).

Dzonkhag: Samtse			Extreme Rainfall Events													
Population 2017:		62590	River basin:		Jaldakha (0 - 10)						Annual precipitation trend			Non-significant		
Population change 2042		-2			Amochhu (11- 14)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
1	Norgaygang	2	4	3	2	2	M	6	5	H	3	2	M	10	8	H
10	Samtse	1	5	2	1	2	L	3	4	M	2	2	M	5	5	M
14	Doomtoed	3	3	2	2	2	M	6	5	H	3	2	M	10	8	M
Other gewogs (not ranked)																
2	Tendruk		6	0	1	2	M	3	2	H	1	2	M	5	2	H
3	Pemaling		6	1	1	3	M	3	9	H	2	3	L	5	12	M
4	Trashichhoeling		4	2	1	2	M	4	4	H	1	2	L	7	7	H
5	Namgyelchhoeling		5	1	2	3	M	3	10	M	2	3	L	6	11	M
6	Sang-Ngag-Chhoeling		5	1	1	3	M	3	9	M	2	2	L	5	10	M
7	Yoeseltse		4	1	2	3	M	4	8	H	2	3	M	7	11	H
8	Ugyentse		5	1	2	3	M	4	8	M	1	3	M	5	11	M
9	Norboogang		6	1	1	2	M	3	9	M	2	3	M	4	11	M
11	Phuentshogpelri		4	1	2	2	M	5	7	M	3	5	M	7	9	M
12	Tading		4	2	2	2	L	4	4	M	2	1	M	7	5	M
13	Dophuchen		3	2	3	2	M	5	4	H	3	2	M	8	6	M
15	Duenchhukha		3	2	2	2	M	6	4	H	3	2	M	8	8	M

Table 6.11 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

						RCP4.5						RCP8.5					
ID	Catchment	Historical levels (m^3/s)		Historical frequency		2035 Change Factor			2085 Change Factor			2035 Change Factor			2085 Change Factor		
		10 years	30 years	1/10 yrs	1/30 year	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag
1	Doyagang	3998	4816	5	2	1	2	M	3	6	H	1	2	M	7	11	H

Table 6.12 Changes in peak flows (1/10 and 1/30 year) under future scenarios at the nearest hydrological stations in Samtse for the Amochhu basin.

6.4.2 What are the issues identified during BU consultation?

Through the consultations, it was reported that the sources of water for Samtse dzongkhag are streams, spring and rivers. The main water related issues that were reported include insufficient water for drinking and irrigation, poor quality of water during the monsoon and drying up of sources. Such a trend in the dzongkhag was observed to be increasing over time and this is mainly due to the increase in the population size, rise in the developmental activities, channels being damaged by landslides and wild animals (mainly elephants) and increase in the infrastructure development.

The communities in the dzongkhag have less supply of water for irrigation as the sources are being converted to RWSS. In addition, the channels are in poor condition and there is high electricity charge for pumping. Phuentshogpelri gewog is ranked at the top for the drinking and irrigation water related issues.

Over time, the dzongkhag is also experiencing water related disasters which were assumed to be mainly due to the climate change. There are increasing trends of river floods, landslides, rainstorms, hailstorms and long period of dry spells. Due to such disasters there are problems of sources being damaged, washing away of farm roads, destruction of cultivable land, washing away of the irrigation channels and destruction to houses. The main causes of such issues are reported to be due to climate change, deforestation, lack of climate resilient planning and illegal felling of timber. From all the gewogs, Samtse gewog is ranked at the top for being highly vulnerable for the water related disasters.

6.4.3 What are the TD results indicating?

- The dry spell duration and frequency for most of the gewogs is projected to slightly decrease as per RCP 4.5 in 2035. For the other RCP's and timeframes, most gewogs are projected to see an increase in dry-spells. Periods of low river flow for the Amochhu are projected to become slightly shorter and less frequent for most of the scenarios.

- The top-down results show that the occurrence of a 1/10 years and 1/30 year rainfall event is projected to increase for all gewogs and RCPs ranging from a factor 1- 3 on the short term to 3-10 for the long term depending on gewog and RCP. Peak river flows show a similar projected trend.

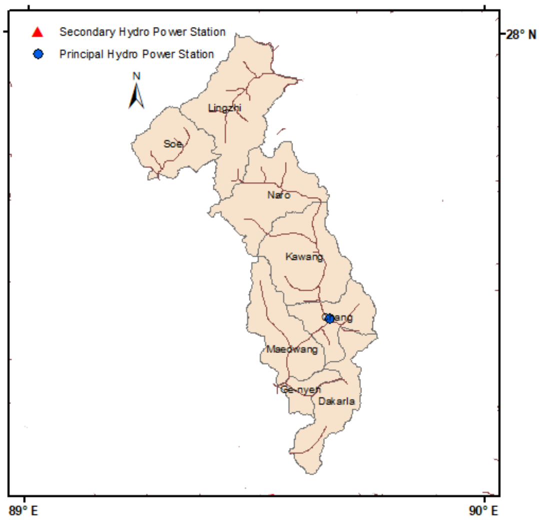
- For landslides the number of critical 7 day accumulated rainfall events are not projected to increase significantly (see Figure 5.7).

6.4.4 Is climate change a serious enhancing factor for the water issues?

A potential increase of duration and frequency of dry spells is a possible outcome of climate change for Samtse dzongkhag and will put further stress on available water sources (on top of the reported issues from the BU analysis) especially in the light of a further increasing water demand (though population is not projected to increase until 2042). An increase of high flow and precipitation events and associated disasters such as landslides and floods leading to mentioned impacts on land, infrastructure and people, is likely to occur.

6.5 Thimphu

6.5.1 Maps and statistics



Administrative map of Thimphu

Dzonkhag: Thimphu				Dry spells in ground water recharge													
Population 2017:		138736		River basin:		Wangchhu						DJF precipitation trend			Non-significant		
Population change 2042 (%):		73				Punatsangchhu (24)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
46	Ge-nyen	3	2	41	35	10	11	L	50	54	H	39	40	L	59	34	M
47	Maedwang	1	1	47	31	12	19	L	60	45	M	49	39	L	48	58	M
48	Chang	2		27	53	11	17	L	109	47	H	108	42	M	54	66	M
49	Kawang		3	33	43	-33	-7	M	-30	51	H	-12	21	M	-32	37	M
Other gewogs (not ranked)																	
23	Soe			37	39	-23	-13	H	-26	-26	H	-22	-13	M	-32	-31	H
24	Lingzhi			39	37	-46	-19	H	-49	-65	H	-42	-19	H	-82	-86	H
45	Dakarla			42	35	-7	20	L	44	40	H	39	31	L	23	31	M
50	Naro			38	38	-41	-37	H	-60	-71	H	-40	-37	H	-71	-97	H

Table 6.13 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

					RCP4.5						RCP8.5					
ID	Sub-catchment	Historical Dry Spells			2035 Relative Change (%			2085 Relative Change (%			2035 Relative Change (%			2085 Relative Change (%		
		Q10 of fL (cms)	Duration (days)	Frequency (count)	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag	Duration	Freq.	Ag
3	Damchhu	8,5	40	37	-44	-54	L	-12	14	M	-7	16	L	-16	8	L

Table 6.14 Changes in low-flow dry spells (duration and frequency) under future scenarios at the nearest hydrological stations in Thimphu dzongkhag for the Wangchhu (3).

Dzonkhag: Thimphu			Extreme Rainfall Events													
Population 2017:		138736	River basin:		Wangchhu						Annual precipitation trend			Significant		
Population change 2042		73			Punatsangchhu (24)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
47	Maedwang	3	3	2	2	2	M	7	4	H	4	2	M	10	6	H
48	Chang	2	3	2	3	3	M	7	5	H	4	4	M	9	8	H
49	Kawang	1	3	2	3	3	M	8	4	H	4	3	M	12	8	H
Other gewogs (not ranked)																
23	Soe		5	0	3	2	H	4	2	H	3	2	H	8	2	H
24	Lingzhi		6	1	2	6	H	4	10	H	2	6	H	7	17	H
45	Dakarla		3	2	3	2	H	8	7	H	4	2	M	10	9	H
46	Ge-nyen		3	2	2	2	H	7	5	H	2	2	M	10	10	H
50	Naro		6	2	3	3	M	4	5	M	3	4	M	6	8	H

Table 6.15 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

						RCP4.5						RCP8.5					
ID	Catchment	Historical levels (m^3/s)		istorical frequenc		2035 Change Factor			2085 Change Factor			2035 Change Factor			2085 Change Factor		
		10 years	30 years	1/10 yrs	1/30 year	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag	1/10 yrs	1/30 year	Ag
3	Damchhu	1378	1712	7	2	1	2	M	4	6	H	2	3	M	10	14	H

Table 6.16 Changes in peak flows (1/10 and 1/30 year) under future scenarios at the nearest hydrological stations in Thimphu dzongkhag for the Wangchhu basin.

6.5.2 What are the issues identified during BU consultation?

The consultation with the relevant officials of Thimphu dzongkhag reported the main sources of drinking water in the dzongkhag as streams, rivers, underground water and springs. All of these water sources are observed to be decreasing. The major problem in the gewog is insufficient supply of drinking water and the main causes of the above-mentioned problem are increase in settlements, drying of water sources, deforestation and harsh weather condition especially during the winter which freezes water pipes due to the low temperatures.

The main sources of irrigation water are streams, springs and river for field crops, horticulture and vegetables. The trend of the water sources is observed to be decreasing. The major problems in the gewog are insufficient water supply for irrigation and open channels which leads to loss of water and the main cause of the above-mentioned problems includes drying up of source and increasing settlements.

Maedwang gewog is reported as the priority gewog for having an issue of drinking water supply and for irrigation.

The major water related hazards in Thimphu dzongkhag as reported through consultation includes, landslides, river floods, GLOFs and flash floods. The trend of landslides is observed to be remaining same whereas the trend of flash floods is not known. The major problems associated with water related hazards in the gewogs are washing away of land and infrastructures and posing risk to properties and lives. This also causes soil erosion and damage of agricultural land and risk of washing away of reservoir tanks and distribution pipes. Moreover, it also causes destruction of land, road, bridge and irrigation channels of the community. The main causes of the water related hazards are due to lose soil, underground water seepage, heavy monsoon and swelling of river. Deforestation, developmental activities, changes in weather pattern and melting of glaciers and erratic rainfall are the other factors that are enhancing water related disasters. Kawang gewog is highly vulnerable and ranked highest for the water related disasters.

Within Thimphu thromde, demkhong Olakha-Changzamtok is reported of having risk of flooding. Demkhong Taba-Dechencholing is reported to have risks of drying of water source as people depend on spring water with no proper water source, most of the residents use same source putting pressure on water source and increasing users.

6.5.3 What are the TD results indicating?

In Thimphu dzongkhag, the dry spell duration and frequency is projected to increase under all scenarios for all 3 priority gewogs with drinking water issues and 2 out of 3 gewogs (see table 6.13) with irrigation water issues. For the other non-ranked gewogs, duration and frequency will generally rather decrease.
The frequency of peak rainfall events for Thimphu dzongkhag is projected to increase with a factor 2-5 for the short term and 4 to more than 10 times for the long term depending on RCP and gewog. Also, landslide triggering rainfall events are likely to increase as in most of the northern regions especially in the long term (see Figure 5.7).

6.5.4 Is climate change a serious enhancing factor for the water issues?

A potential increase of duration and frequency of dry spells, is a possible outcome of climate change for some already stressed areas especially in the light of a further increasing water demand and a substantial expected increase in population until 2042. An increase of high flow and precipitation events and associated disasters such as landslides and floods leading to mentioned impacts on land, infrastructure and people, is likely to occur.

6.6 Conclusions based on the dzongkhag level analysis

It is obvious from the above analysis (and Annex C) that climate change is already playing a role (and will increasingly do so) as a contributing factor to the diverse number of water issues mentioned across all dzongkhags. Most often, the perceived trends (gathered from the BU consultation) in climate related hazards agree with observed climate trends and also generally fit within the range of TD proxy indicator projections. Some key findings:

- There is no systematic correlation between the highest ranked gewogs and gewogs with largest projected impacts based on the TD results. This was also not the expectation as the ranked issues know many causes besides climate. Climatic trends may change in the future and in general there are large uncertainties involved in the analysis.

- An increase in dry spells affecting sources and springs should be accounted for when planning improvements in water supply for drinking water and irrigation especially for the longer term, after 2035. Uncertainty in the projections remains high.

- For the short term, the increase in water demand probably is much more dominant and challenging to adapt the water supply system.

- All flood related disasters are likely to increase in almost every dzongkhag. This is a great challenge especially for the long term.

7 Recommendations on adaptation

7.1 Interpretation of risk and confidence levels

As a start for defining adaptation actions for the NAP the results presented in chapter 5 and 6 have first been analysed according to two questions: How seriously will the risk for the water sector increase and how much confidence do we have in the underlying analysis? Based on these outcomes actions can be defined according to decision making under uncertainty principles outlined in 2.3.3. This analysis has been done qualitatively for the 6 main issues that have serious impacts on the water sectors: 1) Drying of sources; 2) Occurrence of low flows; 3) Pluvial flooding; 4) River flooding; 5) Landslides and 6) GLOFs. The results are shown in Figure 7.1.

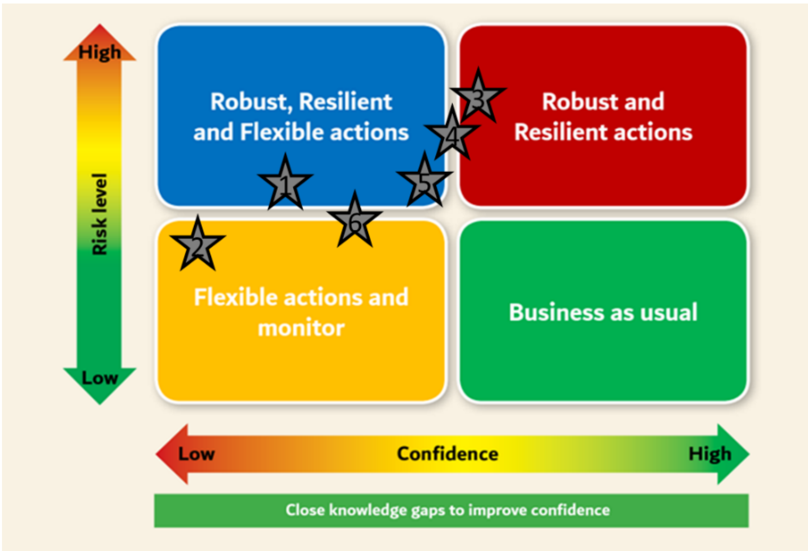


Figure 7.1 Assessment of risk and confidence for a selection of water issues in Bhutan under climate change. 1) Drying of sources; 2) Occurrence of low flows; 3) Pluvial flooding; 4) River flooding; 5) Landslides and 6) GLOFs. And recommendation for type of actions to take (see for explanation textbox 2.1).

With respect to the **risk level** we know (see also 2.3.2) that this is determined not only by the increase of the **hazard**, moving from current to future climate, but also by changes in **exposure** and **vulnerability**. The analyses presented in previous chapters, especially the BU analysis, shows the importance of anticipating changes in exposure and vulnerability in the NAP. Concrete recommendations with respect to this are:

- Take into account the increase in population and per capita water demand when increasing water source and supply capacity. Some figures to support this are available from previous studies (National Environment Commission, 2016). However, it is also advised to revisit them and come up with new estimates based on different socio-economic development projections.

- Take into account land use types (e.g. rural, urban) when considering different zoning based on flood risk maps.

- Consider the resilience of infrastructure in terms of how well it can cope with future more frequent and intense climatological and hydrological hazards (i.e. landslides, floods, high sediment loads) and not only consider construction but also maintenance and repair (fast recovery).

To assess **confidence,** the previously mentioned and presented **agreement** between different information sources (i.e. the 5 GCMs, observed trends and literature) is used as an input. Also, the **quality** of the analysis itself is assessed and more specifically how **representative** it is for the issues mentioned. As the TD analysis is done based upon indicators that are a proxy for the real impacts experienced, it only gives an indirect indication of the size and direction of changes. For example, we cannot tell if periods of decreased ground water recharge are a proper approximation for cause-effect relation between climate/hydrology and observed drying of sources in all places and reported cases. For this reason, the confidence in a national scale analysis for adaptation can never be as high as for a more localized analysis where specific observed impacts can be mechanistically linked to observed and modelled causes.

Assessment per issue:

- **Local drying of sources** (1) – future risk is assessed as above medium, since consequences are clearly already visible; it is mentioned often in the BU assessment and according to the analysis of dry spells it has a medium likelihood to happen more often and with more severe impacts in the future in large parts of the country. The confidence is low to medium because we do not know how well periods of reduced GW recharge are representative of this problem and because agreement between the model projections is only medium.

- **Occurrence of low flows** (2) – future risk is assessed as below medium since we do not see many reports on this issue from the BU analysis. On the other hand, the likelihood of an increase of low flows based on the analysis is low. Low agreement between climate projections and low understanding (and lack of detailed validation of the hydrological model) on the determinants of low flows in rivers and streams (including cryosphere processes) results in a rather low confidence in the analysis.

- **Occurrence of floods, pluvial** (3) and **riverine** (4) – future risk is assessed as rather high since there are already many serious reports on these issues and at the same times the projected changes especially for the second half of the century seem substantial. Confidence is medium as agreement between the projections is often between medium and high, projected climate effects are in accordance with scientific insights. On the other hand, we do not know how impactful a present day 1/10 and 1/30 year rainfall event really is at all locations. This would need better ground truthing, through systematic hazard monitoring.

- **Occurrence of landslides** (5) – As projections in 7-day consecutive rainfall events are rather clear especially for the longer term and there are already many reports on serious impacts, future risk is assessed as rather high. On the other hand, the 7-day rainfall is only one contributing factor to landslides and local geomorphological (slope, soil and land use characteristics) conditions are not part of the analysis (though Figure 2.3 shows that almost the whole of Bhutan is susceptible to landslides). Therefore, the confidence in the analysis especially on the spatial distribution of landslide risk, and not whether risks country wide will increase or not, is rather low.

- **Occurrence of GLOFS** (6) – Melting of glaciers is already occurring and will continue to occur in the future under clearly increasing temperature trends that are stronger at higher altitudes. Also projected extreme precipitation increases add to increasing risks. Together with the occasional reports of historic event, the future risk is assessed as medium. The confidence in the analysis is rather low as local conditions are not considered and the analysis was very general and not done at gewog level.

Based on this assessment, the main direction for adaptation is a flexible strategy that starts with low-regret actions that improve the resilience and robustness of the water sector in Bhutan.

7.2 Recommended strategic directions for adaptation for inclusion in the NAP

Based on the above analysis strategic directions for the NAP are recommended. As an input to these recommendations the actions formulated by the sectors during the BU consultations and the discussions in the workshop on adaptation held 31st of August and in the focus group meetings held on 19th and 20th October 2021 are used.

These strategic directions are built up as follows:

1. As the basis for a healthy water sector and limiting the occurrence and severity of water related hazards such as droughts, floods and landslides; the ecosystem (and its potential to buffer, water, slow down runoff and prevent erosion) should be strengthened and where affected restored. Improved watershed management and nature-based solutions such as low impact developments in urban areas are at the basis for this.

2. Potentially increasing flood risks should be managed by improved planning, including prevention by increasing the discharge capacity of river systems and improving preparedness and response based on real-time information systems.

3. Infrastructure and settlements potentially exposed to water related hazards should be protected against higher risks of floods and landslides.

4. Planning (choice of locations), design and operation of infrastructure should integrate increasing risks of water related hazards under climate change. Resilient infrastructure guidelines are instrumental for this.

5. Enhance Early warning, response and recovery capacity at a local level.

6. Increase robustness of sectoral water supply and demand for drinking and irrigation water to cope with increasing demands and potential risk of increasing

dry spells. This includes both innovation in water supply/irrigation systems and in minimizing water losses and managing demand.

7. Increase the climate resilience of the Hydropower sector through existing and newly built hydropower facilities to cope with more erratic flow patterns and increase of disaster risks. Actions include upstream watershed management and downstream disaster risk management as well as exploration of new technologies.

Below the strategic directions are elaborated into more detail distinguishing between short term and long-term actions and indicating possible key performance indicators to measure progress and success of implementation. Furthermore, responsible institutions are summarized and barriers for implementation are discussed briefly.

7.2.1 Improve ecosystem services

A healthy good functioning ecosystem is the basis for a *resilient water system* that is able to cope with shocks of droughts and extreme rainfall events linked to climate change. Therefore, it is crucial to strengthen the natural capacity of both the natural and cultivated landscape to:

- Improve infiltration and water buffering – It is vital to improve the protection and management of existing watersheds to improve infiltration and water buffering. Therefore, surface- and groundwater resources need to be researched, assessed, mapped and monitored to inform planning and management. Institutions like WUAs need to be capacitated and institutional arrangements for implementation of watershed management (such as PES) implemented. In urban areas low impact development needs to be encouraged.

- Prevent fast runoff and erosion by maximizing infiltration and buffering in ecosystems preventing overgrazing, applying agriculture practices minimizing erosion, wetland restoration and afforestation.

1) Objective: Improve natural capacity for infiltration, water recharge, water buffering and for prevention of fast runoff and erosion.		**Outcome:** Healthy and resilient functioning water & ecosystem.	
Strategic Action	**Short term action** **(0-5 years)**	**Medium term** **(5-15 years)**	**Key performance Indicator (KPI)**
• Ecosystem restoration • Watershed management • Promotion of traditional knowledge and practices in water conservation.	• Assessment of wetlands, watersheds and spring sheds and development and implementation of intervention measures. • Comprehensive water resource assessment, with geo-tagging and monitoring plan. • Integrating of existing watershed management interventions into Local Area Plans/settlement plans and its implementation • Restoration of existing water sources.	• Effective implementation of water legislation and IWRM. • Sustainable management of wetlands, watershed and spring sheds. • Conduct watershed modelling.	• Number of wetlands, watersheds and spring sheds assessed and managed. • Comprehensive water resources assessment and monitoring plan produced. • Number of community

	• Strengthening Water User Associations (WUAs). • Implementation of Ecosystem based Adaptation.	• Monitor infiltration, water buffers, and erosion.	awareness on IWRM and water legislations conducted.
• Strengthening research on water resource management including groundwater resources.	• Research on water resource management including groundwater resources and soil moisture • Enhance hydrological and groundwater modelling. • Carry out studies on the options for household/institution level rainwater harvesting or creating additional water storage capacity	Initiate use of groundwater or discontinue based on findings from the studies.	• Number of studies on groundwater resources conducted. • Real time information on soil moisture in place.
• Strengthen and upscale PES.	• Strengthen and upscale PES. • Review PES framework and field guide		• Number of PES schemes upscaled.
• Formulate and implement storm water and Low Impact Development (LID) plans	• Development and implementation of storm water management plans. • Incorporate LIDs into the urban development plans.		• Storm water management plans developed and implemented. • Impact assessment of LID plans conducted.

<u>Implementation:</u>

- Strategic action on improved watershed management and ecosystem restoration should be led by NECS and the MoAF with support of LGs and the MoWHS.
- Strategic action on research on water resources management including groundwater has to be led by NECS with support of the RUB and NCHM.
- Strategic action on strengthening and upscaling PES schemes has to be led by MoAF with support of LGs.
- Strategic action on LID has to be led by MoWHS supported by LGs.

<u>How to avoid potential barriers?</u>

As the actions proposed have spatial implications, it is important to avoid and settle conflicts with the development sector and reach agreement on land pooling with land owners.
The limited existing capacity within the institutions and local governments should be strengthened (see also enabling actions, 7.2.7) to ensure sustainability. This particularly concerns: limited technical know-how and innovations and lack of adequate database system.

7.2.2 Flood risk management and planning for robust river systems

As both total and peak rainfall amounts are expected to increase, the capacity of rivers to accommodate the associated large discharges without having too much impact on infrastructure and settlements should be enhanced. This can be done by removing bottlenecks and if needed build emergency storage or bypasses. Flood risks can be managed by controlled releases from glacial lakes, instituting no build zones and early warning systems. All actions should be informed by proper basin flood risk assessments and real time monitoring and information systems. Flood protection measures are also part of a flood risk management plan and is treated under objective 3 (see 7.2.3)

2) Objective: Manage flood risk by prevention and improved preparedness and response		**Outcome:** Robust flood risk management and monitoring system.	
Strategic Action	**Short term action (0-5 years)**	**Medium term (5-15 years)**	**Key performance Indicator (KPI)**
• River basin planning.	• Establish basin flood risk management plans. • Conduct feasibility studies to build emergency storage, bypasses and controlled releases from glacial lakes.	• Build emergency storage, bypasses and controlled releases from glacial lakes. • Monitoring and evaluation of river basin management plans.	• Number of feasibility studies conducted to build emergency storage, bypasses and controlled releases from glacial lakes. • Number of river basin management plans prepared and implemented
• Real-time monitoring and forecasting of the flows. • Climate smart river management system.	• Expand and improve hydro-meteorological stations to include tributaries. • Efficient database and information dissemination system on hydro-meteorology. • Enhance seasonal and annual weather forecasts to generate hydrological flow forecasts. • Enhance hydrological modelling and simulation for water resource forecasting	• State-of-art river monitoring and forecasting with decision support systems.	• Number of new and improved hydro-meteorological stations established. • Number of forecasting products with decision support systems.

Implementation:

- Strategic action on improved river basin planning should be led by NECS and MoWHS with support of MoAF, NCHM and LGs.
- Strategic action on real time monitoring, forecasting and smart river management have to be coordinated by NCHM with input from NECS, MoAF, MoWHS, MoHCA, LGs.

How to avoid potential barriers?

As the actions proposed have spatial and budgetary implications and should be integrated with other national economic developmental goals.
The limited existing capacity within the institutions and local governments should be strengthened (see also enabling actions, 7.2.7) to ensure sustainability.

Protect critical infrastructures and settlements against floods and landslides by applying flood mitigation structures, slope stabilization, improved drainage systems in urban areas.

3) Objective: Protect critical infrastructures and settlements.		**Outcome:** Safe, liveable and resilient infrastructure in critical areas for flood/landslide protection	
Strategic action	**Short term action (0-5 years)**	**Medium term (5-15 years)**	**Key performance Indicator (KPI)**
• Provide climate resilient infrastructure in critical areas for disaster risk reduction.	• Review and develop flood and storm water management plans. • Review design of flood protection management protective structures like dams, drainage systems, and barriers in flood-prone areas. • Terracing or slope stabilization of landslide prone areas. • Slope stabilization along PNH and dzongkhag highway. • Strengthen implementation of no build zones on river banks with strict rules and regulations.	• Introduction and implementation of flood/landslide resilient infrastructures • Implementation of the climate resilient infrastructures, recommended in the flood and storm water management plans. • Monitoring and evaluation of climate resilient infrastructures for disaster management.	• Number of dzongkhags/thromdes with flood and storm water management plans developed and implemented. • Monitoring report on climate resilient infrastructures.
• Improved/efficient flood forecasting, preparedness and response system.	• Modelling and forecasting of extreme weather events and dissemination of information to the LGs and other sectors installation of additional early warning systems at critical areas. • Map and target flood prone areas with specific, action-oriented communication before, during and after the flood events.	• Enhance flood forecasting, and hazard and risk mapping.	• Number of flood forecasting products and services. • Number of events-based maps produced.

<u>Implementation:</u>

- Strategic action on provisioning resilient infrastructures should be led by MoWHS and MoHCA with support of LGs and MoAF.

- Strategic action on flood forecasting and subsequent response communication have to be coordinated by NCHM (forecasting) and MoHCA and LGs (preparedness and response) with input from MoAF, MoWHS.

<u>How to avoid potential barriers:</u>

As the actions proposed have spatial implications it is important that urban development is considering the spatial reservations and is not extending to critical areas. Response strategies should be coordinated with planning and local agencies (stakeholders) involved.

7.2.3 Develop more resilient infrastructure

Development of resilient infrastructure needs to be achieved at different scales:

- better *planning* of roads and settlements to avoid risky places,
- *design* of (new or renewal) roads, supply & sanitation infrastructures in a way they are less vulnerable to hazards,
- and *operation and maintenance* of infrastructure (aimed at fast recovery).

The final objective is to limit exposure and reduce vulnerability to climate hazards.

4) Objective: Develop and promote resilient infrastructure		**Outcome:** Resilient infrastructure with limited exposure and reduced vulnerability.	
Strategic action	**Short term action** **(0-5 years)**	**Medium term** **(5-15 years)**	**Key performance Indicator (KPI)**
• Strengthen capacity in designing and developing climate-resilient infrastructure.	• Improved planning, investigation and designing of resilient infrastructures. • Develop climate resilient infrastructure guidelines and master plan. Include build back better principle. • Ensure operation and maintenance of infrastructure (aimed at fast response and recovery). • Identification and mapping of perennial slope (including debris flow site).	• Climate-resilient infrastructure development. • Explore potential for tunnelling at landslide prone areas.	• Climate resilient infrastructure guideline developed and implemented • Number of climate-resilient infrastructures designed and developed accordingly • Number of exploration studies for tunnelling carried out.

<u>Implementation:</u>

Ministries responsible for overseeing design, building and operation of various types of infrastructure networks (water, energy, irrigation, roads, electricity etc.) like MoWHS, MoAF and MoEA should take the lead and coordinate with LGs.

<u>How to avoid potential barriers?</u>

- Cost of building these more resilient infrastructure may be higher (as they may need to be stronger, need more expensive material or larger drainage capacity etc.). Therefore, full life cycle costs should be considered including costs of downtime, future maintenance etc. before taking decisions on investments. This evaluation can be part of the guidelines.
- The limited existing capacity within the institutions and local governments should be strengthened (see also enabling actions, 7.2.7) to ensure sustainability. Retention of trained manpower will be a challenge as well as the limited private sector involvement.

7.2.4 Improve early warning and response & recovery capacity

Expand and improve existing early warning systems for GLOFs and other types of flash floods. Make sure that relief funds (and other mechanisms e.g. insurance) for fast repair and recovery of properties and infrastructures and to compensate for damages are in place. The actions should be incorporated in the flood risk management, storm water management and local area plans as mentioned under objective 1-3.

5) Objective: Enhanced early warning, response and recovery capacity		**Outcome:** Reduced vulnerability to disasters	
Strategic action	**Short term action** **(0-5 years)**	**Medium term** **(5-15 years)**	**Key performance Indicator (KPI)**
• Monitoring of Potentially Dangerous Glacial Lakes (PDGL,) glaciers, snow.	• Expand and improve existing early warning systems for GLOFs and other hazards.	• Glaciers and snow (Hydrological) modelling and forecasting. • Strengthen assessment studies to monitor snow and glaciers.	• Number of upgraded early warning systems in place. • Number of publications on GLOFs and early warning systems.
• Comprehensive Disaster Management (DM) & Contingency Plans (CP) produced and implemented.	• Review and update DM and CP.	• Implement programs and activities under the DM and CP	• Number of DM and CP reviewed and implemented.
• Preparedness for disaster response. • Enhance awareness of communities on water related hazards (GLOF, Floods)	• Ensure relief funds (and other mechanisms e.g., insurance) for fast repair and recovery of properties and infrastructures and to compensate for damages are in place. • Conduct flood simulation exercises to improve the preparedness level of the community (Enabling action). • Conduct awareness program on water related hazards at the community level (Enabling action). • Ensure operation and maintenance of infrastructure (aimed at fast recovery).	• Assessing the community preparedness towards flood and water related disasters.	• Number of awareness of water related disaster conducted and knowledge transferred. • Listing of communities with their preparedness towards flood and water related disasters. • Number of flood related simulation exercises conducted.

<u>Implementation:</u>

- Strategic action on improved monitoring of GLOFS is the responsibility of NCHM and should be coordinated with LGs.

- Strategic action on disaster management and contingency plans should be coordinated by MoHCA with LGs, NCHM, MoEA, and MoAF.
- Strategic action on disaster response should be coordinated by MoHCA with LGs, NCHM, MoAF, MoWHS. Financial institutions are needed to manage the relief funds/insurance.

How to avoid potential barriers?

- Operating & Maintenance costs of the monitoring systems will be higher and should be accounted for.
- For proper functioning of the disaster response it is key to ensure Dzongkhag Disaster Management Committee (DDMC) are functional.

7.2.5 Increase robustness of sectoral water supply and demand

When the natural availability of water resources (see objective 1) becomes limited, either due to increase of dry spells or an increase of water demand, it may be necessary to **generate additional water storage capacity** to overcome periods of drought. **Low regret** actions that can be started at the **short-term** are the restoration of existing sources, study the options for household level rain water harvesting or create additional storage capacity at community level (in GW aquifers, ponds). The fast development of Bhutan at some locations (e.g. larger towns, agricultural or tourism centers) may also require a step-change in water supply systems. For the short-term further study could be started how larger scale multi-purpose reservoirs, larger water supply schemes or sustainable use of ground water can add extra **robustness** on the longer term.

6) Objective: Ensuring safe ***drinking water*** under climate change		**Outcome:** Improved access to safe drinking water.	
Strategic Action	**Short term action (0-5 years)**	**Medium term (5-15 years)**	**Key performance Indicator (KPI)**
• Ensuring proper monitoring, planning and supply of drinking water.	• Assessing the efficiency of existing water treatment facilities and water supply network systems. • Explore alternative water supply technologies. • Expand the implementation of Water Safety Plans (WSPs)and proper water supply systems with adequate design. • Awareness programs for efficient water use. • Provide training on plumbing water management and other related skills. • Develop operation and maintenance guidelines and standards.	• Explore and improve water treatment and supply network systems with proper management mechanisms. • Explore and build additional storage facilities.	• Households/Institutions with safe drinking water. • Water supply duration and quality improved. • Number of WSPs strengthened and implemented. • Number of awareness programs conducted. • Number of officials trained on plumbing water management and other related skills. • Operation and maintenance guidelines and standards published.

• Harvesting rainwater/fog for domestic use.	• Exploring volume of rain water generated at water stressed areas for domestic use. • Developing assessment guide for integration of holistic use of water resources.	• Integrating rainwater/fog harvesting structures into buildings and other amenities.	• Assessment guide for integration of holistic use of water resources developed (Enabling action).
• Promotion of water efficient technologies.	• Enhance research and development on water efficient technologies. • Conduct advocacy on water efficient technologies.		• No. of publications on water efficient technologies. • Number of advocacy programs conducted.
• Reduction of Non-Revenue Water (NRW) losses.	• Study of NRW in critical areas.	• Implementation of improvements to reduce NRW.	• % of NWR reduced in thromdes.
• Strengthen drinking water quality monitoring and surveillance.	• Strengthening laboratory services to test and monitor water quality.	• Strengthening water quality and monitoring information systems.	• No. of additional water quality parameters included in monitoring. • Integrated water quality and monitoring system established. • ISO certification ascertained.
• Strengthen database/inventory on drinking water supply schemes.		• Establishment of a real time water supply monitoring system.	• Functional real time water monitoring systems in place.

Implementation:

- The actions listed above on improving the information base for sustainable supply of drinking water by monitoring and surveillance and by strengthening the data base/inventory of supply schemes is responsibility of MoWHS and MoH with support of LGs and NECS.
- Actions on further exploring rain and fog water harvesting should be coordinated among MoH and MoWHS in collaboration with RUB and NECS.
- Reducing non-revenue water losses is a responsibility of MoWHS in collaboration with LGs, and NECS.
- Promotion of water efficient technologies is a responsibility of MoWHS and MoHCA in collaboration with LGs and MoAF.

How to avoid potential barriers?

Non-revenue water losses is a new concept for Bhutan, that needs awareness raising. Also, a changing mindset towards adoption of fog/rain water harvesting is needed, as it is not common in Bhutan. Technical skills are required to implement the techniques proposed.

Irrigation

To reduce exposure and vulnerability to dry spells, a low regret short term action is to continue and intensify the **improvement of the water use efficiency in domestic and agricultural supply and demand** by applying new irrigation techniques, reduction of water losses in supply network and irrigation channels, modernized sanitation systems. Use can be made of international practices and guidelines on climate resilient agriculture developments (e.g. through FAO) and on WASH (e.g. through the Global Water Partnership (GWP).

7) Objective: Enhance water use efficiency and promote sustainable management of *water for irrigation.*		**Outcome:** Improved resilience of irrigation infrastructure & Increased water use efficiency and water management	
Strategic Action	**Short term action (0-5 years)**	**Medium term (5-15 years)**	**Key performance Indicator (KPI)**
• Improve planning, designing and implementation of climate resilient irrigation infrastructures and systems.	• Rehabilitation of the traditional irrigation system to reduce water loss through climate proof structures integration. • In-situ water harvesting - diverting, inducing, collecting, storing and conserving local surface runoff, spring water and rainwater for agriculture production. • Promote adoption of micro irrigation (drip, sprinkler) by increasing accessibility to farmers through simple, affordable and smart technology. • Climate proofing of the irrigation facilities (HDPE/concrete, check dams). • Incorporate build back better (replacement with climate resilient infrastructures). • Ensure operation and maintenance of infrastructure (aimed at fast recovery).	• Exploring alternative means of irrigation (lift irrigation). • Promote adoption of micro- irrigation (drip, sprinkler) by increasing accessibility to farmers through simple, affordable and smart technology. • Introduce and promote automated irrigation system for alternate wetting and drying (AWD). • Explore tail water management and usage.	• Number of irrigation system rehabilitated (20 major irrigation schemes). • Number of water harvesting structures constructed (25 structures, i.e. 5 structures every year). • Number of households adopting micro-irrigation systems (100 households every year). • Number of climate proof irrigation schemes developed (45 schemes). • Area brought under AWD (2000 Ha). • Number of lift irrigation system initiated. • Length of drainage system constructed for tail water management.
• Strengthen database/inventory on irrigation schemes.	• Development of irrigation schemes database system.	• Conduct modelling and simulations of discharge for proposed irrigation schemes.	• Database on irrigation systems developed. • Number of discharge modelling and simulation conducted for proposed irrigation schemes.

Implementation:

Implementation of all the action should happen under coordination of the department of agriculture of the MoAF in collaboration with LGs. NCHM should support the work with data on water availability in different seasons and under future climate.

How to avoid barriers for implementation?

As agricultural land is often scattered, agricultural land implementation may become inefficient and cost of production may increase as also new more expensive technologies are being used. It is therefore important to make a good assessment in advance and concentrate on areas with highest benefits for such investments.
An important aspect of such assessments is that, irrigation schemes should be sustainably feasible within a watershed, considering other water uses, ecology, scarcity of available water sources and uncertainty in dry spells originating from climate variability and change. For such an assessment monitoring of watersheds and flow data are key (see also objective 1).

7.2.6 Increase the climate resilience of the Hydropower sector

The Hydropower sector will have to deal with both, potential increases in risks to its infrastructure and facilities due to floods and landslide hazards and with potential (uncertain) increases in dry spells threatening the delivery of electricity in the lean season.
Actions have been formulated that reduce the exposure and vulnerability to these climate hazards.

<table>
<tr><td colspan="2">8) Objective: Increased resilience of hydropower infrastructures/technologies to climate change.</td><td colspan="2">Outcome: Resilient HP infrastructure with limited exposure and reduced vulnerability.</td></tr>
<tr><th>Strategic action</th><th>Short term action
(0-5 years)</th><th>Medium term
(5-15 years)</th><th>Key performance Indicator (KPI)</th></tr>
<tr><td>• Review and upgrade design of hydropower plants to improve resilience.</td><td>• Review design and increase capacity of hydropower dams in the context of climate change.
• Integrate climate risk into new hydropower designing (provision for future dam rise and increase flood risks
• Assess the feasibility of pump storage mechanism.
• Identify hydropower operating strategies under modified climate condition.</td><td>• Development of pump storage mechanisms and reservoir type hydropower plants.
• Cascaded water storage schemes both upstream and downstream of existing hydropower plants.
• Assess high altitude reservoirs.
• Upgrade hydropower system (increasing the capacity of spillway, increasing freeboard, resilient turbines).</td><td>• Number of new and transformed hydropower plants/infrastructure which are resilient.
• Number of reports produced annually on assessment of feasibility of climate resilient technologies.</td></tr>
</table>

• Incorporate resilience and watershed management plans while designing hydropower plants.	• Implementation of watershed management plans including check dams at appropriate locations (sedimentation control facilities). • Develop inundation mapping of all the vulnerable communities of hydropower dams based on the flood discharge released from dams. (Ensure that hydropower dams are not a source of disaster downstream).	• Monitoring and evaluation of watershed management plans.	• Number of watershed management activities with areas. • Number of inundation maps produced.
• Assess and incorporate climate resilient energy technologies and power system infrastructure.	• Assess feasibility of climate resilient energy technologies such as solar, wind, bio-gas, hydrogen fuel cells.	• Improve research and development studies on hydropower plants. • Implement climate resilient energy technologies.	• Annual record of decrease in sedimentation issues at hydropower plants. • Maintain energy security (Power generation record).
• Flood forecasting and monitoring to be improved. • Build preparedness through adoption of early warning systems, forecast models, and data management.	• High confidence flow forecast modelling and planning for a more efficient hydropower system and water budgeting. • Ensure timely and effective early warnings issued to the downstream communities. • Develop contingency plans and install Early Warning Systems with real time monitoring.	• Ensure timely and effective early warnings issued to the downstream communities. • Upgrade hydropower system (increasing the capacity of spillway, increasing freeboard, resilient turbines).	• Number of early warning system with real time monitoring instituted. • Number of contingency plans prepared and implemented.

Implementation:

The MoEA is the responsible ministry for implementation in collaboration with the Druk Green Power Corporation and Bhutan Power Corporation for most of these actions. Monitoring and forecasting systems and hydrology and climate data needed for review should come from NCHM, research supported by RUB.

As part of its corporate responsibility the existing and new hydropower facilities should be integrated into watershed management plans which needs coordination with MoAF. LGs need to be involved to act upon early warning systems installed.

How to avoid potential barriers for implementation?

Maladaptation (facilities not well adapted to climate), mal-investments (too high resulting electricity costs) and negative environmental impacts (e.g. issues due to pumping and increased storage needs) need to be avoided by proper feasibility and environmental impact assessment. In such studies, long term viability under both energy demand and climate change scenarios should receive sufficient attention.

7.2.7 Enabling actions

To enable sustainable implementation, actions are needed that improve informed decision making through further research and monitoring, that build capacity at all levels for implementation and raises awareness and support among communities.

Training and capacity building of planners and operators. **Awareness raising** of citizens to make sure that they are capable to respond in a proper way in case of a disaster. For water supply, WUAs could be further capacitated as the have a key role and are responsible for regular monitoring and maintenance of water sources, the appointment of water caretaker and contribution of a monthly budget.

Research & capacity building among local experts. To increase the confidence in future analysis on impact and adaptation, additional studies need to be done for example on the contribution of groundwater and the cryosphere to seasonal water availability under different climate scenarios, on more detailed exposure scenarios (e.g. on future land use and water demand) and at potential and feasibility of specific adaptation strategies such as rain water harvesting, land use changes, nature-based solutions and possible multi-purpose reservoirs. Capacity building among local experts from NCHM, policy makers, water, ecosystem and DR managers should go hand in hand with new knowledge acquired. A start has been made to learn to work with the climate and hydrology and impact data acquired during the current project. Follow up capacity building can be defined that supports a more structural use of the models and data by the institutions in Bhutan.

Monitoring is a key activity, that should have a central role in the NAP as it is the most important way to get a better understanding on climate, hydrology and impacts on the water sector. Monitoring can also support following progress of implementation of actions and their effects. In the end, it is a necessary means to increase confidence in future analyses.

It is recommended to choose a comprehensive, yet feasible, set of indicators that capture most important aspects of the causes (climate and other), interventions (in line with NAP) and impacts (hydrology, sectoral). Indicators could be similar to the ones used in the Bhutan water security index (BWSI) system as earlier applied in Bhutan (NECS, 2016). A follow up definition study for a monitoring framework is recommend as a short term low regret action. Based upon the findings in the current study, an improved monitoring system should further include: watershed and source quality and quantity monitoring, improve hazard reporting (incl. consequences) and improve monitoring of exposure and vulnerability (e.g. of critical infrastructures).

Below the full list of proposed enabling actions is presented. Note that many of the actions have also been mentioned in paragraph 7.2.1-7.2.6.

Enabling actions			
Strategic Action	**Short term action (0-5 years)**	**Medium term (5-15 years)**	**Key performance Indicator (KPI)**
• Review and strengthen WUAs.	• Implementation of WUA guidelines. • Training on IWRM, formation of WUA and legalization, (management, accounting, etc.).	• Monitoring and evaluation of WUAs.	• Number of functional WUAs that are formally registered. • Number of trainings for WUAs conducted.
• Groundwater assessment conducted and used for water supply where feasible.	• Systematic study of groundwater availability, use, risks and potential.	• Initiate use of groundwater or discontinue based on findings from the study.	• Number of groundwater assessment studies carried out.
• Capacity needs assessment and building capacity.	• Improve collaboration and cooperation with relevant institutions. • Carry out capacity needs assessment. • Conduct capacity building.	• Promote research and development practices. • Translate research findings to assist decision making.	• Number of publications. • Number of trainings conducted. • Research findings accommodated into decision making.
• Assessment and review of Acts, Regulations and Policies on Water.	• Evaluation and reassessment of policies and plans on water and water management. • Update Acts and Regulations.	• Updated Strategic plans. • Water roadmap developed.	• Number of Policies, Acts and Regulations reviewed and assessed. • Water roadmap developed.
• Proper monitoring and evaluation systems with budgets.	• Set up an M&E framework for the water sector along the lines of the Bhutan Water Security Index (BWSI).	• Implement the M&E framework along with BWSI.	• Timely reporting of BWSI on an annual basis. • Annual report on BWSI published.
• Assessment and revival of drying springs.	• Systematic study of spring sheds.	• Revival of drying springs.	• Number of studies carried out and springs revived.
• Conduct hydrographic separation (isotope) studies on river basins. • Snow cover extent and glacial mass balance studies.	• Enhance the use of satellite imagery and GIS processing. • Define the area of studies. • Sample collection, testing and analysis and reporting.	• Comprehensive information on snow and glaciers contribution to river systems. • Understanding the impact on the river systems in light of melting glaciers.	• Number of studies carried out. • Number of information shared.

• Review and revise the existing curriculum. • Update the curriculum.	• Review the existing curriculum. • Conduct job market study.	• Courses on water engineering skills developed and implemented at local training institutes/colleges.	• Inclusion and adaptation of units and topics on water. • Trends on enrolment of students in water curriculum.
• Geomorphological studies	• Choose major river systems. • Ascertain the river flow system and changing characteristics of sediment load. • Design and propose adaptation options.	• Delineate and limit the area of development. • Implement the proposed adaptation options.	• Number of geo-morphological studies carried out.
• Capacity development on climate resilient water infrastructures. • Identification and mapping of perennial slope failures (including debris flow site).	• Capacity development on climate resilient water infrastructures. • Training onsite inspection, Aerial survey using Drones and mapping using GIS.	• Capacity development on climate resilient water infrastructures.	• Number of officials trained on climate resilient infrastructure design and construction. • Numbers of officials trained on aerial survey using drones.
• Capacity development to generate forecast information at sub-basin level • Information is disseminated on timely basis to all sectors/communities.	• Capacity development to generate forecast information at sub-basin level. • Capacity to generate water availability on temporal (Daily to seasonal) and spatial (from river basin to sub-catchment) scale.	• Information is disseminated on timely basis to all sectors/communities. • A robust real to near real time information dissemination system with customizable to requirements of different sectors.	• Number of officials trained to generate forecast information at sub-basin level. • A real to near real time weather and water availability information dissemination system in place.
• Capacity development of flood and storm water management.	• Training on assessment and drafting of flood and storm water management plans.		• Number of officials trained in assessment and drafting of flood and storm water management.
• Build capacity on development of Road Asset Management System (RAMS).	• GIS training and analysis.	• GIS training and analysis.	• Number of officials trained on GIS.

• Promote research and development (R&D) in irrigation water management. • Conduct studies on hydrological models to generate information to characterize and manage sub-catchment areas.	• Promote R&D in irrigation water management • Conduct studies on hydrological models to generate information to characterize and manage sub-catchment areas management. • Detailed study on irrigation water shortages.	• Engage academic institutions to conduct research and studies on varying issues and enhance climate-smart irrigation schemes. • Conduct research on crop water requirement- can be enabling. • Promote Research and Development practices for irrigation under the local context.	• Number of studies completed. • Number of research conducted in water management. • Number of initiatives to improve irrigation systems across the country. • Number of irrigation schemes with protection works (check dams). • Increase in command areas with improved/ new irrigation schemes. • Record of assimilation of the research findings.
• Water Quality and Water Treatment Studies	• Water Quality and Water Treatment Studies		• Number of reports on WQM and water treatment published.

7.2.8 Recommendations for research pilots

As mentioned in previous section research needs were identified during the NAP water study. Here suggestions are given for three potential research pilots that should fill these gaps.

On droughts and water supply

A better understanding of the root causes for drying of current sources is needed. For this purpose, dedicated local studies are suggested in which the relative contribution of hydrological processes, land- and water use (and further increase in demand) to the drying of sources and springs are to be assessed. These studies should include detailed monitoring and modelling for a limited number of representative sides in order to be able to upscale conclusions to other areas in Bhutan.
In addition, options for using new sources can be explored and mapped – i.e. alpine lakes, ground water resources in promising areas and the potential and feasibility of specific adaptation strategies proposed in the NAP such as rain water harvesting, land use changes, nature-based solutions and possible multi-purpose reservoirs be explored and assessed as a basis for further planning.

On disaster risk management

Potential flooding and landslide hotspots could be further assessed in more detail than has been done in the current study. Besides better understanding and localization of risks such a study should deliver practical and uniform methodologies for mapping flood risk and landslide susceptibility.

On monitoring

A follow up *definition study for a monitoring framework* is recommend as a short-term low regret action. Based upon the findings in the current study, an improved monitoring system should further include: watershed and source quality and quantity monitoring, improve hazard reporting (including. consequences) and improve monitoring of exposure and vulnerability (e.g. of critical infrastructures). Part of the study could be a pilot on how the improved monitoring could inform an adapted BWSI system.

7.3 Prioritizing regions for adaptation

There are three sources of information produced in this study that could be used to prioritize regions (dzongkhags, gewogs, thromdes) for where to implement adaptation actions first. These rules could be applied in this order:

- First the bottom up analysis should be used. There should be issues reported. Without it there is no clear urgency. The more serious the issues reported, the higher the priority to implement measures. The way the bottom-up analysis was set up was to identify the priority gewogs per dzongkhag for different issues. This makes it difficult to prioritize gewogs across different dzongkhags.

- Secondly areas with a large exposure (and especially if there is also an increase in exposure and water demand to be expected in the future) could be prioritized. If settlements or economic activities are increasing, action for water supply and disaster risk management are required. This means that investments are needed in these areas anyway and that these investments should be done in a climate resilient manner and preferably add robustness to the system. From available figures on future water demand and population statistics (see section) some priority rules can be derived such as:

    - Focus on larger and growing irrigated areas for measures that help agriculture to cope with dry spells.
    - Focus on larger and growing population centres with new economic activities (tourism, industry), for riverine and pluvial flood risks and for drinking water supply.
    - In addition, focus on more remote vulnerable communities for drinking water supply and pluvial flood risks and landslides.

- Lastly, areas could be prioritized based on the top down analysis showing where the climate change impacts are expected to be large in the future. Figure 7.2 and Figure 7.3 show which five dzongkhags and river locations show the highest increase in dry spells, intense rainfall events or peak and low flows.

Based on these rules, areas could be prioritized. Without being conclusive and exhaustive a few examples can be given:

- Thimphu thromde could be a priority area for adaptation to increasing flood risks since it is a bigger populated area where exposure is expected to increase, issues with flooding have been reported in the past and the river peak flow increase under climate change is expected to be considerable.

- Lhuentse dzongkhag could be a priority area for adaptation of agriculture to increasing dry spells since it has a fairly large irrigated area that is expected to increase. Issues in the past were reported. It is both in the top 5 of districts with largest increase in dry spells in GW recharge and river flow.

- Smaller communities and maybe some ‘industries’ in Dagana and WangduePhodrang could be priority locations for improved drinking water supply as water demand is expected to increase substantially and issues with drying sources are being reported. They also come up as priorities from the top down assessment.

Note that in all areas where adaptation actions are implemented, the most vulnerable groups should be included and should benefit the most.

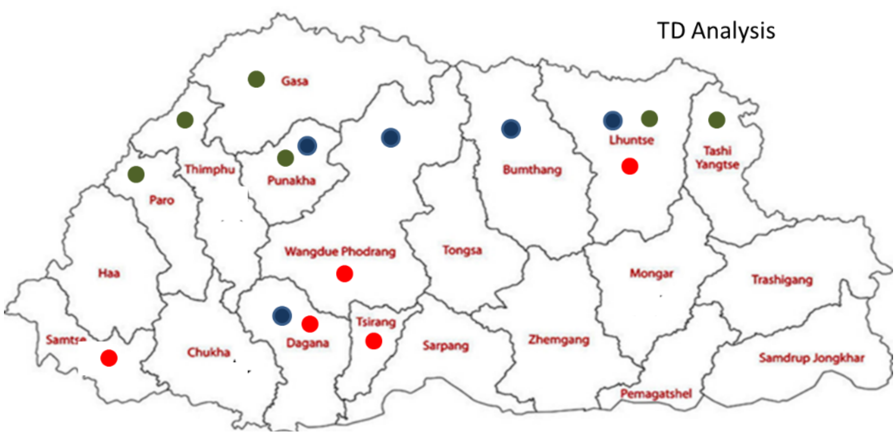


Figure 7.2 Dzongkhags with highest ***rainfall change*** *(blue) based on top down analysis:1. Bumthang,2. Punakha, 3. Dagana, 4. Lhuentse, 5. Wangduephodrang. Dzongkhags with highest* ***drought*** *change (red): 1. Lhuentse, 2. Dagana, 3. Samtse, 4. Tsirang, 5. Wangduephodrang. Dzongkhags with highest* ***landslide change*** *(green)**:** 1. Gasa, 2. Paro, 3. Thimphu, 4. Punakha, 5. Lhuntse, 6. Trashiyangtse*

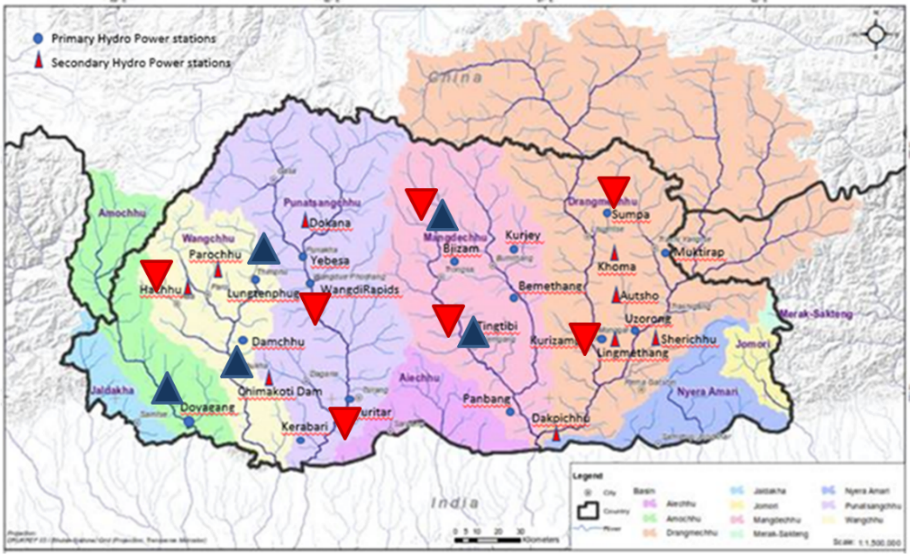


*Figure 7.3 Stations with maximum change in **low flow** periods (red) based on top down analysis: 1. Sumpa / Kurizampa on Kurichhu, 2. Tingtibi/Bjizam on Mangdechhu, 3. Toritar/ Wangdue rapids on Punatsangchhu, 4. Sumpa on Khomachhu, 5. Haa on Haachhu. Stations with maximum change in **peak flow** (blue): 1. Damchoe/ Chimakoti on WangChhu, 2. Tingtibi on Mangdechhu, 3. Lungtenphu on Thimphu Chhu, 4. AmoChhu, 5. Bjizam on MangdeChhu.*

8 Conclusions

The NAP water study has delivered an overview of main water related risks under a changing climate.

- Risks of local dry spells at gewog level are expected to increase under climate change for large parts in the country enhancing the drying of sources that are already clearly visible to date. This will increase the challenge to keep up the speed in supplying the growing demand for drinking, industrial and irrigation water.

- Increase of frequency and duration of low flows in main rivers is assessed as an uncertain risk for Bhutan, as projections of periods of low flows are both showing decrease and increases in dry spells depending on global emission scenarios and time horizon. For RCP4.5 (current emission trajectory) periods of low flows for the short term are rather decreasing than increasing. For the long term the opposite is true. However, given the large uncertainty in the current analysis, it is important to continue monitoring the trend in low flows and improve the understanding of the hydrological processes involved, especially for those streams that are key for water supply.

- The risks of increased floods, both pluvial and riverine are assessed as rather high. There are already many serious reports on these issues and at the same time the projected changes especially for the second half of the century seem substantial.

- Projections in 7-day consecutive rainfall events potentially triggering landslides, point towards a clear increase especially for the longer term. There are already many reports on serious impacts of landslides as well. For a higher confidence assessment though, all contributing factor to landslides including local geomorphological (slope, soil and land use characteristics) conditions should be combined in one analysis.

- Melting of glaciers is already occurring under the current warming and will continue to occur in the future under clearly increasing temperature trends that are stronger at higher altitudes. Historically, GLOFs are a known phenomenon in glacial areas in Bhutan. Most risky sites have been identified and are being monitored. Under projected temperature trends the risks on GLOF events will increase. Also projected extreme precipitation increases may add to increasing risks.

Though the above-mentioned issues are happening throughout the whole of Bhutan, it is evident that not all dzongkhags and gewogs will experience them with the same level of impact. Therefore, the study has also presented results per dzongkhag and gewogs, illustrating the local issues and future projections and its uncertainty.

Based on this assessment, the main direction for adaptation is a flexible strategy that starts with low regret actions that improve the resilience and robustness of the water sector in Bhutan over time. Seven strategic directions for adaptation (and underlying actions for the short and long term) are recommend for inclusion in the NAP: 1) Strengthening ecosystems; 2) Improved flood risk management and planning; 3) Protection of critical infrastructure and settlements; 4) Implementation of resilient infrastructures; 5) Enhance Early warning, response and recovery capacity at local level; 6) Increase robustness of sectoral water supply and demand for drinking and irrigation water; and 7) Increase the climate resilience of the Hydropower sector.

To prepare for further implementation, responsible institutions should prioritize locations for investments, identify funding arrangements and build capacity and issue follow up research that can support better targeted investments.

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A Supplementary information

A.1 List and map of primary and secondary hydrological stations

Figure A.1 List of primary and secondary stations.

Station Name	River Basin	Dzongkhag	Latitude(N)	Longitude(E)	Altitude(m)	
Doyagang on Ammochhu	Amochhu	Chhukha	26:53:12	89:20:06	354.6	Principal stations
Lungtenphug on Wangchhu	Wangchhu	Thimphu	27:26:48	89:39:40	2260	
Damchhu on Wangchhu	Wangchhu	Chhukha	27:14:26	89:31:38	1990	
Bongde on Pachhu	Wangchhu	Paro	27:23:12	89:26:03	2220	
Yebesa on Mochhu	Punatsangchhu	Punakha	27:37:59	89:49:03	1230	
Wangdirapids on Phochhu + Mochhu	Punatsangchhu	Wangdi	27:27:45	89:54:11	1190	
Turitar on Sankosh	Punatsangchhu	Tsirang	27:00:21	90:04:36	320	
Kerabari on Sankosh	Punatsangchhu	Dagana	26:46:06	89:55:41	150	
Bjizam on Mangdichhu	Manas	Trongsa	27:31:28	90:27:17	1848	
Tingtibi on Mangdiechhu (Downstream)	Manas	Zhemgang	27:08:50	90:41:59	530	
Kurjey on Chamkharchhu	Manas	Bumthang	27:35:13	90:44:13	2600	
Sumpa on Kurichhu	Manas	Lhuntse	27:39:50	91:12:54	1170	
Bemethang on Chamkharchhu (Singkar)	Manas	Zhemgang	27:16:50	90:56:15	1300	
Kurizampa on Kurichhu	Manas	Mongar	27:16:26	91:11:37	519	
Muktirap on Kholong Chhu	Manas	Trashi Yangtse	27:35:16	91:29:40	1640	
Uzorong on Gongri	Manas	Tashigang	27:15:38	91:24:30	554	
Pangbang on Dangme chhu	Manas	Zhemgang	26:50:30	90:50:30	136	
Hachhu	Wang Chhu	Haa	27:22:16	89:17:08	2700	Secondary Stations
Samdingkha on Phochhu	Punatasangchhu	Punakha	27:38:28	89:51:50	1220	
Tingtibi on Dakpichhu	Manas	Zhemgang	26:50:30	90:57:30	580	
Nikachhu Dam site	Chendebji					
Sumpa on Khomachhu	Manas	Lhuntse	27:39:34	91:12:46	1145	
Autsho on Kurichhu	Manas	Lhuntse	27:25:59	91:10:38	814	
Sherichhu on Sherichhu	Manas	Mongar	27:15:15	91:24:36	542	
Chimakoti Dam on Wangchhu	Wangchhu	Chhukha	27:06:34	89:32:02	1820	

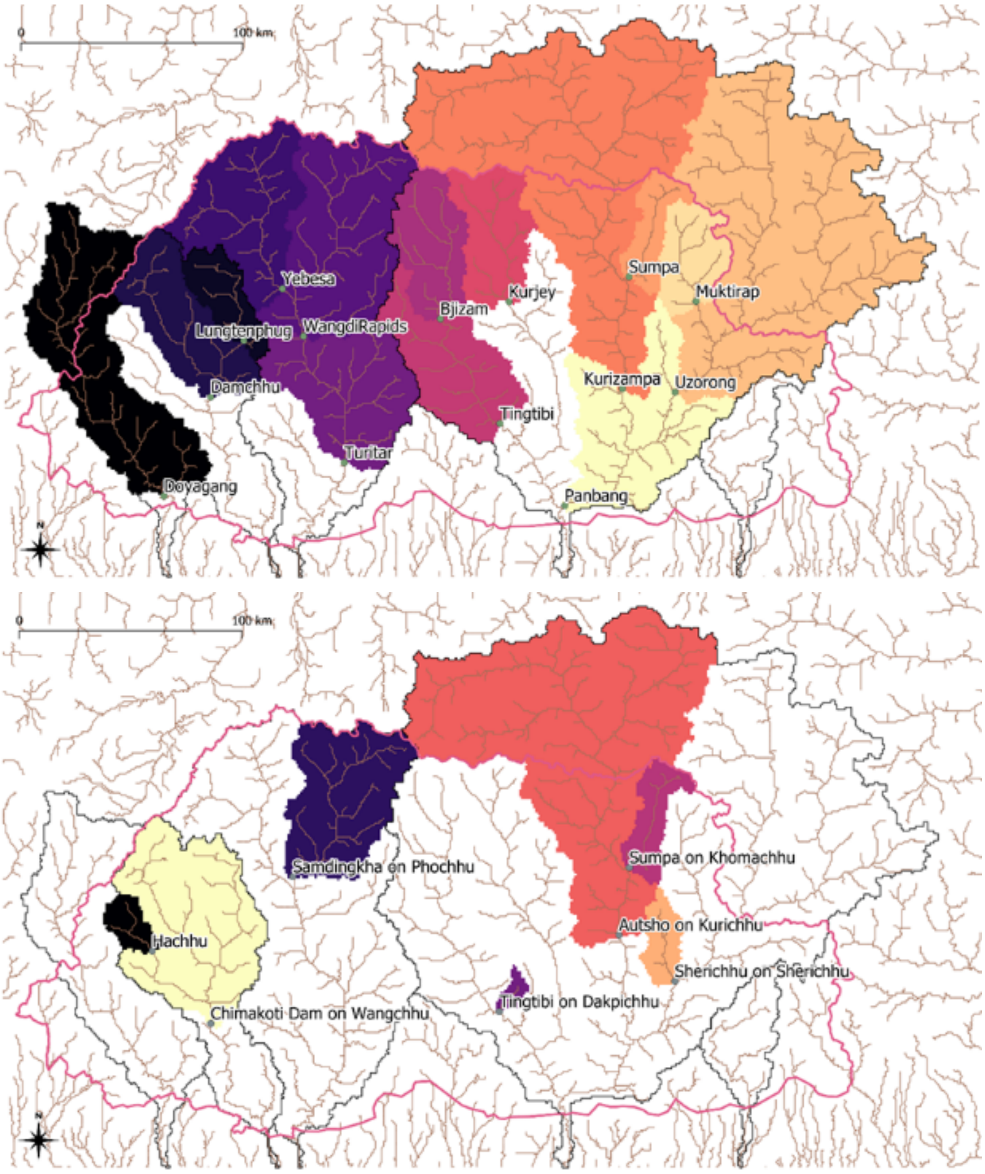


Figure A.2 Location of hydrological stations and corresponding sub-catchments.

A.2 List of gewog names and id numbers per dzongkhag

Gewog name	Dzongkhag name	Id
Chhoekhor	Bumthang	81
Ura	Bumthang	82
Chhumig	Bumthang	83
Tang	Bumthang	128
Doongna	Chhukha	34
Maedtabkha	Chhukha	35
Loggchina	Chhukha	36
Phuentshogling	Chhukha	37

Geling	Chhukha	38
Samphelling	Chhukha	39
Darla	Chhukha	40
Bongo	Chhukha	41
Getana	Chhukha	42
Bjagchhog	Chhukha	43
Chapchha	Chhukha	44
Tseza	Dagana	89
Largyab	Dagana	90
Khebisa	Dagana	91
Tsangkha	Dagana	92
Drukjeygang	Dagana	93
Trashiding	Dagana	94
Tsenda-Gang	Dagana	95
Nichula	Dagana	96
Karmaling	Dagana	97
Lhamoi Dzingkha	Dagana	98
Karna	Dagana	99
Gesarling	Dagana	100
Dorona	Dagana	101
Gozhi	Dagana	102
Laya	Gasa	51
Lunana	Gasa	52
Khamaed	Gasa	53
Khatoed	Gasa	54
Gakiling	Haa	16
Sangbay	Haa	17
Bji	Haa	18
Samar	Haa	19
Uesu	Haa	20
Kar-tshog	Haa	21
Kurtoed	Lhuentse	127
Gangzur	Lhuentse	129
Khoma	Lhuentse	130

Minjey	Lhuentse	131
Maenbi	Lhuentse	132
Maedtsho	Lhuentse	133
Jarey	Lhuentse	134
Tsaenkhar	Lhuentse	135
Gongdue	Monggar	174
Jurmed	Monggar	175
Silambi	Monggar	176
Saling	Monggar	177
Tsamang	Monggar	178
Tsakaling	Monggar	179
Shermuhoong	Monggar	180
Chhaling	Monggar	181
Monggar	Monggar	182
Drepoong	Monggar	183
Ngatshang	Monggar	184
Balam	Monggar	185
Dramedtse	Monggar	186
Na-Rang	Monggar	187
Chagsakhar	Monggar	188
Kengkhar	Monggar	189
Thang-Rong	Monggar	190
Tsento	Paro	22
Doteng	Paro	25
Dopshar-ri	Paro	26
Hoongrel	Paro	27
Wangchang	Paro	28
Lamgong	Paro	29
Loong-nyi	Paro	30
Sharpa	Paro	31
Dokar	Paro	32
Nagya	Paro	33
Norboogang	Pema Gatshel	152
Chhoekhorling	Pema Gatshel	153

Dechhenling	Pema Gatshel	154
Dungmaed	Pema Gatshel	155
Chhimoong	Pema Gatshel	156
Yurung	Pema Gatshel	157
Chongshing	Pema Gatshel	158
Khar	Pema Gatshel	159
Shumar	Pema Gatshel	160
Zobel	Pema Gatshel	161
Nanong	Pema Gatshel	162
Goenshari	Punakha	55
Kabisa	Punakha	56
Chhubu	Punakha	57
Toedwang	Punakha	58
Shelnga-Bjemi	Punakha	59
Dzomi	Punakha	60
Lingmukha	Punakha	61
Barp	Punakha	62
Guma	Punakha	63
Talog	Punakha	64
Toepaisa	Punakha	65
Langchenphu	Samdrup Jongkhar	163
Serthig	Samdrup Jongkhar	164
Samrang	Samdrup Jongkhar	165
Pemathang	Samdrup Jongkhar	166
Phuntsthogthang	Samdrup Jongkhar	167
Dewathang	Samdrup Jongkhar	168
Jangchhubling	Samdrup Jongkhar	169
Gomdar	Samdrup Jongkhar	170
Wangphu	Samdrup Jongkhar	171
Martshala	Samdrup Jongkhar	172
Lauri	Samdrup Jongkhar	173
Norgaygang	Samtse	1
Tendruk	Samtse	2
Pemaling	Samtse	3

Trashichhoeling	Samtse	4
Namgyelchhoeling	Samtse	5
Sang-Ngag-Chhoeling	Samtse	6
Yoeseltse	Samtse	7
Ugyentse	Samtse	8
Norboogang	Samtse	9
Samtse	Samtse	10
Phuentshogpelri	Samtse	11
Tading	Samtse	12
Dophuchen	Samtse	13
Doomtoed	Samtse	14
Duenchhukha	Samtse	15
Senggey	Sarpang	103
Shompangkha	Sarpang	104
Dekiling	Sarpang	105
Samtenling	Sarpang	106
Gelegphu	Sarpang	107
Chhuzanggang	Sarpang	108
Serzhong	Sarpang	109
Umling	Sarpang	110
Tareythang	Sarpang	111
Jigmichhoeling	Sarpang	112
Chhudzom	Sarpang	113
Gakiling	Sarpang	114
Soe	Thimphu	23
Lingzhi	Thimphu	24
Dakarla	Thimphu	45
Ge-nyen	Thimphu	46
Maedwang	Thimphu	47
Chang	Thimphu	48
Kawang	Thimphu	49
Naro	Thimphu	50
Khamdang	Trashi Yangtse	136
Boomdeling	Trashi Yangtse	137

Yangtse	Trashi Yangtse	138
Tongmajangsa	Trashi Yangtse	139
Jamkhar	Trashi Yangtse	140
Ramjar	Trashi Yangtse	141
Toedtsho	Trashi Yangtse	142
Yalang	Trashi Yangtse	143
Yangnyer	Trashigang	191
Sagteng	Trashigang	192
Phongmed	Trashigang	193
Radhi	Trashigang	194
Bidoong	Trashigang	195
Bartsham	Trashigang	196
Samkhar	Trashigang	197
Shongphu	Trashigang	198
Kanglung	Trashigang	199
Udzorong	Trashigang	200
Khaling	Trashigang	201
Lumang	Trashigang	202
Thrimshing	Trashigang	203
Kangpar	Trashigang	204
Merak	Trashigang	205
Nubi	Trongsa	84
Draagteng	Trongsa	85
Tangsibji	Trongsa	86
Langthil	Trongsa	87
Korphu	Trongsa	88
Patshaling	Tsirang	115
Barshong	Tsirang	116
Mendrelgang	Tsirang	117
Rangthangling	Tsirang	118
Tsholingkhar	Tsirang	119
Gosarling	Tsirang	120
Shemjong	Tsirang	121
Tsirang Toed	Tsirang	122

Sergithang	Tsirang	123
Pungtenchhu	Tsirang	124
Doonglagang	Tsirang	125
Kilkorthang	Tsirang	126
Kazhi	Wangdue Phodrang	66
Saephu	Wangdue Phodrang	67
Dangchhu	Wangdue Phodrang	68
Nyishog	Wangdue Phodrang	69
Bjednag	Wangdue Phodrang	70
Gangteng	Wangdue Phodrang	71
Phobji	Wangdue Phodrang	72
Athang	Wangdue Phodrang	73
Darkar	Wangdue Phodrang	74
Gase Tshowogm	Wangdue Phodrang	75
Gase Tshogongm	Wangdue Phodrang	76
Nahi	Wangdue Phodrang	77
Ruebisa	Wangdue Phodrang	78
Thedtsho	Wangdue Phodrang	79
Phangyuel	Wangdue Phodrang	80
Pangkhar	Zhemgang	144
Trong	Zhemgang	145
Nangkor	Zhemgang	146
Shingkhar	Zhemgang	147
Bardo	Zhemgang	148
Gozhing	Zhemgang	149
Ngangla	Zhemgang	150
Bjoka	Zhemgang	151

A.3 Example questionnaire used in bottom-up consultations.

Similar questions were used for irrigation, hydropower and disaster risk management.

List of questions used for the focussed group discussions to identify drinking water issues
1. Which are the areas in the gewog with the drinking water issues? (Please specify the areas)
2. What are the main issues related to drinking water in those areas?
3. What are the main causes of the above issues?
4. When did these problems start?
5. How did the community respond to the issues so far?
6. What are some on-going activities and measures in the gewog to resolve those issues?
7. What can be done in the gewog to address these issues in future?
8. Are there any specific vulnerable groups of people in your gewog? Who are they and why?
9. How will they be engaged in the future plans?
10. Any suggestions for improvement of drinking water in your gewog?

B Additional National-level results

B.1 Dry spell and water supply risk for RCP8.5

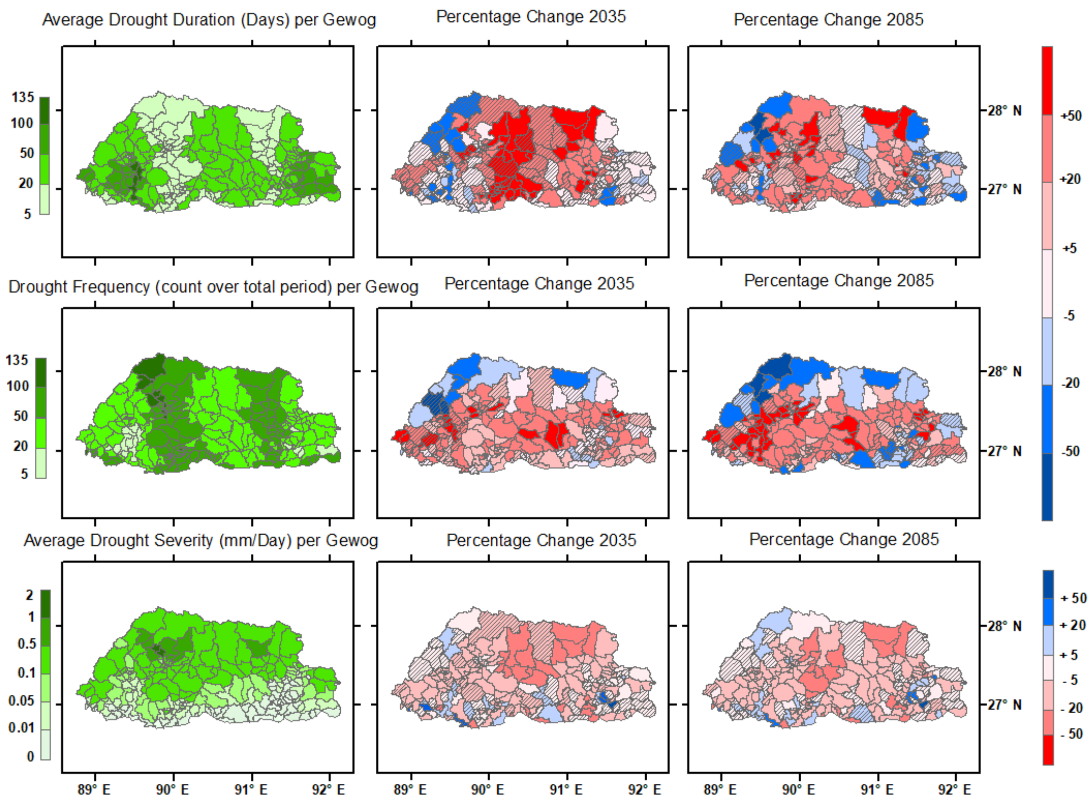
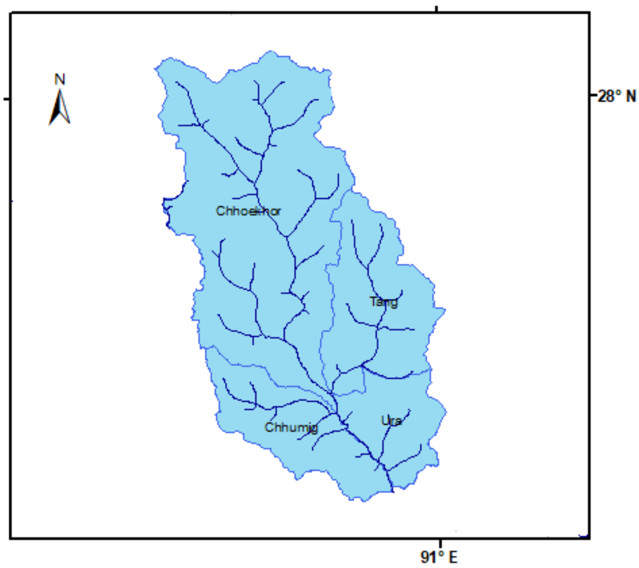


Figure B.1 Dry spells (defined here as groundwater recharge < 10 percentile) duration, frequency and intensity under historic climate (left column) and future climate (2035 and 2085) for RCP8.5. Hatched areas indicate gewogs where no more than 3 GCMs project the same direction of change.

C Dzongkhag-level risk characterization

In the following paragraphs, tables of changes in dry spell duration and frequency and peak rainfall return periods (1/10 and 1/30) are presented. In the accompanying text, these changes are qualified using the following guidelines for peak rainfall. If the change factor is small (1 or 2) no large changes in extreme events are expected, medium (3-10), is a serious increase, or large (>10). If the change factor in 1/30 is larger than 1/10 rainfall event this indicates that rainfall becomes more erratic.

C.1 Bumthang



Administrative map Bumthang

Dzonkhag: Bumthang				Dry spells in ground water recharge													
Population 2017:		17820		River basin:		Mangdechhu						DJF precipitation trend			Non- Significant		
Population change 2042 (%):		9										(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
81	Chhoekhor	1	1	39	38	-20	5	L	29	3	L	48	8	L	-3	-16	M
83	Chhumig	3	3	38	37	-20	35	M	29	46	M	38	41	M	-17	41	M
128	Tang	2	2	37	40	-13	2	M	29	2	L	44	2	M	-11	2	M
Other gewogs (not ranked)																	
82	Ura	4	4	25	54	0	26	L	13	26	M	56	28	M	16	28	M

Table C.1 shows the combination of top-down (TD) and bottom-up (BU) results for Bumthang dzongkhag. Left panel shows ranked gewogs according to water related issues for drinking water and irrigation water based on bottom-up consultation. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085 for RCP4.5 and 8.5 respectively.

Dzonkhag: Bumthang			Extreme Rainfall Events													
Population 2017:			River basin:		Mangdechhu						Annual precipitation trend			Non - significant		
Population change 2042 (%):											(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
81	Chhoekhor	1	5	1	2	3	H	4	7	H	2	5	H	10	15	H
83	Chhumig	2	5	1	2	5	H	5	10	H	3	8	H	9	28	H
128	Tang	3	6	1	2	5	H	4	12	H	2	8	H	9	23	H
Other gewogs (not ranked)																
82	Ura		6	1	2	5	H	4	13	H	3	9	H	8	31	H

Table C.2 shows the combination of top-down (TD) and bottom-up (BU) results for Bumthang dzongkhag for water related disasters and extreme precipitation analysis. Left panel shows gewogs ranked based on reported water related disaster as per bottom-up consultation. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during the BU consultation?

From the bottom-up consultation, 4 gewogs were studied and ranked based on the issues reported on drinking water and irrigation water. The major source of water for drinking and irrigation are streams, springs and ponds. The gewog faces the problem of insufficient water, poor water quality, open channels leading to water loss through seepage and sources located away from the settlement. The main reasons for such problem are due to the lack of alternative sources, deforestation due to the increase in settlement in the community and drying up of the water sources. Moreover, it was also reported that the issues are because of the improper management of the water and watersheds.

An assessment on water-related disaster for Bumthang shows that Chhoekhor gewog, located in the low-lying area is most vulnerable to floods due to the increase in the glacial melts which can lead to the bursting of lakes. Through the BU consultation, landslides and soil erosion are also an issue that prevails in the community where the private land owner of Gaytsa and Bhim village of Changphel are identified as the vulnerable groups based on the exposure to water related hazards. Due to the change in climate, the rainfall pattern becomes erratic and sometimes is incessant. Such changes cause flash floods, river floods and landslides destroying the cultivable land of the people in the community. Pangkhar, Ura Dozhi chiwog, Khangrab, Kizom and Dazur are the identified vulnerable chiwogs.

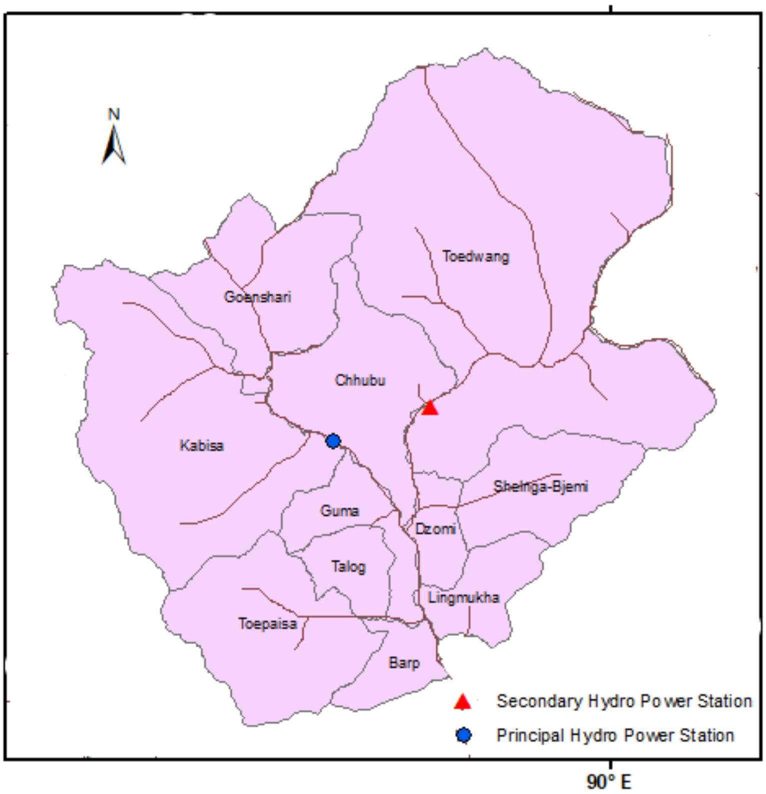
What are the TD results indicating?

The top-down result shows that the change factor for the 1/10 precipitation for all the gewogs in Bumthang dzongkhag is small for both the RCPs in 2035. The gewogs will experience no large changes in precipitation pattern in 1/10 but in 1/30 years the gewogs will experience larger changes, indicating a more erratic rainfall pattern in future. In 2085, both the RCPs show that the gewogs will experience serious increase in the precipitation rate in 1/10 years and 1/30 years. Based on the TD, for both RCP4.5 and RCP8.5, the dry spell duration will decrease for all gewogs for both periods except for Ura gewog. Chhumig gewog has highest increase in dry spell frequency of 35% both for 2035 and 2085. Ura gewog has not been ranked as having an issue for both drinking and irrigation, but the drought/dry spell for Ura is more than Chhoekhor and Tang based on the TD analysis.

Conclusion

The main source of water for Bumthang dzongkhag is stream. The water availability in the local area is going to decrease but the river source is likely to increase due to the melting of ice and snow due to the rise in temperature as projected. Moreover, it also shows that the dry spell duration will decrease for all the gewogs for both the periods except for Ura gewog. This is because the other three gewogs are located near the larger rivers. In case of water related disaster, the other three gewogs are vulnerable due to their location near larger rivers. As per the projection the annual precipitation trend will be high for all the gewogs in the future.

C.2 Punakha



Administrative map of Punakha

Dzonkhag:Punakha				Dry spells in ground water recharge													
Population 2017:		28740		River basin:		Punatsangchhu						DJF precipitation trend			Significant		
Population change 2042 (%):		35										(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
61	Lingmukha	2	2	84	17	0	12	M	-2	29	M	27	22	M	45	3	M
62	Barp	3		46	30	-10	13	M	-2	53	H	-6	35	M	3	47	M
63	Guma	1	1	24	55	13	2	M	-8	25	M	15	46	M	9	43	M
57	Chhubu		3	22	56	41	-14	M	35	-7	M	24	16	H	32	21	M
Other gewogs (not ranked)																	
58	Toedwang			20	61	20	3	L	-3	26	M	19	22	M	21	22	M
59	Shelnga-Bjemi			30	46	-13	4	M	1	22	M	32	37	M	30	51	H
60	Dzomi			33	42	-7	31	H	-10	57	M	2	21	M	-2	45	M
55	Goenshari			17	68	19	-12	M	13	7	H	32	21	H	52	24	H
56	Kabisa			40	34	-11	6	L	-21	38	H	19	19	H	35	41	H
64	Talog			73	20	-6	5	M	-6	20	H	19	34	H	40	68	H
65	Toepaisa			22	57	12	5	M	-2	12	M	74	59	M	15	102	M

Table C.3 shows the top-down and bottom-up results. Left penal shows ranked gewog based on the reported water related issues such as drinking water and irrigation water. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under the climate change and associated agreement between GCM projection for 2035 and 2085. In addition, information on population and change, which gewog (IDS) belongs to which river basin and on the historic precipitation trends are given in the table header.

Table C.4 shows the combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disaster. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projection for 2035 and 2085. In addition, information on population and change, which gewog (IDS) belongs to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Punakha			Extreme Rainfall Events													
Population 2017:		28740	River basin:		Punatsangchhu						Annual precipitation trend			Significant		
Population change 2042		35									(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
60	Dzomi	3	6	1	2	5	M	5	15	H	3	8	H	8	28	H
62	Barp	1	5	2	2	3	M	4	7	H	3	4	M	7	10	H
63	Guma	2	2	2	3	3	M	8	5	H	5	3	H	11	10	H
Other gewogs (not ranked)																
55	Goenshari		5	1	2	6	H	4	13	H	5	9	H	11	20	H
56	Kabisa		5	2	2	4	M	5	8	H	4	5	H	8	13	H
57	Chhubu		5	2	2	4	H	4	6	H	3	5	H	8	11	H
58	Toedwang		2	1	4	3	M	13	7	H	7	7	H	23	20	H
59	Shelnga-Bjemi		5	2	2	2	M	5	6	H	3	8	M	9	12	H
61	Lingmukha		5	1	2	4	M	6	14	H	3	7	H	8	24	H
64	Talog		3	2	5	3	M	12	5	H	7	3	M	17	10	H
65	Toepaisa		3	2	3	2	M	8	5	H	4	3	M	11	9	H

What are the issues identified during the BU consultation?

Consultation with the relevant officials of Punakha dzongkhags were carried out and 3 gewogs were ranked and studied as per the issues discussed with the officials. For Punakha dzongkhag springs, streams, underground water, ponds and rain water are the main sources of water. It was found that the sources are decreasing over time.

Through the consultation, it was reported that the community faces the problem of water shortage and poor quality of water. Some of the causes of water shortages in the community were attributed to increase in settlements leading to deforestation and further increase in the users. Barp gewog is identified as the vulnerable gewog for such issues as there are new settlers in the community adding to the number of users with limited alternative water sources. The community has observed that the sources are drying and they have become more dependent on rain water. The quality of the water is also an issue for the community and it is mainly due to the water turbidity during the monsoon season and pollution caused by animals as well as humans.

The BU consultation reports that Punakha dzongkhag is at risk of GLOF (Glacial Lake Outburst Flood). Tshokorna village, Lorena village, Tsekha, Yangchenkha and Bjimithang, Lhaku, Changyul and Khuruthang, Gumkarmo, Samdingkha and Khawajara are identified as the vulnerable groups if a GLOF occurs. This could happen if there is an earthquake or extreme rainfall which will damage properties, crops and lead to loss of lives. Flood is the major water related issue that is expected by the community due to the presence of Thorthormi lake which is vulnerable and fragile. Other than floods, storms and hailstorms are reported as water related issues caused by the excessive rainfall/ untimely rainfall resulting in destruction of crops and properties.

What are the TD results indicating?

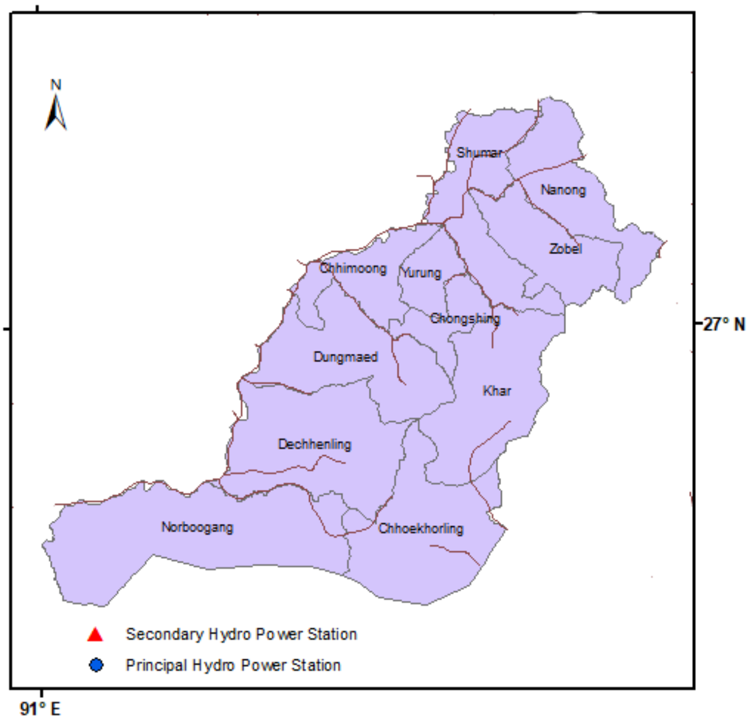
For the TD study, 11 gewogs of Punakha dzongkhag were studied. As per the RCP 4.5 projection for the 2035, most gewogs will not experience any large changes in precipitation except for Guma, Toedwang, Talog and Toepaisa whereas for RCP 8.5 only Toedwang and Talog will experience any changes higher than a factor 3, in all others remaining the same in 1/10 years. In 1/30 years, the gewogs will have medium changes except for Goenshari with large changes based on RCP 4.5 and based on RCP 8.5 Dzomi, Goenshari, Toedwang, Lingmukha, Shelnga- Bjemi are the gewogs which will experience the large changes. The RCP result for the 2085 projection, Guma, Toedwang, Lingmukha, Talog and Toepisa will experience high changes whereas the rest of the gewogs will experience medium changes in 1/10 years. For 1/30 years, most of the gewogs will experience high changes in precipitation except for Guma, Talog and Toepisa. Based on RCP 8.5, all the gewogs will experience large changes for both the 1/10 and 1/30 years.

As shown in the table above, the priority gewogs under Punakha for dry spells includes Barp in the first rank, followed by Gumi and then Dzomi. As per the RCP 4.5, for both the years 2035 and 2085, the occurrence of dry spells will decrease except for Chubu but as per the RCP 8.5, for both the years the dry spells will increase except for Barp and Dzomi. Although Toepisa gewog is not ranked as priority gewog, the frequency of the dry spells in that gewog shows a huge increase as per the projection in 2085.

Conclusion

The main source of water for the Punakha dzongkhag is rivers and streams. The precipitation is projected to decrease in the future. Though the availability of water is abundant from the streams and rivers at present, the sources are drying up at a faster rate. The community is highly vulnerable to GLOFs. With the decrease in precipitation rate, the rate of drought/dry spells in the dzongkhag will increase in the future. Toepisa gewog is vulnerable for dry spells as per the frequency studied. As per the water related disaster ranking Barp is identified as the most vulnerable gewog in the dzongkhag.

C.3 Pema Gatshel



Administrative map of Pema Gatshel

Dzonkhag: Pema Gatsel				Dry spells in ground water recharge													
Population 2017:		23632		River basin:		Nyera Ama Chhu (151, 152, 158, 161)						DJF precipitation trend			Non-Significant		
Population change 2042 (%):		-2				Drangmechhu (151,152,153,154,156,157,158,159,160,161)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
160	Shumar	1	3	33	42	-7	31	H	-10	57	M	-2	29	L	-5	33	L
161	Zobel	2		84	17	0	12	L	-2	29	M	-1	12	M	4	12	M
162	Nanong		1	46	30	-10	13	M	-2	53	M	3	23	L	-21	33	M
155	Dungmaed		2	17	68	19	-12	L	13	7	M	23	6	L	-13	-15	M
156	Chhimoong	3		40	34	-11	6	M	-21	38	M	4	12	M	6	-26	M
Other gewogs (not ranked)																	
157	Yurung			22	56	41	-14	M	35	-7	M	41	-4	M	30	-14	M
158	Chongshing			20	61	20	3	M	-3	26	M	12	23	M	32	3	M
159	Khar			30	46	-13	4	M	1	22	L	14	20	L	8	-11	L
153	Chhoekhorling			24	53	29	-15	M	23	-9	M	39	-19	M	1	-21	M
154	Dechhenling			20	64	-10	-11	M	1	6	L	3	-9	L	2	19	M
152	Norboogang			17	65	-3	-6	M	-18	5	M	3	-3	M	-20	-14	M

Table C.5. shows the combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related issues such as drinking water and irrigation. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Pema Gatsel			Extreme Rainfall Events													
Population 2017:		23632	River basin:		Nyera Ama Chhu (151, 152, 158, 161)						Annual precipitation trend			Non-Significant		
Population change 2042		-2			Drangmechhu (151,152,153,154,156,157,158,159,160,161)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
153	Chhoekhorling	3	8	3	1	2	M	1	3	M	2	1	H	3	3	H
156	Chhimoong	1	6	2	2	3	M	2	4	H	2	3	H	3	5	H
161	Zobel	2	8	2	1	2	M	3	4	H	2	3	H	3	5	H
Other gewogs (not ranked)																
152	Norboogang		6	3	2	3	M	1	2	H	2	1	H	3	3	H
154	Dechhenling		6	2	2	2	H	2	4	M	2	3	H	3	5	H
155	Dungmaed		6	2	2	2	M	2	4	M	2	3	H	3	5	H
157	Yurung		4	2	3	4	M	2	3	H	4	3	H	5	5	H
158	Chongshing		6	2	2	3	M	2	4	H	2	3	H	3	5	H
159	Khar		8	2	1	2	M	3	4	H	1	3	H	3	4	H
160	Shumar		6	2	2	3	M	2	4	M	2	2	H	4	5	H
162	Nanong		8	2	1	2	M	2	4	H	2	2	H	3	5	H

Table C.6 shows the combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

The Bottom-Up consultation with the relevant stakeholders and officials was carried out for Pema Gatshel dzongkhag. Similar to the other dzongkhags, Pema Gatshel dzongkhag also has an issue of availability of drinking water, water for cultivation and the quality of water. Although the sources of water for this dzongkhag are streams, springs and rain, it was observed that the sources are decreasing over time. Nanong and Chhimoong villages are the affected gewogs. As stated by the officials, the reason for the prevalence of such issues are due to increasing developmental activities, mining, felling of tress for the settlements and due to the decline in the traditional practices of offering *soelkha* to the local deities. The communities have also noticed the change in climate especially through precipitation patterns in the region. The dzongkhag has reported issues of the water quality and the reason is mainly because of the mining activities contributing to high content of lime and calcium in the water. Water quality tests like pH level and micro nutrients content test was never analysed for all the gewogs and moreover the quality of water is also affected due to pollution caused domestic and wildlife.

The dzongkhag produces paddy, maize, groundnut, sugarcane, potato, onion, radish, cabbage, cauliflower, chili, beans, ginger, mango, litchi, pear and banana. For cultivation, they use streams but now the trend is observed to be decreasing. Almost all the gewogs under this dzongkhag face the same issues and the factor that causes such issues are leakage from the irrigation pipe, open channels resulting in loss of water and inadequate supply of water especially during the dry season. Furthermore, difficult terrain and steep topography obstruct the efficient supply of water. Some villages are located far from the water sources leading to inadequate supply of water. It was also reported that there are no irrigation channels in the villages of Zobel, Chimong, Yurung, Khar, Dechenling and Chongshing.

Some of the water related issues that are identified in the dzongkhag includes landslides, dry spells, soil erosion, windstorm and hailstorm. These disasters damage the crop, cause land fragmentation, farmland damages, increase pest and diseases and irregular rainfall hampering the growth of the cash-crops. Norbugang gewog is an isolated village with high risk of flash floods and river floods in the bordering plains which will greatly affect the gewog. The vulnerable groups for this dzongkhag include old people, women headed household, disable people and people with limited land holding mainly due to drought.

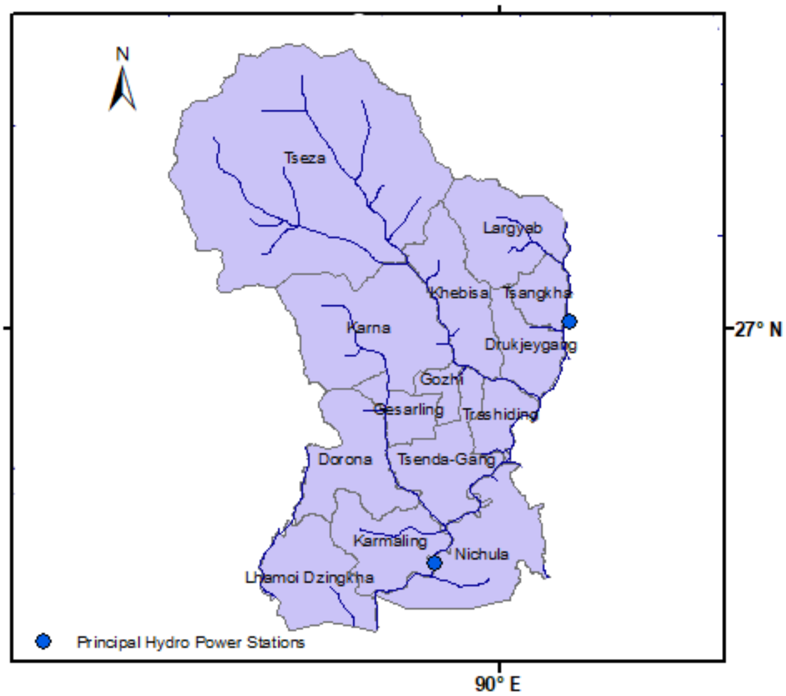
What are the TD results indicating?

11 gewogs of Pema Gatshel dzongkhag were studied for the top-down consultation. For 2035, based on RCP 4.5 and 8.5 projection, most of the gewogs will not experience any large changes in the precipitation except for Yurung with medium changes in 1/10 year frequency. And for 1/30 years, most of the gewogs will experience medium changes except for Chhoekorling, Zobel, Dechhenling, Dungmaed, Khar, Nanong and Shumar. For 2085 projection, RCP 4.5 shows that all the gewogs will remain the same except for Zobel and Khar in 1/10 years, where they will experience medium changes and in 1/30 years all the gewogs are expected to experience medium changes. The RCP 8.5 result shows that for 1/10 and 1/30 years, all the gewogs will experience medium changes in the precipitation.
Based on RCP 4.5 and 8.5 the dry spell duration will decrease for both the years in all the gewogs except for Dungmaed, Yurung and Chhoekorling in 2035 and for 2085 the dry spell duration will decrease in all gewogs except for Shumar, Yurung and Chongshing.

Conclusion

The dzongkhag is more dependent on the sources like springs and streams. The dzongkhag is facing the problem of water availability, where the trend is observed to be decreasing. Dry spells, flash floods and erosion are some of the water related disasters that are prevalent in the dzongkhag. As per the projection the rainfall rate is expected to decrease in all the gewogs leading to the water availability problem and moreover the dzongkhag is highly vulnerable to dry spells and other water related disasters.

C.4 Dagana



Administrative map of Dagana dzongkhag

Dzonkhag: Dagana				Dry spells in ground water recharge													
Population 2017:		24965		River basin:		Punatsangchhu						DJF precipitation trend			Non-Significant		
Population change 2042 (%):		11										(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
89	Tseza		2	21	61	12	30	L	37	36	H	9	16	M	20	41	M
91	Khebisa		1	14	81	5	27	M	18	33	M	0	25	M	18	27	M
92	Tsangkha		3	11	89	31	26	M	39	27	H	65	19	H	45	20	M
95	Tsenda-Gang		3	13	88	44	25	M	69	16	H	46	18	M	91	15	M
100	Gesarling	3		14	81	29	33	M	65	16	M	57	26	M	99	22	H
101	Dorona	1		27	49	38	0	M	35	22	M	26	44	M	35	33	H
102	Gozhi	2		9	98	50	22	M	66	30	M	48	16	M	80	22	M
Other gewogs (not ranked)																	
90	Largyab	5	7	13	87	-13	30	M	34	38	M	33	36	M	43	36	M
93	Drukjeygang	9	8	10	98	7	19	M	33	20	M	60	16	M	24	18	M
94	Trashiding	4	5	10	96	23	9	L	24	8	H	68	1	M	65	9	M
96	Nichula		11	14	78	26	-13	M	18	-18	M	19	-6	M	20	-24	M
97	Karmaling	7	12	18	64	34	5	M	18	14	M	8	19	M	2	2	L
98	Lhamoi Dzingkha	11	13	18	65	6	-3	M	-4	-9	L	-5	0	L	33	-22	H
99	Karna	12	6	14	84	9	24	M	33	23	M	25	10	M	17	27	M

Table C.7 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Dagana			Extreme Rainfall Events													
Population 2017:	24965		River basin:		Punatsangchhu						Annual precipitation trend			Non - significant		
Population change 2042	11										(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
96	Nichula	3	6	1	1	4	M	3	10	H	2	5	M	5	10	H
97	Karmaling	2	5	1	1	4	M	4	11	H	2	5	M	6	16	H
98	Lhamoi Dzing	1	5	2	1	2	M	5	7	M	2	2	M	6	7	H
Other gewogs (not ranked)																
89	Tseza		4	2	2	3	H	6	8	H	3	4	M	9	9	H
90	Largyab		4	1	3	7	H	6	16	H	3	9	H	8	21	H
91	Khebisa		5	2	2	3	M	5	8	H	3	4	M	6	10	H
92	Tsangkha		3	2	4	4	H	7	7	H	5	5	H	11	9	H
93	Drukjeygang		3	2	4	3	H	7	6	H	4	4	M	9	9	H
94	Trashiding		3	2	4	2	M	7	7	H	4	3	M	8	9	H
95	Tsenda-Gang		4	3	2	2	M	5	3	H	3	2	M	8	4	H
99	Karna		4	3	3	1	M	6	6	H	3	3	M	9	8	H
100	Gesarling		4	2	3	2	M	5	7	H	3	3	M	8	9	H
101	Dorona		6	3	1	1	M	4	4	M	2	2	M	6	6	M
102	Gozhi		3	2	4	3	M	7	8	H	4	3	M	9	9	H

Table C.8 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

The bottom up consultation for Dagana dzongkhag reported that the source of water for the dzongkhag are streams, springs, water-pond at Susigaon and rivers. Water related issues that was reported through the official consultation includes insufficient water for drinking and irrigation, poor quality of water during the monsoon and drying up of sources. Such trends in the dzongkhag was observed to be increasing over time. The people of Dagana face such issues mainly due to the increase in the population, rise in the developmental activities, lack of sense of ownership, irrigation channels being damaged by landslides and wild animals (mainly elephant) and poor management of water at the source. The Shamgang village, which is 9km with 18 households, Dargeling and Keykan villages which is 9km with 18 households under Pogo Chiwog are some of the areas with issues of insufficient water. The dzongkhag also has a problem regarding the irrigation of fields due to the drying up of source and open channel leading to the loss of water due to seepage.

Dagana dzongkhag is also experiencing water related hazard and it was assumed to be mainly due to climate change. There are increasing trends of river floods, landslides, rainstorms, hailstorms and drought. Due to such disasters, there are problems of sources being damaged, washing away of farm roads, destruction of the cultivable land, washing away of the irrigation channels and destruction to houses. As per the consultation, the main causes of such issues are due to climate change, deforestation, lack of climate resilient planning and practice of grazing land at Tsangkha gewog. During the monsoon, Laptsakha which is located along the steep slopes are prone to the landslides and flash floods. Burichu, Thasa and Tsendagang gewog are located along the banks of Sunkosh river and are highly vulnerable to the landslides and river floods.

What are the TD results indicating?

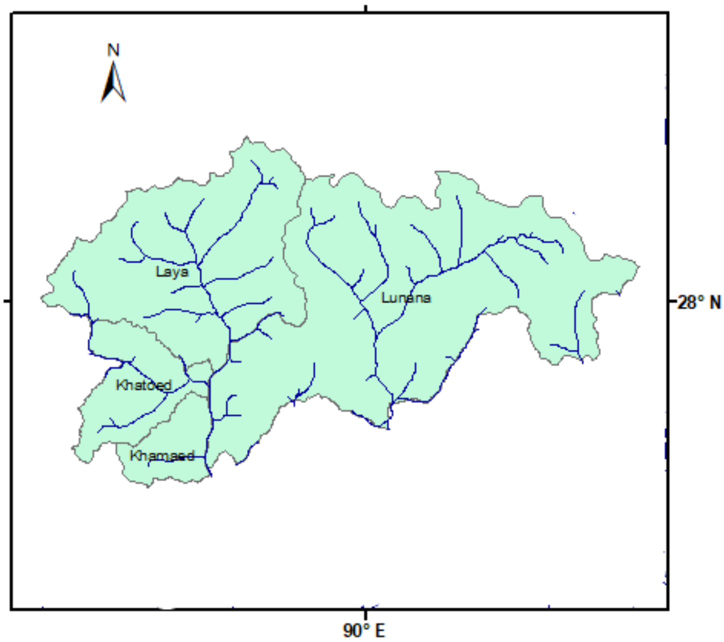
For 2035 projection, based on RCP 4.5 and RCP 8.5 the gewogs will experience medium changes except for Nichula, Karmaling and Lhamoi Dzingkha in 1/10 years.

In 1/30 years, most of the gewogs will experience medium changes except for Largyab. For the 2085 projection, both the RCPs shows that most of the gewogs will experience high changes in precipitation in both 1/10 and 1/30 years except for Nichula, Karmaling, Lhamoi Dzingkha, Khebisa, Tsendagang, Gesarling and Dorna, where those places will experience medium changes. The dry spell duration will increase for all the gewogs in 2035 and 2085 as per RCP 4.5 except for Khebsia, Largyab, Drukjegang, Lhamoi Dzingkha and Karna. And as per RCP 8.5 the dry spell duration will decrease but in gewogs such as Tsangkha, Geserling, Drukjegang and Trashiding, the dry spell duration will increase in 2035. For the year 2085 the dry spell duration will decrease for all the gewogs except for Tseza gewog.

Conclusion

It was reported that the communities in the dzongkhag depend on the streams and rivers as their water source for the daily usage. Consistent with the other dzongkhags, Dagana dzongkhag also faces water related problems. The change in precipitation rate is also observed through projections in RCP 4.5 and RCP 8.5, indicating a higher probability of water related disaster. Laptsakha which is located along steep slopes, Burichu, Thasa and Tsendagang gewog which are located along the banks of Sunkosh river are some of the vulnerable groups to landslides, flash flood and erosion.

C.5 Gasa



Administrative map of Gasa

Dzonkhag: Gasa				Dry spells in ground water recharge													
Population 2017:		3952		River basin:		Punatsangchhu						DJF precipitation trend			Non-Significant		
Population change 2042 (%):		43										(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
51	Laya	2		10	122	-28	-52	M	-38	-85	H	-30	-47	M	-45	-97	M
52	Lunana	1		14	93	-14	-27	M	3	-23	M	42	-10	M	29	-33	M
53	Khamaed		1	13	99	4	-4	M	35	4	M	54	7	M	69	20	M
54	Khatoed	3	2	11	110	-15	-26	M	9	-20	M	34	-23	M	41	-37	H

Table C.9. Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Gasa			Extreme Rainfall Events													
Population 2017:		3952	River basin:		Punatsangchhu						Annual precipitation trend			Significant		
Population change 2042		43									(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
51	Laya	3	6	2	2	2	M	4	4	H	3	3	H	6	7	H
52	Lunana	1	3	2	3	2	M	7	5	M	6	3	H	12	9	H
54	Khatoed	2	6	2	2	3	M	5	5	H	2	4	H	8	9	H
Other gewogs (not ranked)																
53	Khamaed		6	1	2	6	M	4	14	H	2	8	M	8	23	H

Table C.10. Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

From the bottom-up consultation it was reported that the source of water in the dzongkhag includes streams, lakes, rivers, mineral springs and rain water. The availability of water from the sources are found to be decreasing. The people in the dzongkhag depend on these sources for both drinking and irrigation purposes. The dzongkhag officials have stated that there is an increasing issue of insufficient supply of water for both drinking and irrigation, accessibility issues as the sources are located at the lower elevations, open channels leading to the loss of water and people becoming more dependent on the seasonal water sources. There is also a problem related to the quality of water mainly due to the presence of the remains of the dead animals. The construction activities, increase in population, damage of pipelines and ice blockage are the factors that contribute to the water related issues. Moreover, lack of maintenance budget and management issues due to the lack of sense of ownership adds to the water issues in the dzongkhags.

Gasa dzongkhag is vulnerable to the disasters such as GLOFs and flash floods which happens frequently, rainstorms, cyclones, and erosion. Dry spells during the agricultural season are also evident in the dzongkhag. Water related disasters such as floods and GLOFs leads to destruction of several bridges, settlements in the valley along the river. During dry spells, soil becomes dry and the problem of pest and diseases in the crops arises. Under Laya gewog, Taktsekha and Taley village are prone to GLOFs as they are located along the glacial fed river. Lunana gewog which lies along the upper stream of Phochhu river is also at risk for GLOFs.

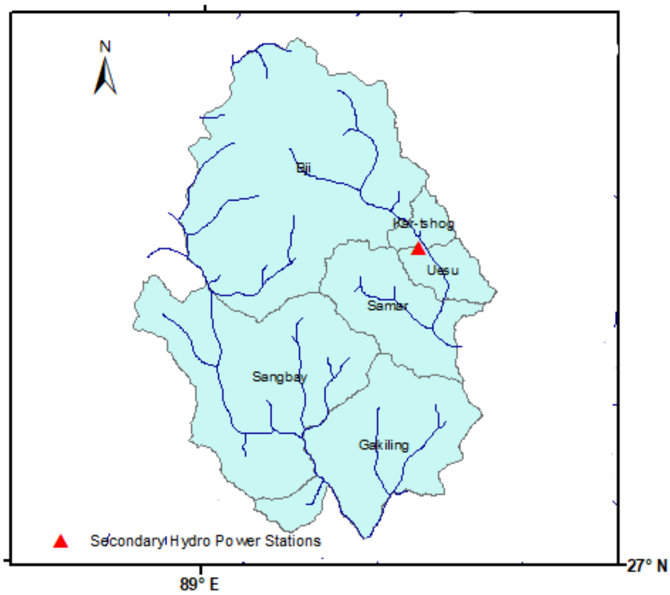
What are the TD results indicating?

Based on the TD results, for 2035 all the gewogs will not experience large changes in precipitation in 1/10 years except for Lunana gewog based on both RCP 4.5 and 8.5. In 1/30 years, the change factor for precipitation in Khamaed gewog is projected to be high. For 2085, both RCP 4.5 and RCP 8.5 projects that all the gewogs will experience high change in precipitation in 1/10 and 1/30 years. For both RCP 4.5 and 8.5, the dry spell duration and dry spell frequency will decrease for all the gewogs except for Khamaed in 2085.

Conclusion

The gewogs mainly depend on streams and lakes for the daily activities. Though there is an availability of water, it is obstructed by the geographical location. People in this dzongkhag are at risk in regards to GLOFs which would destroy the whole community. And in case of droughts/dry spells, the dzongkhag is less vulnerable to dry spells except for the Khamaed gewog.

C.6 Haa



Administrative map of Haa

Dzonkhag:Haa				Dry spells in ground water recharge													
Population 2017:		13655		River basin:		Amochhu (15, 16,17)						DJF precipitation trend			Non-Significant		
Population change 2042 (%):		0				Wangchhu (18,19,20)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
16	Gakiling	1	3	62	24	6	4	L	23	83	H	17	58	L	15	54	M
21	Kar-tshog	3	1	48	30	-2	-3	L	29	50	H	24	47	L	26	53	M
19	Samar	2	2	51	29	28	-14	M	61	3	M	23	17	L	61	7	M
Other gewogs (not ranked)																	
17	Sangbay	5	5	42	35	32	-11	M	70	26	H	38	26	L	43	23	M
20	Uesu	4	4	45	32	31	-16	M	43	34	H	28	12	L	45	41	M
18	Bji	6	6	31	46	5	-9	M	13	-11	M	20	-13	M	-20	-37	M

Table C.11. Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Haa			Extreme Rainfall Events													
Population 2017:	13655		River basin:		Amochhu (15, 16,17)						Annual precipitation trend			Non - significant		
Population change 2042	0				Wangchhu (18,19,20)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
16	Gakiling	1	4	2	2	1	M	5	4	H	2	2	M	8	9	M
17	Sangbay	2	4	0	2	2	M	5	2	H	2	2	M	7	2	H
19	Samar	3	3	2	3	2	M	9	5	H	3	2	M	11	9	H
Other gewogs (not ranked)																
18	Bji		5	1	2	4	M	4	8	M	3	7	M	8	19	H
20	Uesu		3	2	3	2	M	9	5	H	3	2	M	12	9	H
21	Kar-tshog		4	1	3	2	M	4	6	H	5	5	M	8	12	H

Table C.12. Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

Through the bottom up consultation, it was reported that the water sources for the people of Haa dzongkhag includes streams, springs and rivers. They mainly depend on these sources for their day to day activities. As per the consultation, these sources are observed to be drying up at a fast rate. The community faces the problem of poor water quality and insufficient water supply leading to the social conflicts. The communities especially Chhoraphakha and Barachhu villages in the dzongkhag has an issue with the blockages of pipes mainly in winter due to the harsh weather conditions. From the consultation report, it was found that the main causes of such issues are due to the loss of forest (for the construction activities in the dzongkhag), climate change (extreme weather conditions), new settlements and natural reduction of quantity of water at the source. The quality of water is also an issue in the dzongkhag, especially Samar gewog and Gakiling gewog where the water sources have high lime content. For irrigation purposes, the communities depend on the same sources but they face the problem of insufficient water due to the lack of proper channels leading to the loss of water. Such issues mainly occur due to the lack of awareness, rise in population, change in climate and weak and poor-quality irrigation channels.

The dzongkhag is also vulnerable to disasters such as flash floods, cyclones, hailstorms, landslides, rainstorms, river floods and soil erosion mainly during summer and dry spells during the winter. This disaster damages the crops. The availability of the water to the households are being affected due to the destruction at the sources. Bji gewog is one of the gewogs which is affected by landslides during the summer season which mainly happens along the roadsides. The trends of such disasters are observed to be on the rise and the main factors for such events includes, change in climate, soil erosion and loss of forest.

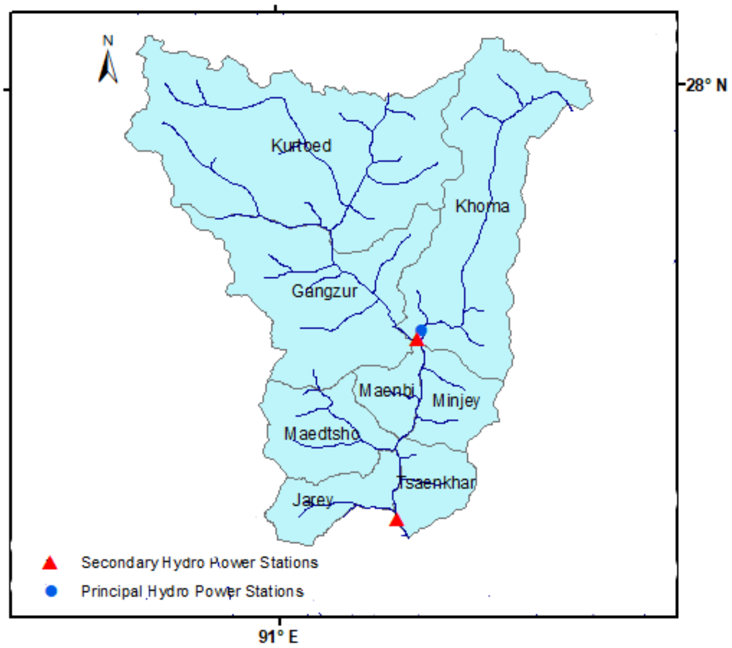
What are the TD results indicating?

In 2035, both the RCPs shows that in 1/10 years all the gewogs will experience medium change in the precipitation and in 1/30-year Bji gewog will experience high change while other gewogs will experience medium change. For the 2085 projection, based on RCP 4.5 Samar and Uesu will have high change factor in 1/10 year and similarly Bji and Kartshog will also experience high change factor in 1/30 year. RCP 8.5 shows that all the gewogs are expected to experience high changes in the precipitation in both 1/10 and 1/30 year except for Sangbay in 1/30 year with no large changes. The dry spell duration and dry spell frequency will decrease based on RCP 4.5 and 8.5 in 2035 and the dry spell duration will also decrease for all the gewogs in 2085 except for Samar and Sangbay.

Conclusion

For Haa dzongkhag, people depend on water from streams and springs. They are common water sources in the dzongkhag. The dzongkhag faces water problems mainly due to the harsh climate and due to the change in climate. For the study, 6 gewogs were selected and their precipitation rate were studied for RCP 4.5 and 8.5. It was found that the dzongkhag is most vulnerable to the disasters like cyclones, flash floods, hailstorms and river floods. Projection shows that the rainfall will increase in the future ensuring fewer dry spells.

C.7 Lhuentse



Administrative map of Lhuentse

Dzonkhag:Lhuentse				Dry spells in ground water recharge													
Population 2017:		14437		River basin:		Drangmechhu						DJF precipitation trend			Significant		
Population change 2042 (%):		-39										(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
127	Kurtoed	3		18	73	56	-32	M	80	-23	H	112	-26	M	58	-34	H
129	Gangzur	1	1	17	78	18	6	M	63	8	M	70	1	M	37	12	M
134	Jarey	2	2	20	65	6	29	M	28	35	H	34	31	M	34	23	M
130	Khoma		3	18	76	55	-16	M	80	-13	H	99	-18	M	64	-18	H
Other gewogs (not ranked)																	
131	Minjey	7		16	76	6	38	M	19	42	H	28	42	M	12	50	M
132	Maenbi	6		15	79	5	30	M	21	41	H	37	39	M	17	46	M
133	Maedtsho	8		20	66	9	24	M	31	36	H	55	20	M	32	26	M
135	Tsaenkhar	9		14	80	2	22	M	19	28	M	23	22	M	14	32	M

Table C.13 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Lhuentse			Extreme Rainfall Events													
Population 2017:		14437	River basin:		Drangmechhu						Annual precipitation trend			Non - significant		
Population change 2042		-39									(historic):			Decreasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
129	Gangzur	1	8	1	2	5	H	4	14	H	2	9	H	8	24	H
134	Jarey	2	5	1	2	5	H	5	13	H	4	6	H	10	33	H
130	Khoma	3	6	1	3	8	H	5	17	H	4	14	H	20	75	H
Other gewogs (not ranked)																
127	Kurtoed		5	1	1	3	H	3	10	H	3	5	H	10	18	H
131	Minjey		7	2	2	4	H	5	14	H	3	7	H	9	23	H
132	Maenbi		6	2	3	4	H	7	13	H	4	7	H	10	22	H
133	Maedtsho		7	2	2	3	H	5	10	H	3	10	H	9	21	H
135	Tsaenkhar		5	1	3	9	H	7	19	H	4	13	H	10	39	H

Table C.14 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and *associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.*

What are the issues identified during BU consultation?

The main sources of water for drinking and irrigation purpose in the dzongkhag includes, streams, springs, underground water, rivers and rain water. Through the consultation, the problems reported are of insufficient water supply, poor water quality, open channels leading to the loss of water and frequent erosion which creates problem in the dzongkhag. The community faces such problems mainly because of the drying up of the water sources, expansion in the settlements causing deforestation and long monsoon months which affects the quality of water due to mud and high turbidity. The location of water sources away from the community is also reported as one of the problems in water supply. It was also reported that the cause of insufficient water supply in the community is also because of the illegal harvesting of the logs from the forest which causes disturbances to the water sources and sometimes lead to drying up of sources. For Tangmachu chiwog and Takila, the sources are unreliable mainly during the rainy season as most of the sources are washed away by floods.

The dzongkhag is at risk for flash floods, landslides, GLOFs (in Sampa and Thinleypang), river floods and erosion. The trend of these disasters is found to be increasing and causing destruction to infrastructure and lives. Moreover, it also causes contamination, damages the road and irrigation channels. It was reported that the main factors for such an event are due to climate change namely heavy rainfall, untimely rainfall and unpredictable weather conditions. Gangzur village is identified as a vulnerable group as the whole catchment area and source was washed away by the flash flood.

What are the TD results indicating?

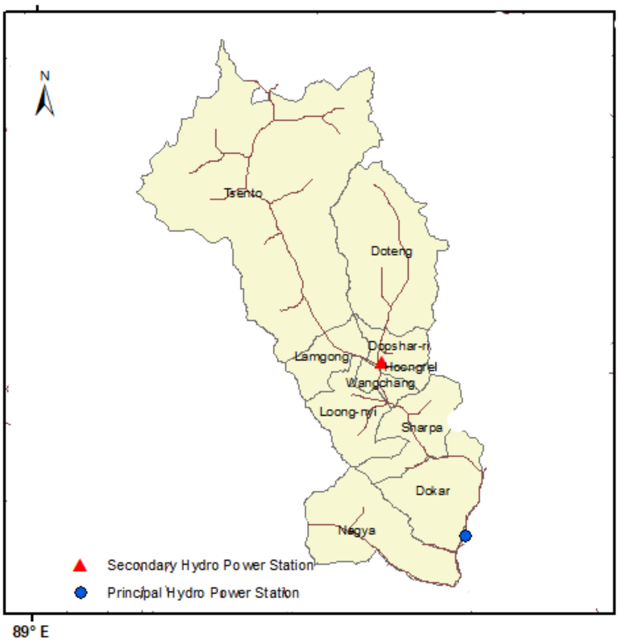
For Lhuentse dzongkhag, 8 gewogs were studied for the top-down consultation. In 2035, RCP 4.5 shows that all gewogs will experience medium change in precipitation in 1/10 and in 1/30 Khoma and Tsaenkhar will experience high changes. In 2085, Maenbi and Tsaenkhar will experience high changes while other gewogs will experience medium changes in 1/10 year; in 1/30year all the gewogs will experience high changes. For 2035 projection, RCP 8.5 shows that there will be medium change in 1/10 year and in 1/30 year all the gewogs will experience increase the change except for Kurtoed with medium change. And in 2085, all the gewogs will experience increase in the change factor in both 1/10 and 1/30 year.

RCP 4.5 shows that in 2035 the dry spell duration will decrease except for Kurtoed, Gangzur and Khoma whereas dry spell frequency will fall. In 2085, the dry spell duration will increase for all the gewogs but dry spell frequency will decrease. The analysis from the RCP 8.5 shows that the dry spell duration will increase and dry spell frequency will fall for both the years.

Conclusion

The study for Lhuntse dzongkhag shows that the people are experiencing high water related issues. Tangmachu chiwog and Takila are the two communities that face water problems mainly due to unreliable sources. For drinking and irrigation purposes the communities mainly depend on the streams. Flash floods, landslides and GLOF are the disasters that are expected in the dzongkhag. Through the projection analysis, the precipitation rate is expected to decrease in all the gewogs and the rate of dry spells in the gewog is projected to increase.

C.8 Paro



Administrative map of Paro

Dzonkhag: Paro				Dry spells in ground water recharge													
Population 2017:		46316		River basin:		Wangchhu						DJF precipitation trend			Non-Significant		
Population change 2042 (%):		51										(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
31	Sharpa	1	1	53	27	4	26	M	36	93	H	-5	52	L	24	78	M
32	Dokar	2	2	122	12	-14	50	H	-14	150	M	-14	75	M	-17	142	M
27	Hoongrel	3	3	30	45	22	0	M	76	53	H	-2	58	L	42	40	M
Other gewogs (not ranked)																	
22	Tsento	9	8	46	32	-5	-16	M	1	-12	L	-20	-59	L	-15	-12	M
28	Wangchang	4	6	15	75	10	19	M	41	57	L	23	55	M	30	60	M
29	Lamgong	6	4	41	35	16	-14	L	46	54	H	11	37	L	31	49	M
30	Loong-nyi	5	7	27	50	25	2	M	80	26	H	24	28	L	51	36	M
25	Doteng	8	9	49	30	-2	-17	L	-22	-3	M	5	-70	L	-40	-37	M
26	Dopshar-ri	7	5	57	25	-1	28	M	24	96	H	-14	84	L	19	104	M
33	Nagya	10	10	87	17	21	12	M	13	100	H	11	29	M	13	76	M

Table C.15 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag:	Paro		Extreme Rainfall Events														
Population 2017:		46316	River basin:		Wangchhu						Annual precipitation trend (historic):			Significant Increasing			
Population change 2042		51															
					RCP 4.5						RCP 8.5						
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085			
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	
26	Dopshar-ri	2	3	2	3	3	M	7	5	H	5	3	M	8	7	H	
27	Hoongrel	3	3	2	3	3	M	7	5	M	6	3	M	9	7	H	
28	Wangchang	3	2	2	4	3	M	10	4	M	5	3	M	12	7	M	
31	Sharpa	1	2	2	4	2	M	11	5	M	5	2	M	17	7	M	
Other gewogs (not ranked)																	
22	Tsento		5	0	3	2	M	5	2	H	4	2	M	8	2	H	
25	Doteng		3	2	4	3	M	7	4	H	7	4	M	13	7	H	
29	Lamgong		4	1	2	2	M	5	5	M	5	2	M	7	9	M	
30	Loong-nyi		3	2	3	2	M	7	4	M	4	2	M	12	7	M	
32	Dokar		2	2	4	2	M	10	5	H	4	2	M	15	9	H	
33	Nagya		2	1	4	4	H	10	9	H	5	4	M	15	17	H	

Table C.16 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

In the bottom-up consultation, it was reported that the major sources for drinking water and irrigation are rivers, springs, and underground springs. The gewog faces the problem of insufficient water, poor water quality, open channels leading to water loss through seepage and sources located far away from the settlements. The main reasons for such problems are due to the lack of alternative sources, deforestation due to increase in settlements and timber permit for felling of trees near to the water sources mainly in Balakha. Moreover, it is also reported that water sources are observed to be drying up and there is improper management of the watershed as well as water sources. As mentioned, the water sources for cultivation is also from springs, streams and mostly from rivers. Farmers face the challenges of insufficient supply of water for their crops due to the increase in agricultural activities where the practice mass cultivation has started, as well as frequent diversion of the river and due to the change in the precipitation pattern.

An assessment on water-related disaster for Paro shows the gewogs located in the low-lying areas are most vulnerable to the floods due to the increase in the glacial melts leading to bursting of lakes. Through the consultation, landslides and soil erosion are also an issue that prevails in the community. There was an incident of Chadozampa bridge being washed away and the road to Phobana was damaged. Moreover, the properties, livestock and arable land of the community are washed away by the flash floods and erosion which is a major loss.

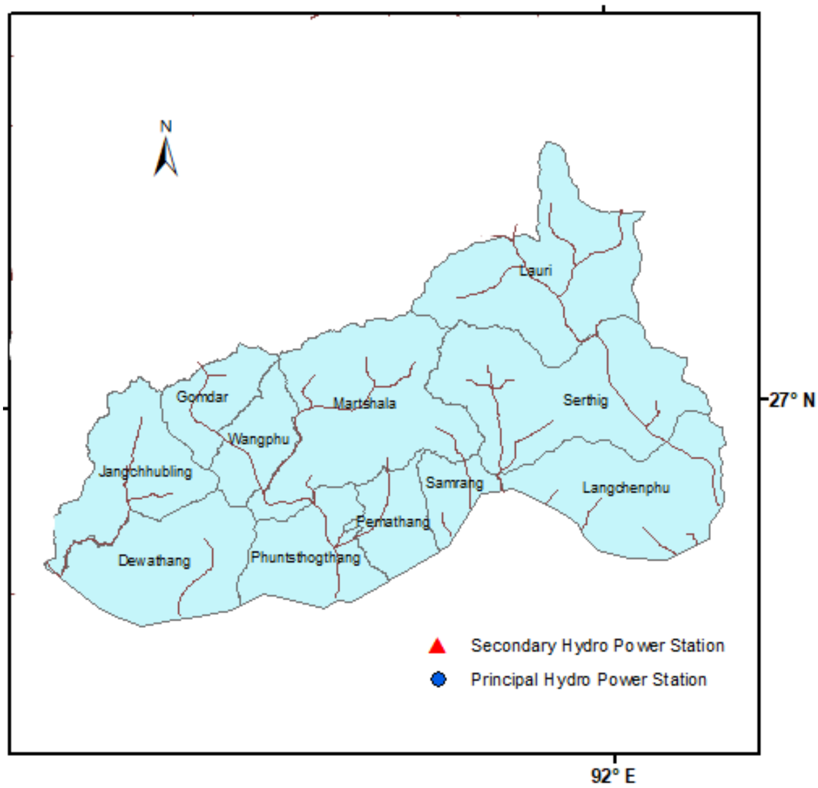
What are the TD results indicating?

In 2035, based on RCP 4.5, all the gewogs under Paro dzongkhag will experience medium change in the precipitation for both 1/10 and 1/30 years. For 2085, the projection shows that all the gewogs will experience increase in change whereas in 1/30 year, Nagya gewog is expected to experience a higher increase in the change factor while other gewogs will experience medium change. As per RCP 8.5, in 2035 Hoongrel and Doteng gewogs are expected to experience high change in 1/10 years whereas in 1/30 years all the gewogs will experience medium change. And for 2085, for both 1/10 and 1/30 years, all the gewogs will experience high change in precipitation except for Tsento with no changes in 1/30 years. The analysis for the dry spells through RCP 4.5 and RCP 8.5 shows a decrease rate for all the gewogs for both 2035 and 2085 except for Hoongrel and Loong-nyi.

Conclusion

The main source of water for Paro dzongkhag is streams. The water availability in the local area is going to increase due to the melting of ice and snow owing to the rise in temperature and high precipitation rate as projected. Moreover, it also shows that the drought/dry spells duration will decrease for all the gewogs for both the periods except for the Hoongrel and Loong-nyi gewog. In case of water related disasters, villages such as Chadozampa and Phobana are vulnerable to erosion and landslides. As per the projection, the annual precipitation trend will be high for all the gewogs in the future.

C.9 Samdrup Jongkhar



Administrative map of Samdrup Jongkhar

Dzonkhag: Samdrup Jongkhar				Dry spells in ground water recharge													
Population 2017:		35079		River basin:		Nyera Ama Chhu (162-172)						DJF precipitation trend			Non-significant		
Population change 2042 (%):		-9				Jomori (162,163)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
163	Langchenphu		3	24	55	13	2	M	-8	25	M	5	11	M	-23	-2	M
166	Pemathang		1	12	89	11	4	M	7	12	M	10	11	M	0	1	L
167	Phuntsthogthang	3	2	15	85	6	1	M	6	12	M	30	11	L	1	19	L
169	Jangchhubling	2		40	35	-17	23	H	-22	49	M	-26	29	M	-19	26	M
170	Gomdar	1		84	17	-15	35	M	-23	59	M	-23	35	H	-23	35	M
Other gewogs (not ranked)																	
164	Serthig			73	20	-6	5	L	-6	20	M	6	10	M	-11	20	L
165	Samrang			22	57	12	5	L	-2	12	M	13	7	M	-19	4	M
168	Dewathang			27	50	-16	4	M	-17	16	M	-18	18	M	-29	2	M
171	Wangphu			75	19	-1	5	M	6	26	M	-8	26	M	-4	5	M
172	Martshala			69	21	2	5	M	6	24	M	5	14	M	7	33	L
173	Lauri			70	21	-10	19	M	16	24	M	-8	33	M	-9	43	M

Table C.17 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Samdrup Jongkhar			Extreme Rainfall Events													
Population 2017:		35079	River basin:		Nyera Ama Chhu (162-172)						Annual precipitation trend			Non-significant		
Population change 2042		-9			Jomori (162,163)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
163	Langchenphu	3	8	2	1	2	M	2	4	M	2	4	M	3	6	H
167	Phuntsthogth	2	7	2	1	3	M	2	3	M	2	3	M	3	4	H
170	Gomdar	1	8	2	1	3	M	2	4	H	2	3	H	3	5	H
Other gewogs (not ranked)																
164	Serthig		8	2	1	2	M	2	6	M	2	4	H	3	7	H
165	Samrang		8	2	1	3	H	2	5	M	2	4	H	3	6	H
166	Pemathang		10	3	1	2	M	1	3	M	1	2	M	2	4	H
168	Dewathang		8	3	1	2	M	3	2	H	2	1	M	3	3	H
169	Jangchhubling		9	2	1	3	M	2	4	M	1	3	M	2	4	H
171	Wangphu		9	2	1	3	M	2	4	H	1	3	H	2	5	H
172	Martshala		8	2	2	3	H	2	5	H	2	4	H	4	6	H
173	Lauri		5	2	2	2	H	4	3	H	2	3	H	6	5	H

Table C.18 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

Through the bottom-up consultation, 11 gewogs were studied based on issues on water for drinking and irrigation purpose. The major sources of water include rivers, streams and springs but for Langchenphu gewog the water sources are not known. The dzongkhag faces the problem of insufficient water, poor water quality, land use change, increase in fallow land and sources located away from settlements. The factors causing such problems are due to deforestation, increase in settlements, drying up of sources, landslides, pipelines disturbed by wild animals and issuance of timber permit for felling trees without proper assessments. Farmers face the challenges of insufficient water supply to their agricultural fields due to the increase in population leading to increase in demand for the water for their fields, the sources are disturbed during the construction activities and the sources are now observed to be drying up.

In this dzongkhag, water related disasters that are more frequent includes flash floods, river floods, windstorms and landslides and it is due to fragile soil and precipitation, climate change, heavy monsoon and mining activities. The disaster imposes threats to the community, where their houses are at risk of being washed away together with the arable fields and disturbing the supply of water.

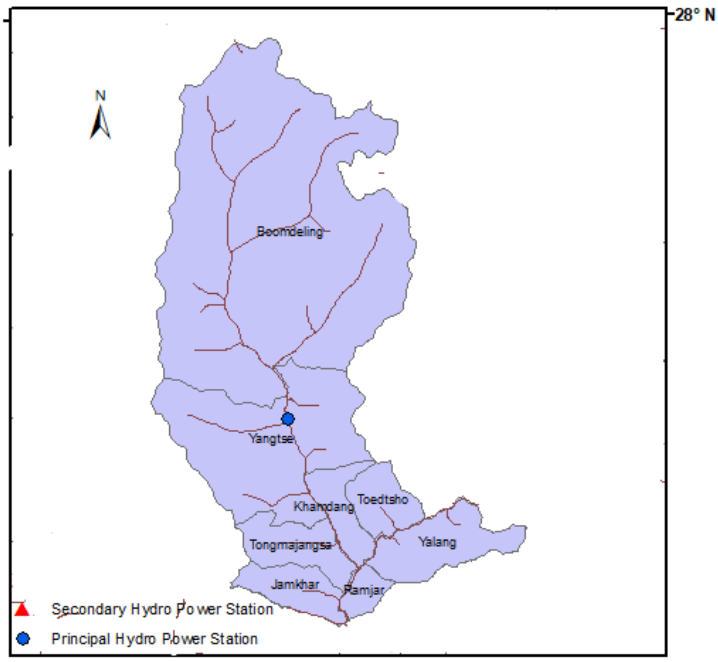
What are the TD results indicating?

For Samdrup Jongkhar dzongkhag, both RCPs shows that all the gewogs will experience medium change in the precipitation in 2035. In 2085, RCP 4.5 shows that Serthig gewog will experience high change in 1/10 and 1/30 years while other gewogs will experience little change. RCP 8.5 shows that in 2085, Lauri gewog is expected to have high change in precipitation while others gewogs with little change in 1/10 year and in 1/30 years gewogs like Langchenphu, Serthig, Samrang and Martshala will experience an increase whereas other gewogs are projected to experience medium change. And the dry spell duration for all the gewogs will decrease for both the years based on RCP 4.5 except for Gomdar which shows increase in the dry spell rate. RCP 8.5 also shows the same result where in both the years, dry spell duration is projected to decrease except for Phuentshothang.

Conclusion

The major sources of water include rivers, streams and springs. In the future, the precipitation rate is expected to increase in all the gewogs, whereby the rate of the dry spells in the gewogs is projected to decrease. However, two gewogs namely Gomdar and Phuentshothang are exceptional. These gewogs are projected to face less water related issues for drinking and irrigation but high probability of water related disaster.

C.10 Trashiyangtse



Administrative map of Trashiyangtse

Dzonkhag:Trashi Yangtse				Dry spells in ground water recharge													
Population 2017:		17300		River basin:		Drangmechhu						DJF precipitation trend (historic):			Significant Decreasing		
Population change 2042 (%):		-27															
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
140	Jamkhar	3		45	31	-7	26	M	9	55	M	31	45	M	-12	55	M
141	Ramjar	2	1	35	37	8	14	M	32	22	H	27	14	H	15	35	M
136	Khamdang	1	2	38	36	-4	8	M	27	28	M	37	36	M	-8	56	M
143	Yalang		3	68	21	-15	24	M	-9	71	M	-5	67	M	-10	38	M
Other gewogs (not ranked)																	
139	Tongmajangsa			47	29	-17	38	M	-6	69	M	2	52	M	-29	62	M
137	Boomdeling			38	39	-17	-3	M	-24	26	M	16	5	M	-34	-5	M
138	Yangtse			36	40	-10	-2	L	-6	25	M	9	28	M	-17	30	M
142	Toedtsho			42	34	-8	26	M	9	44	M	25	53	M	-13	56	M

Table C.19 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Trashi Yangtse			Extreme Rainfall Events													
Population 2017:		17300	River basin:		Drangmechhu						Annual precipitation trend (historic):			Non-significant Increasing		
Population change 2042		-27														
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
137	Boomdeling	1	7	2	2	5	H	5	12	H	4	10	H	12	30	H
138	Yangtse	2	4	1	2	4	M	6	11	H	4	7	H	11	25	H
142	Toedtsho	3	4	1	2	3	M	5	7	H	3	5	H	9	23	H
Other gewogs (not ranked)																
139	Tongmajangsa		4	1	2	3	M	4	7	H	4	6	H	8	18	H
136	Khamdang		4	1	2	4	M	5	8	H	4	7	H	9	20	H
140	Jamkhar		4	1	2	3	M	4	7	H	4	5	H	8	18	H
141	Ramjar		4	1	2	3	M	5	7	H	4	7	H	8	18	H
143	Yalang		2	1	4	2	M	8	6	H	6	5	H	16	13	H

Table C.20 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

The main sources of drinking water are springs and streams. All of these water sources are observed to be decreasing and there are issues in getting access to water. The communities in the dzongkhag depends on the same sources for drinking and irrigation purposes. The main problems are insufficient water due to inaccessibility, water sources located far away, drying up of water source and low quality of water for drinking. The main causes for the problems are reported to be due to climate change, increase in population, frequent disruption of water supply system and settlements at upstream of water sources and blockages of pipes due to ice during peak winter. Due to the increase in population, there are a lot of people developing agricultural field which leads to the water shortage problem and increase in competition for the water resources. Out of 8 gewogs, Khamdang gewog is at the top rank in regards to the water related disaster risk.

As per the consultation with the Trashiyangtse dzongkhag, it was found out that the major water related disaster in the dzongkhag are flash floods and river floods, landslides, rainstorms, hailstorms and drought. The trend of these hazards is observed to be remaining same. These disasters cause damages to water pipelines at source, impose risk to settlements and infrastructures near the river banks, washing away of farm lands and disruption of drinking water and irrigation water supply. Road construction activities in the communities, lack of proper drainage system, heavy and prolonged monsoon season, lack of risk mitigation and preparedness plan are also some of the triggers for these issues. Boomdeling gewog is found to be the highest gewog with issues related to water related disaster in the dzongkhag.

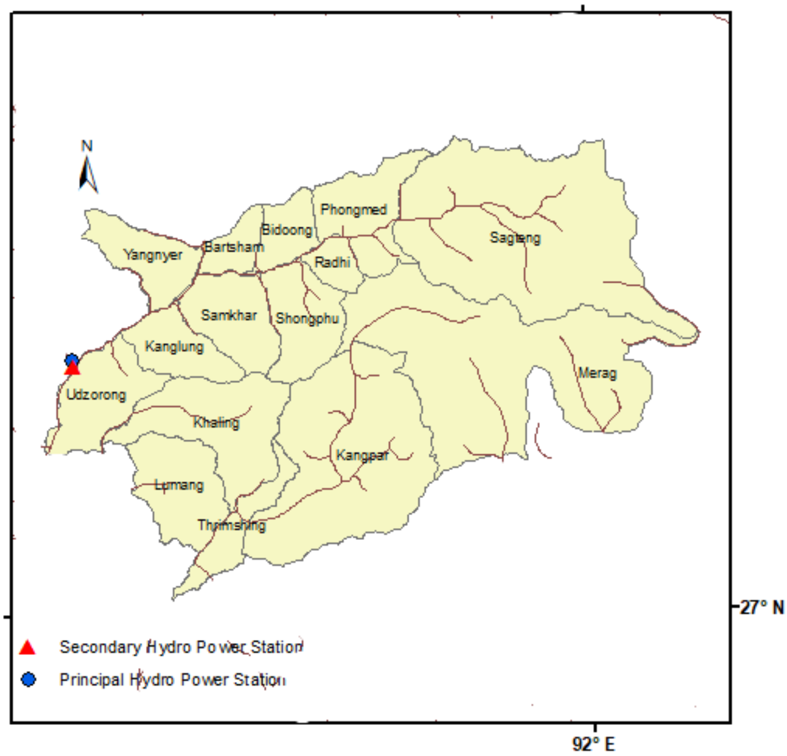
What are the TD results indicating?

For the Trashiyangtse dzongkhag, based on RCP 4.5 in 2035, Yalang gewog will experience medium change in precipitation while other gewogs will experience little change in 1/10 years whereas in 1/30 years, all the gewogs are expected to experience medium change except for Yalang with little change. In 2085, all the gewogs will have high change in precipitation while others will experience medium change. Based on RCP 8.5, in 2035 Yalang gewog will experience high change in precipitation while all others will experience medium change in 1/10 and for 1/30 years, all the gewogs will experience high change in precipitation except for Toedtsho, Jamkhar and Yalang with medium change. For 2085, the result indicates that all the gewogs are expected for the high change in precipitation pattern for both 1/10 and 1/30 years. The projection shows that there will be extreme precipitation in the dzongkhag. The dry spell duration for the dzongkhag will decrease as indicated by the results of RCP 4.5 and RCP 8.5 in 2035 and 2085 whereas the dry spell frequency will increase for both the years in the future.

Conclusion

The main sources of drinking water are springs and streams. All the gewogs in the dzongkhag depend on the same sources for both drinking and irrigation purposes. The dzongkhag faces water insufficiency problem for drinking and irrigation purposes. Through the bottom up consultation, Khamdang gewog is at the top rank in regards to the drinking water issues and supply of water for irrigation for the farmers and Boomdeling gewog for water related disaster that is occurring more frequently.

C.11 Trashigang



Administrative map of Trashigang

Dzonkhag:Trashigang				Dry spells in ground water recharge													
Population 2017:		45518		River basin:		Drangmechhu (191-202)						DJF precipitation trend			Significant		
Population change 2042 (%):		-40				Merak-Sakteng(192,205), Nyera-Ama chhu(203,204)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
195	Bidoong	3	3	44	31	-15	26	L	18	42	M	8	39	M	12	19	M
196	Bartsham	1	1	40	34	-3	12	M	6	32	M	17	12	M	5	26	M
204	Kangpar	2	2	63	23	-2	9	M	8	22	M	11	26	M	1	17	M
Other gewogs (not ranked)																	
191	Yangnyer			44	32	-13	16	M	9	47	M	29	25	M	16	38	M
192	Sagteng			49	30	-11	3	L	18	7	M	5	17	L	-6	-17	L
193	Phongmed			59	25	-21	8	L	-2	32	M	2	28	M	-26	36	M
194	Radhi			59	24	-7	21	M	4	54	M	16	21	M	-14	38	M
197	Samkhar			69	21	-5	5	L	-7	38	M	17	24	M	-24	43	M
198	Shongphu			70	21	-18	29	M	3	38	M	1	48	M	-15	52	M
199	Kanglung			72	20	-13	5	M	13	15	M	6	25	L	-18	50	M
200	Udzorong			23	56	13	-14	M	-5	18	L	40	2	L	6	-27	M
201	Khaling			69	21	-3	10	M	8	48	M	1	29	M	-12	52	M
202	Lumang			33	41	0	-7	M	10	34	M	27	-10	M	24	-12	L
203	Thrimshing			69	21	-1	5	M	1	33	M	-5	24	M	-8	38	M
205	Merag			47	31	4	-13	M	19	-3	M	15	-3	M	16	-13	M

Table C.21 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Trashigang			Extreme Rainfall Events													
Population 2017:		45518	River basin:		Drangmechhu (191-202)						Annual precipitation trend			Non-significant		
Population change 2042		-40			Merak-Sakteng(192,205), Nyera-Ama chhu(203,204)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
196	Bartsham	3	3	1	2	3	M	5	7	H	4	4	H	10	14	H
197	Samkhar	2	5	1	2	2	M	3	3	H	2	4	H	6	12	H
198	Shongphu	1	3	1	3	2	M	5	5	H	5	4	H	12	14	H
Other gewogs (not ranked)																
191	Yangnyer		3	1	3	2	M	5	5	H	3	4	H	12	12	H
192	Sagteng		3	1	2	3	M	6	5	M	4	5	M	10	14	H
193	Phongmed		4	1	2	2	M	3	3	H	3	5	H	9	10	H
194	Radhi		2	1	4	1	M	9	6	H	7	5	H	19	13	H
195	Bidoong		3	1	3	2	M	5	6	H	4	4	H	11	10	H
199	Kanglung		5	1	1	2	M	3	4	H	2	4	H	6	12	H
200	Udzorong		5	1	1	2	L	3	4	H	2	4	H	5	8	H
201	Khaling		5	1	1	2	M	3	3	H	2	4	H	6	8	H
202	Lumang		5	1	2	3	M	3	6	M	2	4	H	5	10	H
203	Thrimshing		7	2	2	2	M	2	4	M	2	3	H	5	5	H
204	Kangpar		4	1	3	3	H	4	6	H	4	5	H	8	14	H
205	Merag		5	1	2	3	M	4	4	H	3	4	H	6	13	H

Table C.22 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header. RCP4.5 is shown in the upper table and RCP8.5 in the lower table.

What are the issues identified during BU consultation?

The main sources of drinking water are streams, rivers, underground water and springs. All of these water sources are observed to be decreasing. The community faces the problem of insufficient water and supply of poor water quality. The main causes of the above-mentioned problems are increased developmental activities, increasing population, drying water sources, increasing settlements, winter weather causing blockages and climate change. For the cultivation of the paddy and vegetables, farmers face the issues of insufficient supply of water in their fields as there is an increase in household numbers dependent on farming. The incidences of floods at the sources which washes away the water sources is one of the main reasons leading to insufficient supply of the water.
The dzongkhag is at risk for flash floods, landslides, river floods, cyclones and erosion. The trend of these disasters is found to be increasing and it causes destruction to infrastructure and lives. Moreover, there are also contamination, damages of roads and irrigation channels and arable land which are washed by the floods and landslides. Through the consultation, it is reported that the causes of these issues include the climate change, heavy rainfall, untimely rainfall, steep gradient, construction activities and unpredictable weather condition. Shongphu gewog is vulnerable to water related disaster as this gewog is located near the Drangmechhu.

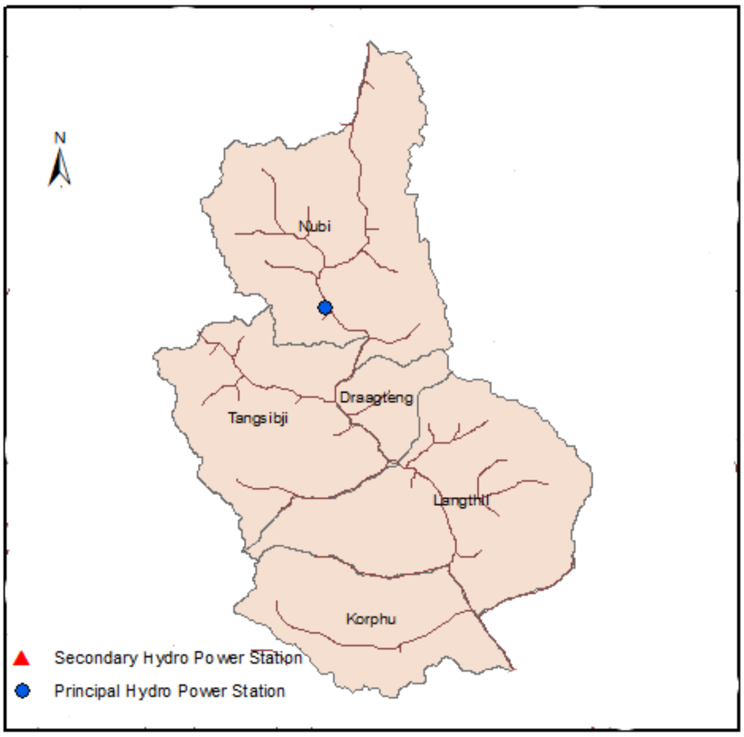
What are the TD results indicating?

In 2035, there will be medium change in all the gewogs in the precipitation in 1/10 and 1/30 years based on the RCP 4.5 except for Udzorong with low change in 1/30 years. For the 2085 projection, Sakteng and Radhi gewogs are expected to experience high change in 1/10 years and for 1/30 years, all the gewogs will have high change factor except for Samkhar, Phongmed and Khaling experiencing medium change. As per RCP 8.5, in 2035 Radhi gewog is expected to see increase in precipitation in 1/10 and medium change in 1/30 years. All the gewogs are expected to experience high changes in precipitation for both 1/10 and 1/30 years in 2085. Based on the RCP 8.5 projection, it shows that there will be extreme precipitation in the dzongkhag in both the years. The dry spell duration for Trashigang dzongkhag will decrease in both the years as shown by the results of RCP 4.5 and RCP 8.5 projection.

Conclusion

The main sources of drinking water are streams, rivers, underground water and springs. All of these water sources are observed to be decreasing. As per the projection, the dzongkhag will experience high precipitation rate in the future. Bartsham gewog is identified as the gewog which has high issues of water for drinking and irrigation and Shongphu gewog is ranked as highly vulnerable for the water related disaster.

C.12 Trongsa



Administrative map of Trongsa

Dzonkhag:Trongsa				Dry spells in ground water recharge													
Population 2017:		19960		River basin:		Mangdechhu						DJF precipitation trend			Non-significant		
Population change 2042 (%):		39										(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
87	Langthil	1	2	39	37	-15	38	L	18	38	M	46	41	M	1	51	M
88	Korphu	3	1	41	35	-7	6	L	19	20	M	25	54	M	0	37	M
85	Draagteng	2	3	33	42	10	40	L	34	43	H	79	43	M	41	36	H
Other gewogs (not ranked)																	
86	Tangsibji			34	42	25	29	L	64	38	H	87	36	M	45	31	M
84	Nubi			45	33	1	30	L	33	42	M	59	33	M	14	39	M

Table C.23 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Trongsa			Extreme Rainfall Events													
Population 2017:		19960	River basin:		Mangdechhu						Annual precipitation trend			Non-significant		
Population change 2042		39									(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
84	Nubi	1	5	3	2	1	M	5	3	H	3	2	M	10	8	H
85	Draagteng	3	5	3	2	1	M	5	3	H	3	2	M	10	8	H
87	Langthil	2	5	2	3	3	H	5	9	H	4	5	H	9	16	H
Other gewogs (not ranked)																
86	Tangsibji		5	2	1	2	M	6	5	H	3	3	M	10	13	H
88	Korphu		6	3	2	2	H	4	5	H	2	3	H	6	9	H

Table C.24 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

From the bottom-up consultation, 5 gewogs were studied and ranked based on the issues reported on drinking water and water for irrigation. The major source of water for drinking and irrigation are streams, springs and ponds. All the gewogs in the dzongkhag face the problems of insufficient water, poor water quality, open channels leading to water loss through seepage, deforestation, non-regulated water uses and sources located away from the settlement. The main reasons for such problems are due to the deforestation caused by the increase in settlements in the community and drying up of the water sources, contamination of sacred /spiritual sites and decline in performing ritual for the local deities.

For water-related disasters, it was reported that the rainfall pattern has become erratic and incessant which causes floods, river floods and landslides destroying cultivable land in the community. Industrial activities have been on the rise leading to deforestation. Crop damages due to floods and landslides are on the rise. Through the consultation, Langthil gewog was ranked at the first place for the issues related to drinking water and irrigation and Nubi gewog for water related disasters.

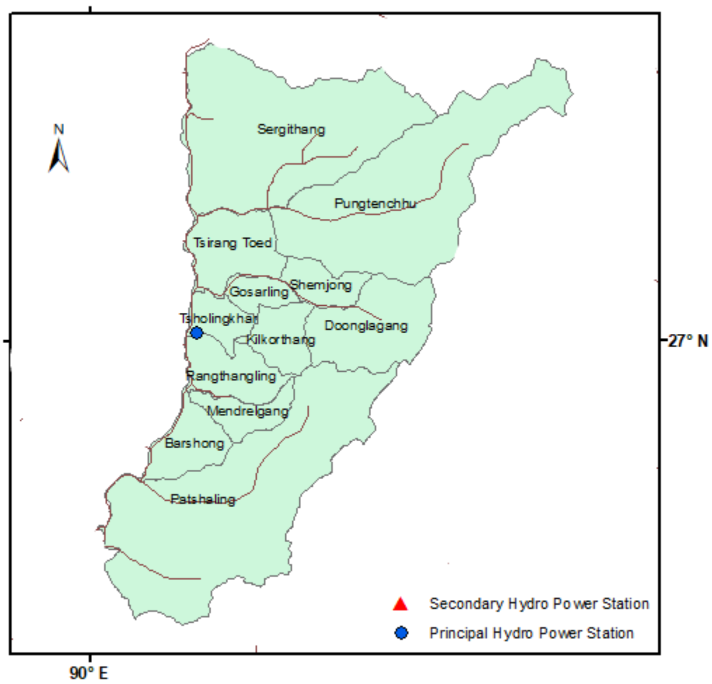
What are the TD results indicating?

For the Trongsa dzongkhag, in 2035 both the RCPs show that there will be medium change in the precipitation pattern. And in 2085, RCP 4.5 indicates that all the gewogs will experience a medium range change in precipitation amount except for Tangsibji and Langthil with high change. RCP 8.5 shows that the change factor will be high for all the gewogs. Based on the TD, for RCP4.5 the dry spell duration will decrease for all gewogs for both periods except for Draagteng, and Nubi gewog and RCP 8.5 indicates a rise in the dry spell duration in both the periods except for Langthil gewog.

Conclusion

The major source of water for drinking and irrigation are streams, springs and ponds. The dzongkhag faces the problem of insufficient water for drinking and irrigation purposes. The main reasons for such problems are due to the deforestation attributed to the increase in settlements in the community and drying up of the water sources, contamination of sacred /spiritual sites and decline in performing ritual for the local deities. Langthil gewog was ranked at the first place for the issues related to drinking water and irrigation and Nubi gewog for water related disasters.

C.13 Tsirang



Administrative map of Tsirang

Dzonkhag: Tsirang				Dry spells in ground water recharge													
Population 2017:		22376		River basin:		Punatsangchhu						DJF precipitation trend			Non-significant		
Population change 2042 (%):		30										(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
121	Shemjong	3	3	21	61	19	18	L	21	38	M	57	36	M	36	49	M
122	Tsirang Toed	1	1	13	81	31	17	M	31	25	M	67	25	M	42	27	M
124	Pungtenchhu	2	2	30	45	2	44	L	22	38	M	63	38	M	24	49	M
Other gewogs (not ranked)																	
117	Mendrelgang			14	77	10	17	M	2	32	M	43	21	M	9	18	M
118	Rangthangling			10	100	16	14	M	17	32	M	51	26	M	8	27	M
119	Tsholingkhar			7	107	32	5	L	25	3	M	68	7	M	70	8	M
120	Gosarling			18	65	37	9	M	30	22	M	80	18	M	35	23	M
115	Patshaling			19	66	23	17	M	27	18	M	83	18	H	27	30	M
116	Barshong			14	74	18	19	M	18	30	M	58	19	M	20	19	M
123	Sergithang			14	85	54	19	M	55	26	H	108	11	M	97	12	M
125	Doonglagang			21	58	16	5	M	23	17	H	66	14	M	44	29	M
126	Kilkorthang			14	78	13	0	L	19	12	M	60	18	H	43	15	M

Table C.25 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Tsirang			Extreme Rainfall Events													
Population 2017:		22376	River basin:		Punatsangchhu						Annual precipitation trend (historic):			Non-significant Increasing		
Population change 2042		30														
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
121	Shemjong	3	4	3	2	1	M	6	5	H	4	3	M	7	6	H
122	Tsirang Toed	1	5	1	2	7	H	4	14	H	3	10	H	6	19	H
124	Pungtenchhu	2	6	2	3	4	H	4	9	H	3	6	H	6	11	H
Other gewogs (not ranked)																
117	Mendrelgang		5	2	2	3	H	4	6	H	2	4	M	5	7	H
118	Rangthangling		4	2	3	3	H	5	7	H	3	5	H	6	7	H
119	Tsholingkhar		3	2	4	3	H	7	7	H	5	5	H	10	9	H
120	Gosarling		5	2	2	4	M	5	6	HGH	3	5	M	6	10	H
115	Patshaling		5	3	2	2	M	3	3	H	2	2	M	5	4	H
116	Barshong		3	2	4	3	M	7	6	H	4	3	M	7	7	H
123	Sergithang		4	2	2	4	H	7	9	H	4	5	H	9	12	H
125	Doonglagang		5	3	2	1	M	4	4	H	3	3	M	5	6	H
126	Kilkorthang		5	2	2	2	H	5	7	H	3	4	H	5	10	H

Table C.26 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

The main source of drinking water in this dzongkhag is springs. Water sources are observed to be decreasing in the dzongkhag. The dzongkhag has a problem of insufficient supply of water for both drinking and irrigation, especially in Takthang, Norbuthang and Kabelzhing chiwogs. Wangphu chiwog has water quality issues leading to health and sanitation issues. And these problems are due to the deforestation at the water source, naturally drying up of sources or not enough water at source, settlements at long distance from water sources and settlements at the sources leading to pollution/contamination of the water source. For cultivation purposes, the communities depend on the same sources. The communities have reported water shortage problems leading to the water related conflicts. There are issues of crop failure and low yield of crops. And the main cause of such issues are drying up of water source, increase in the population and decline in the local beliefs to conserve water sources. Global warming (erratic rainfall and increase in temperature) and disturbance to water sources due to farm roads and construction of other infrastructures are also mentioned as causes of these problems during the consultation.

Through the consultation, it was reported that dzongkhag experiences landslides, rainstorms, flash floods, and soil erosion. The trend of these water related issues are found to be increasing. The major problems associated with water related hazards in the gewogs are damages of infrastructures, loss of water through seepage and increase of fallow land. Some of the other problems include damage to the crops and the delay in the crop yield, the activities regarding the livestock has been affected due to the destruction caused by the disasters and loss of fertile land. The likely causes of the major water related hazards are unstable area with steep slope, change in rainfall pattern, pollution and rapid economic development activities that are taking place in the dzongkhag.

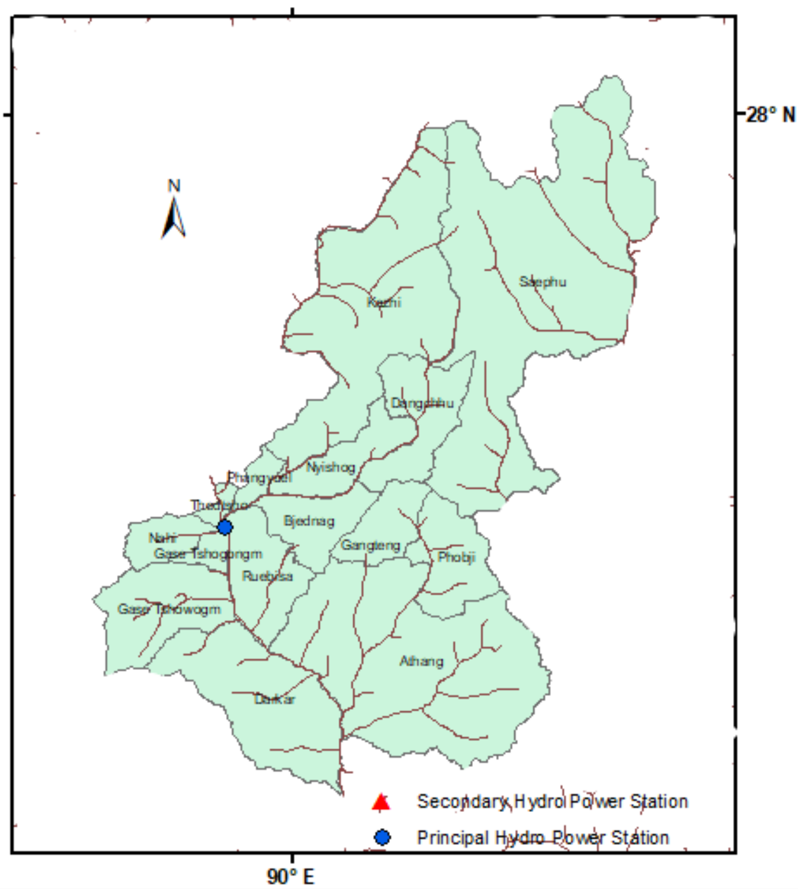
What are the TD results indicating?

In 2035, both the RCP shows that all the gewogs are expected to experience medium change in the precipitation except for Tsirang Toed and Pungtenchhu with high change factor. Similarly, for 2085 projection, both the RCPs indicate high changes in precipitation rate. Based on the 2085 projection from both the RCPs, the precipitation rate for this dzongkhag will increase for all the gewogs. The dry spell duration this dzongkhag will increase in the both the years based on RCP 4.5 and 8.5, where Sergithang gewog will experience the highest drought.

Conclusion

The main source of drinking water is spring. The water source is observed to be decreasing in the gewogs. The communities of the dzongkhag depend on these sources for both drinking and irrigation purposes. Through the top-down and bottom-up consultation, Tsirang Toed is ranked highest with issues related to water for drinking, irrigation and water related disaster.

C.14 Wangdue Phodrang



Administrative map of Wangdue Phodrang

Dzonkhag:Wangdue Phodrang				Dry spells in ground water recharge													
Population 2017:		42186		River basin:		Punatshangchhu (66-80)						DJF precipitation trend			Non-significant		
Population change 2042 (%):		31				Mangdechhu (67)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
78	Ruebisa	2		14	89	-11	21	M	47	43	H	41	30	M	63	51	M
79	Thedtsho	3		10	107	-8	15	M	31	31	H	22	12	M	31	13	M
80	Phangyuel	1		14	86	-16	20	M	21	35	H	39	21	M	31	53	M
75	Gase Tshowogm		2	17	77	-13	9	L	50	47	H	17	18	M	12	49	M
76	Gase Tshogongm		1	10	102	-15	11	M	65	36	H	29	22	M	47	19	M
73	Athang		3	18	70	-6	34	L	41	31	H	79	37	M	50	29	M
Other gewogs (not ranked)																	
67	Saephu			37	40	6	2	L	46	2	M	72	2	M	7	2	M
68	Dangchhu			29	49	30	22	L	78	33	H	127	22	M	64	29	M
69	Nyishog			20	66	5	58	M	13	77	H	33	53	M	30	59	H
70	Bjednag			16	80	-17	42	M	16	72	H	44	50	M	27	69	M
71	Gangteng			21	64	71	-6	M	114	2	M	178	0	M	109	5	M
72	Phobji			34	42	12	29	L	46	43	M	65	36	M	50	29	M
66	Kazhi			18	75	25	-8	L	61	20	M	71	12	M	81	-19	M
74	Darkar			12	95	-16	9	M	53	25	H	33	14	M	40	36	M
77	Nahi			18	74	-12	12	M	52	92	H	38	68	M	28	73	M

Table C.27 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Wangdue Phodrang			Extreme Rainfall Events													
Population 2017:		42186	River basin:		Punatshangchhu (66-80)						Annual precipitation trend			Non-significant		
Population change 2042		31			Mangdechhu (67)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
73	Athang	1	4	2	3	3	H	6	9	H	4	4	H	11	13	H
74	Darkar	3	6	1	3	11	H	4	21	H	3	9	M	6	25	H
78	Ruebisa		4	1	3	5	H	6	16	H	5	12	H	9	25	H
79	Thedtsho	2	5	1	3	8	H	5	14	H						
Other gewogs (not ranked)											3	4	H	12	16	H
67	Saephu		4	1	2	3	M	5	7	H	3	4	H	14	16	H
66	Kazhi		3	1	2	2	M	6	7	M	4	3	M	14	12	H
68	Dangchhu		4	2	2	2	M	8	6	H	3	7	H	8	22	H
69	Nyishog		5	1	2	3	M	5	11	H	2	7	M	6	16	H
70	Bjednag		5	1	2	2	H	4	10	H	4	2	M	10	10	H
71	Gangteng		4	2	2	2	M	6	5	H	3	2	M	12	12	H
72	Phobji		4	2	2	2	M	7	6	H	5	4	H	12	9	H
75	Gase Tshowogm		3	2	5	3	H	9	6	H	3	6	H	6	10	H
76	Gase Tshogongm		7	2	3	5	H	4	6	H	6	5	H	9	9	H
77	Nahi		3	2	5	4	M	8	5	H	6	11	H	9	19	H
80	Phangyuel		5	1	2	4	M	6	13	H	3	6	H	8	23	H

Table C.28 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

The main sources of drinking water in Wangdue dzongkhag are springs. The water sources are observed to be decreasing. The major problem in the dzongkhag includes insufficient water and poor water quality for consumption. The main cause of the above-mentioned problem is, drying up of source, less rainfall which causes low recharge, drying up of sources, increase in settlements and improved sanitation which uses lots of water.

The main sources of irrigation water are spring for field crops and vegetables. The trend of the water sources is observed to be decreasing. The dzongkhag faces the problem of insufficient supply and open channels leading to the inefficient irrigation of

water in the fields. It is mainly due to the change in the climate, drying up of the sources, increase in the settlements and construction activities which are observed to be disturbing the water sources.
The dzongkhag has experienced and observed the change in the climate, where the temperature has increased with erratic weather patterns. There are increases in developmental activities and explosions of population. With erratic and unpredictable weather patterns and incessant rainfall, the dzongkhag is experiencing floods, GLOFs, and landslides which causes damages to the properties and lives, damage to the agricultural land and low crop production. There are also cases of dry spells in some years causing low crop yield. Out of 15 gewogs, Phangyuel gewog is ranked highest for the issues related to drinking and irrigation and Athang gewog for water related disaster.

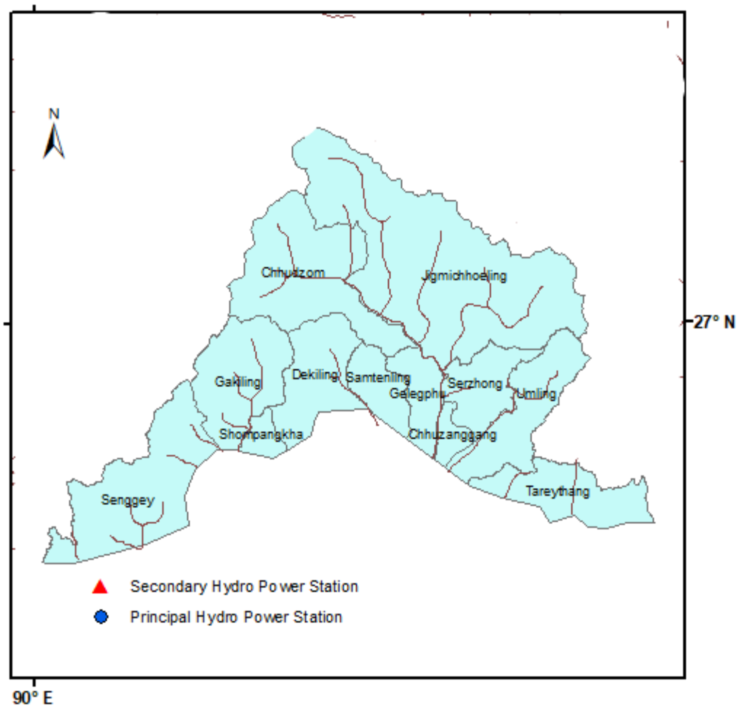
What are the TD results indicating?

RCP 4.5 shows that in 2035, all the gewogs will experience a medium change in the precipitation in for 1/10 and 1/30 years except for Darkar and Thedtsho with high change rate in 1/30 year. For 2085, both the RCPs show high changes in the precipitation. The dry spell duration for this dzongkhag will decrease in 2035 based on RCP 4.5 except for Gangteng and in 2085 the dry spell duration will increase. And RCP 8.5 shows that the dry spell duration will increase for both the years.

Conclusion

The main sources of drinking water in Wangdue Phodrang dzongkhag are springs. The water sources are observed to be decreasing. It is mainly due to the change in the climate, drying up of the sources, increase in the settlements and construction activities which disturbs the water sources and causes the water related issues for drinking and irrigation. Phangyuel gewog is ranked first for the issues related to drinking and irrigation and Athang gewog for water related disasters. This dzongkhag is expected to experience high rate of drought/dry spells in the future.

C.15 Sarpang



Administrative map of Sarpang

Dzonkhag: Sarpang				Dry spells in ground water recharge													
Population 2017:		46004		River basin:		Aiechhu						DJF precipitation trend (historic):			Non-significant Decreasing		
Population change 2042 (%):		37															
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
107	Gelegphu	1		14	78	25	4	L	9	-5	M	40	0	M	22	-21	M
108	Chhuzanggang	3		10	81	4	16	M	2	15	M	40	14	M	8	5	M
109	Serzhong		2	15	79	17	-10	M	21	14	M	59	11	M	34	-10	M
111	Tareythang		1	16	69	1	13	M	6	26	M	11	12	H	10	4	M
104	Shompangkha	2	3	19	59	38	-8	L	30	0	M	80	2	M	12	-12	M
Other gewogs (not ranked)																	
106	Samtenling			13	80	22	5	M	50	9	M	75	-2	M	45	-10	M
103	Senggey			24	53	12	-2	L	4	11	M	37	17	M	2	17	M
105	Dekiling			19	68	55	-9	M	58	7	M	92	6	M	44	32	M
110	Umling			27	49	5	-18	M	-2	39	M	14	10	M	7	10	L
112	Jigmichhoeling			32	44	19	23	M	51	32	H	79	34	M	29	34	M
113	Chhudzom			23	57	7	26	L	32	37	H	87	32	H	45	40	H
114	Gakiling			22	59	21	10	M	20	29	M	67	32	M	27	32	M

Table C.29 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Sarpang			Extreme Rainfall Events													
Population 2017:		46004	River basin:		Aiechhu						Annual precipitation trend (historic):			Non-significant Increasing		
Population change 2042		37														
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
104	Shompangkha	3	6	1	2	3	M	3	7	H	2	5	M	3	10	H
107	Gelegphu	1	5	2	1	2	H	3	4	H	2	3	M	4	4	H
108	Chhuzanggan	2	5	2	2	1	M	2	2	H	2	2	M	4	4	H
Other gewogs (not ranked)																
103	Senggey		5	1	2	3	M	3	5	H	2	3	M	4	9	H
105	Dekiling		4	3	3	1	M	4	3	H	4	1	M	6	6	H
106	Samtenling		5	3	1	1	M	3	2	H	2	2	M	4	3	H
109	Serzhong		5	3	2	1	M	3	2	H	2	2	M	4	2	H
110	Umling		5	2	2	1	M	2	2	M	2	2	M	3	4	H
111	Tareythang		4	1	2	2	M	3	4	M	2	3	M	3	4	H
112	Jigmichhoeling		5	3	2	1	M	4	3	H	2	1	M	5	5	H
113	Chhudzom		4	3	3	1	M	6	3	H	4	1	M	6	6	H
114	Gakiling		5	3	2	2	M	3	4	H	3	2	M	4	6	H

Table C.30 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

In the bottom-up consultation, 12 gewogs were ranked based on issues reported regarding drinking and irrigation water. The major sources for drinking and irrigation water are rivers, springs, and underground springs. The dzongkhag faces the problems of insufficient water, poor water quality, open channels leading to water loss through seepage, community conflicts because of inequitable water distribution, poor water quality during monsoon season, water supplied based on timing in all chiwogs which is not enough. The main reasons for such problems are lack of alternative sources, deforestation, drying up of water sources, management issues in water distribution systems, destruction of water sources by water related disasters, damage of water sources and distribution lines by wild animals (elephants and wild boars). Moreover, it developed into a semi-urban area and more water issues are anticipated considering the high rate of new settlements, multiple users including industries, municipality and institutions from a single source. The water sources for cultivation is also from springs, streams and mostly from rivers. Farmers face the challenges of insufficient supply of water to their fields due to the increase in agriculture activities where they practice mass cultivation, frequent diversion of the river, change in the precipitation pattern and most of the irrigation channel falls on fragile landscapes making them vulnerable to slides.

An assessment on water-related disaster for Sarpang dzongkhag reports river floods, flash floods, landslides and thunderstorms/windstorms as the main water related disasters. The trend of these water related disasters are observed to be increasing. The major problem associated with the disasters are washing away of farm land over time, traffic disruption, diversion from normal water course, loss of vegetation along the bank, decrease in land holdings and crop production and future implications for providing substitute land. These disasters cause destruction to the properties, livestock and arable land of the people in the communities of the dzongkhag. They are mainly caused by erratic rainfall patterns leading to change in volume of water flow along the bank; the soil profile and texture which is easily eroded due to sandy and loose river banks; confluence/downstream river systems and prone to flooding; illegal surface collection works along the vulnerable areas; establishment of crushing units along the bank and piling of stones along the banks disturbing normal course of flow during the increase in volume and disruption of irrigation water supply.

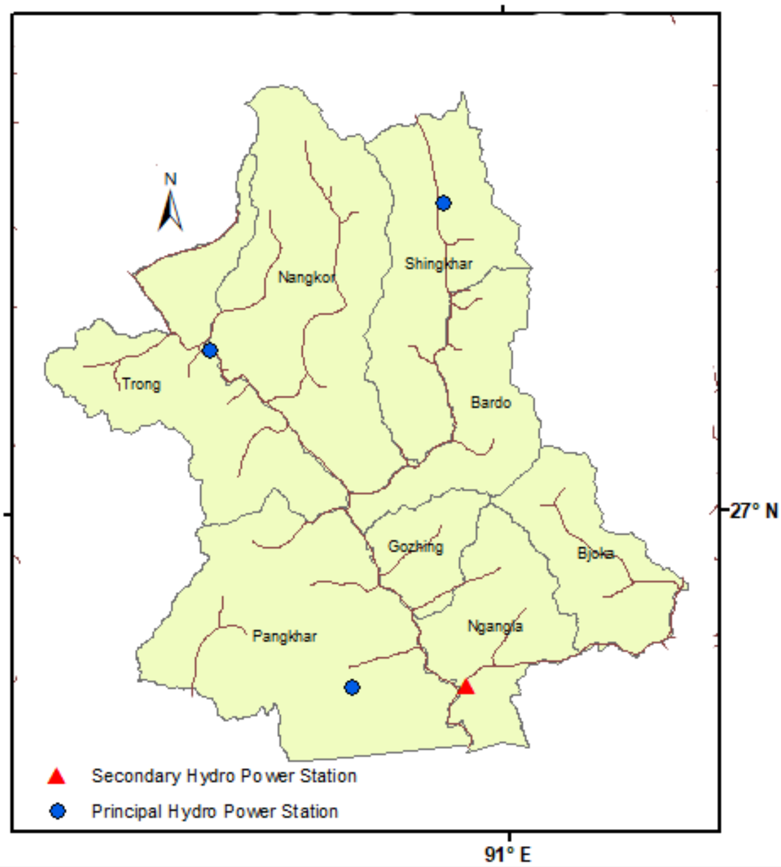
What are the TD results indicating?

For Sarpang dzongkhag, the change factor of 1/10 year precipitation for 2035 mostly shows no large change under both RCP scenarios while it shows medium changes for 2085 under both RCPs. An almost similar pattern can be seen for 1/30 year precipitation with only 5 gewogs (Shompangkha, Gelegphu, Senggye, Tareythang and Gakiling and Chhudzom) showing medium changes for 2035. Under RCP 4.5, the change factor for 2085 of 1/30 years precipitation is greater than that of 1/10 years, indicating that rainfall might become more erratic for Shomphangkha, Gelegphu, Senggye, Tarythang and Gakiling gewogs. The same can be interpreted for the 5 gewogs of Shompangkha, Umling, Senggye, Tareythang and Gakiling. The dry spell duration for Sarpang dzongkhag will increase in 2035 where Dekiling gewog will experience the highest and in 2085 the drought will decrease except for Dekiling and Jigmechoeling. This is as per RCP 4.5 and in case of RCP 8.5 the dry spell duration will increase in both the years.

Conclusion

The major sources for drinking water and irrigation are rivers, springs, and underground springs. The dzongkhag will receive less precipitation in future as per the projection. And it is projected that the dry spell duration will increase in the future for this dzongkhag. From the gewog ranking, Gelegphu gewog is ranked first in regard to the vulnerability of water related disaster and Tareythang for drinking water issues and for irrigation.

C.16 Zhemgang



Administrative map of Zhemgang

Dzonkhag:Zhemgang				Dry spells in ground water recharge													
Population 2017:		17763		River basin:		Mandgechhu (44 - 49)						DJF precipitation trend			Non-significant		
Population change 2042:		-34				Aiechhu (144), Drangmechhu (150,151)						(historic):			Decreasing		
						RCP 4.5						RCP 8.5					
		BU Ranking		Historic		2035 Change (%)			2085 Change (%)			2035 Change (%)			2085 Change (%)		
Gewog ID	GewogName	D- Water	I-Water	Duration	Frequency	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.	Duration	Frequency	Ag.
144	Pangkhar	2	2	27	49	17	-10	L	22	24	M	33	16	H	24	-29	M
145	Trong	1		39	36	1	19	M	13	53	M	26	50	M	-3	72	M
148	Bardo		1	42	33	1	3	L	37	24	M	36	27	M	18	36	M
149	Gozhing		3	48	29	-4	3	L	36	31	M	16	0	M	-9	28	M
150	Ngangla	3		43	32	6	-3	M	2	38	L	16	12	M	-21	-16	L
Other gewogs (not ranked)																	
147	Shingkhar			48	30	-12	30	M	14	10	H	24	53	M	7	27	M
146	Nangkor			50	29	-22	17	M	8	41	M	13	52	M	-7	31	M
151	Bjoka			41	34	3	-15	M	22	32	M	34	-9	M	9	-26	L

Table C.31 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change (%) in dry spell duration (consecutive days) and frequency (number of events in 40 years) under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

Dzonkhag: Zhemgang			Extreme Rainfall Events													
Population 2017:		17763	River basin:		Mandgechhu (44 - 49)						Annual precipitation trend			Non-significant		
Population change 2042		-34			Aiechhu (144), Drangmechhu (150,151)						(historic):			Increasing		
					RCP 4.5						RCP 8.5					
			historic count		change factor 2035			change factor 2085			change factor 2035			change factor 2085		
Gewog ID	GewogName	Disaster Ranking	1/10 year precip	1/30 year precip	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.	1/10 year precip	1/30 year precip	Ag.
147	Shingkhar	1	3	1	3	2	H	6	7	H	4	5	H	13	15	H
146	Nangkor	3	6	2	2	3	H	3	5	H	3	4	H	6	11	H
151	Bjoka	2	6	1	2	3	M	3	5	H	2	4	H	4	8	H
Other gewogs (not ranked)																
144	Pangkhar		4	2	2	2	M	3	2	M	3	2	M	4	3	H
145	Trong		6	1	2	3	H	3	8	H	3	5	H	5	14	H
148	Bardo		5	1	1	2	H	3	6	M	2	4	H	5	8	H
149	Gozhing		5	1	1	2	H	2	5	M	2	3	H	4	6	H
150	Ngangla		5	1	2	3	M	2	5	H	2	4	H	3	7	H

Table C.32 Combination of top-down and bottom-up results. Left panel shows ranked gewogs based on reported water related disasters. Right panel shows the change in return period of extreme rainfall under climate change and associated agreement between GCM projections for 2035 and 2085. In addition, information on population and change, which gewogs (IDs) belong to which river basin and on the historic precipitation trend are given in the table header.

What are the issues identified during BU consultation?

The consultation with the relevant officials of Zhemgang dzongkhag reported that the main sources of drinking water are streams and springs. All of these water sources are observed to be decreasing. The major problem in the dzongkhag is insufficient water supply. The main causes of the above-mentioned problem are drying up of water sources, increase in settlements and construction activities. In addition, other causes include wearing out of old structures and old pipe connections and no alternative sources. The existing sources are located far away from the settlements. The sources for irrigation are streams, springs and rain water for field crops. The trend of the water source is observed to be decreasing. The major problems in the gewog are insufficient water for their fields and earthen drains as irrigation canals which leads to loss of water through seepage. The main causes of the above-mentioned problems are as follows: drying of water sources, increase in developmental activities, increase in the settlements, poor quality of irrigation channels, and soil erosions due to erratic rainfall. In the dzongkhag, Trong gewog is facing highest water related issues for drinking and irrigation compared to the other gewogs in the dzongkhag.

The major water related disasters that occurs in this dzongkhag are flash floods, river floods, landslides, hailstorms, rainstorms and soil erosions. The trend of these water related disasters is observed to be remaining the same. The major problems associated with water related disasters in the gewog are destruction of arable land, damages of the infrastructures, insufficient water supply. The likely cause of the major water related disasters is due to the climate change which leads to untimely and unfavourable rainfall. Shingkhar gewog is experiencing the highest water related disasters in the dzongkhag.

What are the TD results indicating?

For 2035, both the RCP result shows that the change in the precipitation is projected to be medium. For 2085, RCP 4.5 shows that all the gewogs will have change of medium scale except for Shingkhar with high change in 1/10 years and it will be similar for 1/30 years where Shingkhar, Trong and Bardo gewogs with high change factor, while other gewogs will experience medium change. As per RCP 8.5, in 2085 all the gewogs are expected to experience medium change in precipitation patterns except for Shingkhar and Nangkor in 1/10 years whereas in 1/30 year all the gewog will experience high precipitation change except for Phangkhar. In the case of dry spell duration, based on RCP 4.5 and 8.5 results show a decrease except for Pangkhar in 2035 but shows an increase in 2085.

Conclusion

The main sources of drinking water are streams and springs. All of these water sources are observed to be decreasing. The major problem in the dzongkhag is insufficient water supply for both drinking and irrigation purpose. Through the bottom up consultation and top-down consultation, it is known that Shingkhar gewog is experiencing the highest water related hazards in the dzongkhag and Trong gewog in terms of drinking water and irrigation issues.

D Adaptation option per sector

In this annex the priority actions for the NAP are presented as they have been assembled by the local experts during the workshop on the 31st of August 2021. The priorities are based upon two rounds of qualitative assessment during this workshop:

- During the first round the participants were challenged to assess the completeness of the adaptation options, whether both hazard and exposure and vulnerability are addressed by the options and what actions are low-regret and add to resilience, robustness and flexibility of the water sector under future climate change (see 3.3). The result of this step was a complete list divided in short term actions and long-term options.

- In the second round, priorities were rearranged based upon a quick qualitative assessment of costs, effectiveness, co-benefits and potential negative trade-offs. In addition, the participants were asked how the actions could be institutionalized, i.e. what institute should lead, which policies should be linked, and which stakeholders should be involved. The result of this step was a top 5 of priority actions for the short term and recommendations on implementation and financing.

The combined result of both steps is presented below per sector.

D.1 Drinking water

Priority	Adaptation action	Implementation
Top 5 SHORT TERM priority actions (start of implementation within next 5 years)		
1	Joint planning for watershed protection and management (including source revival) with relevant central agencies. This may include actions like: - Regulation of activities within protected zones to prevent degradation. - Afforestation to protect water sources. - Monitoring of sources and springs (Recharge mapping of the water sources, yield measurement of the water sources).	MoAF with MoWHS, WMD, MoH, DLG, NECS, Communities
2	Smart management of water (Installation of leak detecting device, data logger, SCADA) real-time monitoring of the water networks in major towns.	MoWHS/Thromde
3	Strengthen and formation of WUAs	NECS

4	Develop a database system: Integration of the water database system (WASIS, WQMIS, WWSI, etc.)	MoWHS, MoH, NECS
5	Promote and integrate spiritual and cultural aspects for preservation of water sources/water bodies.	MoHCA
Other potential SHORT TERM options (not ranked)		
- Construct reservoir tanks with proper distribution systems with proper zoning system (Dzongkhag Metering Zone DMA) - Replace damaged water pipes with better technologies - Strengthen implementation of Water Safety Plan (WSP) and integration of climate resilient components - Ensure periodic water quality testing - Enhance water treatment facilities to ensure safe drinking water - Explore rainwater harvesting - Develop inventory for water infrastructures		
LONGER TERM options (after 5 years)		
- Promote Payment for Environmental Services. - Design institutional based water pricing and tariff system in urban centres		

Financing opportunities for implementing these actions are seen with the Green Climate Fund (GCF), Global Environmental Facility (GEF) for the LDC, Asian Development Bank (ADB), Government of India (GOI), Royal Government of Bhutan (RGOB) and the World Health Organization (WHO).

A brief reflection:

Most of the priority actions proposed are low regret and mostly involve soft or enabling adaptation action not directly including new infrastructures. They are for a large part targeting capacity building in the sector. Physical interventions will be formulated within improved watershed management and may be a result of explorations and inventories mentioned. This will increase the resilience and flexibility of the sector to respond to dry spells. However, it remains uncertain for the short term to what extent additional robustness is created to cope with increasing water shortages (that may predominantly be caused by increasing demand).

There are three overlapping actions with the irrigation water sector: strengthening the water user associations (WUAs) and reinforcing cultural aspects of water conservation and improved watershed planning and management.

D.2 Water for irrigation

Priority	Adaptation action	Implementation
Top 5 SHORT TERM priority actions (start of implementation within next 5 years)		
1	Renovation of existing irrigation systems with retrofit of climate resilient features during renovation itself	Food and Nutrition Security Policy; 21st Century Economic Roadmap, Bhutan Water Policy
2	Install new quality irrigation systems with adoption of climate smart irrigation	
3	Monitoring program for structures once completed	
4	Multi-stakeholder involvement in irrigation systems management	
5	Adequate financial assistance for repair and maintenance MT	
Other potential SHORT TERM options (not ranked)		
- Water source protection and awareness - Adopt climate smart irrigation systems such as water harvesting and micro-irrigation technology (pond irrigation, sprinkler irrigation, drip irrigation, rain water harvesting etc) - Frame proper management rules and regulation of water usages - Construction of lined irrigation channel or closed channel with HDPE pipes to reduce water loss in the medium term - Formation and proper management of WUAs - Advocate beneficiary households on the importance of WUA; - Diversification of water sources - Strengthen the weather and hydrological monitoring and forecasting capacity - Documentation of indigenous knowledge systems (Cultural practices and rituals) - Standards or guidelines for climate resilient infrastructure for agriculture (designs) - on farm water storage/conservation (on farm ponds/changes in agronomic practices for water conservation)		
LONGER TERM options (after 5 years)		
- Adequate financial assistance for repair and maintenance - Ensure quality construction of irrigation channel - Explore crops which consume less water - Revival of abandoned ponds - Monitoring program for structures once completed - Resource allocation for structures for O&M - Integrated drinking and irrigation systems - Protection and management of watershed		

Financing opportunities are seen with multilateral funds (e.g.: GCF, GEF), Financial institutes (e.g. World Bank (WB), ADB) and the RGoB. Payment for ecosystem/environmental services is considered as another option that needs to be further elaborated.

A brief reflection:

Most of the priority actions proposed are aimed at a better management and improvement of irrigation infrastructures. This will improve the robustness and resilience of part of irrigation system. For the improvement of the whole sector also increased reliability of water sources and crops and land use should be considered. Therefore, it remains uncertain for the short term to what extent additional robustness is created to cope with increasing water shortages (that may predominantly be caused by increasing demand).

There are three overlapping actions with the drinking water sector: strengthening the water user associations (WUAs) and reinforcing cultural aspects of water conservation and improved watershed planning and management

D.3 Water related disasters

<table>
<tr><th>Priority</th><th>Adaptation action</th><th>Implementation</th></tr>
<tr><td colspan="3">Top 5 SHORT TERM priority actions (start of implementation within next 5 years)</td></tr>
<tr><td>1</td><td>Enhance use of Global Numerical Weather Prediction (NWP) products to improve the downscaling skills to local level and improve the data processing, forecast, warnings and advisories.</td><td rowspan="5">- FYPs, World Meteorological Organization Data Policy
- Disaster Management Rules and Regulation 2014 (during policy revision)
- Disaster Management Act 2013</td></tr>
<tr><td>2</td><td>Strengthen or develop early warning systems considering all the vulnerable groups and specific disaster locations with corresponding details of all adaptive capacity.</td></tr>
<tr><td>3</td><td>Enhancement of national hydro-meteorological observation stations to improve temporal and spatial distribution of the stations for future studies on proper flood hazard assessment and management.</td></tr>
<tr><td>4</td><td>Enhance delivery of weather, climate and flood information services through effective decision support system</td></tr>
<tr><td>5</td><td>Detailed mapping of GLOF/Flood risk zones</td></tr>
<tr><td colspan="3">Other potential SHORT TERM options (not ranked)</td></tr>
<tr><td colspan="3">- River dredging and river embankment construction
- Enhancement of disaster management capacity for communities, local and central agencies
- Construction of slope stabilization structures (gabion, retention walls, bioengineering etc.) at the landslide and flood-prone areas
- Raise awareness about water-related hazards (GLOF, flood)</td></tr>
</table>

- Enhancement of community-based disaster risk management (CBDRM) plans
LONGER TERM options (after 5 years)
- Diversion of rivers with potential threats - Resettlement of the vulnerable households/communities residing in areas prone to high risk of water related disasters - Propagate environment friendly road construction practices and technologies and maintain proper causeway and drainage on roads

Financing opportunities are seen with Green Climate Fund (GCF), Asian Development Bank (ADB), Global Environment Facility (GEF), Adaptation Fund (AF), Special Climate Change Fund (SCCF), World Bank (WB), United Nations Environment Programme, Japan International Cooperation Agency, Korean International Cooperation Agency, European Union, Government of India (GOI), Bhutan Trust Fund for Environmental Conservation, RGoB

A brief reflection:

The priority actions proposed are aimed at a better data collection, information management and improvement of early warning products. This will improve the resilience through adaptive capacity of the communities and responsible disaster risk managers. It is suggested to combine these priority actions with actions to ‘raise awareness about water-related hazards (GLOF, flood)’, ‘enhancement of disaster management capacity for communities, local and central agencies’ and ‘enhancement of community-based disaster risk management (CBDRM) plans’ into an integrated plan to improve DRM. In this way data and information can be improved to feed into DRM plans, EWS and awareness raising. Flood information systems should also be informed by systematically monitoring hazards. The latter could be explicitly mentioned.

In addition, the risk maps should inform the engineering actions and potential resettlements that will make the DRM more robust across Bhutan.

D.4 Hydropower

<table>
<tr><th>Priority</th><th>Adaptation action</th><th>Implementation</th></tr>
<tr><td colspan="3">Top 5 SHORT TERM priority actions (start of implementation within next 5 years)</td></tr>
<tr><td>1</td><td>Investment in reservoir storage plants and pump storage projects – in Punatsangchhu basin, Drangmechhu basin</td><td rowspan="5">- Electricity Act,
- Economic Development Policy,
- Sustainable Hydropower Development Policy,
- Economic Roadmap, Water roadmap
- Dam Safety Guidelines</td></tr>
<tr><td>2</td><td>Understand snow and glacier contribution better - Understanding current and future water resources</td></tr>
<tr><td>3</td><td>Diversion of streams between dam site and powerhouse - Feeding channel</td></tr>
<tr><td>4</td><td>Hard coating of turbines</td></tr>
<tr><td>5</td><td>Dam safety audit – (that includes an additional climate stress test)</td></tr>
<tr><td colspan="3">Other potential SHORT TERM options (not ranked)</td></tr>
<tr><td colspan="3">- Dredging works
- Regular maintenance for mini and micro hydropower plants
- Bunakha Reservoir is planned to cascade and support THP and CHP
- Funding conservation in the catchment for Wangchhu
- More study and investment to study reservoir storage plants</td></tr>
<tr><td colspan="3">LONGER TERM options (after 5 years)</td></tr>
<tr><td colspan="3">- Upstream check dams,
- High altitude reservoirs,
- Study possibility for hydro-peaking (there is the possibility of using it as an adaptation for winter domestic needs)
- Study of groundwater in detail
- In-depth assessment of flow regime changes in the smaller stream due to natural changes and higher consumptive uses,
- Pumped- storage hydropower plants, and
- Watershed protection.</td></tr>
</table>

A brief reflection:

The hydropower sector is investing in new locations and in improving the robustness and resilience of their infrastructure against higher future variability in river flows. Therefore, reservoir storage is planned to be added to bridge periods of dry spells, dam safety is audited and measures are taken to better protect against peak flows and sediments.

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