CLIMATE CHANGE VULNERABILITY ANALYSES AND MAPPING FOR NATIONAL ADAPTATION PLAN (NAP) FORMULATION PROCESS IN BHUTAN

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Glossary of Bhutanese Terms

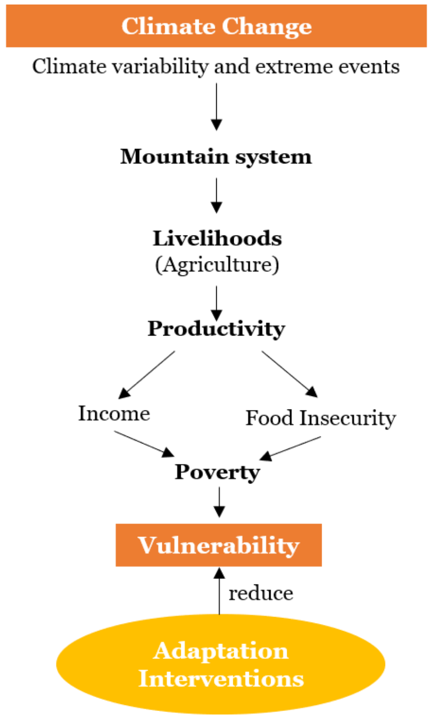
Chiwog	Village or a group of few hamlets
Dzongkhag	District
Drungkhag	Sub-District
Gewog	A county, the lowest government administrative unit, made up of a group of villages.
Gups	Head of the Gewog
Thromde	Municipality

List of Acronyms

AWS	Automated Weather Stations
CCVA	Climate Change Vulnerability Assessment
CI	Climate Information
COP	Conference of Parties
CSOs	Civil Society Organizations
CNDP	Comprehensive National Development Plan
DDM	Department of Disaster Management
DGM	Department of Geology and Mines
DoFPS	Department of Forests and Park Services
DHPS	Department of Hydropower and Power Systems
DRE	Department of Renewable Energy
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EWS	Early Warning System
FYP	Five-year plan
GBCL	Green Bhutan Corporation Limited
GCF	Green Climate Fund
GCM	General Circulation Models
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GLOF	Glacial Lake Outburst Flood
GNH	Gross National Happiness
IPCC	Intergovernmental Panel on Climate Change
LDC	Least Developed Country
LEG	Least Developed Countries Expert Group
LGs	Local Governments
LUCs	Linked Urban Centres
MoAF	Ministry of Agriculture and Forests
MoEA	Ministry of Economic Affairs
MoF	Ministry of Finance
MoHCA	Ministry of Home and Cultural Affairs
MoIC	Ministry of Information and Communications
MoLHR	Ministry of Labor & Human Resources
MoWHS	Ministry of Works and Human Settlement
NAP	National Adaptation Plan
NCHM	National Center for Hydrology and Meteorology
NCWC	National Commission for Women and Children
NDCs	Nationally Determined Contributions
NEC-S	National Environment Commission Secretariat
NSB	National Statistics Bureau
PRECIS	Providing Regional Climates for Impacts Projects
RCPs	Representative Concentration Pathways
RGoB	Royal Government of Bhutan
RUB	Royal University of Bhutan
SEA	Strategic Environment Assessment
SEVI	Socio-Economic Vulnerability Index
SDGs	Sustainable Development Goal
SSP	Shared Socioeconomic Pathways
TCB	Tourism Council of Bhutan
TWG	Technical Working Group
UN	United Nations
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMD	Watershed Management Division

1. Introduction

Climate change, including climate variability and extreme events can directly and indirectly impact on the environment and socio-economic sectors like agriculture and food security, water resources, human health, terrestrial ecosystems and biodiversity (Field, 2014). Mountains, the rich repositories of biodiversity and water and providers of ecosystem services, are among the most sensitive regions to climate change impacts. Rising temperatures, seasonal shifts in glacier and snowmelt induced runoff, and increased frequency of extreme events are threatening the lives and livelihoods of people living in the mountain regions. The changes in the precipitation pattern and magnitude impacts the flow regimes across Bhutan under climate change context (TNC, 2020). This impact on water flow and availability is a concern for drinking water supply, agricultural production and hydropower generation. More so because, a large population depends on spring water for drinking and irrigation purposes (TNC, 2020). Thus, water availability is under threat with declining and varied precipitation pattern.



The Intergovernmental Panel on Climate Change mentions that by 2100, South Asian countries, including Bhutan, will experience increase in average temperatures, with increases in daily minimum and maximum temperatures, mostly taking place at higher altitudes (IPCC, 2014). This is also confirmed by detailed analysis conducted by the NCHM (2019). Climate change vulnerability and risk assessment calls for due consideration to differentiated gendered impacts. Vulnerability is caused by various factors as mentioned and hence different groups are thus differently vulnerable based, in part or in whole, or their gender, age, social status, health and wealth/poverty; on disability or other social cultural characteristics (UNDP, 2016). Climate change is disproportionately harsh on vulnerable groups, majority being rural communities, particularly women. The study, "Gender and Climate Change in Bhutan with a Focus on a Nationally Determined Contribution Priority Areas: Agriculture, Energy and Waste" published by National Commission of Women and Children (NCWC) in partnership with UNDP (2020), revealed, "Gender differences are visible with respect to CC vulnerability, participation in CC decision making and action, and in diverse levels of benefit sharing. The responsibilities held by women become more difficult, productivity decreases, and women and girls are disproportionately affected with male out migration, violence and sexual exploitation, health problems, and deteriorating working conditions".

Additionally, recent studies as part of the current NAP programme[1] also shows that Bhutan will experience more extreme weather events (both more extreme and with increased frequency), but impacts are likely to be incremental in the near future and will only become more evident in the coming decades (NCHM, 2019). In this situation, there is a need to conduct the climate change vulnerability/risk assessment in Bhutan.

1.1. Bhutan and Climate Change

Bhutan, a landlocked least developed country (LDC) in the Himalayan mountains with a population of 727,145 (PHCB, 2017) of covering an area of 38,394 sq. km, is highly vulnerable to climate variability and extreme events due to the very active geological conditions, great variations in slope, high-elevation terrain (WWF, 2011). Climatic events, such as heavy rainfall, are becoming more common and lead to floods, erosion and landslides in Bhutan. Apart from this, the mountainous region is becoming increasingly susceptible to glacial lake outburst floods (GLOFs), which are thought to be a result of glacial melting due to climate change (Gurung et. Al, 2017). These climatic hazards are affecting a range of sectors in Bhutan. The decrease in agricultural crop yields,

[1] Climate data report, Deltares for UNDP and NECS Bhutan, 2021 (draft as of May 2021), NAP climate risk study for water.

hydropower generation due to changes in water distribution and glacial lake outburst floods leads to loss of lives and infrastructure, as well as threats to biodiversity due to species migration, invasive species and increasing propensity for forest fires in Bhutan. People in Bhutan are primarily dependent on natural resources, facing multiple challenges associated with climatic hazards and under development (Johnson & Hutton, 2014). Globally, there is tendency for women and girls to depend more on natural resources for their livelihoods which also lends itself to increased vulnerability. This also resonates with Bhutan as the agriculture sector continues to be dominated by women with "the proportion of females (58.8%) working in the agriculture sector being higher than that of males (41.7%)" (NSB, 2020). This indicates that Bhutanese women also face increased vulnerability.

However, existing studies[2] do not fully address quantifying the impacts and understanding "how big a problem this is." This is mostly due to:

- Limited by inadequate climate projection scenarios, representation at finer spatial scales and data coverage for top-down models;
- Limited to community perceptions on vulnerabilities and impacts and expert judgement that do not necessarily quantify the outputs for bottom-up models;
- Scope is limited to adequately represent each sector's vulnerabilities and impacts across different geographical regions such as Dzongkhags etc.
- Lack of information on the Dzongkhag level socio-economic vulnerability

Therefore, the detailed vulnerability/risk assessment is required to address all of the above-mentioned points. This assessment can help to identify climate change impact hotspots (vulnerable regions and communities) to provide inputs for successful adaptation measures and strategies in Bhutan. In doing so, gendered vulnerability will also be assessed.

1.2. Understanding of the objectives

The objective of this assignment is to complement climate hazard assessments conducted for Bhutan with analyses and mapping of vulnerability at Dzongkhag level, with a focus on socio-economic and non-climatic, development data with view of enhancing the understanding of the scale of impact of climate change and providing actionable information about the social and economic impacts of climate change to inform adaptation planning. The key focus here is how socio-economic vulnerability will increase/decrease in the short and long term taking into consideration existing climate hazard and projection data. Along with the socio- economic and environmental vulnerability, gender is a key determinant of understanding gendered impacts leading to vulnerability. Hence the assessment deems necessary in gauging the gender differentiated population at risk in the vulnerable Dzongkhags.

1.3. Methodology

Many different methods and approaches have been used to quantitatively assess the vulnerability and risk at different scales (Cutter et al., 2003; O'Brien et al., 2004; Polsky et al., 2007; Hahn et al., 2009; Nguyen, 2015; Armas and Gavris, 2016; Žurovec et al., 2017; Das et al., 2020). In this study, Risk and Vulnerability indices were constructed at the Dzongkhag level.

The first step for a climate change vulnerability assessment (CCVA) with a focus on socio-economic factors is to develop impact chains based on existing literature and studies. Impact chains are a good foundation for a qualitative vulnerability assessment. An impact chain describes a cause-effect-relationship among elements that contribute to the consequences of a given combination of hazard and exposed system. Impact chains were then updated as per a detailed list of indicators. As far as possible the team aimed at gathering gender disaggregated data, where relevant. These indicators were mapped to their respective stakeholders with the assistance of national consultants. This list of indicators was filled up with the existing publicly available data sources and reports. In parallel, stakeholder consultations were undertaken to assess if the indicator data is available or not

[2] Such as the NCHM (2016), TNC (2020), ADB (2014)

(Annexure 1). Once this was completed the vulnerability index was calculated and followed by subsequent preparation of GIS maps. The training of TWG and validation workshop will take place in due time. For the training of TWG (Technical Working Group), the team will try to ensure equal participation of men and women.

It is important to note that while there is less availability of climate data (hazard) and socio-economic data (as depicted in the Annexure 2) in Bhutan it is possible to move ahead with vulnerability assessment. For the NAP process, it is important that the climate vulnerability assessment helps establish a broad consensus about climate change hazards in the Dzongkhags and its likely impacts. Moreover, the focus of a socio-economic vulnerability assessment is more on exposure, adaptive capacity and sensitivity indicators of the object. Therefore, data and information availability on those parameters are key and more important for this assessment. The team has therefore selected ideal indicators that specifically cover more vulnerable population such as women, children, disabled people and elderly. Additionally, people engaged in agriculture was also considered as a sector as it is a climate sensitive sector.

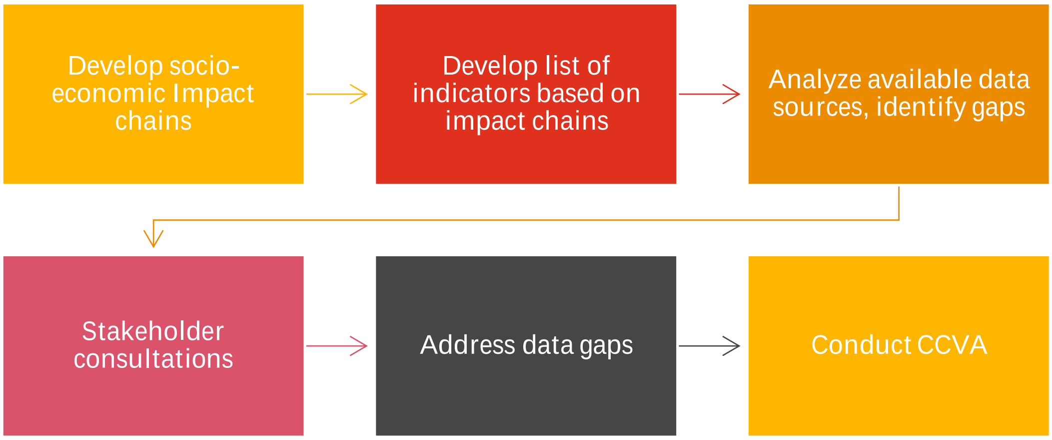


Figure 1: Process for the CCVA

The vulnerability and risk assessment are based on the Climate Change Risk Assessment Framework as per the fifth assessment report (AR5) of Intergovernmental Panel on Climate Change (IPCC). The framework is depicted below:

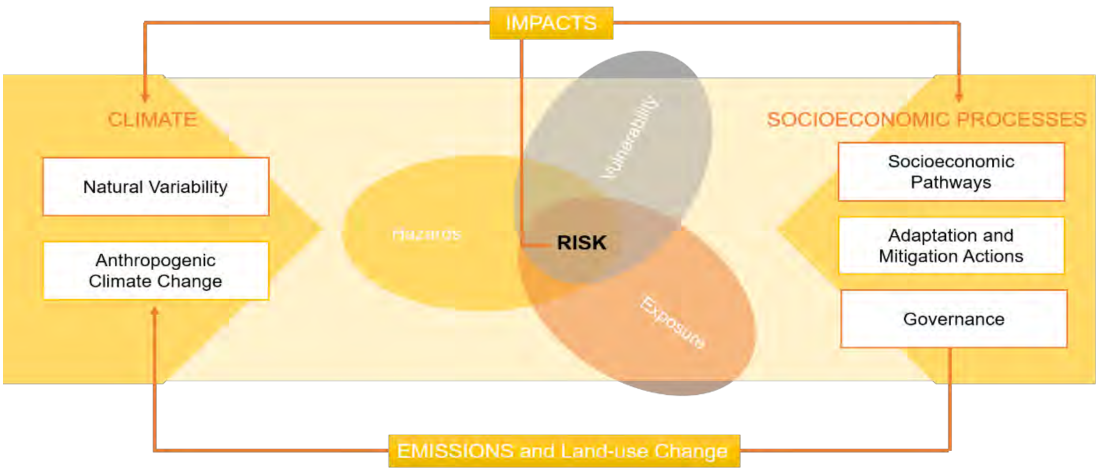


Figure 2: The contributing factors of Risk (adapted from IPCC AR5, 2014, P.1046)

Risk (or impact) (R) is a function of hazard (H), exposure (E) and vulnerability (V). It is used primarily to refer to the risks of climate-change impacts (IPCC, 2014).

$$R = f\ (H, E, V)$$

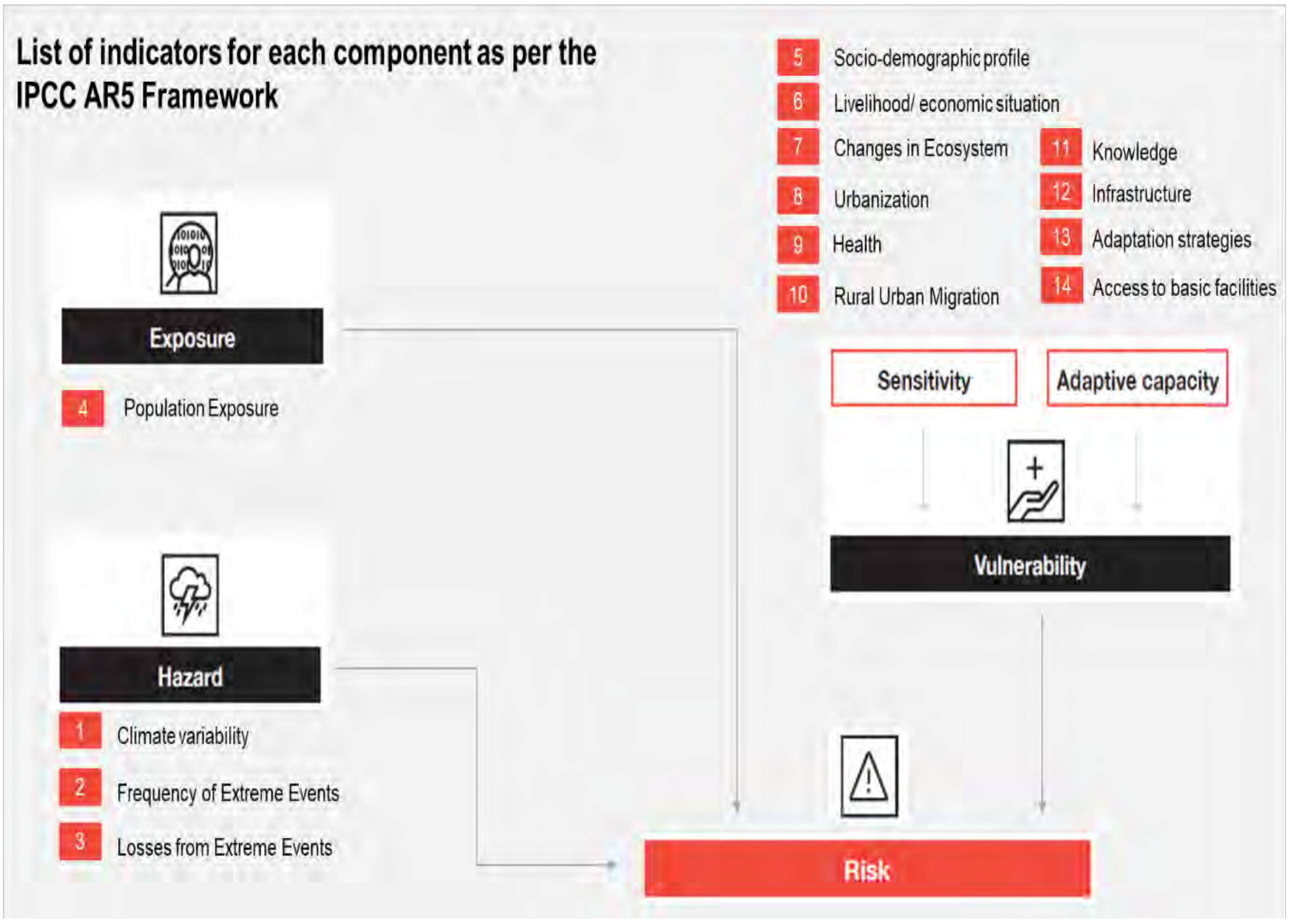
Table 1: Risk and its components

<table>
<tr><th colspan="2">RISK</th></tr>
<tr><td colspan="2">The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.</td></tr>
<tr><th>Hazard</th><th>Exposure</th></tr>
<tr><td>The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. Potential climate hazards could be heatwaves, sea level rise, heavy rainfall events, GLOFs etc.</td><td>The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.</td></tr>
<tr><th colspan="2">Vulnerability</th></tr>
<tr><td colspan="2">The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.</td></tr>
<tr><th>Adaptive capacity</th><th>Sensitivity</th></tr>
<tr><td>The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences of climate change.</td><td>Predisposition of society and ecosystems to suffer harm as a consequence of intrinsic and context conditions making it plausible that such systems once impacted will collapse or experience major harm and damage due to the influence of a hazard event.</td></tr>
<tr><td colspan="2">Source: IPCC AR4 (2007), AR5 (2014)</td></tr>
</table>

It is understood that risk includes an external dimension, which is climate-related stress (e.g. weather extremes) represented by the "hazard", as well as an internal dimension, which comprises "exposure" and "vulnerability (sensitivity and adaptive capacity)". The internal dimension describes the moderating attributes (socio-economic, physical or environmental) of the system.

$$R = f\ (H, E, S, AC)$$

In the present study, we have examined climate change vulnerability using its major components and their location-specific sub-components. Major components, namely, demographic, social, economic, food and water, and infrastructural components were used to examine the degree of sensitivity and adaptation. The climate change risk assessment (CCRA) framework and its indicators can be summarized as per the figure given below:



Risk as a function of hazard, exposure, sensitivity and adaptive capacity

The following steps were followed to calculate the vulnerability and risk for all the Dzongkhags of Bhutan:

Step 1: *Development of impact chains and Selection of Indicators:* Impact chains help understand the factors that drive vulnerability in a system and their cause-and-effect relationship. These were developed based on the key functions of Risk, Hazard, and Vulnerability. Further the indicators to be considered for hazards, exposure, sensitivity, and adaptive capacity components were identified and data was obtained for them.

Step 2: *Descriptive statistics:* After the collection of data, the team prepared a descriptive statistics table that described the basic features of the data. The descriptive statistics provides a useful and simple summary of all types of data used in this study. (Attached as Annexure 4).

Step 3: *Normalization of data:* The data was normalized (N) by removing the units and converting all the values into dimensionless units that are expressed as values between 0 and 1.

$$N_{ij}^{p} = \frac{Xij - Min\ i\ (Xij)}{Max\ i\ (Xij) - Min\ i\ (Xij)} \text{...................... (1) (HDI, UNDP, 2007)}$$

Where, *Xij* is the actual value, *Max i (Xij)* and *Min i (Xij)* are maximum and minimum values, respectively.

Step 4: *Major component:* After normalization, the indicators (sub-components) were averaged using the formula of *simple arithmetic mean* to get the value of average index (AI) for each major component:

$$AI = \sum N_{ij} / n \text{................ (2) (Hahn et al., 2009)}$$

Where, AI is the value of average index for major components, Nij represents the normalized value of indicators /sub-components and n is the number of indicators in each major component.

Step 5: *IPCC Contributing factors:* The major components as described in the earlier step were multiplied with a balanced weighted method allocated to get the values of IPCC contributing factors (Hazard, Exposure, Sensitivity and Adaptive capacity).

$$CF = \sum (W_i \; x \; A_i)/\sum W_i$$ .... (3) (Sullivan et al., 2002)

Where, Ai is the major component and Wi is the weight of each major component.

Weighting methods vary (Hahn et al., 2009). Eakin and Bojorquez-Tapia (2008) mentioned that equal weighting makes an implicit judgment about the degree of influence of each indicator. Vincent (2004, 2007) and Sullivan et al. (2002) suggest expert opinion and stakeholder discussion, respectively, to determine weighting schemes.

Present study uses a weighted arithmetic aggregation (Fritzsche et al., 2014) or balanced weighted average approach (Sullivan et al., 2002) where each sub-component contributes equally to the overall index even though each major component is comprised of a different number of sub-components. This is based on the underlying assumption that all sub-components included in the conceptual framework are equally important (Lindén, 2018). Weighted arithmetic aggregation method is a common, simple and transparent aggregation procedure in risk and vulnerability analysis (Fritzsche et al., 2014).

Step 6: *Vulnerability Index:* The values of sensitivity and adaptive capacity were aggregated to obtain the vulnerability index (VI) value for all the Dzongkhags of Bhutan. There are different approaches to calculation of vulnerability. A simple VI was calculated based on the following major components: Socio-demographics, Economic situation, Health, Knowledge, Infrastructure, Basic facilities
Aggregation of the value of sensitivity and adaptive capacity values was done as per the formula given below:

$$VI = \frac{Sensitivity}{Adaptive\ capacity}$$ .... (4) (Subiyanto et al., 2020)

Socio-economic vulnerability index (SEVI) is same as vulnerability index (VI).

Step 7: *Risk Index:* The values of IPCC contributing factors were aggregated to obtain the risk index value for all the Dzongkhags of Bhutan.

$$RI = Hazard \; x \; Exposure \; x \; \frac{Sensitivity}{Adaptive\ capacity}$$ ....(5) (Subiyanto et al., 2020)

Step 8: *Vulnerability and Risk Mapping:* The value for risk/vulnerability index ranges from 0 to 1, with higher values reflecting higher degree of risk/vulnerability. The entire range was divided into five categories and assigned a qualitative indicator of risk (from very low to very high) (Žurovec et al., 2017).
Quantile classification method was used in vulnerability and risk mapping. In a quantile classification, each class contains an equal number of features. Quantile assigns the same number of data values to each class. There are no empty classes or classes with too few or too many values. The template for the risk matrix was prepared for the Dzongkhags.

1.3.1. Stakeholder Consultations and Data Sources

Based on existing studies that were reviewed, a set of 41 indicators were identified for analysis. These were, as mentioned earlier, finalized after consultations with stakeholders to confirm their availability at the Dzongkhag level. Besides consultation, data for the 41 indicators used for the climate risk and vulnerability analysis for Bhutan were collected from the following sources for the years 2005-2017: Population Housing and Census, Dzongkhag at a Glance, Statistical Yearbook, Bhutan Living Standard Survey, RNR statistics report, Land use Landcover assessment report from 2010 and 2016 obtained from National Land Commission, Annual Report of Tourism Council of Bhutan. Climate hazard data was provided by data from Department of Disaster Management (DDM) under MoHCA. The list of stakeholders engaged for data collation have been given in Annexure 1. The list of indicators and their reference studies for selection are listed in the Annexure 2. The data source for the indicators is also provided.

The team mapped the vulnerability and risk of the communities in Bhutan using the available secondary data. The National Consultants also conducted consultations with Asst. Environment Officers (AEO) and Gewog Administrative Officers (GAOs) in order to validate climate hazards at the Gewog level.

The historical climate data consists of two key indicators of climate - temperature and rainfall. The standard deviation method has been used to capture the year-to-year changes from 1996 to 2020 for observed data for all 20 Dzongkhags, provided by NCHM.

1.3.2. Future Projections

There were three level of projections that were done for this assignment:

1. Climate Variability (Hazard)
2. Population (Exposure)
3. Socio-economic Indicators (Vulnerability)

Climate Projections: For the climate change projections data on maximum temperature, minimum temperature and rainfall, was obtained for near-, mid-, end-century for two Representative Concentration Pathways. The future climate projection data is from the GCM Ensemble data that was reviewed by Deltares for the ongoing *Assessment of climate risks on water resources for National Adaptation Plan (NAP) formulation process in Bhutan* along with comparison with observed data from NCHM.

The following climate emission scenarios have been used for future climate risk assessment.

Scenario Name	Scenario 1 RCP4.5	Scenario 2 RCP 8.5
Description	• Optimal Scenario where emissions peak around midcentury at around 50% higher than 2000 levels and then decline rapidly over 30 years and then stabilise at half of 2000 levels. • CO_2 concentration continues on trend to about 520 ppm in 2070 and continues to increase but more slowly. • Population and economic growth are moderate • Total energy consumption is slightly higher, while oil consumption is fairly constant through to 2100. Nuclear power and renewables play a greater role.	• Business As Usual (BAU) scenario in which emissions continue to increase rapidly through the early and mid-parts of the century. • Concentrations of CO_2 in the atmosphere accelerate and reach 950 ppm by 2100 and continue increasing for another 100 years. • Population growth is high, reaching 12 billion by centuries end. • This scenario is highly energy intensive with total consumption continuing to grow throughout the century reaching well over three times current levels; Fossil fuel use grows rapidly until 2070 after which it drops even more quickly. Coal provides the bulk of the large increase in energy consumption
Reference	World Bank CCKP, 2020	

Population Projections: For the Future Risk and Vulnerability assessment, the Bhutan Population Projections by NSB (2019) were used primarily. These are available at 5-year intervals. Additionally, for the Future Risk Model 3 population projections with policy were used from the Comprehensive National Development Plan for Bhutan 2030. In this case, internal migration in relation to several regional development projects, namely, industrial estate development in Sarpang, Samtse, Samdrup Jongkhar, Monggar and other dzongkhags, is considered based on the positive impacts from the proposed Linked Urban Centres (LUCs) as per the CNDP 2030, which is based on the strategy for national spatial structure and the Alternative G of Alternative Development Pathways developed in the CNDP 2030.[3] The new population numbers are taken into account by assuming the increase in in-migrants or the decrease in out-migrants by 25% towards 2030/2050 within the dzongkhags, which comprise the LUCs.

Socio-economic Indicator Projections: Due to limited socio-economic data points from two Census years (2005 and 2017), all the socio-economic indicators were projected using the absolute rate of change. While for

[3] Under the CNDP 2030 project a Strategic Environmental Assessment (SEA) was undertaken for assessing the environmental and social implications of Policies, Plans and Programmes (PPPs). Six prototypes were been elaborated for the development alternatives, which effectively represent the full spectrum of development possibilities available to the country taking into consideration the CNDP 2030. Each of the alternatives represented a reasonable, realistic and relevant development pattern. It was concluded that Alternative G is the most preferable (the best) alternative of all the development alternatives. Alternative G would prioritize both economic growth and the conservation of culture and tradition in Bhutan. This alternative will be most effective for tackling existing social issues in Bhutan. The negative impacts will be moderate as compared to others. Therefore, it was considered for the current assessment.

the present and future social-economic vulnerability maps were prepared at the Dzongkhag level, wherever data was available Gewog level maps were also prepared.

For Future Risk Model 3, Local Governments Key Result Areas (LGKRAs) and National Key Result Areas (NKRAs) as per the 12th Five Year Plan were reviewed to calculate the rate of change required to reach development targets by 2023. Access to electricity and Area under Irrigation were two indicators that were used from these plans as these relate directly to increase in adaptive capacity (Elaborated in Section 2.3.3). Further the DoA Agriculture Statistics (2015) indicates that 28% of households have difficulties with insufficient irrigation supply. Therefore, targets from the National Irrigation Master Plan (2016) were considered as they aim to expand by 10,800 ha of irrigated land by 2032 through existing irrigation improvement project and new irrigation system development.

Additionally, GDP growth rate projections as per the Comprehensive National Development Plan (CNDP) for Bhutan 2030 and Shared Socioeconomic Pathways (SSPs): SSP1: Sustainable Pathway, developed by the International Institute for Applied Systems Analysis (IIASA), Austria and the National Center for Atmospheric Research (NCAR), United States was reviewed. As per both studies, the estimated average annual GDP growth rates between 2018 and 2023, and between 2023-2030 are about 5.5% and 6.9%, respectively. Considering both SSP1 and CNDP 2030, GDP growth rate of 6% was considered as a proxy indicator for increasing overall adaptive capacity.

Following indicators were used for the future projections:

Contributing Factor	Component	Indicator	Source of Rate of Change
Adaptive Capacity	All other indicators		GDP growth rate proxy as per CNDP 2030 and SSP1
	Access to basic facilities / Household amenities	Area Under Irrigation	Dzongkhag Key Result Areas from 12th FYP, NIMP (2016)
	Adaptation strategies	Access to electricity enhanced	Dzongkhag Key Result Areas from 12th FYP
Exposure	Community & Land cover	Population density	CNDP 2030, NSB (2019)

1.3.3. Time Slices

Future Risk and Vulnerability assessments were conducted for 2022, 2027, 2032, 2037, 2042, 2047 and 2050 taking 5-year intervals as similar to the population projection study by NSB. This was done to keep the findings and assessment aligned to the census years.

Present		Future	
Vulnerability	Risk	Vulnerability	Risk
2017		2022, 2027, 2032, 2037, 2042, 2047, 2050	

1.3.4. Confidence Level and Limitations

For all the indicators government sources were used to avoid any data discrepancies. Analysis at temporal scales beyond 2050 was not possible due to the limited historical data since doing so may have a high forecast error. It is also understood that new development plans such as the 21st Century Economic Roadmap may drive the development trajectory and drive investments and future growth at national and sub-national levels. This may change the projected risk as per this study. However, the indicators and framework used in this study can be used to update the assessment.

Global shocks such as pandemics, technological breakthroughs, economic crises and other natural or human-made disruptions (so-called 'wildcards') are irregular but expected features of socioeconomic development.

However, the projections in this study assume there are no ‘wildcard’ events. These trends or events have low probabilities of occurrence (under 10%) or probabilities that cannot be quantified.

- Model 1 and 2: Socio-economic growth with and without climate change: The projected SEVI pertaining to the socio-economic growth without climate change is projected to sustain the trend of an index ($\bar{X} = 1.38; \sigma_X = 0.02; SE = 0.01$) with 95% significance level ($CI@95\% = [1.36 - 1.39]$). The mean annual SEVI is expected to stand at 1.38 with std. deviation of 0.02 and standard error of 0.01. The confidence interval of mean is computed, and the index is expected to lie between 1.36 and 1.39 if projected again with fresh data.
- Model 3: Growth with adaptation pathways: Future Risk (RCP 4.5): Similarly, the projected future risk with adaptation pathways’ index trend will sustain ($\bar{X} = 0.064; \sigma_X = 0.009; SE = 0.004$) at 95% level of significance ($CI@95\% = [0.05 - 0.07]$). Conversely, the index trend for RCP 8.5 will sustain over the projected years ($\bar{X} = 0.056; \sigma_X = 0.008; SE = 0.003$) at 95% level of significance ($CI@95\% = [0.05 - 0.06]$).
- Estimated population at risk: The number of people projected to be at risk in the future ($\bar{X} = 3{,}99{,}462; \sigma_X = 55{,}344; SE = 20{,}918$) is significant at 95% level ($CI@95\% = [3{,}58{,}462 - 4{,}40{,}461]$).

The difficulty in identifying potential impacts in terms of frequency and volume of extreme climate events, limited availability of annual data for indicators at Dzongkhag and Gewog level; and uncertainties in cause-and-effect relationships are some of the limitations for the risk assessment.

2. Dzongkhag-Level Vulnerability and Risk Assessments

Vulnerability and risk assessments are often designed to support and improve adaptation planning, with the overall objective of reducing vulnerability in the region or sector under consideration. Selection of adaptation measures can be based on the assessment of drivers of vulnerability with their index value. Thus, this impact chain helps understand the drivers of vulnerability and risk for developing targeted adaptation planning to reduce vulnerability. The impact chain that describes the relationship between the factors that drive vulnerability in Bhutan is presented in the Figure 3 below:

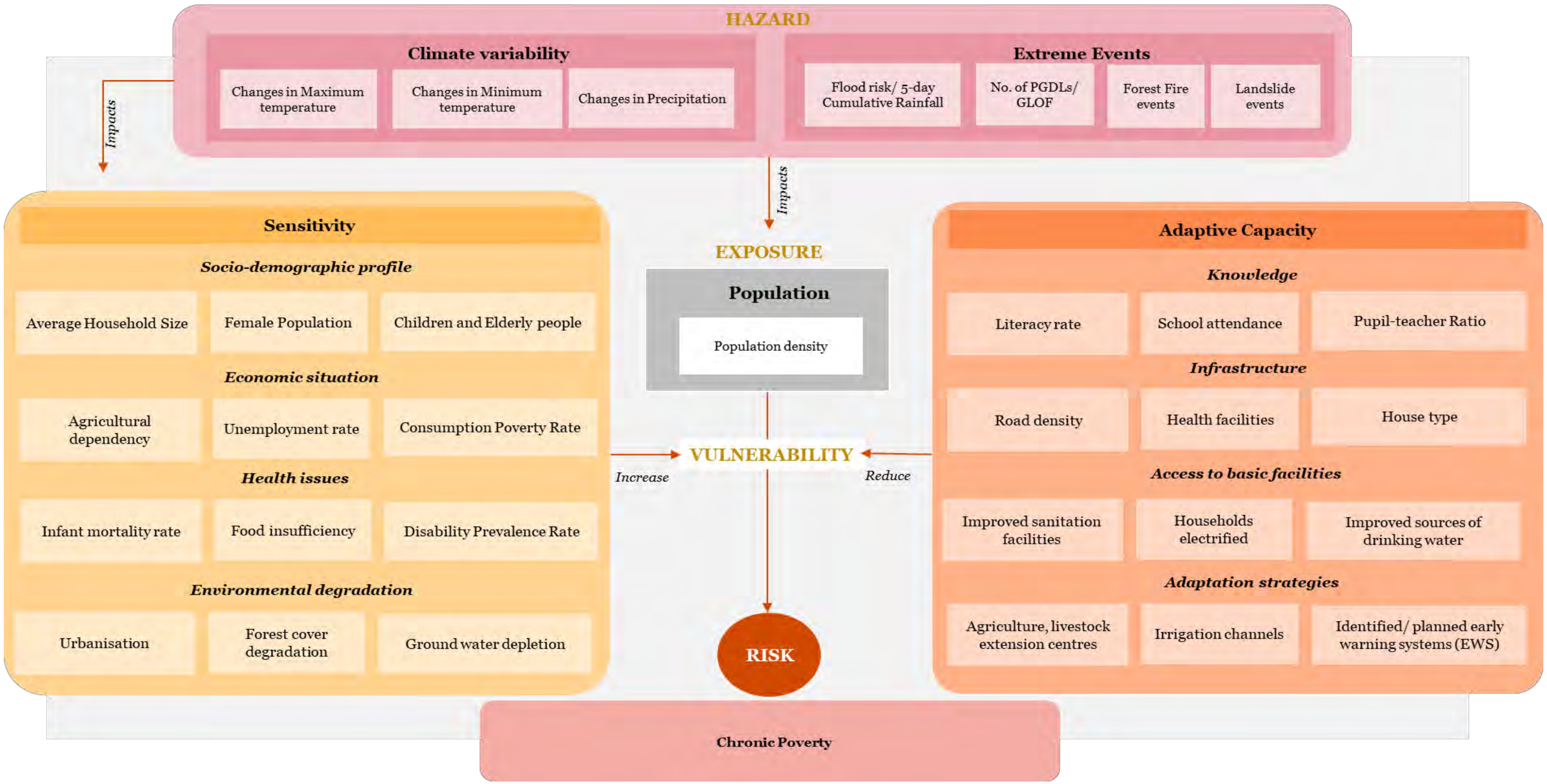


Figure 3: Socio-economic Climate Change Impact Chain (Developed by PwC)

All the risk components (except adaptive capacity) are scored at three levels that are colour coded from green (low) to red (high). This ranking is also used to highlight Dzongkhags that are higher or lower for each of these factors. These ranks can be understood as follows:

- Low: Refers to Dzongkhags that will adjust to climate induced shock/hazard without any disruption to its livelihood/ economy baring some minor adjustments. Such a Dzongkhag will be able to adjust to extreme events (for example by using its capital assets) without needing significant external support.
- Moderate: Refers to Dzongkhags that require some level of external assistance to overcome the given shock.
- High: Dzongkhags in this category can be likened to an intensive care situation in a hospital. These Dzongkhags may require expert assistance to recover from the impacts of shocks. It may be understood that without timely support during disasters high vulnerability Dzongkhags/ households may become defunct (IDRC, 2016).

The basic features of the data can be reviewed through looking at the descriptive statistics table given in Annexure 3.

2.1. Hazard

As per the impact chain described earlier following are the three major components and its indicators used to assess hazards for each of the Dzongkhags: Climate variability, Extreme weather events (that may cause loss of life, injury, or other health impacts, as well as damage and loss of property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources) and number of deaths from these climate-induced disasters in the past 10 years.

The climate variability profile analyses the changes in two important indicators of climate - temperature and rainfall. The standard deviation method has been used to capture the year-to-year changes from 1996 to 2020 for observed data for the two parameters. This was provided by NCHM.

Table 2: List of Indicators for Hazard Index

IPCC Risk Framework (2014)	Major Components	Sub-components (Indicators)	Unit	Rationale for selection
Hazard	Climate variability	*Average Maximum Temperature (standard deviation)*	Celsius	Changes in temperature and precipitation are the key drivers for climate impacts
		Average Minimum Temperature (standard deviation)	Celsius	
		Average precipitation (standard deviation)	MM	
	Extreme events	*Landslide impacted area*	Acre/ %	Frequency of extreme climate events and the area that is impacted add to the overall socio-economic impacts from climate change. These have been calculated as an average over the past 10 years.
		Flood Impacted Area	Acre	
		Hailstorm impacted area	Acre	
		GLOF impacted area	Acre	
		Windstorm s impacted houses	Acre	
		Total forest area impacted by wildfire	Acre	
	Impact	*No. of deaths due to climate disaster last 10 years*	Number	Number of deaths illustrates the impact of climate disasters.

		Houses damaged in last 10 years due to climate disasters	Number	
		Total financial losses due to climate disasters	Ngultru m	

The average yearly temperature data for the Dzongkhags of Bhutan shows that majority of the Dzongkhags have observed an increasing trend. Greater increase has been observed in lower/ southern Bhutan as compared to the rest of the country. In terms of climate variability, change in maximum and minimum temperature, over the period from 1996-2020 we see Trongsa and Chhukha experienced most change, closely followed by Lhuentse and Dagana.

Based on the analysis of CRU data which was considered as representative of historical data by NCHM, it has revealed a decreasing trend in rainfall at mean annual scales with high variability (NCHM, 2021). It showed wet summer monsoon (JJAS) and dry winter (DJF) season. It can be inferred that the rainfall amounts are highest for the summer season (JJAS) while the other seasons are less, highlighting an increasing intensity of rainfall. The variation is also more in the southern belt of the country. The Bhutan State of Climate describes climate data of 2020 when compared with the long-term average and not the trend. This variability is also visible as per the Figure 4 below.

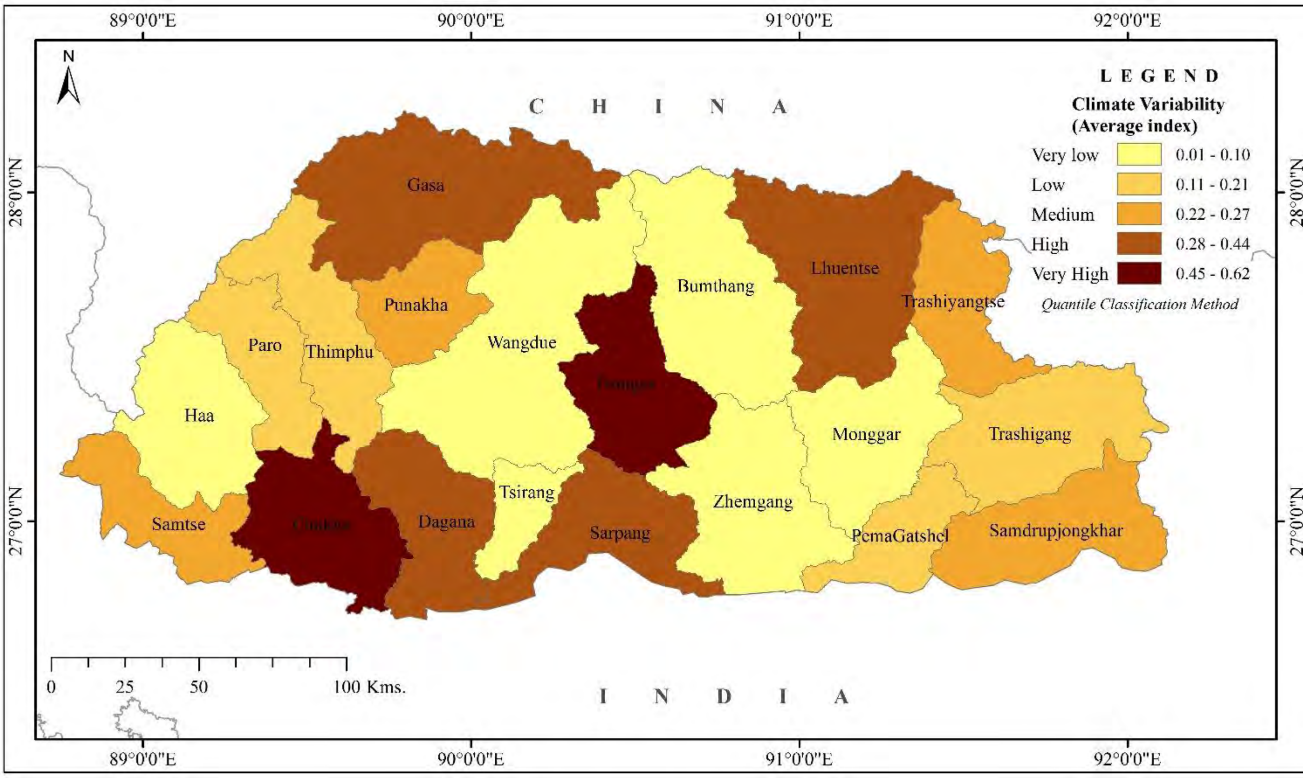
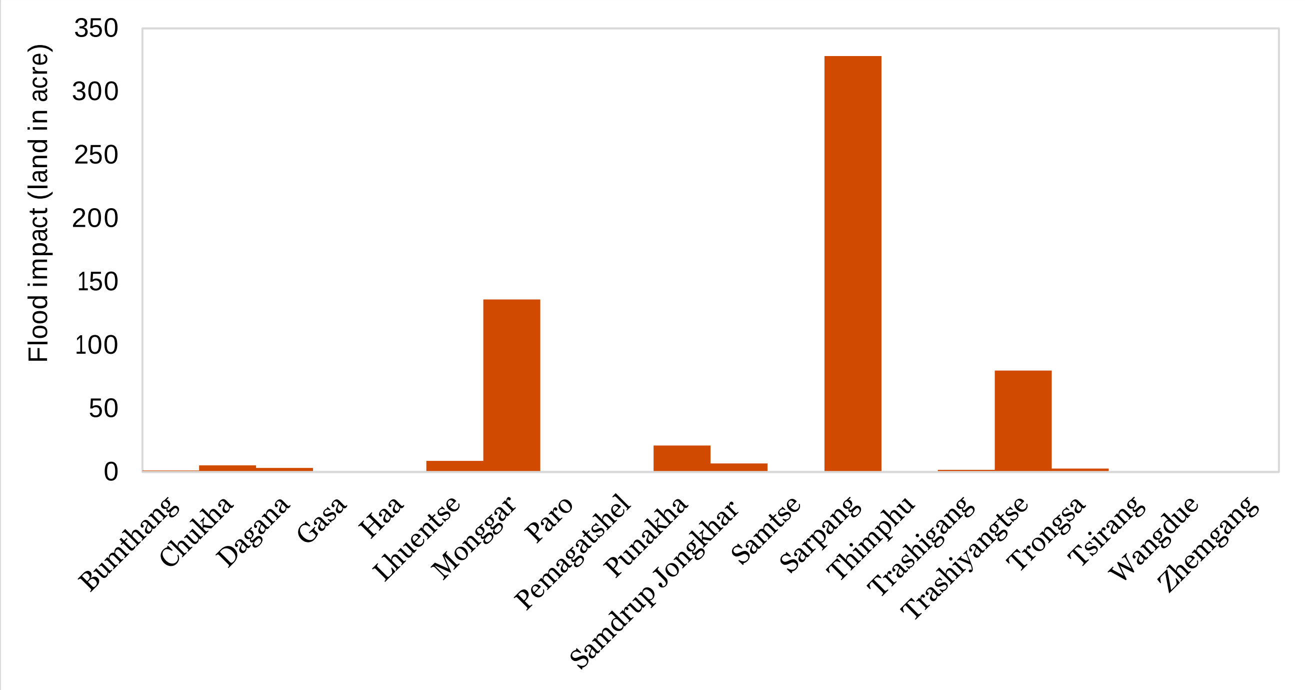


Figure 4: Climate Variability Map

GLOF hazard has only been experienced in Punakha Dzongkhag. But as per the NCHM/DGM (2019) assessment, there are 17 Potentially dangerous glacial lakes, with a major of nine lakes in the Pho Chhu sub basin, three in Mangde Chhu sub basin, two in Mo Chhu sub basin, two in Chamkhar Chhu sub basin and one in Kuri Chhu sub basin. This presents a future hazard risk for Gasa, Lhuentse and Bumthang. Further these impacts may have 'knock on' effects on communities and infrastructures downstream affecting agriculture land, heavy critical infrastructure like hydro projects, bridges, national highways, and new townships like Bajo.

Bhutan has experienced several flash floods during monsoon, especially in the southern foothills. It has caused several damages to agriculture land, settlements etc. affecting the livelihood of habitants. Sarpang is high on the hazard component due to flood risk.



Forest fires and hailstorm area affected in Monggar have added to its high level of hazard besides the number of deaths due to these events (DDM,2020). Samtse is very high on the hazard component due to landslide risk.

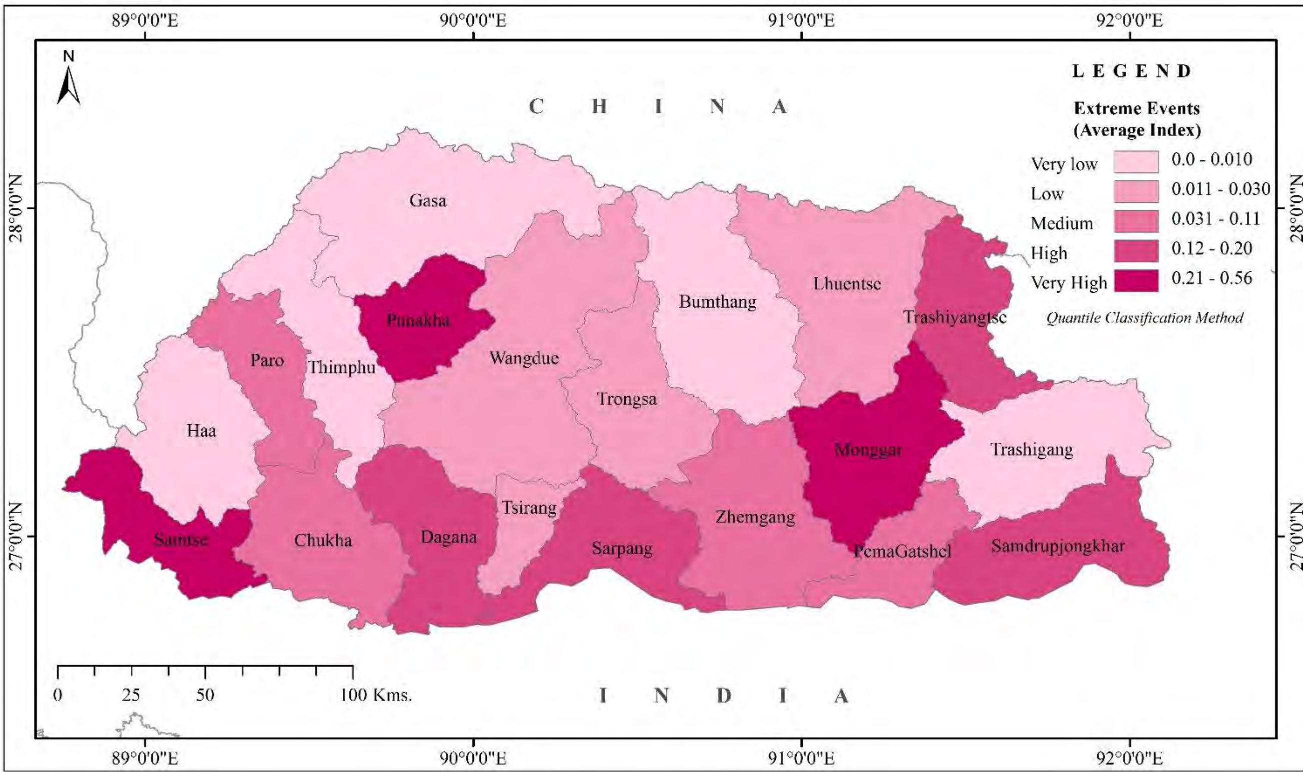


Figure 5: Extreme Events Map

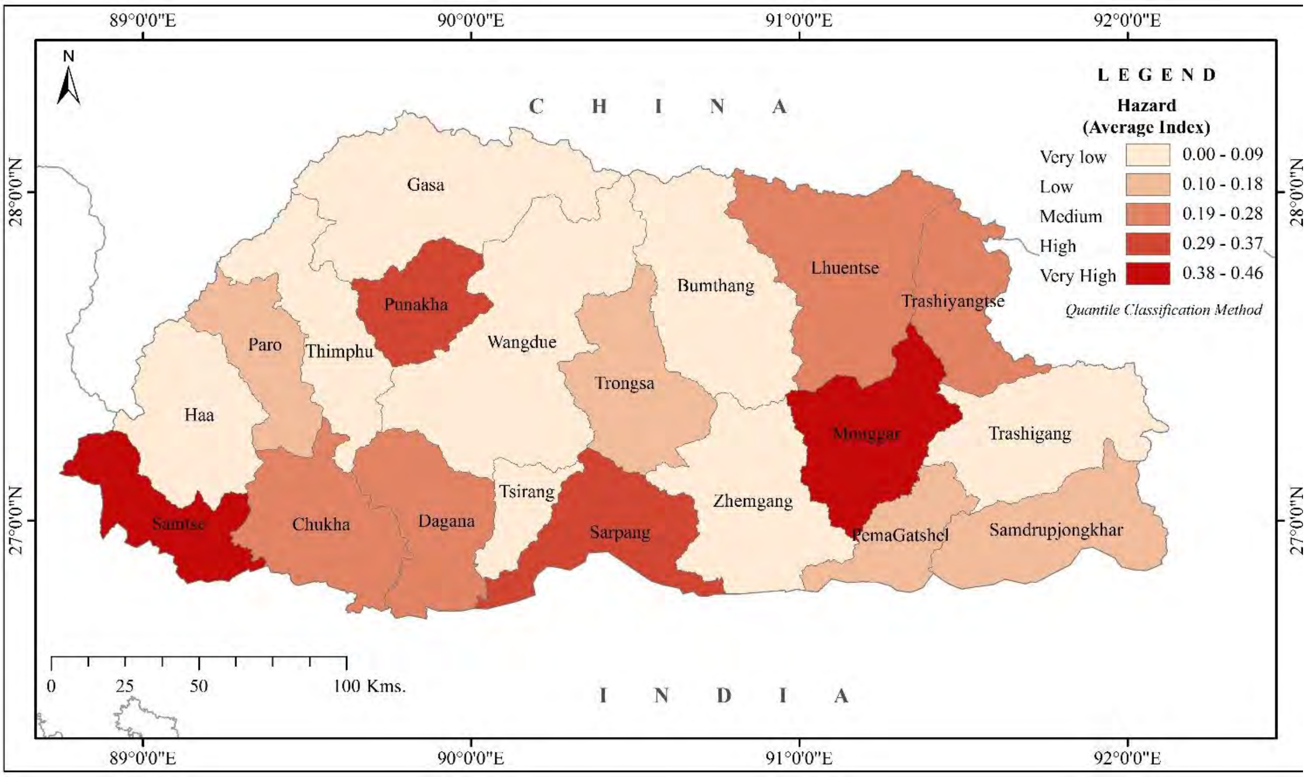


Figure 6: Hazard Index Map

The overall climate hazard ranking brings Monggar, Sarpang and Samtse at the highest. The least affected Dzongkhags from extreme climate events and climate variability are Bumthang, Thimphu, and Tsirang.

2.2. Exposure

The exposure component encompasses two broad elements – population and the landcover/ environment. The current analysis uses population density as its key component, as socio-economic vulnerability directly impacts the community itself. Population as a whole has been taken as the exposure component as it affects all, however, the susceptibility of more vulnerable populations such as women, children, elderly and disabled people have been considered under the sensitivity component. Female headed households and population engaged in agriculture have been also covered under sensitivity.

Chhukha, Samtse, Thimphu and Trashigang have a population of over 50,000 and the population density is especially high in Chhukha, Samtse and Thimphu. In addition, Monggar, Paro, Samdrup Jongkhar, Sarpang and Wangdue Phodrang have a population of over 35,000. It shows that the western region of Bhutan has a large aggregation of population, and central and eastern regions also have Dzongkhag centres with increasing population. High population density also impacts other socio-demographic indicators such as unemployment, dependency ratio etc.

Table 3: Exposure Indicators

IPCC Risk Framework (2014)	Major Components	Sub-components (Indicators)	Unit	Rationale for selection
Exposure	Community	Population density	Persons per sq.km.	Higher population density increases exposure risk. Further socio-economic vulnerability impacts the population itself.

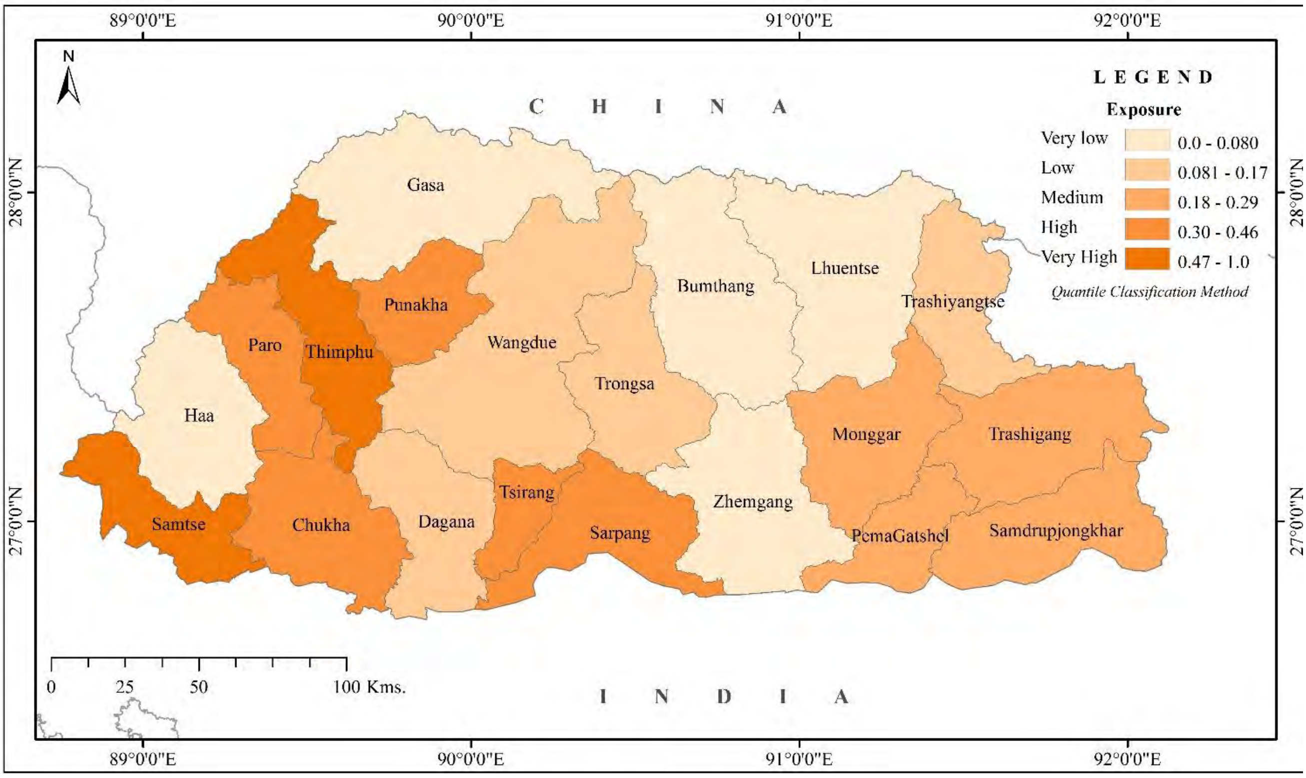


Figure 7: Exposure Index Map

2.3. Vulnerability

The IPCC defines vulnerability as the degree to which individuals and systems are susceptible to or unable to cope with the adverse effects of climate change, including climate variability and extremes. The vulnerability of human health to climate change is a function of:

- Sensitivity: which includes the extent to which the natural or socio-economic systems on which livelihood outcomes depend, are sensitive to changes in weather and climate (the exposure–response relationship) and the characteristics of the population, such as the level of development and its demographic structure;
- Adaptive Capacity: Ability to reduce the burden of a specific adverse health or socio-economic outcome (the adaptation baseline), the effectiveness of which determines in part the exposure–response relationship.

Dzongkhag-level vulnerability assessment helps identifying the administrative units (Dzongkhags) where the majority of the regulatory and developmental decision-making occurs. Vulnerability assessment carried out at Dzongkhag level can depict the profile of vulnerability at the country level showing Dzongkhags under different vulnerability categories such as low, medium and high vulnerability. Such information helps in the identification of priority Dzongkhags for resource allocation, prioritising the allocation of adaptation funds and adaptation interventions. Gewog level vulnerability was also assessed and is provided in Annexure 5.

During the assessment, adaptive capacity of men and women was reviewed and disaggregated wherever possible. The Climate Change and Gender Study (NCWC, 2020) found that men are more aware than women about climate action initiatives such as climate smart agriculture, energy efficient technologies etc. Hence understanding gendered adaptive capacity will allow development of targeted interventions and improve outcomes of adaptation actions. As women depend on natural resources for livelihood, they are more exposed to hazards like health risks, increased drudgery such as walk for hours to fetch water, loss of livelihood due to depletion of resources etc. In Bhutan, the proportion on females (59.3%) working in the agriculture sector is higher. So, care was taken to have the sensitivity and adaptative capacity indicators for women and other vulnerable groups such as children and elderly.

2.3.1. Sensitivity

Sensitivity reflects the degree of response to a given shift in climate. As a result, the biophysical effects of climate change on environment and community are broadly grouped under the sensitivity component. These include the changes in the natural ecosystems (e.g. forests) as well as managed systems such as agriculture. It also includes the household size and the existing sensitive sections of the community.

Table 4: List of Indicators for Sensitivity Index

IPCC Risk Framework (2014)	Major Components	Sub-components (Indicators)	Unit	Rationale for selection
Sensitivity	Socio-demographic profile	*Average household size*	Number	Households with large number of members have limited resource, more work responsibilities that affect the resilience to and recovery from hazards.
		Female Headed Households	%	These are communities that are at higher risk of climate impacts due to multiple factors including due responsibilities, sector specific employment, and lower wages. Female headed households in developing countries deserve special attention since they are typically disadvantaged regarding the access to land, labour, credit and insurance markets, discriminated against by cultural norms and suffering from high dependency burdens, economic immobility (Klasen et.al, 2011). Similarly, children and elderly have limited functioning due to their physical, intellectual and communication capabilities, and require support. In a household they are particularly more vulnerable to food and water scarcity. Extreme climate events leading to food insecurity and nutritional deprivations in a household will have lifelong impacts on children and can prove fatal for the elderly (UNICEF, 2020).
		Children	%	
		Elderly people	%	
	Economic status	*Population Involved in Agriculture*	%	Extreme events (heavy rainfall, flooding, dry spells, cyclone) impacts on Economic security (such as damage to crops, livestock and equipment). Consumption poverty rate includes the necessary consumption expenditures and time needed to achieve a minimum standard of living
		Unemployment rate	%	
		Consumption Poverty Rate	%	
		Out Migration rate	%	
	Health issues	*Infant mortality rate*	Number	Infant mortality rate (IMR) and Maternal Mortality Rate (MMR) is an important marker of the overall health of a society. As per IPCC (2019), climate stresses are impacting the four pillars of food security (availability, access, utilisation, and stability). Food security will be exacerbated in households having an existing food insufficiency. They are
		Food insufficiency (not enough food to feed all household members)	%	
		Disability Prevalence Rate	%	

				more susceptible to impacts. Similarly, households having a disability are also more sensitive to climate impacts as disabled people have a lower coping capacity from climate impacts due to mental, physical or emotional impairment (Cutter 2003).
	Environmental degradation	*Change in agriculture land*	%	The decrease in forest area is an indication of environmental degradation. While increase in agriculture land would mean increased dependency on a climate sensitive sector. Urbanization, particularly if not approached from climate resilient angles, can put additional pressures on natural resources- another climate-sensitive sector.
		Change in Forest Area	%	
		Urbanization	%	

A large household size, larger number of female-headed households, child and elderly dependency ratio add to a high sensitivity index. Households with large number of dependents often have inadequate resources and hence limited resilience and recovery from hazards (Cutter 2003). Decrease in these socio-demographic sub-component indicators values help through less resource consumption that affect the resilience and recovery from hazards. The socio-demographic profile of Zhemgang, Bumthang and Lhuentse have a contribution towards its sensitivity.

Thimphu has the largest household size among all Dzongkhags (4.20 person/family) but due to low child and elder dependency the overall sensitivity of the Dzongkhag is low. Bumthang has 64.6% of its households led by females which is the highest among all Dzongkhags as compared to 16.6% in Samtse, the lowest. This results in a higher sensitivity to climate change hazards for Bumthang.

As mentioned above in Table 4, female headed households are typically disadvantaged regarding the access to land, labor, credit and insurance markets, discriminated against by cultural norms and suffering from high dependency burdens, economic immobility. Even if female-headed households are not poorer, they may be more vulnerable to poverty as they face higher risks and/or have fewer options for post climate impact coping strategies (Klasen et.al, 2011). In Dzongkhags such as Bumthang, Paro, Haa, Thimphu, Punakha, Wangdue Phodrang, Gasa and parts of Chhukha there is prevalence of matrilineal succession and polyandry. While women are in general more susceptible in these dzongkhags, as per a recent study Bhutanese woman were found to be better off in terms of equality in many fields of social and household life (Sariyev, O., Loos, T.K., Zeller, M. et al, 2020).

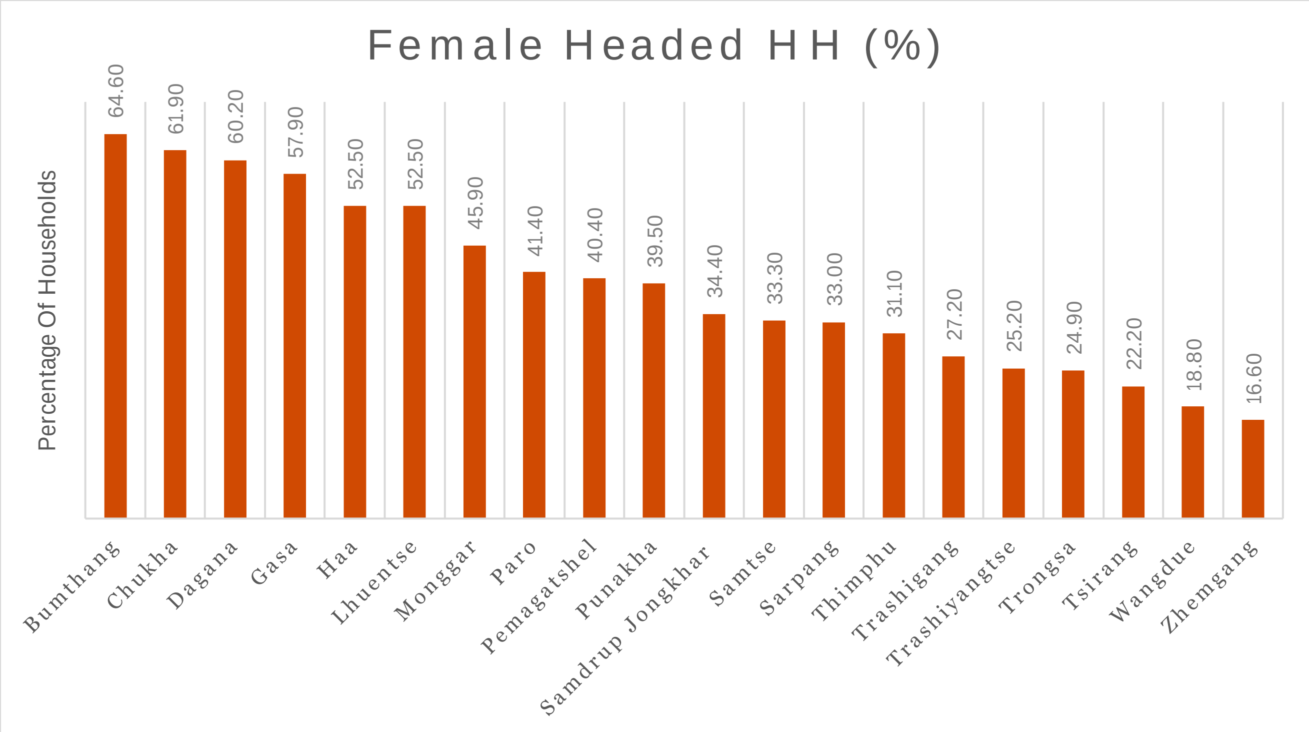


Figure 8: Female Headed Households by Dzongkhag

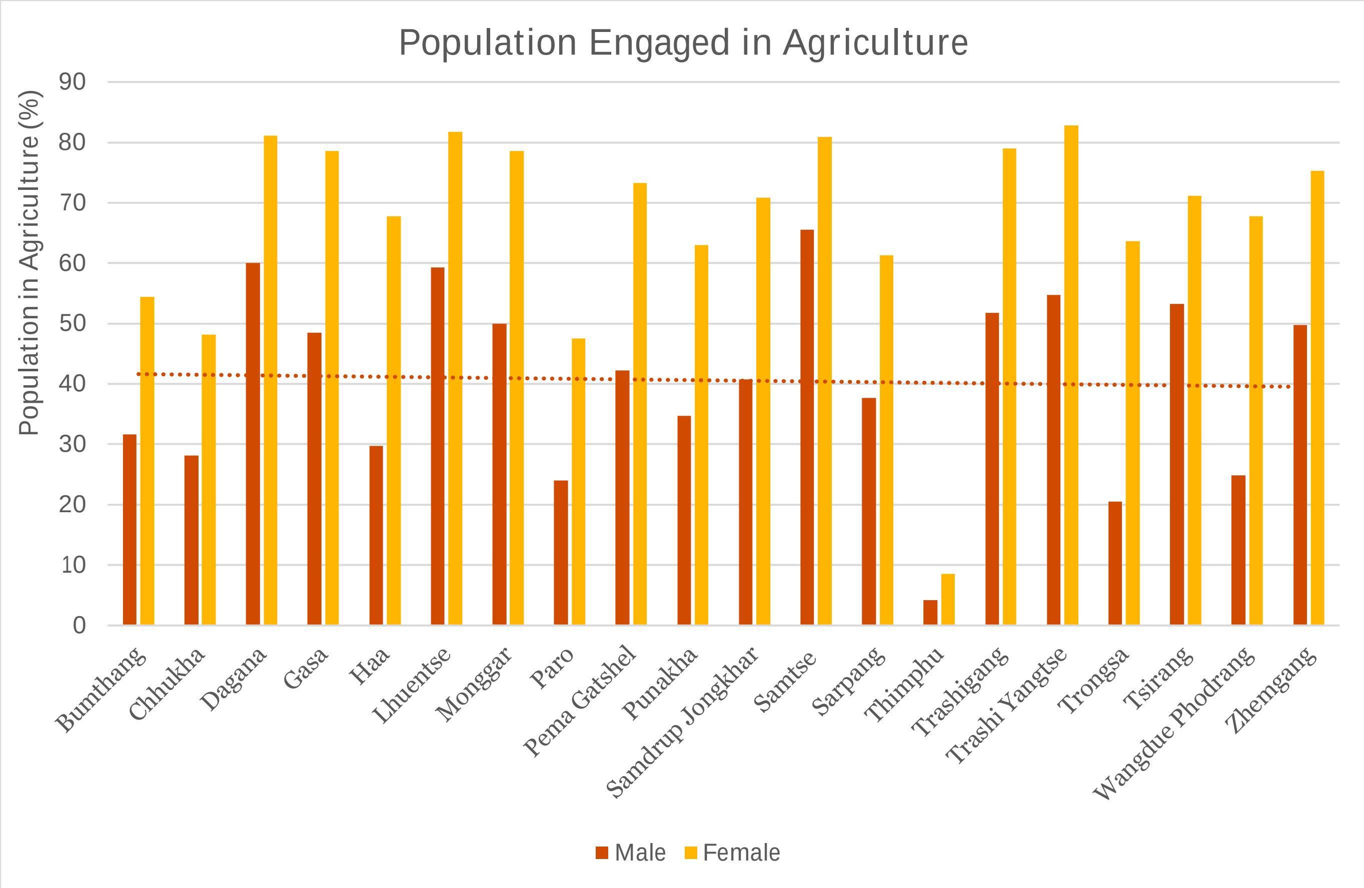


Figure 9: Population Engaged in Agriculture Disaggregated (2017)

Figure 10: Socio-Demographic Profile Map

Climate change impacts such as dry spells, extreme rainfall events, GLOFs, hailstorms etc., may render entire regions unproductive, thereby leading to climate induced migration, the proliferation of precarious and informal work, and an increase in unemployment (ILO, 2018). This effect on livelihoods and economic status of households is estimated by looking at population involved in agriculture, the unemployment rate, consumption poverty rate and out migration rate. Higher population involvement in Agriculture, high unemployment and poverty rate add to high sensitivity index. These factors increase vulnerability as they are very easily impacted by climate change. It is considered that Dzongkhags in western region have high GNH Index due to less poverty. In addition, Dzongkhags in remote area with high poverty rate also show high GNH Index due to natural diversity. However, Dzongkhags from central western to eastern region show low GNH Index, in spite of medium poverty rate.

Unemployment rate exceeds national average in Paro, Sarpang, Thimphu and Tsirang. Thimphu has the highest unemployment rate with 6%, followed by Paro (2.8%), and Chhukha (2.7%). In terms of distribution, Thimphu Dzongkhag has the highest unemployed persons followed by Paro, Chhukha and Samtse Dzongkhags. Thimphu has remarkably high unemployment with 6.9 %, that is more than double of national average. It is assumed that job opportunities in Thimphu can't keep up with the demand caused by influx of population heading to capital city.

Dagana, Samtse and Trashigang have the highest sensitivity to climate change arising out of their livelihood and economic situation. Out-migration is highest in Trashigang with nearly 11.67% in 2017. This reflects the absence of local employment or unavailability of basic facilities. Samtse Dzongkhag's sensitivity also arises from nearly 71.56% of the population being involved in a climate sensitive sector as agriculture.

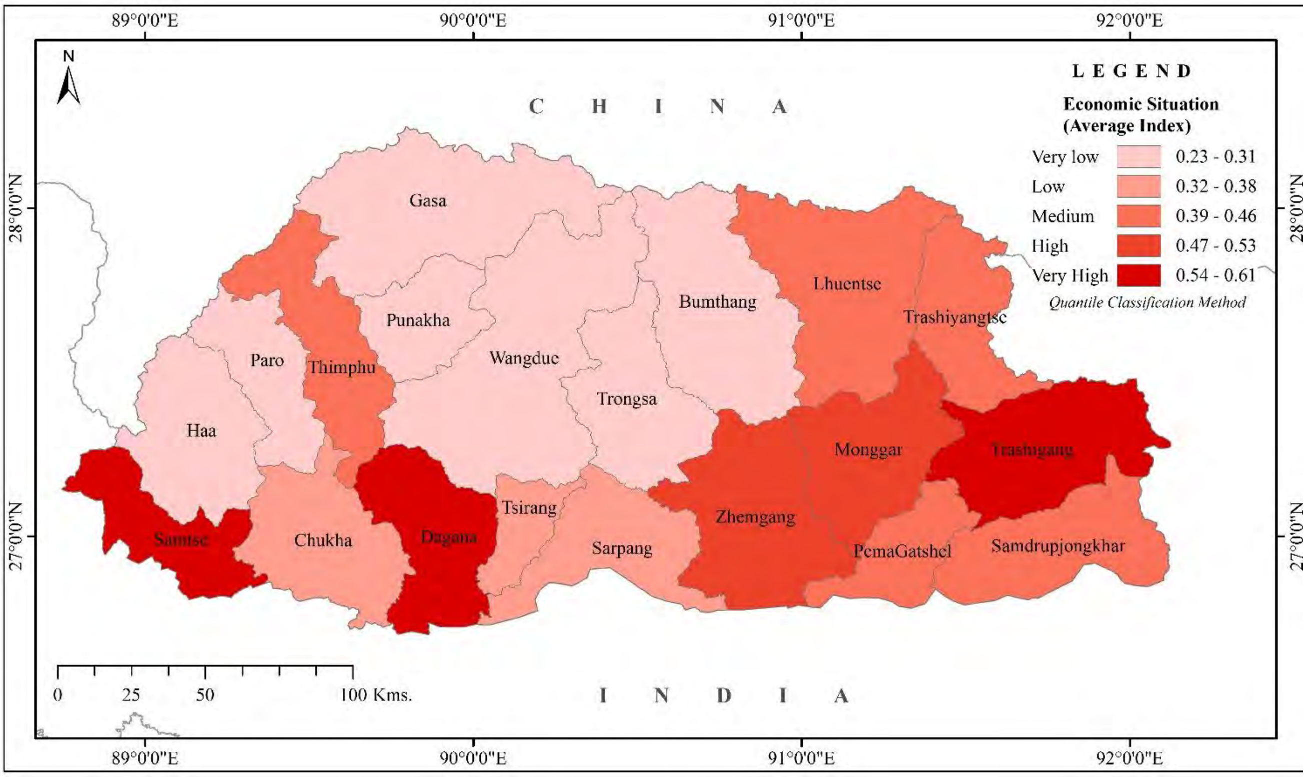


Figure 11: Economic/ Livelihood Situation Map

The infant mortality rate in Gasa is the highest at 63.5, but Dagana has a high percentage of population experiencing food insufficiency and the prevalence of disability that increases its overall sensitivity in the health sector. For environmental degradation there was decrease in forest land and agriculture land in Paro, Punakha, Monggar and Pema Gatshel increasing their overall sensitivity index.

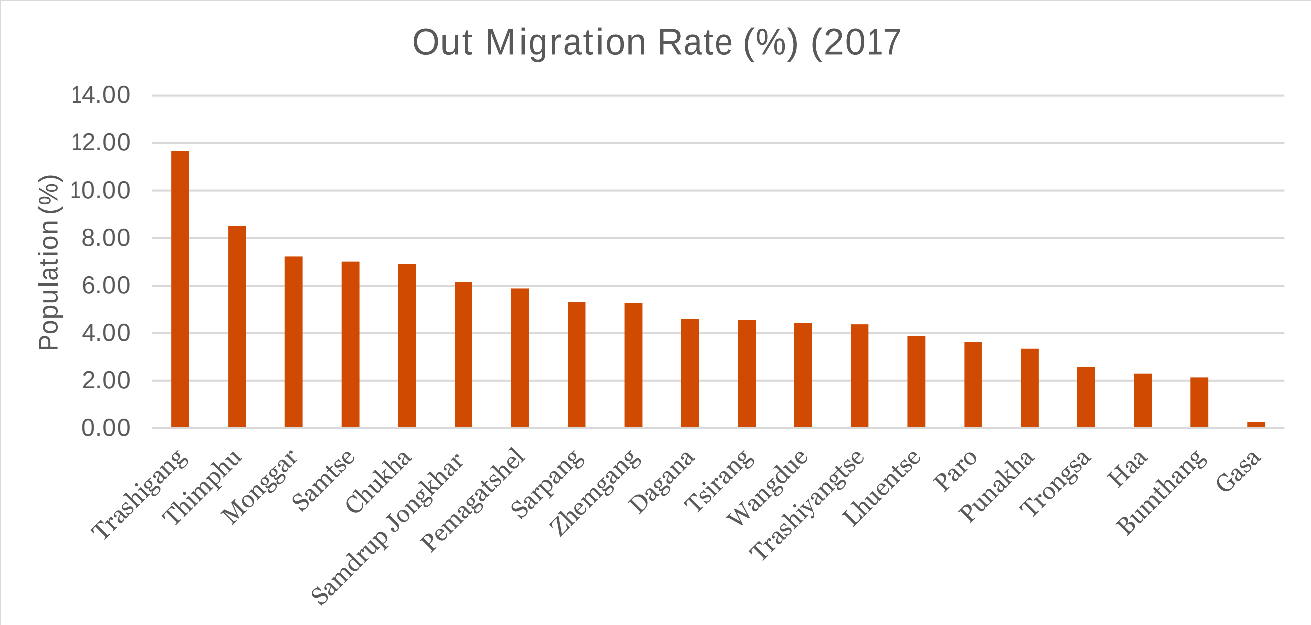


Figure 12: Out Migration Rate (2017)

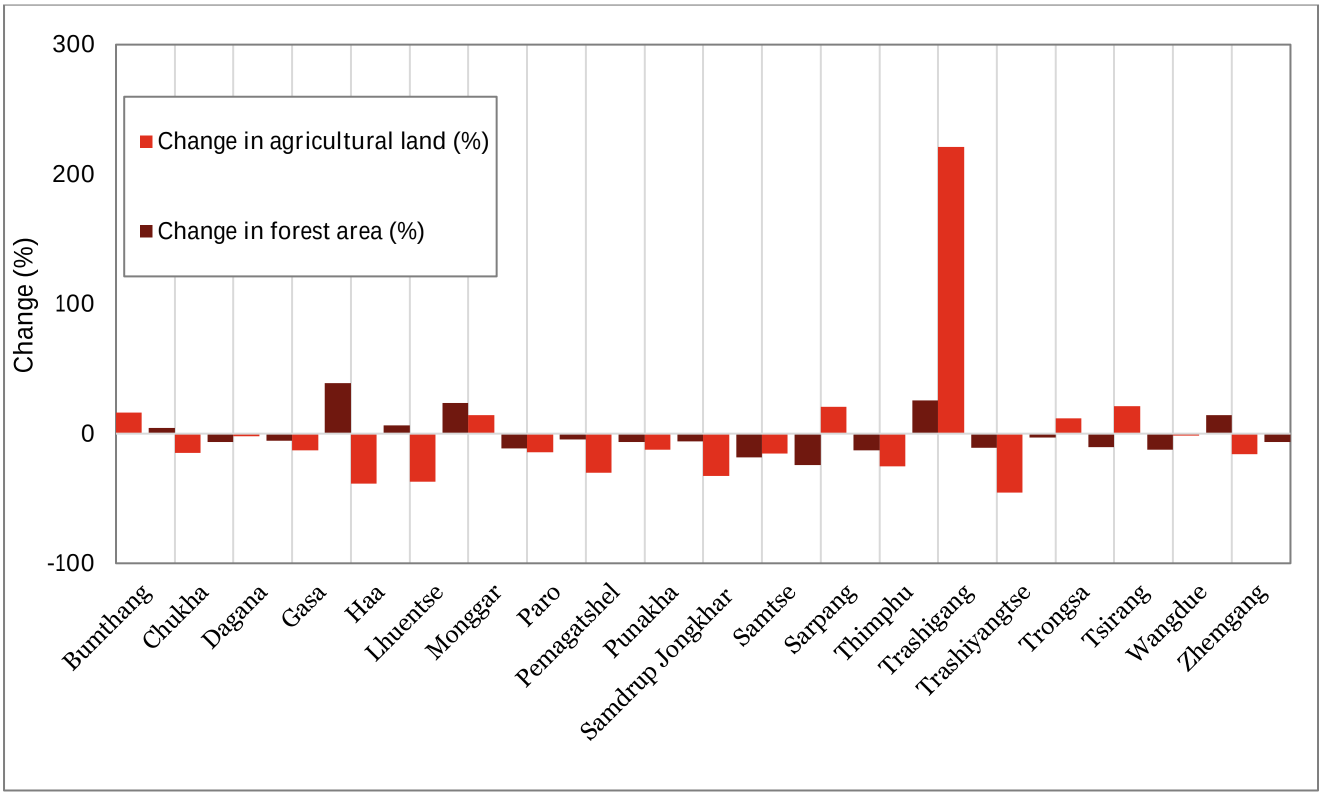


Figure 13: Change in Agriculture and Forest Land (2017)

Monggar experienced a high level of urbanization between 2005 to 2017. During the same period, it experienced a decrease of 11.28% in its forest area. Environmental degradation may also be understood through slope. Even vegetated areas, especially in areas with steep areas and poor soils are more prone to erosion and landslides (especially hills in southern Bhutan). Steep areas are also prone to result in flash floods, there is increase hazard due to natural slope of the region. Areas with proportion of percent slope under 25%, is suitable for both agriculture and industry. It is over 15% in Bumthang, Gasa, Paro, Samdrup Jongkhar, Samtse, Sarpang, Thimphu and Wangdue Phodrang, especially high in Bumthang (total 22.14%) and Sarpang (22.77%) (Bhutan RNR Statistics, 2015).

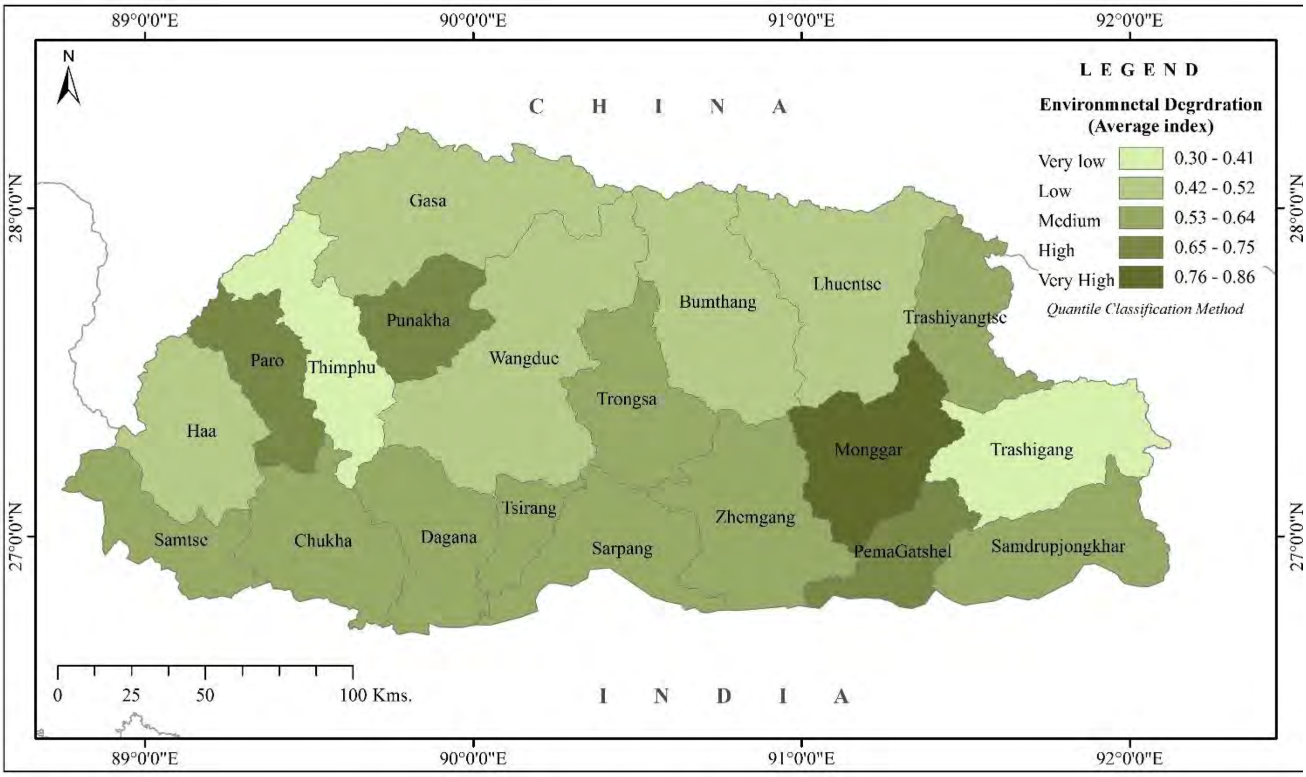


Figure 14: Environmental Degradation (Average Index)

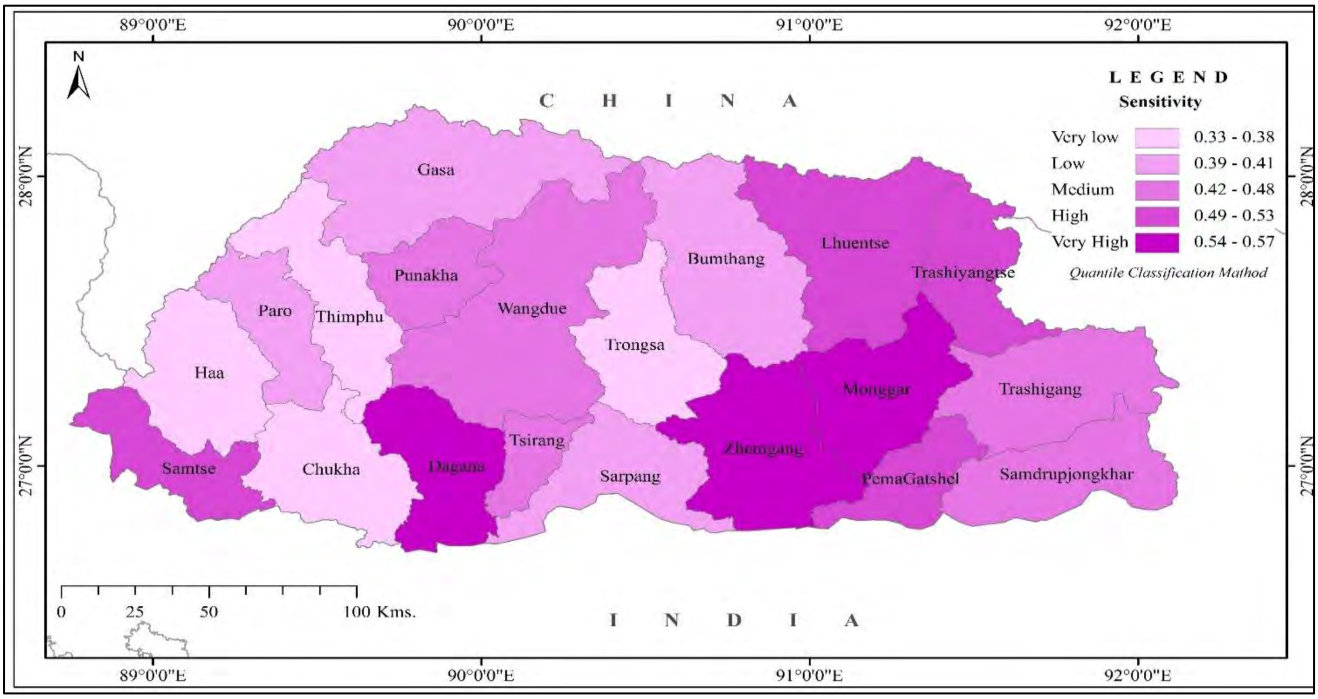


Figure 15: Sensitivity Index Map by Dzongkhag

As evident from the Sensitivity Index map, almost entire Bhutan is in the low to high sensitivity category. However, after combining all the major sensitivity components, Chhukha, Bumthang and Samtse are at the highest sensitivity for climate impacts considering the existing socio-demographic profile of household size, female headed households, child and elderly dependency ratio. This also takes into consideration the economic status of the population in the Dzongkhag, health facilities and environmental degradation.

2.3.2. Adaptive Capacity

Adaptive capacity describes the general ability of systems and individuals to adjust to potential damages, to take advantage of opportunities and to cope with the consequences of climate change. The primary goal of building coping capacity for adaptation is to reduce future socio-economic vulnerability to climate variability and change. It can be addressed through improved knowledge, climate-resilient infrastructure, higher access to basic needs and financial resources. Further specific adaptation measures such as climate resilient irrigation infrastructure, early warning systems etc. improve adaptive capacity.

Table 5: List of Indicators for Adaptive Capacity Index

IPCC Risk Framework (2014)	Major Components	Sub-components (Indicators)	Unit	Rationale for selection	Key Vulnerable Groups
Adaptive capacity	Knowledge	*Literacy rate*	%	Education and awareness about issues such as climate change, health increase the adaptive capacity of the communities	All populations (gender disaggregated)
	Infrastructure	*Permanent housing (Wall - Cement/ Concrete)*	%	Infrastructure is an important dimension of adaptive capacity. Higher the standard of infrastructures (– permanent house, sanitation, electricity, road networks), higher the adaptive capacity and lower vulnerability.	All populations (specifically elder, disabled populations)
		Road density	Km of road		
		Health Facilities	Number		
	Economy	*Labour Force Participation Rate*	%	These are key factors for economic growth in Bhutan. Tourism and Cottage and small industries are among the biggest GDP contributor besides hydropower.	All populations (specifically migrants, agriculture dependent)
		Establishments covered by Dzongkhag and Area	Number		
		Total Number of Tourist Arrivals by Dzongkhag	Number		
	Access to basic facilities / Household amenities	*Drainage Facilities*	%	Households with access to health care, market, school, bank have higher ability to respond to and recover from the impacts of hazards. Houses with access to improved source of drinking water are less susceptible to frequency of associated diseases to climate change.	All populations (specifically women, children)
		Reliable water supply/HH with functional piped water supply (%)	%		
		Improved sanitation facilities	%		
		Households electrified	%		
		Cooking fuel - LPG	%	LPG is cleaner and more efficient than traditional cooking fuels. It also reduces the costs associated with less efficient cooking fuels, thereby improving access to energy which would've been unaffordable for low income households (UNFCCC, 2009).	

IPCC Risk Framework (2014)	Major Components	Sub-components (Indicators)	Unit	Rationale for selection	Key Vulnerable Groups
	Adaptation strategies	*Agricultural Assets (Machinery and Equipment)*	Number	Irrigation, agricultural assets are an important adaptation-enabler as it enables farmers save crops during dry spells. Irrigation is known to provide a buffer to farmers in semi-arid regions to the effects of recurrent dry spells and erratic rainfall patterns, reducing the vulnerability of agricultural production.	Agriculture dependent population
		Community Forest Groups per Dzongkhag/ Plantations by Green Bhutan Corporation Limited (GBCL)	Number		
		Identified/ planned early warning systems (EWS)	Number		
		Percentage of irrigated area	%		

Housing made of non-concrete or stone such as bamboos, mud, grass, reeds, thatch, and loosely packed stones are vulnerable to extreme climatic events and the hygienic conditions are reduced, increasing the likelihood of disease or other problems.

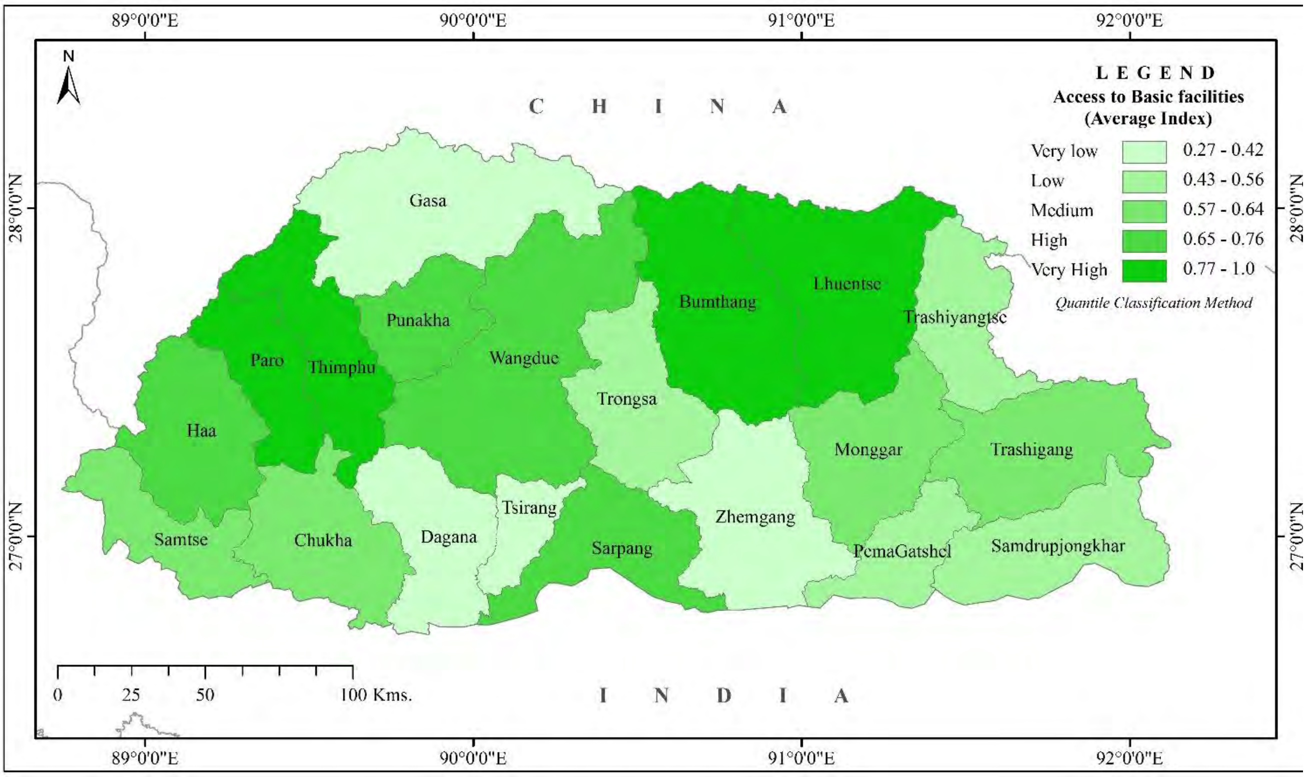


Figure 16: Availability and Access to Basic Facilities

Further, good road connectivity enhances community's capacity to access markets for both their input and output. Therefore, the increasing distance of the communities to good roads is inversely related to the infrastructural capacity to adapt to climate change. The low in the above map (Fig 12) represents low infrastructure availability in the Dzongkhag. Thimphu and Paro score high among these indicators as nearly 70% of the households are made of concrete in these Dzongkhags. The road density is highest in Tsirang, however, only 29% of the population reside in concrete or permanent houses.

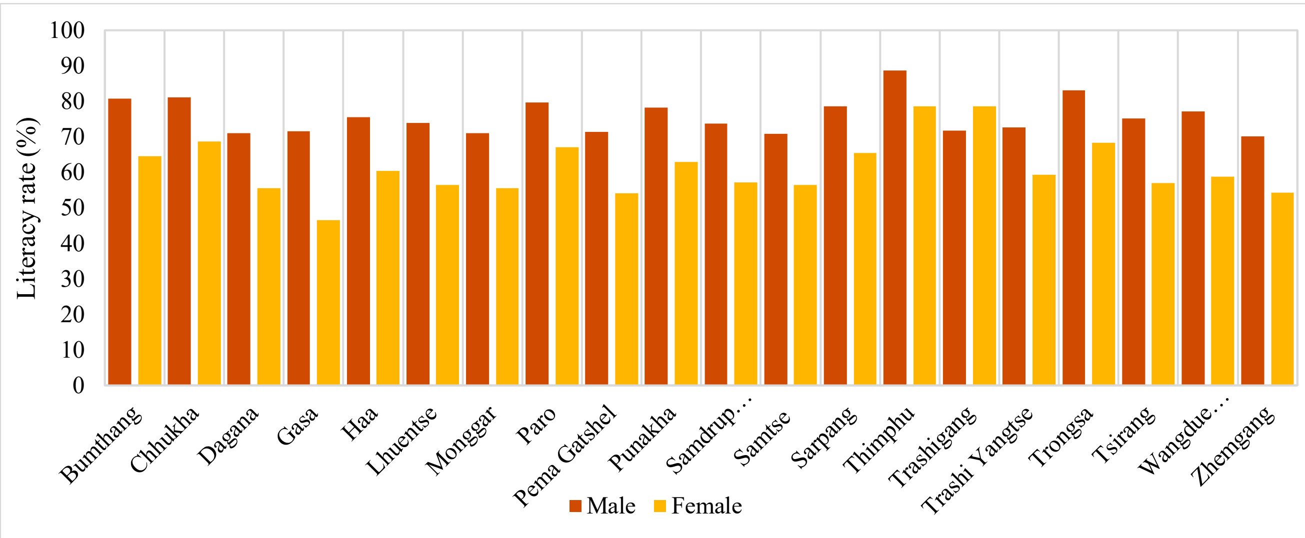


Figure 17: Literacy Rate

Safe drinking water, drainage facilities coverage, electricity, clean cooking fuel are some of the indicators for improved basic facilities that increase adaptive capacity of communities. Although collectively, adaptive capacity has increased, the Climate Change and Gender Study (2020) revealed, "To cope with climate change, men are more inclined to look for alternative employment and/ or to migrate". This has led to increased responsibilities held by women, increased vulnerability to violence and sexual violence and poor working conditions.

Proportion of household with functional piped water is above 90% in most Dzongkhags, except Dagana and Gasa. Proportion of drainages is low in Bumthang, Gasa, Thimphu, Trashiyangtse, Tsirang and Zhemgang. It appears that drainage system is insufficient not only in remote Dzongkhag, but also in Dzongkhags with large population. Thimphu has the highest percentage for these adaptive capacity indicators followed by Paro and Bumthang with nearly 99% coverage of electricity and safe drinking water availability. Zhemgang scores the lowest in this sub-component of adaptive capacity with only 70% coverage of electricity, 41% with drainage facilities and only 47% of the population using LPG as cooking fuel.

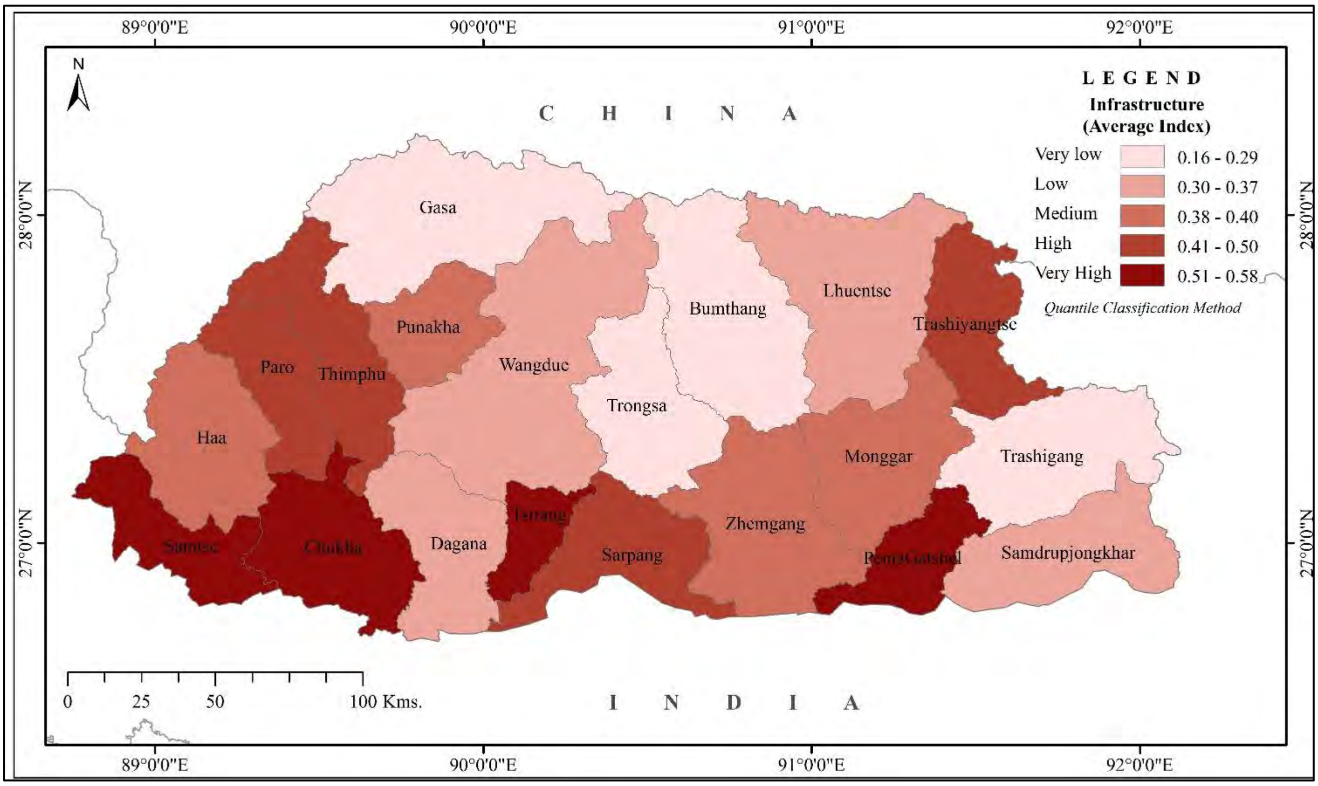


Figure 18: Infrastructure Availability (Average Index)

Strong economic situation of Dzongkhags is also based on tourist arrivals. Considering the tourist arrivals as per the Statistical Yearbook 2017, between 2012-17 tourist arrivals increased in 13 Dzongkhags and decreased in seven Dzongkhags. Paro experienced most tourist visitation in 2017 due to Paro International Airport, and it appears that those tourists move to Punakha and Thimphu. Tourist arrivals in Punakha increased by over 3 times in 5 years as well as those in Thimphu by 1.4 times. Tourists visiting Yangtse increased by 20 times in 5 years. The state of economy of Paro, Thimphu and Punakha is better than others due to high annual average of tourist arrivals in the last 10 years. Moreover, they also have more establishments (such as production and manufacturing industries including all Large, Medium, Cottage and Small Industries, trade and service industries) per area as compared to others. A weak or low economy will take time to cope with the extreme climate events.

Additionally, Chhukha has the aggregation of industry due to hydroelectric power stations and industrial estate at Pasakha. In similar way, it is considered that Paro and Phuentsholing as the international gate way for tourists have certain number of small and cottage industrial firms related to service and accommodation.

Adaptation strategies such as better machinery, irrigation systems and early warning systems increase the overall resilience of the Dzongkhags. Participation in Community Forest Groups could enhance social networking and increases social capital. A high availability of these indicators will have a higher adaptive capacity. There are only five Dzongkhags that have an early warning system (Punakha, Wangdue, Gasa, Trongsa, Bumthang). As per the discussion with DDM, we understand that three other Dzongkhags Paro, Thimphu and Chhukha have planned to build Early Warning Systems in the coming years.

Around 13% of the households in Wangdue also have machinery and equipment for agriculture. Samtse with a total of 14,802.65 Ha cultivated agriculture land has the highest percentage of area under irrigation (15%) (RNR Statistics, 2017). As per the National Irrigation Information System confirms that there are 2,582 km of irrigation channels, covering 32,338 ha of agricultural land with 46,096 beneficiary households in Bhutan. The covered area accounts for 42% of utilized agricultural land.

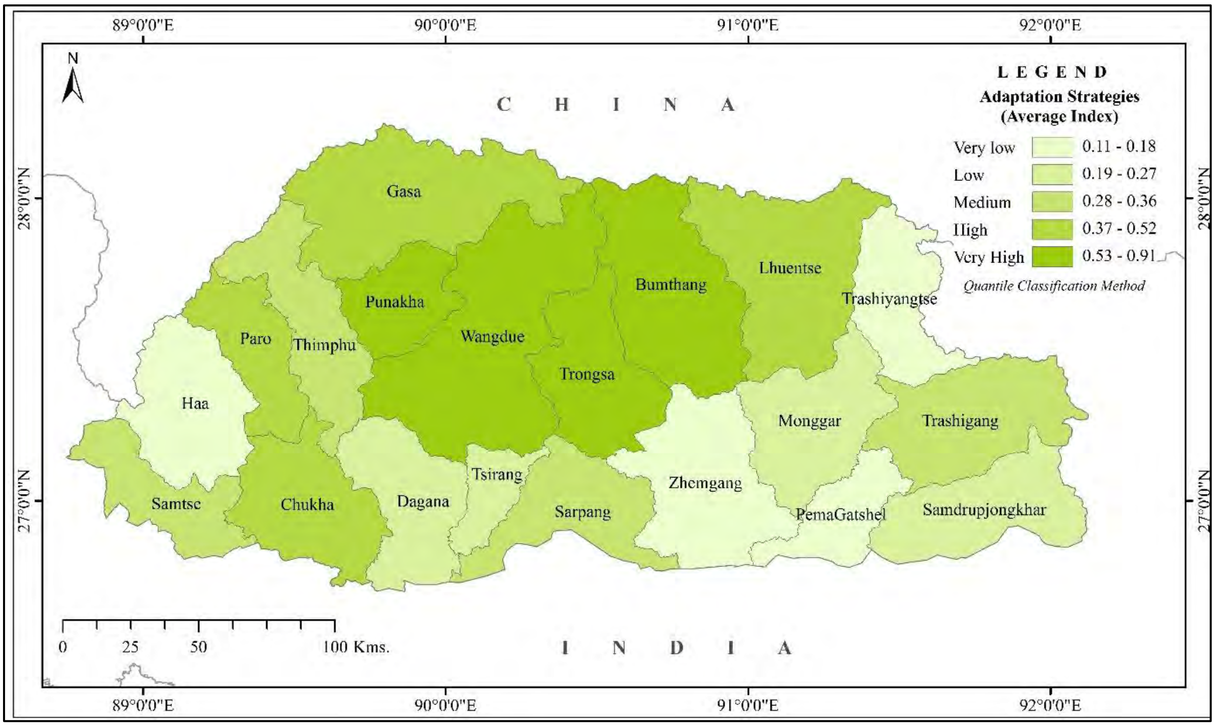


Figure 19: Adaptation Strategies (Average Index)

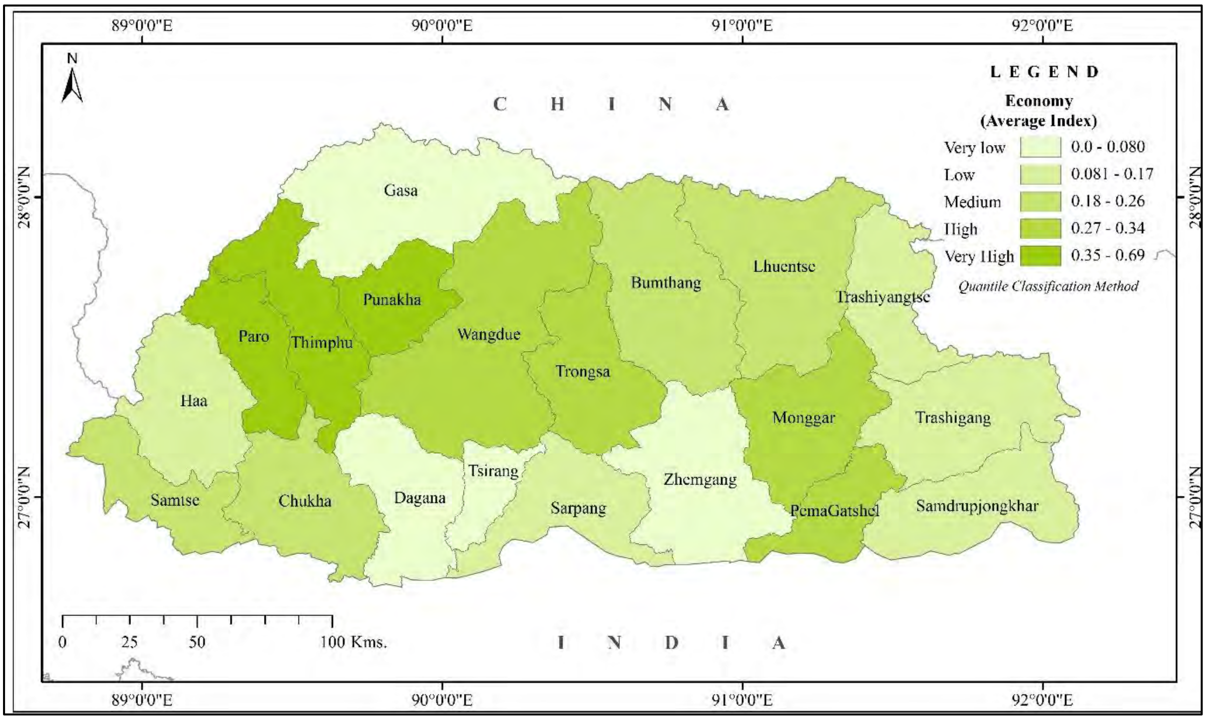


Figure 20: Economy Average Index By Dzongkhag

Taking into consideration all sub-components of adaptive capacity – Knowledge, Infrastructure, Economy, Access to basic facilities / Household amenities and adaptation strategies, we find that Zhemgang, Dagana and Gasa are the Dzongkhags with the lowest adaptive capacity. A low adaptive capacity increases overall climate vulnerability and risk. These Dzongkhags if hit by an extreme climate event may take longer to recover and will require external support as the existing systems and communities are not as well equipped as other Dzongkhags.

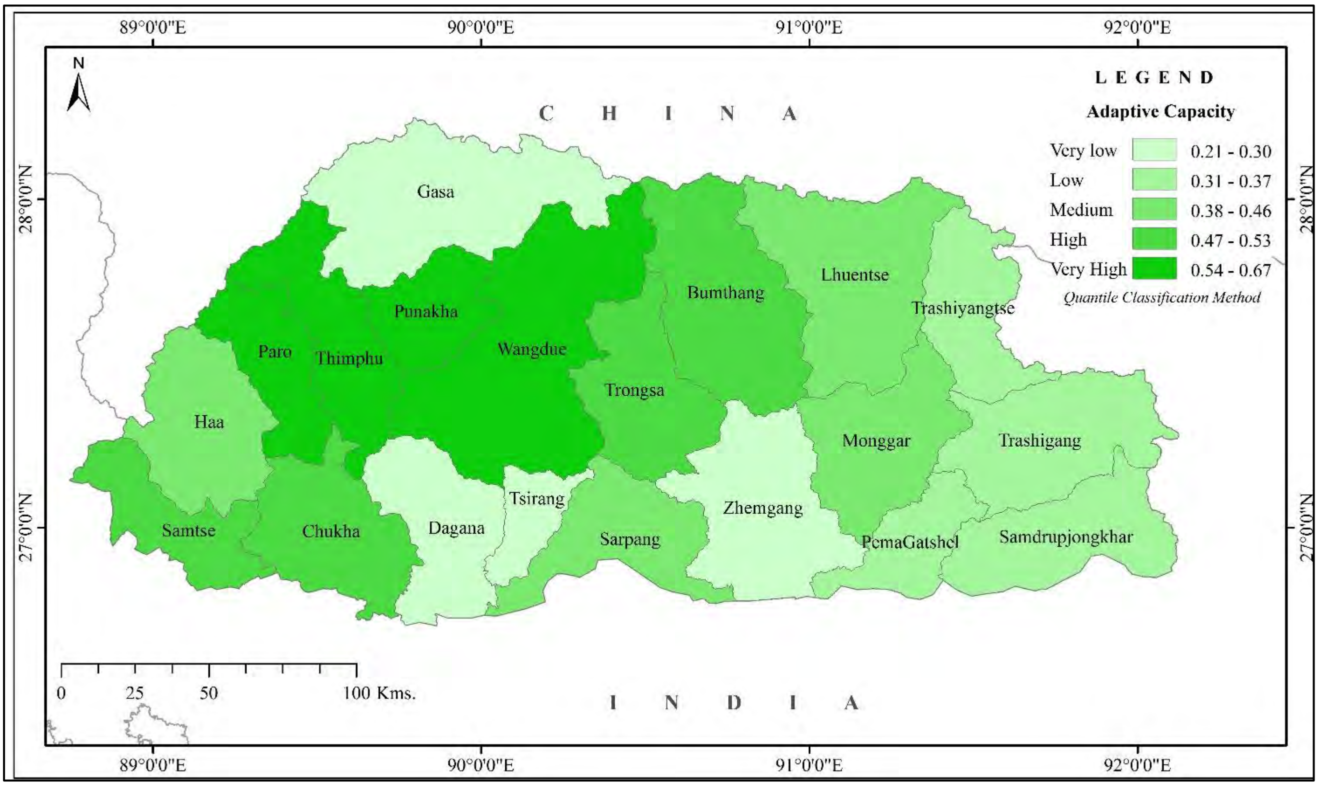


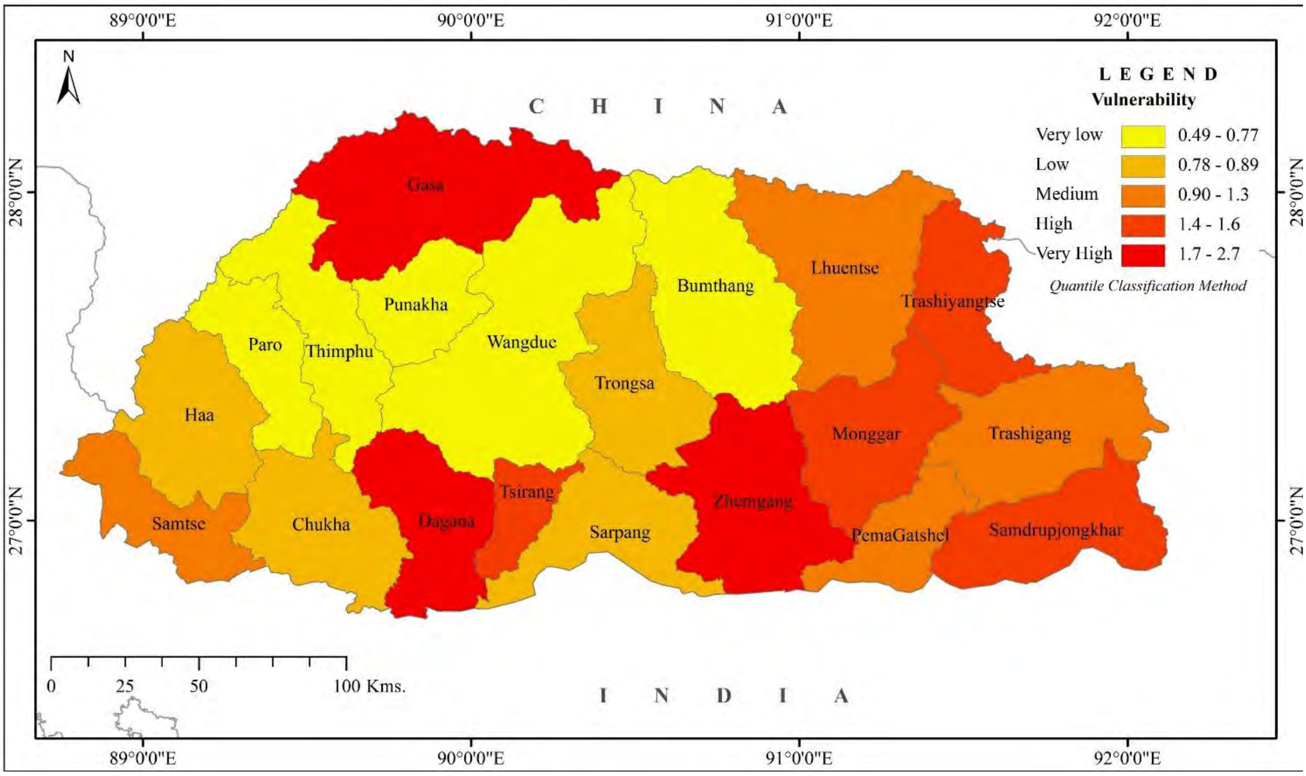
Figure 21: Adaptive Capacity Index Map

It can be understood that Dzongkhags with the lowest adaptive capacity are among the most vulnerable. These Dzongkhags require adequate development interventions to reduce its socio-economic vulnerability. The current vulnerability calculated is based on existing sensitivity and available adaptive capacity. The vulnerability ranking of the Dzongkhags are as follows:

Table 6: Vulnerability Index and Rank

Dzongkhag	Hazard Index	Exposure Index	Adaptive capacity Index	Sensitivity Index	Vulnerability Index	Vulnerability Rank
Bumthang	0.00	0.08	0.53	0.41	0.77	16
Chhukha	0.20	0.54	0.48	0.38	0.78	15
Dagana	0.25	0.20	0.27	0.56	2.12	2
Gasa	0.09	0.00	0.25	0.40	1.61	3
Haa	0.08	0.09	0.39	0.35	0.89	12
Lhuentse	0.25	0.09	0.46	0.52	1.12	10
Monggar	0.46	0.18	0.39	0.57	1.46	6
Paro	0.13	0.52	0.60	0.40	0.67	19
Pema Gatshel	0.18	0.33	0.37	0.50	1.34	8
Punakha	0.31	0.37	0.63	0.48	0.77	17
Samdrup Jongkhar	0.17	0.26	0.34	0.48	1.43	7
Samtse	0.33	0.71	0.47	0.50	1.07	11
Sarpang	0.37	0.34	0.44	0.39	0.89	13
Thimphu	0.06	1.00	0.67	0.33	0.49	20
Trashigang	0.07	0.21	0.35	0.43	1.22	9
Trashiyangtse	0.19	0.16	0.35	0.53	1.50	5
Trongsa	0.18	0.15	0.47	0.37	0.78	14
Tsirang	0.04	0.51	0.30	0.48	1.59	4
Wangdue Phodrang	0.07	0.13	0.59	0.43	0.73	18
Zhemgang	0.07	0.09	0.21	0.56	2.69	1

To further understand the risk, it would be needed to include the hazard and exposure factors. Dzongkhags with a strong economy, infrastructure and basic facilities have a higher adaptive capacity such as Thimphu, Punakha and Paro.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C H I N A
I N D I A
LEGEND
Vulnerability
Very low 0.49 - 0.77
Low 0.78 - 0.89
Medium 0.90 - 1.3
High 1.4 - 1.6
Very High 1.7 - 2.7
Quantile Classification Method
Gasa
Punakha
Paro
Thimphu
Wangdue
Bumthang
Lhuentse
Trashiyangtse
Trongsa
Haa
Monggar
Trashigang
Tsirang
Zhemgang
Samtse
Chukha
Dagana
Sarpang
PemaGatshel
Samdrupjongkhar
0 25 50 100 Kms.

2.4. Present Risk

Risk (or impact) as mentioned earlier is a function of hazard, exposure and vulnerability. Taking into consideration the earlier components following is the risk ranking that is obtained. When the existing socio-economic vulnerabilities are compounded with the climate hazards and population density, we get Samtse, Monggar, Sarpang, Punakha and Dagana as five most at risk from climate impacts in Bhutan.

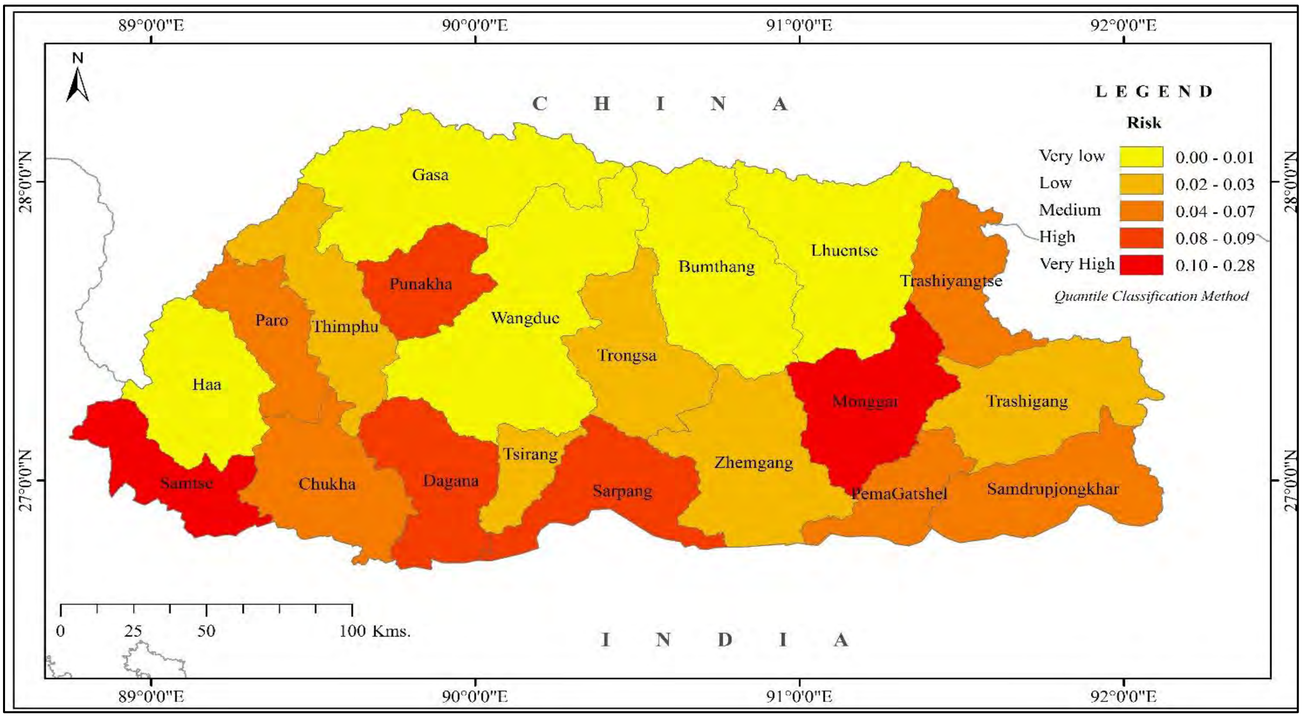


Figure 22: Risk/ Impact Index Map

After assessing the Gewog level socio-economic vulnerability, the top three most vulnerable Gewogs were considered in these five Dzongkhags as having the population at risk. The female population, children (0-14) and elderly are among the highest risk in these locations.

Dzongkhag / Gewog	Total	Populations at Risk		
		Female	Children (0-14 yr.)	Elderly (65+yr.)
Samtse	62,590	30,568	16,884	4,041
Duenchhukha	2,159	982	552	142
Namgyalchhoeling	3,141	1,470	912	208
Pemaling	3,262	1,569	822	301
Monggar	37,150	18,903	11,399	2,643
Thang-Rong	1,606	890	532	154
Kengkhar	1,844	968	615	174
Balam	912	494	297	78
Sarpang	46,004	21,986	11,215	2,612
Chhudzom	2,664	1,204	660	158
Jigme Chhoeling	3,258	1,515	788	262
Gakiling	2,125	1,020	515	122
Dagana	24,965	12,009	7,024	1,664
Khebisa	1,215	618	363	102
Dorona	752	337	185	46
Largyab	843	389	221	58
Punakha	28,740	13,661	7,364	1,829
Kabisa	2,542	1,246	763	192
Todewang	1,313	693	380	140
Goenshari	694	281	136	65

Table 7: Risk Index and Ranking

Dzongkhag	Hazard Index	Exposure Index	Adaptive capacity Index	Sensitivity Index	Vulnerability Index	Risk Index	Risk Ranking
Bumthang	0.00	0.08	0.53	0.41	0.77	0.00	19
Chhukha	0.20	0.54	0.48	0.38	0.78	0.08	6
Dagana	0.25	0.20	0.27	0.56	2.12	0.11	4
Gasa	0.09	0.00	0.25	0.40	1.61	0.00	20
Haa	0.08	0.09	0.39	0.35	0.89	0.01	17
Lhuentse	0.25	0.09	0.46	0.52	1.12	0.03	13
Monggar	0.46	0.18	0.39	0.57	1.46	0.12	2
Paro	0.13	0.52	0.60	0.40	0.67	0.05	10
Pema Gatshel	0.18	0.33	0.37	0.50	1.34	0.08	7
Punakha	0.31	0.37	0.63	0.48	0.77	0.09	5
Samdrup Jongkhar	0.17	0.26	0.34	0.48	1.43	0.06	8
Samtse	0.33	0.71	0.47	0.50	1.07	0.25	1
Sarpang	0.37	0.34	0.44	0.39	0.89	0.11	3
Thimphu	0.06	1.00	0.67	0.33	0.49	0.03	12
Trashigang	0.07	0.21	0.35	0.43	1.22	0.02	15
Trashiyangtse	0.19	0.16	0.35	0.53	1.50	0.05	9
Trongsa	0.18	0.15	0.47	0.37	0.78	0.02	14
Tsirang	0.04	0.51	0.30	0.48	1.59	0.03	11
Wangdue Phodrang	0.07	0.13	0.59	0.43	0.73	0.01	18
Zhemgang	0.07	0.09	0.21	0.56	2.69	0.02	16

3. Socio-economic Vulnerability

Socio-economic vulnerability is defined as an inherent property of a system arising from its internal characteristics (Cutter, 2003). It is determined by the socio-economic factors, such as economic status - wealth, income, poverty, education levels, housing quality, tenure type, built environment, family structure, age, gender, marginalisation, food insecurity, access to insurance, etc. It can be assessed as a function of sensitivity and adaptive capacity to climate change (Brooks et.al, 2003).

The identification of socially vulnerable Dzongkhags and the components contributing to social vulnerability is an important element for the preparation of the location-based hazard specific plans and climate inclusive development strategies for the vulnerable areas of Bhutan.

Based on a comprehensive review of the literature and the available secondary data sets, 14 socio-economic variables were selected for the socio-economic vulnerability analysis at the Dzongkhag level. All the factors determining the socio-economic vulnerability – household structure, gender, education, occupation, socio-economic status, migration have been considered during this selection. The selected variables are important to identify the socio-economically vulnerable communities exposed to multiple hazards. All variables can be measured at the interval level. The description of the variables used in the present study is provided below.

Table 8: Description of the socio-economic variables considered in the social vulnerability analysis

IPCC AR5	Major Components	Sub-components	Rationale	Reference Study
Sensitivity	Socio-demographic profile	*Average Household Size*	Households with large number of members have limited resource, more work responsibilities that affect the resilience to and recovery from extreme events	Cutter et al., 2003; Hajat et al., 2003; Armas and Gavris, 2013; Nguyen, 2015
		Female population (%)	Females have more difficult time during recovery from extreme events than male, due to their family care responsibilities, sector-specific employment, and lower wages	
		Dependency ratio	Economically dependent population are more sensitive to extreme events. As low socio-economic status can reduce adaptive capacity to livelihood shocks.	Cutter et al., 2003; Schmidlin, 2009; Samanta et al., 2017
	Economic situation	*Population involved in agriculture (%)*	Agriculture- dependents are more impacted by hazard events and climate variability than other workers.	Das et al, 2021; Heltberg & Bonch-Osmolovskiy, 2011; Nguyen, 2015
		Out migration Rate (%)	Migrant workers are considered one of the most vulnerable social groups to climate change risks, specifically to livelihood uncertainties such as the loss of livelihood opportunities, resources and assets.	
	Health issues	*Disability Prevalence Rate (%)*	Persons with Disability (PWDs) face greater risk of vulnerability because of obstruction in mobility and are most sensitive groups during extreme events	Heltberg & Bonch-Osmolovskiy, 2011; Nguyen, 2015
Adaptive Capacity	Knowledge	*Literacy rate (%)*	Literacy and labor force participation rate provide the ability to understand warning information and access to recovery information	Cannon et al., 2003; Schmidlin, 2009; Su et al., 2015
	Economy	*Labor Force Participation Rate (%)*		

IPCC AR5	Major Components	Sub-components	Rationale	Reference Study
	Infrastructure	*% of permanent house*	Households with permanent house have higher adaptive capacity and lower vulnerability.	Cutter et al., 2003; Schmidlin, 2009; Samanta et al., 2017
	Basic facilities	*Electricity (%)*	Households with access to basic facilities have higher ability to respond to and recover from the impacts of hazards.	Cannon et al., 2003; Nguyen, 2015; Samanta et al., 2017
		Safe drinking water (%)		
		Improved sanitation (%)		
	Strategies	*Agricultural assets*	Agricultural assets and Irrigation are important adaptation-enabler as it enables farmers to save crops during dry spells.	Cutter et al., 2003; Vincent, 2004; Fekete, 2009; Nguyen, 2015
		Irrigated area (%)		

The index value of socio-economic vulnerability was estimated and mapped for all the Dzongkhags of Bhutan to examine the spatial dimension, while two set of maps for the years of 2005 and 2017 indicate temporal change. To visualize the results in a geographic context, two separate choropleth maps for 2005 and 2017 were prepared using Arc GIS software. Quantile classification method was used in SEVI mapping.

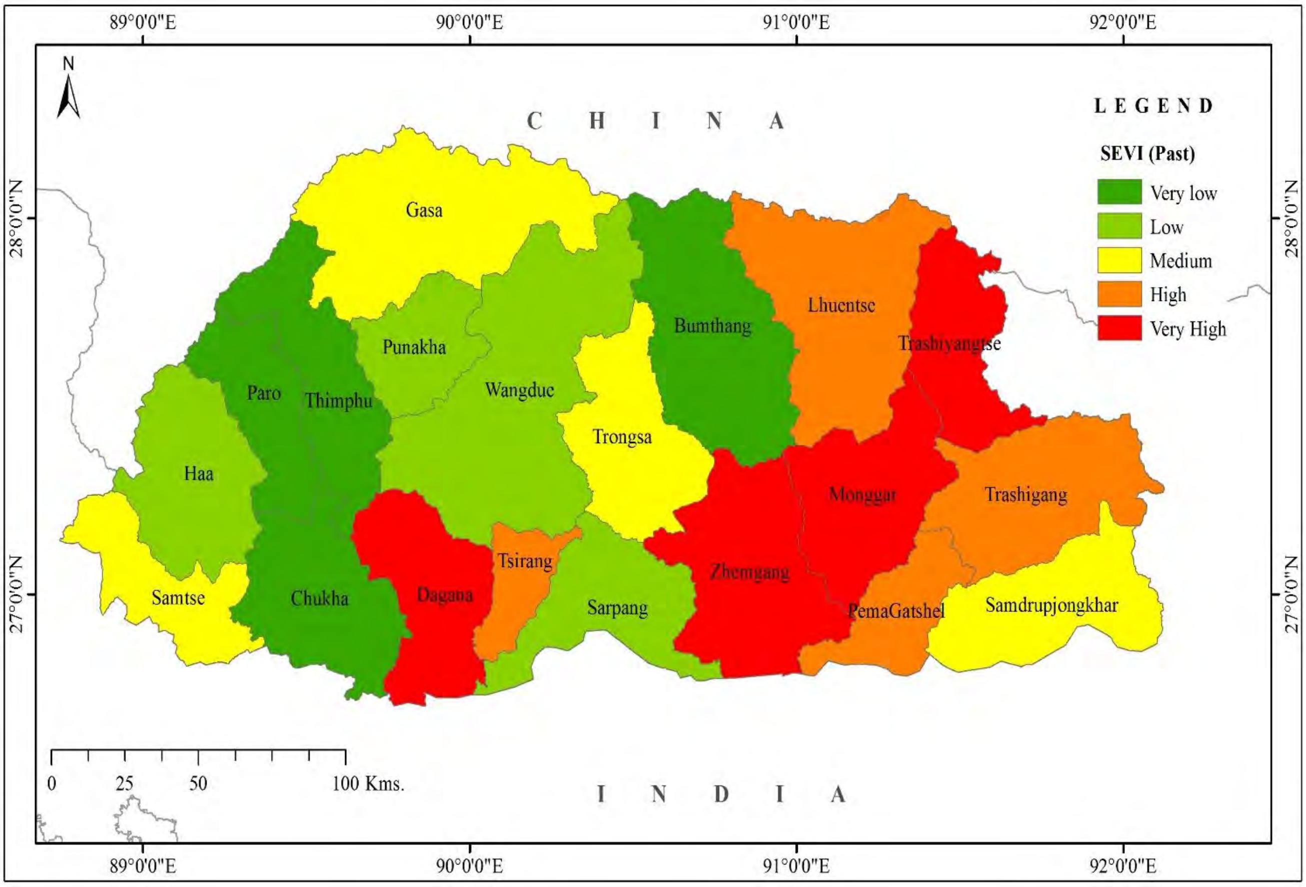


Figure 23: Past socio-economic vulnerability map of Bhutan

The most vulnerable Dzongkhags are Zhemgang, Dagana and Monggar in 2005, and Gasa, Zhemgang and Trashiyangtse in 2017.The most socially vulnerable Dzongkhags are concentrated in the eastern part of country.

Dzongkhags close to the cities of Thimphu, Paro have a very low social vulnerability, as they have more economic opportunities and better access to services such as grid electricity, piped water and road transport.

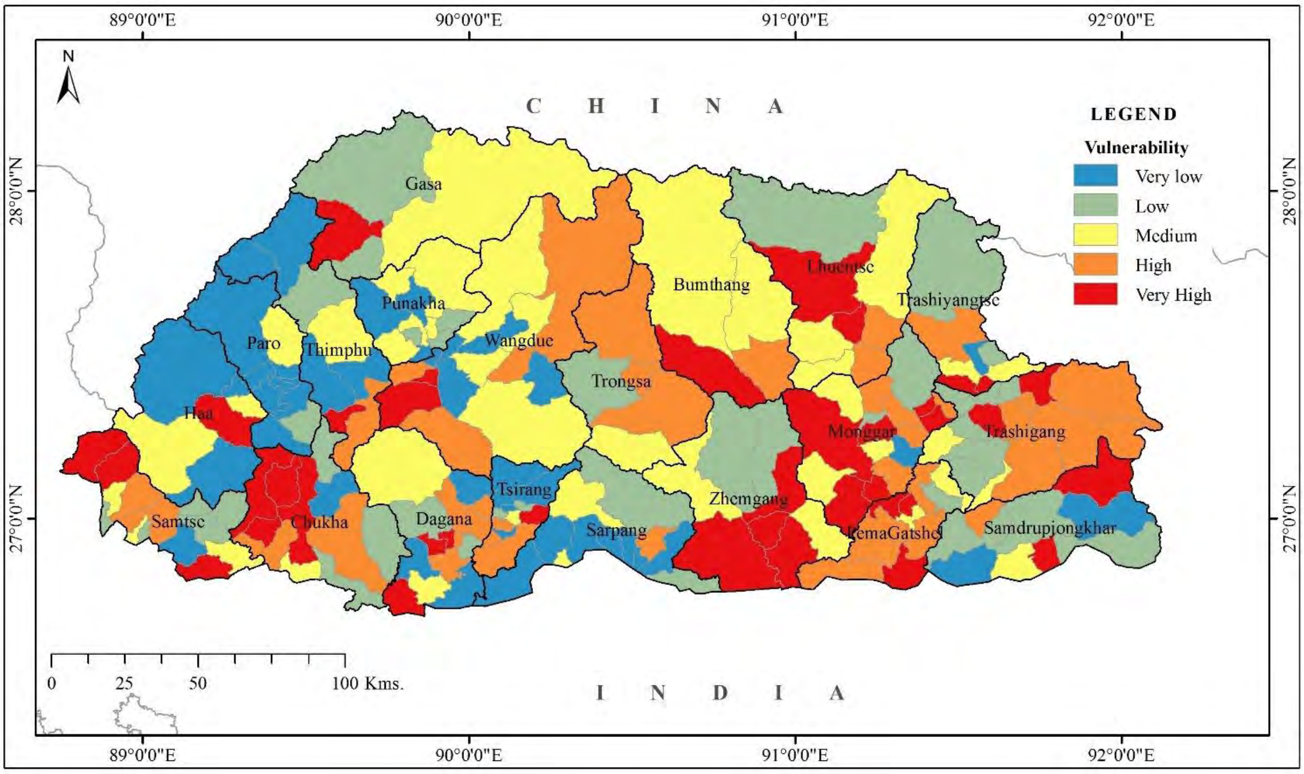


Figure 24: Present Socio-Economic Vulnerability Index Map

Table 9: Temporal change detection matrix

Socio-economic vulnerability Matrix		Present Socio-economic vulnerability					
		Very Low	Low	Medium	High	Very High	Total
Past socio-economic vulnerability	Very Low	2	2				4
	Low	1	2	1			4
	Medium	1		1	1	1	4
	High			2	1	1	4
	Very High				2	2	4
	Total	4	4	4	4	4	20
Change (2005-2017)			Negative		No		Positive

Out of total 20 Dzongkhags, between 2005 and 2017, six Dzongkhags had significant increase in social vulnerability. In several places social vulnerability reduced in 2017 compared to 2005, reflecting improvement in access to basic services like safe drinking water, sanitation, electricity connection, and the development of alternative livelihood options. The spatio-temporal change matrix indicates that social vulnerability status however remains unchanged in eight Dzongkhags of Bhutan during the period of 2005 and 2017. It is understood that the major changes in socio-economic vulnerability cannot be achieved in one decade, but this study shows the efficacy to develop location based emergency plans/ hazard preparedness by identifying the chronically vulnerable population and specific socio economic aspects of their life (like poverty, water, sanitation, housing etc.) which accentuate such vulnerability.

Table 10: Socio-Economic Vulnerability and Population at Risk

Dzongkhag	SEVI score	Ranking	Populations at Risk		
			Female	Children (0-14 yr.)	Elderly (65+yr.)
Gasa	3.48	20			
Lunana	3.33	1	1906	1098	290
Laya	1.01	81	1152	671	388
Khatoed	0.85	134	1447	798	322
Zhemgang	2.42	19			
Bardo	1.50	8	803	551	453
Goshing	1.37	14	1272	780	376
Shingkhar	1.25	29	600	322	612
Trashiyangtse	1.75	18			
Yalang	1.26	27	1099	864	291
Yangtse	1.21	39	483	236	423
Toedtsho	1.19	46	893	613	363

The exact population of vulnerable groups in these Dzongkhags are as given above in Table 10. Lunana is among the most vulnerable Gewog in the most vulnerable Dzongkhag Gasa. Measures to address literacy rate, infrastructure, access to basic facilities are most needed in this Gewog, especially as these affect the female population due to their special sanitation and hygiene needs. The next two Gewogs in Gasa are slightly lower but still vulnerable. This study also identifies that the components like strong dependency on agriculture and natural resources, living in temporary house, illiteracy, lack of access to safe drinking water, sanitation and other services make them more sensitive to hazard events and climate variability. Migration (in and out) also has a significant impact on the spatio-temporal trends of social vulnerability. Due to the absence of younger people, the remaining aged population eventually become dependent on social services and government support for their livelihoods. The population increase because of influx of immigrants create a more diverse population, requiring more development. Both these factors contribute to social vulnerability to natural hazards in Bhutan.

Thimphu is the most vulnerable among the Class A Thromdes. This is mostly due to high dependency ratio and high presence of temporary housing structures increasing vulnerabilities to climate hazards.

Table 11: Vulnerability Index of Class A Thromdes

Dzongkhag		Chhukha	Samdrup Jongkhar	Sarpang	Thimphu
Thromde		Phuentsholing	Samdrup Jongkhar	Gelephu	Thimphu
Sensitivity	*Average Household Size (No.)*	3.60	3.70	4.00	4.00
	Female population (%)	45.60	46.20	47.80	48.50
	Children (%)	20.85	26.69	21.80	23.78
	Elderly (%)	2.55	2.95	3.82	3.57
	Food insufficiency (%)	3.27	4.57	3.79	2.39
	Disability Prevalence Rate	1.00	1.10	1.60	1.10
Adaptive Capacity	*School attended (%)*	79.68	78.03	77.34	80.08
	Permanent housing structure (%)	94.22	91.16	94.97	79.20
	Electricity (%)	98.58	98.73	98.71	99.00
	Cooking (%)	92.30	91.82	90.86	92.43
	Improved Sanitation Facilities(%)	82.50	85.50	86.90	86.00
	Access to Improved Sources of Drinking Water (%)	99.50	99.40	99.90	99.60
Index & Rank	Sensitivity	0.37	0.42	0.45	0.43
	Adaptive Capacity	0.86	0.85	0.88	0.82
	Vulnerability Index	0.44	0.50	0.51	0.53
	Vulnerability Rank	4	3	2	1

4. Future Risk

To understand how communities/regions may be affected by future climatic change, future climate change risk Dzongkhag level maps have been produced. Climate change scenarios and different timescales have been assessed to understand the future evolution of vulnerability and risk in Bhutan. Future climate data for the Dzongkhags of Bhutan shows that majority of the Dzongkhags have observed an increasing trend in climate adversities. Greater increase has been observed in lower/ southern Bhutan as compared to the rest of the country. Samtse is experiencing greater rise in maximum and minimum temperature, closely followed by Trashigang, and Pema Gatshel, whereas Zhemgang, Trongsa and Sarpang have greater rise in rainfall.

In this study, three models have been developed taking into consideration various timescales, RCP scenarios:

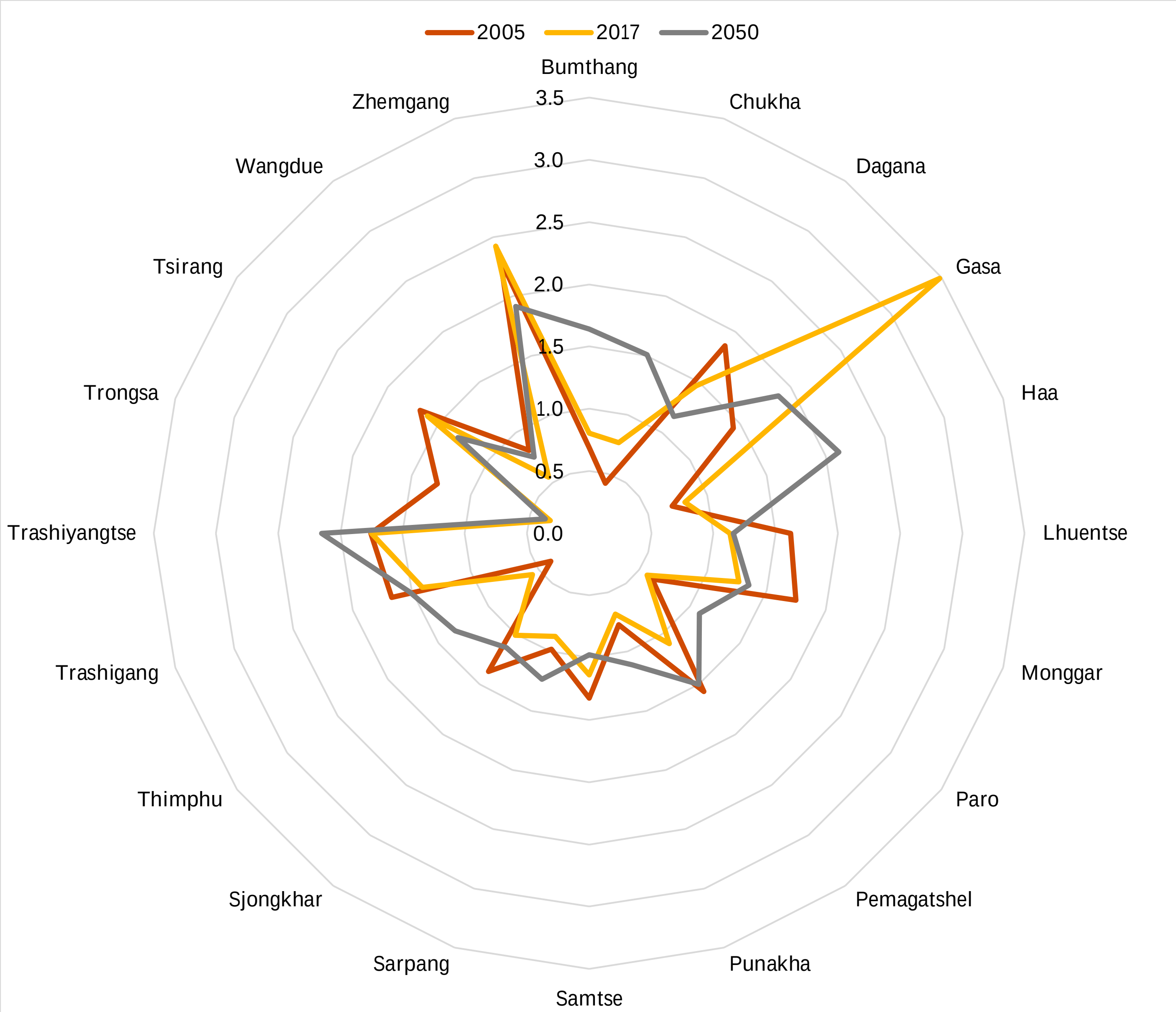
- Model 1 – Growth with no Climate Change: From previous and existing census and other reports projections for socio-economic indicators have been prepared and mapped at the Dzongkhag level.
- Model 2 – Growth with Climate Change / Future risk: Future vulnerability, exposure and climate data were aggregated to obtain the future risk index value for all the Dzongkhags of Bhutan.
- Model 3 – Growth with Adaptation: Adaptation futures have been taken into consideration using existing development plans, GDP growth models as per the CNDP 2030, Shared Socioeconomic Pathways (SSPs). GDP Growth rate was considered to calculate rate of increase in adaptive capacity.

4.1. Model 1: Socio-economic growth without Climate Change

Based on the available Census data (2005 and 2017), absolute rate of change, and using the population projections from NSB (2019), all the socio-economic indicators as mentioned earlier for SEVI were projected for 2022, 2027, 2032, 2037, 2042, 2047, 2050 and future social-economic vulnerability maps were prepared at the Dzongkhag level. While for the present SEVI, data was available and Gewog level assessment was possible, this is not possible for the future projections.

Table 12: Model 1 SEVI Projections (2005-2050)

Dzongkhag	2005	2017	2022	2027	2032	2037	2042	2047	2050
Bumthang	0.69	0.80	1.32	1.46	1.53	1.56	1.60	1.63	1.64
Chhukha	0.42	0.76	1.22	1.34	1.40	1.44	1.47	1.49	1.51
Dagana	1.86	1.46	1.38	1.36	1.29	1.23	1.20	1.17	1.16
Gasa	1.43	3.48	2.12	2.05	1.99	1.94	1.91	1.89	1.88
Haa	0.70	0.81	1.69	1.88	1.96	2.01	2.05	2.09	2.11
Lhuentse	1.62	1.13	1.31	1.28	1.24	1.21	1.18	1.17	1.16
Monggar	1.75	1.26	1.50	1.46	1.42	1.39	1.37	1.36	1.35
Paro	0.63	0.57	0.89	0.99	1.03	1.05	1.07	1.09	1.10
Pema Gatshel	1.57	1.10	1.45	1.51	1.51	1.50	1.50	1.50	1.50
Punakha	0.77	0.68	1.03	1.10	1.11	1.10	1.10	1.11	1.11
Samtse	1.33	1.14	1.15	1.11	1.06	1.02	1.00	0.98	0.97
Sarpang	0.98	0.87	1.18	1.22	1.22	1.22	1.22	1.23	1.23
Samdrup Jongkhar	1.37	1.01	1.22	1.19	1.17	1.15	1.14	1.14	1.14
Thimphu	0.38	0.56	1.05	1.14	1.20	1.24	1.27	1.31	1.33
Trashigang	1.67	1.41	1.82	1.70	1.63	1.57	1.54	1.53	1.52
Trashiyangtse	1.75	1.75	2.39	2.36	2.28	2.22	2.19	2.16	2.15
Trongsa	1.29	0.33	0.33	0.35	0.35	0.35	0.36	0.36	0.37
Tsirang	1.68	1.61	1.59	1.52	1.44	1.38	1.34	1.32	1.31
Wangdue Phodrang	0.82	0.56	0.72	0.75	0.75	0.75	0.75	0.75	0.75
Zhemgang	2.31	2.42	2.53	2.24	2.09	2.01	1.96	1.93	1.91


2005
2017
2050
Bumthang
Chukha
Dagana
Gasa
Haa
Lhuentse
Monggar
Paro
Pemagatshel
Punakha
Samtse
Sarpang
Sjongkhar
Thimphu
Trashigang
Trashiyangtse
Trongsa
Tsirang
Wangdue
Zhemgang
3.5
3.0
2.5
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4.2. Model 2: Socio-economic growth with Climate Change

Model 2 was developed using the observed data from NCHM and projection developed under the ongoing *Assessment of climate risks on water resources for National Adaptation Plan (NAP) formulation process in Bhutan* by Deltares. Risk (or impact) as mentioned earlier is a function of hazard, exposure and vulnerability. The scenario wise future risk maps for the 20 Dzongkhags were prepared for 2022, 2027, 2032. 2037, 2042, 2047 and 2050. Quantile classification method was used in future risk mapping. Results indicate that by 2050, under RCP 4.5, Tsirang, Paro, Samtse, Thimphu, Pema Gatshel will be showing very high risk which means a total population of 469,595 will be exposed to a very high climate change risk.

The risk maps also indicate that future risk status remains unchanged in almost all the Dzongkhags during the period between 2022 and 2050. Dzongkhags like Punakha, Samdrup Jongkhar, Zhemgang, Sarpang, Trashiyangtse show an increasing trend in relative ranking of future risk. It is understood from the results that major changes in socio-economic vulnerability may not be achieved in one decade. However, with comprehensive adaptation measures, the relative risk will decline gradually over a decade as evident in Figures below.

Dzongkhag	Future climate (RCP 4.5)			Future climate (RCP 8.5)		
	Tmax (SD)	Tmin (SD)	Rainfall (SD)	Tmax (SD)	Tmin (SD)	Rainfall (SD
Bumthang	0.33	0.37	239.29	0.51	0.48	225.87
Chhukha	0.29	0.31	342.96	0.45	0.42	292.63
Dagana	0.29	0.31	337.71	0.45	0.42	303.56
Gasa	0.35	0.42	165.29	0.53	0.53	189.05
Haa	0.30	0.34	276.57	0.47	0.43	243.64
Lhuentse	0.35	0.38	235.25	0.53	0.50	218.88
Monggar	0.30	0.32	322.41	0.46	0.42	292.03
Paro	0.32	0.36	229.19	0.49	0.45	217.91
Pema Gatshel	0.29	0.31	333.85	0.49	0.41	315.07
Punakha	0.32	0.37	219.99	0.45	0.47	228.32
Samtse	0.29	0.31	295.02	0.45	0.41	294.42
Sarpang	0.29	0.32	350.89	0.45	0.42	284.49
Samdrup Jongkhar	0.29	0.31	353.33	0.45	0.42	326.22
Thimphu	0.33	0.37	214.29	0.50	0.47	212.13
Trashigang	0.30	0.32	282.63	0.45	0.41	271.94
Trashiyangtse	0.30	0.33	300.28	0.47	0.43	277.34
Trongsa	0.29	0.31	345.86	0.45	0.42	323.24
Tsirang	0.31	0.35	259.26	0.48	0.45	255.24
Wangdue Phodrang	0.34	0.37	245.66	0.52	0.48	226.89
Zhemgang	0.29	0.31	343.63	0.45	0.41	311.53

As per the future scenarios of Model 2, following are the estimated population at risk:

Dzongkhag		Thimphu	Tsirang	Paro	Samtse	Pema Gatshel	Total
2022	Male	81,349	12,220	25,944	31,759	11,994	163,266
	Female	77,038	11,551	24,979	31,280	11,805	156,653
	Total	158,386	23,771	50,922	63,038	23,799	319,916
2027	Male	91,304	13,028	28,235	31,609	12,125	176,301
	Female	88,368	12,230	27,651	31,808	11,812	171,869
	Total	179,672	25,259	55,886	63,417	23,937	348,171
2032	Male	101,316	13,791	30,475	31,167	12,159	188,908
	Female	99,886	12,854	30,302	32,078	11,706	186,826
	Total	201,203	26,645	60,777	63,245	23,865	375,735
2037	Male	111,128	14,484	32,599	31,221	12,086	201,518
	Female	111,324	13,403	32,865	28,828	11,481	197,901
	Total	222,452	27,887	65,464	60,049	23,567	399,419

Dzongkhag		Thimphu	Tsirang	Paro	Samtse	Pema Gatshel	Total
2042	Male	120,595	15,099	34,581	32,794	11,912	214,981
	Female	122,531	13,875	35,312	30,255	11,148	213,121
	Total	243,126	28,974	69,892	63,048	23,061	428,101
2047	Male	129,672	15,641	36,419	34,218	11,653	227,603
	Female	133,481	14,281	37,648	31,556	10,731	227,697
	Total	263,152	29,923	74,067	65,774	22,383	455,299
2050	Male	129,672	15,641	36,419	34,218	11,653	227,603
	Female	150,379	15,129	41,096	24,821	10,567	241,992
	Total	280,051	30,770	77,515	59,039	22,220	469,595

Figure 25: Future Risk Index (RCP 4.5)

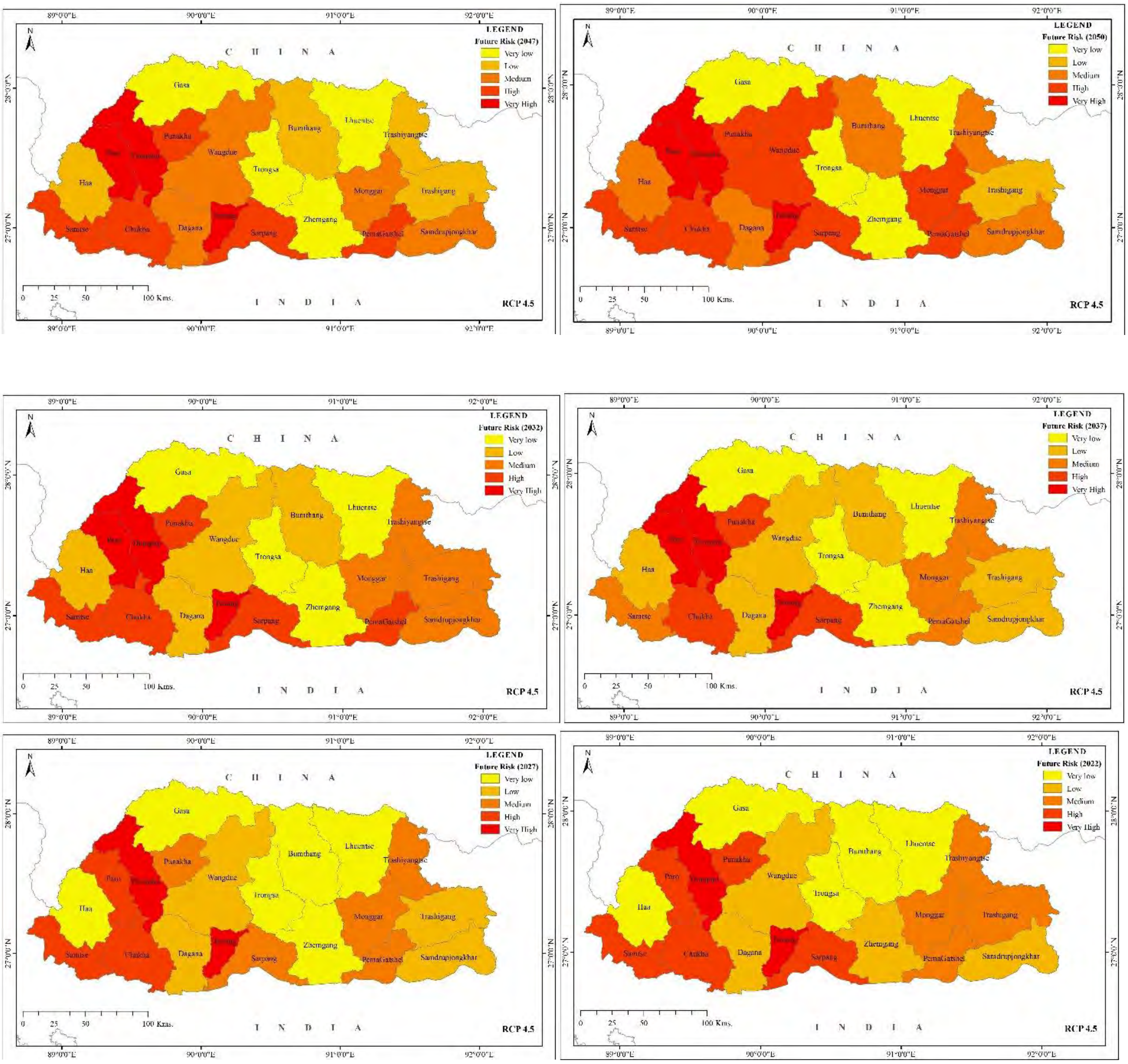
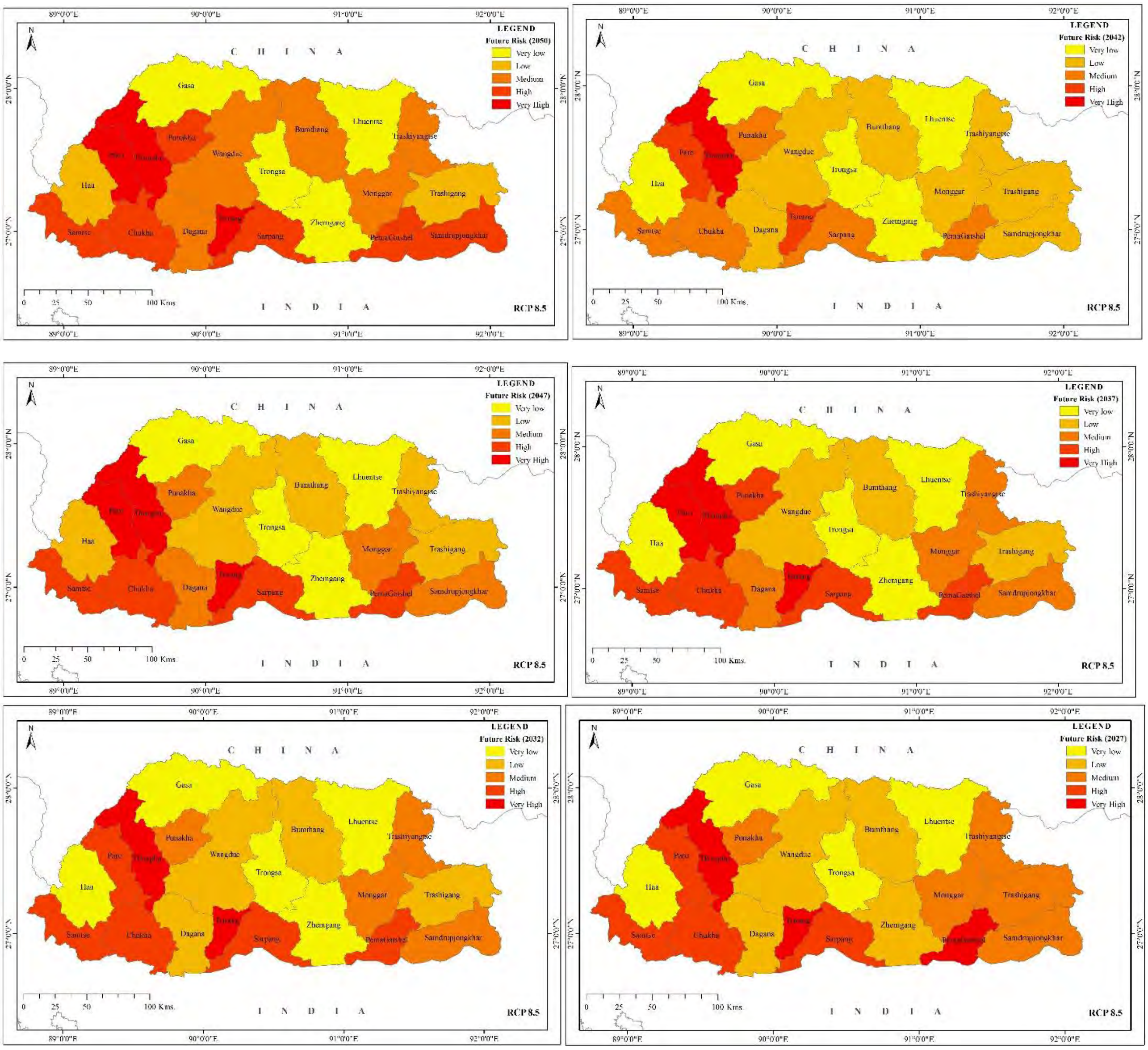


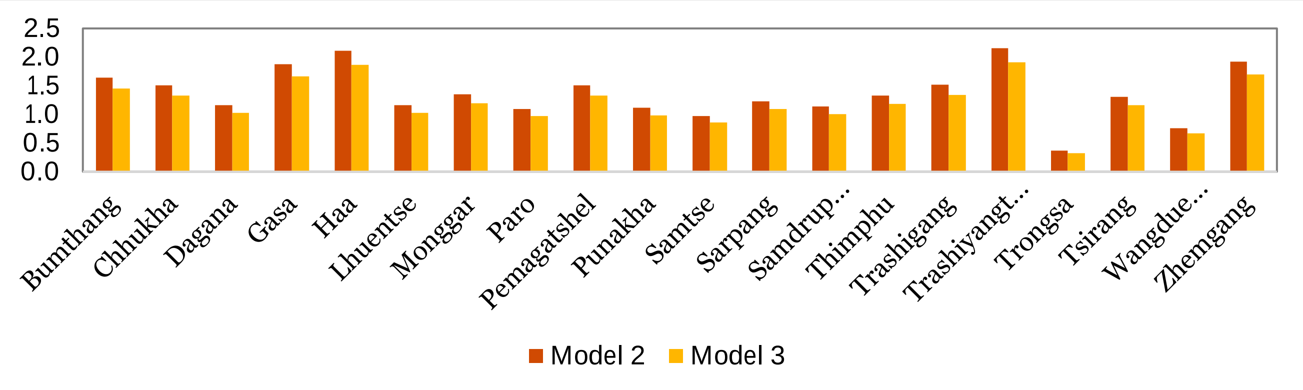
Figure 26: Model 2: Future Risk Index (RCP 8.5)



4.3. Model 3: Growth with Adaptation Pathways

The exploration of alternative socio-economic futures is an important aspect of understanding the potential consequences of climate change. Sustainable development or adaptation strategies that actively reduce socioeconomic inequality, poverty and population growth in Bhutan are ultimately the most effective way of reducing the total number of people categorized as exposed and vulnerable to climate change risks.

As mentioned earlier in the Section 1.3.2, updated population numbers as per the CNDP 2030 were used. As per this, the population of Thimphu will amount to 188,800 as of 2030 and continue to grow at this rate, followed by that of Sarpang, which will amount to 70,600 in 2030, while Chukka and Samtse will reach 68,800 and 67,600 in 2030, respectively. The population growth rates of Central-Eastern and Eastern regions in the case with policy interventions will be higher than those of the case without policy interventions. These correspond to the basic concept of the strategy for national spatial structure and the Alternative G of SEA described in the CNDP 2030, which emphasizes the development of Central-Eastern and Eastern regions.[4]



Considering the rate of change in GDP as per the SSP 1: Sustainability Pathway and CNDP 2030, the change in risk across 2022, 2027, 2032. 2037, 2042, 2047 and 2050 was calculated. The adaptive capacity was increased as per the existing development plans and GDP growth rate.

Dzongkhag	Future Risk (RCP 4.5)						
	2022	2027	2032	2037	2042	2047	2050
Bumthang	0.04257	0.02432	0.02831	0.03129	0.03379	0.03583	0.04070
Chhukha	0.15853	0.08970	0.10491	0.11631	0.12585	0.13358	0.15190
Dagana	0.06507	0.03305	0.03509	0.03633	0.03735	0.03816	0.04260
Gasa	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Haa	0.04073	0.02327	0.02702	0.02976	0.03204	0.03389	0.03837
Lhuentse	0.03143	0.01541	0.01610	0.01632	0.01635	0.01621	0.01749
Monggar	0.10409	0.05177	0.05573	0.05830	0.06023	0.06153	0.06833
Paro	0.16738	0.09748	0.11499	0.12843	0.14058	0.15141	0.17471
Pema Gatshel	0.10790	0.05772	0.06425	0.06847	0.07190	0.07459	0.08362
Punakha	0.13300	0.07393	0.08411	0.09140	0.09800	0.10392	0.11881
Samtse	0.16218	0.08004	0.08527	0.08860	0.09122	0.09314	0.10372
Sarpang	0.13463	0.07241	0.08208	0.08949	0.09601	0.10160	0.11599
Samdrup Jongkhar	0.07744	0.03883	0.04231	0.04470	0.04666	0.04818	0.05390
Thimphu	0.51469	0.29611	0.35597	0.40519	0.45243	0.49655	0.58052
Trashigang	0.10115	0.04788	0.05006	0.05124	0.05208	0.05254	0.05765
Trashiyangtse	0.10081	0.05065	0.05396	0.05594	0.05733	0.05819	0.06422
Trongsa	0.01298	0.00724	0.00834	0.00914	0.01000	0.01092	0.01272

[4] Under the CNDP 2030 project a Strategic Environmental Assessment (SEA) was undertaken for assessing the environmental and social implications of Policies, Plans and Programmes (PPPs). Six prototypes were been elaborated for the development alternatives, which effectively represent the full spectrum of development possibilities available to the country taking into consideration the CNDP 2030. Each of the alternatives represented a reasonable, realistic and relevant development pattern. It was concluded that Alternative G is the most preferable (the best) alternative of all the development alternatives. Alternative G would prioritize both economic growth and the conservation of culture and tradition in Bhutan. This alternative will be most effective for tackling existing social issues in Bhutan. The negative impacts will be moderate as compared to others. Therefore, it was considered for the current assessment.

Dzongkhag	Future Risk (RCP 4.5)						
	2022	2027	2032	2037	2042	2047	2050
Tsirang	0.25015	0.12410	0.13204	0.13753	0.14262	0.14710	0.16550
Wangdue Phodrang	0.04295	0.02330	0.02637	0.02855	0.03057	0.03239	0.03699
Zhemgang	0.05014	0.02236	0.02280	0.02309	0.02325	0.02321	0.02527

Dzongkhag	Future Risk (RCP 8.5)						
	2022	2027	2032	2037	2042	2047	2050
Bumthang	0.03958	0.02261	0.02632	0.02909	0.03141	0.03331	0.03783
Chhukha	0.13719	0.07762	0.09078	0.10065	0.10891	0.11559	0.13145
Dagana	0.06394	0.03248	0.03448	0.03570	0.03670	0.03749	0.04186
Gasa	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Haa	0.02859	0.01633	0.01897	0.02089	0.02248	0.02378	0.02693
Lhuentse	0.02991	0.01466	0.01532	0.01553	0.01555	0.01543	0.01664
Monggar	0.08999	0.04476	0.04818	0.05041	0.05207	0.05320	0.05908
Paro	0.12794	0.07451	0.08789	0.09817	0.10745	0.11573	0.13354
Pema Gatshel	0.16074	0.08598	0.09572	0.10200	0.10711	0.11112	0.12457
Punakha	0.07588	0.04218	0.04799	0.05215	0.05591	0.05929	0.06779
Samtse	0.15718	0.07758	0.08264	0.08587	0.08840	0.09026	0.10052
Sarpang	0.09854	0.05301	0.06008	0.06550	0.07028	0.07437	0.08490
Samdrup Jongkhar	0.08211	0.04118	0.04486	0.04739	0.04947	0.05109	0.05715
Thimphu	0.43123	0.24809	0.29825	0.33949	0.37907	0.41603	0.48638
Trashigang	0.08228	0.03895	0.04072	0.04168	0.04236	0.04273	0.04689
Trashiyangtse	0.09074	0.04559	0.04857	0.05035	0.05161	0.05238	0.05780
Trongsa	0.01392	0.00777	0.00894	0.00980	0.01073	0.01171	0.01364
Tsirang	0.23903	0.11859	0.12617	0.13142	0.13628	0.14057	0.15815
Wangdue Phodrang	0.03991	0.02165	0.02450	0.02653	0.02841	0.03010	0.03438
Zhemgang	0.04803	0.02142	0.02184	0.02212	0.02227	0.02223	0.02421

As per the future scenarios of Model 3, following are the estimated population at risk:

Dzongkhag	2022	2027	2032	2037	2042	2047	2050
Bumthang	18,585	18,656	18,727	18,798	18,869	18,941	19,013
Chhukha	71,292	71,492	71,692	71,893	72,094	72,296	72,498
Dagana	25,817	25,928	26,040	26,151	26,264	26,377	26,490
Gasa	4,394	4,459	4,524	4,591	4,658	4,727	4,796
Haa	13,896	13,913	13,929	13,946	13,963	13,980	13,996
Lhuentse	13,505	13,281	13,060	12,844	12,630	12,421	12,215
Monggar	36,506	36,291	36,076	35,864	35,652	35,442	35,233
Paro	52,099	52,985	53,885	54,801	55,733	56,681	57,644
Pema Gatshel	23,536	23,472	23,409	23,346	23,283	23,220	23,157
Punakha	31,469	31,897	32,331	32,770	33,216	33,668	34,126
Samtse	62,476	62,395	62,314	62,233	62,152	62,071	61,990
Sarpang	50,097	50,738	51,388	52,045	52,712	53,386	54,070
Samdrup Jongkhar	35,134	35,057	34,980	34,903	34,826	34,749	34,673
Thimphu	167,258	171,322	175,486	179,750	184,118	188,592	193,175
Trashigang	42,093	41,415	40,749	40,092	39,447	38,812	38,187
Trashiyangtse	16,596	16,438	16,282	16,127	15,974	15,823	15,672
Trongsa	22,349	22,834	23,329	23,836	24,353	24,881	25,421
Tsirang	23,725	23,929	24,135	24,342	24,552	24,763	24,976
Wangdue Phodrang	42,800	43,344	43,894	44,451	45,016	45,588	46,167
Zhemgang	16,649	16,411	16,176	15,945	15,717	15,492	15,271

5. Conclusion and Recommendations

Bhutan experiences high level of poverty, hazards and the challenges of under-development. Strong dependence on agriculture, comparatively low economic growth, illiteracy, lack of access to safe drinking water, sanitation and other services makes the several regions of the country vulnerable to climate induced hazards. In addition, the eastern part of Bhutan appears socio-economically more vulnerable than the western and central parts.

This study may help design location-based and hazard specific plans and development strategies for these vulnerable areas. The climate vulnerability and risk index acts as a diagnostic tool, which gives RGoB a tool to understand resilience of Dzongkhags based on key socio-economic parameters, and shape adaptation planning, practice and investment. The risk index can also be used for monitoring through repeating calculations, with updated indicator values. It should be clearly understood that in a climate change vulnerability assessment the index is the starting point, not the end. The calculation of the index is useful if it is used for a more in-depth analysis or linked to qualitative tools, which help identify and test the adaptation solutions. The contextual linkages will then become clearer and the information the index components provide (for example how a certain Dzongkhag has reached its (non-)vulnerability level, where it lags behind, etc.) will be relevant from the policy and practice perspectives.

Adaptation measures beyond normal development activities as envisaged in the 12th FYP and CNDP 2030 may be required to address these challenges in the vulnerable Dzongkhags of Bhutan. These need to be multi-faceted and gender sensitive. Together these have the potential to reduce the overall vulnerability and social distress and improve the standard of living of residents despite climate shocks and changing climate conditions.

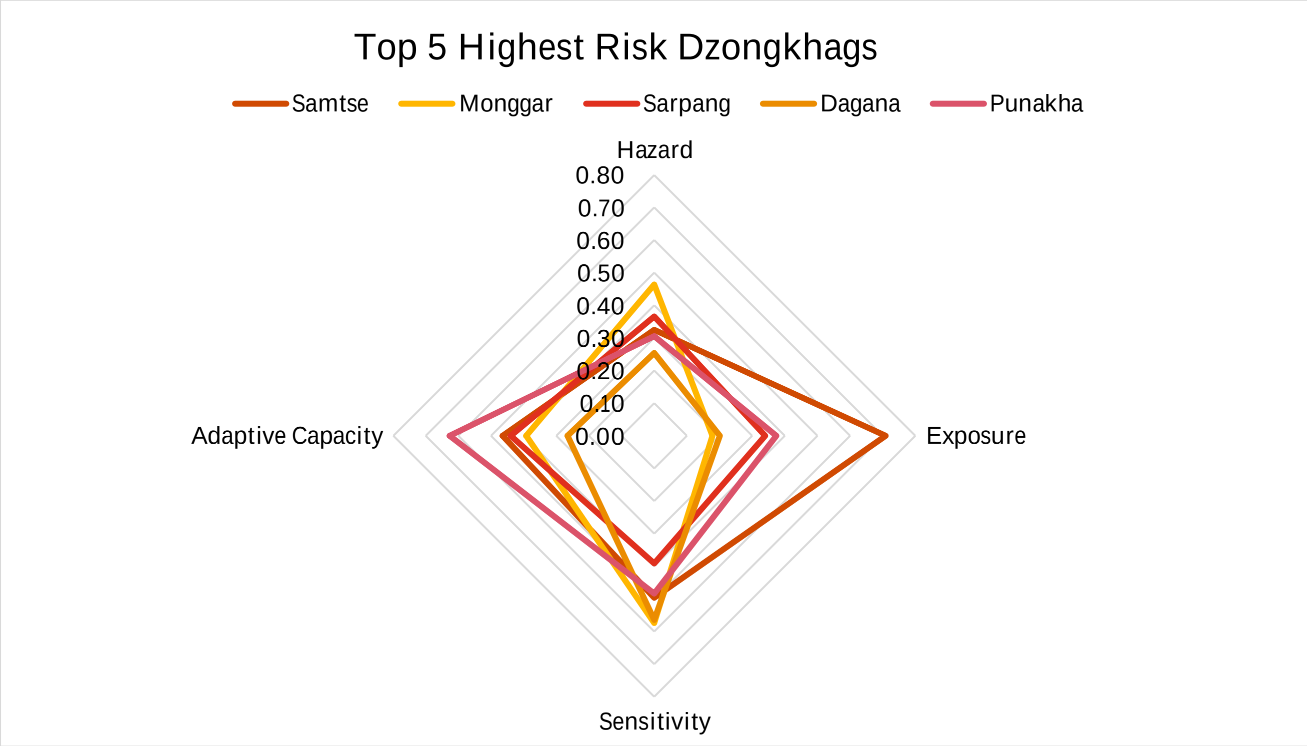


Figure 27: Dzongkhags at Highest Risk

The assessment team reviewed the major findings on hazards, exposure, sensitivity, and adaptive capacity, and based on the major and sub-components responsible for high climate risk, developed a preliminary set of adaptation strategy recommendations. In terms of hazards, there are several climate changes that are anticipated across Bhutan: increasing temperature, and intensity of flooding and landslides, along with continued interannual rainfall variability. Samtse, Monggar, Sarpang, Dagana and Punakha are among the Dzongkhags that are at the highest climate risk. Strengthening their social system with provision of economic opportunities is essential for lessening socio-economic vulnerability. Education and awareness among local communities may ameliorate the understanding of the magnitude and implications of severe weather events.

5.1. Risk and Vulnerability Specific Recommendations

5.1.1. Recommendations for Present Climate Risk

Samtse	An estimated 8,562 across Duenchhukha, Namgyalchhoeling and Pemaling are presently at high climate risk. This includes the vulnerable population. Adaptation action may start with these Gewogs and focus on building measures to reduce landslide, hailstorm damage. There should also be focus on building health infrastructure.
Monggar	Around 4,362 people, including the vulnerable population is at risk in Thang-Rong, Kengkhar, Balam. Adaptation action may focus on literacy rate which is among the lowest and livelihood support.
Sarpang	Sarpang has high infant mortality, disability prevalence and food insufficiency; any adaptation planning may start there. There is an estimated 8,047 people at risk between Chhudzom, Jigme Chhoeling and Gakiling. There may also be a focus on supporting families with large household size.

5.1.2. Recommendations for Future Climate Risk

Thimphu	The Dzongkhag will experience highest future climate risk due to high in-migration/ urbanization and population growth. Key adaptation action should focus on addressing urban growth as well as unemployment level.
Pema Gatshel	It will experience high rainfall deviation (decrease). Key adaptation actions may focus on addressing agricultural literacy and permanent housing.
Samtse	Samtse has high future and present risk. It will experience the most increase in temperature and that will impact its already high dependent population on agriculture. Adaptation actions must also aim to reduce agriculture dependency through alterative livelihood options.

5.1.3. Recommendations for Socio-economic vulnerability: Gewogs

Gasa: Lunana	Lunana in Gasa has the highest socio-economic vulnerability of all Gewogs. This is due to very low electricity coverage. Very few housing structures in Lunana are made of concrete, only around 19%. Permanent affordable low carbon housing maybe the first step in increasing resilience of the Gewog.
Thimphu: Naro	In Naro, there is a high food insufficiency with 14% experiencing it. This increases its overall vulnerability. Moreover only 27% have access of clean cooking fuel (LPG) in the town. Adaptation focus may be on these parameters.
Chhukha: Getana	Getana has among the highest household size across all Gewogs with 5.2 members per family. The population also consists of more than 50% of women. Vulnerability is high as the Geog has low literacy (38%). Gender sensitive resilience planning may be an adaptation strategy.

5.1.4. Recommendations for Socio-economic vulnerability: Towns

Pema Gatshel: Kherigonpa Town	Kherigonpa has the highest disability prevalence rate among all towns. This substantially increases the climate vulnerability of the town. This is compounded by low access to improved sanitation services. Adaptation action must ideally aim to address these.
Haa: Jyenkana Town	The vulnerability in this town is due to less access to sanitation and safe sources of drinking water. This increase sensitivity to climate change especially when nearly 48% of the population is children.
Dagana: Sankosh Town	For Sankosh Town, high socio-economic vulnerability is due to a higher percentage of female population and elderly. Access to safe drinking water and sanitation services must be increased.

5.2. General Recommendations

5.2.1. Development of a Risk Index for Gewogs

Local Government officials could undertake climate risk assessments based on the framework and methodology used in this study for Gewogs. As the current framework in this study is based on IPCC methodology it can be standardized for Gewogs. However, it requires building capacity for risk assessment. Climate Risk and Vulnerability assessment should ideally be carried out also at a below Gewog level. It can act as a diagnostic tool to pinpoint vulnerability of Chiwogs/ Gewogs based on key socio-economic parameters, and shape adaptation planning, practice and investment at a local level.

For example, risks from flooding was a major concern among Gewogs during our consultation. A tentative local adaptation plan could be to draft vulnerability maps for each community along a river flood plain with the participation of community organizations (this activity initially can be informed by the results of this assessment in identifying the Gewogs).

5.2.2. Gender Sensitive Resilience Planning

Building on this foundation, the detailed assessment of adaptation and coping mechanisms would be useful, especially if linked to the biophysical environment and its recent changes. During the course of detailed assessment adaptation at local level there is need to ensure attention is given to address gender differences in capabilities to cope with climate change adaptation. Specifically, make women's equal access to information, credit and other productive and reproductive resources a priority; develop and apply gender-sensitive criteria and indicators for monitoring and evaluation of the results of ongoing adaptation actions.

5.2.3. Informed migration decisions for urbanization

Vulnerability for Trashigang and Thimphu also arises from the high level out and in-migration they experience. It is required that migration across Bhutan is well-informed and monitored to avoid excessive urbanization. High population density also increases the exposure to climate hazards. There are two levels of information that is needed:

- Bhutan needs to have a realistic statistical account of their number and an understanding of the nature of the mobility to develop policies and provide services for seasonal migrant workers. Official agencies need to estimate short-term movements, or migrations induced due to climate change/ seasonal variation which are in fact the bulk of migratory movements (Chand, 2013).
- Migration choices are based partly on perceptions of vulnerability and opportunities, which are often based on scant information. Migrants sometimes overestimate the benefits of moving. Without material resources, information, and contacts, they may move, not to the most suitable next habitat, but to the most accessible one (World Bank, 2018).

Policies that allow for better information gathering for understanding seasonal/climate induced migration and facilitation of information that helps in orientation, increasing migrants' financial literacy, and their legal status for them to make informed migration choices and improved adjustment to host areas.

5.2.4. Dynamic Data Collation

A vulnerability assessment is inherently a data intensive process and hence non-availability of the latest data remained a major challenge. The assessment had to rely on socio-economic data obtained from Census 2005 and 2017. This indicates that generation of data on important indicators in regular and relatively shorter intervals is required for effective vulnerability assessment for NAP process. It is important to add, census data is collected after a gap of 10 years and is "stock data", unable to capture the sharp increase or shifts in migration or food insufficiency etc. that has occurred in Bhutan. Such gaps may lead to not addressing adaptation interventions on a timely manner.

5.2.5. Capacity Building for Climate Resilience and Vulnerability Assessments

The key to effective adaptation planning is to have key government officials sensitized to climate change adaptation action. Strengthening the capacity of officials and institutions to prevent and mitigate climate change risk exposure can be accomplished by implementing two broad and ambitious activities:

- Develop institutional courses to train specialized personnel on climate change, planning, and risk management. Academic institutions such as the Royal University of Bhutan, TVET institutes and private institutions can be supported to develop these trainings.
- Train officials and other technical personnel to facilitate the development of land-use plans and vulnerability assessments that integrate climate change adaptation. Personnel from local governments such as the Gups, Thromde officers, to name a few, could be targeted for the training.

Especially in case of rapidly urbanizing Thromdes, improving urban and land use planning to minimize exposure to climate change and risks to natural disasters involves providing guidance and capacity building on how to integrate climate change adaptation into planning processes; and stabilizing roadways to reduce landslide risk to mention a few.

5.2.6. Management and Conservation of Water and WASH services

Besides the water-sensitive agriculture sector, the urban sector in Bhutan is already highly exposed to climate variability, due to its high population density. Climate change impacts—including reductions in water availability and the increased frequency and intensity of flash floods and landslides—would generate additional stress on the current capacity of utilities to safely deliver water, sanitation and hygiene (WASH) services. The strategies for management and conservation of water resources are to strengthen institutions and create awareness related to climate change, conservation and improving the management and conservation of water sources (springs and streams); and promote the efficient use and management of water related to potable use and irrigation for agriculture. These can be broadly done by:

- Training environmental and natural resource management professionals to understand the relationship between management and conservation of the environment and natural resources and climate change;
- Strengthening inter-institutional coordination across all related ministries and sectors to plan, coordinate, and address climate change through improved management and conservation of water sources;and
- Awareness for sanitation and hygiene besides support for better drainage facilities.

For recommendations for promoting the efficient use and management of water related to potable use, irrigation for agriculture can be addressed by the following approaches: promoting best adaptation practices in water management use (e.g., maintenance of drainage systems, establishment of native plant species on river easements to control erosion and siltation, controlling water quality and reducing waste, educating users to reduce water waste, and increasing the number and use of water efficient systems including drip irrigation, etc.). Improving irrigation infrastructure can ensure an adequate supply of water for agriculture and compensate for increased crop water requirements.

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Annexure 1: List of Stakeholders Consulted

Preliminary Consultations conducted for data collation:

- DDM- Sonam Deki and Dorji Wangchuk
- NSB- Tashi Namgay
- MOF- Phuntsho Wangmo
- DLG- Sangay Dorji
- MOH- Chador Wangdi
- GNHC- Chhimi Dema
- Additionally, we had inputs on indicators from NECS during sectoral meetings

Annexure 2: List of Indicators and Data Availability

IPCC Risk Framework (2014)	Major Components	Sub-components (Indicators)	Unit	Scale (s) Available	Year (s) available	Data Source
Hazard	Climate variability	*Maximum temperature (standard deviation)*	Celsius	Dzongkhag	1996-2016	NCHM
		Minimum temperature (standard deviation)	Celsius	Dzongkhag	1996-2017	NCHM
		Average precipitation (standard deviation)	MM	Dzongkhag	1996-2018	NCHM
	Extreme events	*Landslide events*	Area %	Dzongkhag	2010-18	DDM
		Flood impact (land in acre)	Acre	Dzongkhag	2010-18	DDM
		Hailstorm acre affected last 10 years	Number	Dzongkhag	2010-18	DDM
		GLOF impact (land in acre)	Number	Dzongkhag	2010-18	DDM
		Forest fire events/ Total forest area impacted by wildfire per year	Number/ Ha	Dzongkhag	2010-18	DDM/DoFPs
	Impact	*Houses damaged last 10 years*	Number	Dzongkhag	2010-18	DDM
		Total financial losses due to climate induced disasters	Number	Dzongkhag	2010-18	DDM
		Death/injuries due to extreme events in last 10 years	Number	Dzongkhag	2010-18	DDM
Exposure	Community	*Population density*	Persons per sq.km.	Gewog	2017	PHCB
Sensitivity	Socio-demographic profile	*Female headed households*	%	Dzongkhag	2017	PHCB
		Average household size	Number	Gewog	2017	PHCB
		Children	%	Gewog	2017	PHCB
		Elderly people	%	Gewog	2017	PHCB
	Economic status	*Population Involved in Agriculture*	%	Dzongkhag	2017	PHCB
		Outmigration Rate	%	Dzongkhag	2017	PHCB
		Consumption Poverty Rate	%	Dzongkhag	2017	PHCB
	Health issues	*Infant mortality rate*	Number	Dzongkhag	2017	PHCB
		Food insufficiency (no enough food to feed all household members)	%	Gewog	2017	PHCB
		Disability Prevalence Rate	%	Gewog	2017	PHCB
	Environmental degradation	*Urbanisation (urban population growth rate)*	%	Gewog	2005, 2017	PHCB
		Change in agricultural land	%	Dzongkhag	2010-2018	DoA
		Change in forest area	%	Dzongkhag	2010-2018	DoFPS
Adaptive capacity	Knowledge	*Literacy rate*	%	Gewog	2017	PHCB
	Infrastructure	*Permanent housing (Wall, Floor, Roof - Cement/Concrete)*	%	Gewog	2017	PHCB
		Road density	Number	Dzongkhag	2017	PHCB
		Health facilities per 1000 pop	Number	Dzongkhag	2017	PHCB
	Economy	*Tourist Arrivals*	%	Dzongkhag	2017	PHCB
		Establishments covered by Dzongkhag and Area	%	Dzongkhag	2017	PHCB
		Labour Force Participation Rate	%	Gewog	2017	PHCB

IPCC Risk Framework (2014)	Major Components	Sub-components (Indicators)	Unit	Scale (s) Available	Year (s) available	Data Source
	Access to Basic facilities	*Drainage facilities*	%	Dzongkhag	2017	PHCB
		Reliable water supply/HH with functional piped water supply	%	Dzongkhag	2017	PHCB
		Improved sanitation facilities	%	Gewog	2017	PHCB
		Electricity coverage	%	Gewog	2017	PHCB
		Cooking fuel - LPG	%	Gewog	2017	PHCB
	Adaptation strategies	*Percentage of irrigated area*	Km	Dzongkhag	2017	PHCB
		Agricultural assets		Dzongkhag	2017	PHCB
		Community Forest Groups per Dzongkhag/ Plantations by GBCL	Number	Dzongkhag	2017	PHCB
		Identified/ planned early warning systems (EWS)	Number	Dzongkhag	2017	PHCB

Annexure 3: Population Projection

Source: Population Projections for Bhutan 2017-2047 (2019), National Statistics Bureau of Bhutan

Dzongkhag	2017			2022			2027			2032			2037			2042			2047			2050		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Bumthang	9396	8424	17820	9456	8835	18291	9562	9217	18780	9593	9545	19138	9539	9807	19346	9405	10005	19410	9205	10149	19353	9174	10311	19485
Chhukha	36041	32925	68966	36016	33804	69820	36145	34496	70641	35965	34919	70884	35446	35043	70489	34614	34888	69501	33520	34506	68025	33120	34696	67816
Dagana	12956	12009	24965	13410	12322	25732	13961	12567	26528	14437	12713	27150	14816	12750	27566	15097	12684	27781	15291	12536	27827	15720	12371	28091
Gasa	2104	1848	3952	2283	2007	4290	2487	2166	4653	2687	2318	5006	2878	2461	5338	3055	2591	5646	3221	2711	5932	3458	2712	6171
Haa	7435	6220	13655	7522	6290	13812	7648	6316	13964	7718	6283	14001	7723	6188	13912	7666	6037	13704	7557	5842	13399	7578	5773	13351
Lhuentse	7407	7030	14437	7032	6599	13631	6655	6068	12723	6185	5430	11616	5626	4693	10319	4991	3873	8864	4297	2991	7288	3927	2851	6777
Monggar	18247	18903	37150	17498	18886	36383	16758	18711	35469	15805	18340	34144	14641	17766	32407	13294	17014	30308	11804	16120	27923	10982	16081	27062
Paro	23941	22375	46316	25944	24979	50922	28235	27651	55886	30475	30302	60777	32599	32865	65464	34581	35312	69892	36419	37648	74067	39059	38456	77515
Pema Gatshel	11922	11710	23632	11994	11805	23799	12125	11812	23937	12159	11706	23865	12086	11481	23567	11912	11148	23061	11653	10731	22383	11610	10611	22220
Punakha	15079	13661	28740	16228	14562	30790	17547	15439	32986	18827	16247	35073	20027	16962	36988	21133	17580	38713	22148	18116	40264	23615	17982	41597
Samdrup Jongkhar	18329	16750	35079	18256	16652	34908	18255	16406	34661	18093	15979	34072	30411	32064	62475	29368	31788	61156	28089	31298	59388	30851	-1035	29816
Samtse	32022	30568	62590	31759	31280	63038	31609	31808	63417	31167	32078	63245	31221	28828	60049	32794	30255	63048	34218	31556	65774	34609	24430	59039
Sarpang	24018	21986	46004	25696	23776	49472	27633	25559	53192	29494	27259	56753	17755	15369	33124	17256	14597	31852	16622	13698	30320	15929	52267	68196
Thimphu	72522	66214	138736	81349	77038	158386	91304	88368	179672	101316	99886	201203	111128	111324	222452	120595	122531	243126	129672	133481	263152	142878	137173	280051
Trashigang	23414	22104	45518	21981	20871	42852	20517	19335	39853	18744	17472	36216	16674	15304	31978	14355	12881	27236	11844	10266	22110	10583	9896	20479
Trashi Yangtse	8719	8581	17300	8397	8300	16697	8084	7920	16004	7671	7429	15100	7159	6831	13991	6562	6142	12703	5896	5382	11278	5526	5244	10770

Dzongkhag	2017			2022			2027			2032			2037			2042			2047			2050		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Trongsa	11878	8082	19960	14108	8761	22868	14817	9438	24256	15457	10087	25545	16003	10690	26693	16451	11240	27691	16809	11745	28555	17835	11499	29334
Tsirang	11526	10850	22376	12220	11551	23771	13028	12230	25259	13791	12854	26645	14484	13403	27887	15099	13875	28974	15641	14281	29923	16458	14311	30770
Wangdue Phodrang	24302	17884	42186	27802	19056	46858	29210	20194	49404	30482	21242	51724	31569	22167	53736	32463	22967	55430	33182	23658	56840	34976	23209	58185
Zhemgang	9195	8568	17763	8781	8145	16926	8368	7611	15979	7845	6954	14799	7214	6182	13396	6489	5313	11803	5692	4371	10063	5257	4213	9470
Total	380453	346692	727145	397732	365519	763246	413948	383312	797264	427911	399043	826956	438999	412178	851177	447180	422721	869899	452780	431086	883864	473145	433051	906196

Annexure 4: Descriptive Statistics

Indicators	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Temperature (stdv.)	20	0.06	0.43	0.49	0.45	0.02	0.00
Rainfall (stdv.)	20	10.60	9.75	20.34	15.61	2.85	8.12
Flood impact (land in acre)	20	328.00	0.00	328.00	29.33	78.09	6097.54
GLOF impact (land in acre)	20	0.98	0.00	0.98	0.05	0.22	0.05
Landslide Events 2019 (area %)	20	0.48	0.00	0.48	0.11	0.13	0.02
Hailstorm acre affected last 10 years	20	172.81	0.00	172.81	33.29	52.01	2705.22
Forest Fire area total acre last 10 years	20	5907.48	0.00	5907.48	481.00	1362.84	1857326.05
Houses damaged last 10 years	20	753.00	6.00	759.00	250.25	217.86	47462.93
No of deaths due to climate disaster last 10 years	20	15.00	0.00	15.00	1.55	3.71	13.73
Total financial losses due to climate induced disasters	20	303.94	0.00	303.94	39.59	91.94	8453.46
Population Density (per sq. km)	20	76.08	1.34	77.42	22.31	18.19	330.88
Avg. HH Size	20	0.70	3.50	4.20	3.80	0.19	0.04
Female Headed HH (%)	20	48.00	16.60	64.60	39.18	15.01	225.18
Children (%)	20	11.60	20.66	32.27	26.82	2.60	6.78
Elderly (%)	20	5.93	3.83	9.77	6.55	1.42	2.02
Population involved in agri	20	65.86	5.70	71.56	50.86	16.74	280.28
Out migration Rate	20	11.41	0.26	11.67	5.00	2.54	6.47
Consumption Poverty Rate (%)	20	33.00	0.30	33.30	9.80	8.49	72.05
Un-Employment Rate (%)	20	5.30	0.70	6.00	1.71	1.15	1.33
Food Insufficiency (%)	20	7.31	2.65	9.96	6.47	2.17	4.69
Infant Mortality Rate	20	57.00	6.50	63.50	19.62	12.42	154.21
Disability Prevalence Rate (%)	20	2.60	1.20	3.80	2.40	0.63	0.40
Urbanization (%)	20	491.98	-4.59	487.39	102.89	129.88	16869.16
Change in agricultural land (%)	20	267.03	-45.68	221.35	0.36	55.84	3118.23
Change in forest area (%)	20	63.17	-24.09	39.08	-1.24	15.90	252.70

Indicators	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Literacy rate (%)	20	24.06	59.85	83.91	68.42	6.02	36.21
Labor Force Participation Rate (%)	20	22.60	48.80	71.40	59.50	6.28	39.40
Tourist Arrivals (%)	20	27.83	0.00	27.83	5.00	8.85	78.29
Establishments covered by Dzongkhag and Area (%)	20	52.00	0.10	52.10	4.99	11.31	127.93
% Permanent	20	56.97	13.24	70.22	37.96	17.16	294.33
Road density	20	1.24	0.04	1.28	0.54	0.32	0.10
Health facilities per 1000 pop	20	4.60	0.25	4.86	1.74	1.17	1.36
Electricity coverage (%)	20	30.00	70.00	100.00	90.78	8.60	74.03
Safe drinking water (%)	20	4.10	95.30	99.40	98.38	0.90	0.81
Drainage facilities (%)	20	51.40	41.40	92.80	72.01	15.17	230.00
Improved Sanitation Facilities (%)	20	28.90	55.10	84.00	71.39	7.43	55.16
Cooking fuel (%)	20	67.30	25.80	93.10	58.44	22.10	488.62
Agricultural assets	20	12.12	1.84	13.96	7.34	3.95	15.60
Irrigated area (%)	20	14.69	0.34	15.03	5.00	4.07	16.56
Identified/ planned early warning systems (EWS)	20	1.00	0.00	1.00	0.33	0.44	0.19
Community Forestry (No.)	20	82.00	7.00	89.00	40.20	18.35	336.91
Valid N (listwise)	20						

Annexure 4: Town Level Vulnerability Index

Dzongkhag	Town	Sensitivity	Adaptive Capacity	Vulnerability Index	Vulnerability Rank
Haa	Jyenkana Town	0.53	0.57	0.92	1
Dagana	Dagapela Town	0.54	0.60	0.90	2
Pema Gatshel	Kherigonpa Town	0.55	0.66	0.82	3
Bumthang	Bumthang Town	0.49	0.66	0.75	4
Zhemgang	Panbang Town	0.42	0.58	0.73	5
Trongsa	Kengarabten Town	0.44	0.61	0.71	6
Dagana	Sankosh Town	0.45	0.65	0.70	7
Dagana	Lhamoi Dzingkha Town	0.57	0.81	0.70	8
Thimphu	Khasadrapchu Town	0.48	0.71	0.67	9
Monggar	Kilikhar Town	0.47	0.72	0.65	10
Chhukha	Darla Town	0.57	0.89	0.64	11
Samdrup Jongkhar	Jomtsangkha Town	0.47	0.74	0.64	12
Pema Gatshel	Khothakpa Town	0.55	0.88	0.63	13
Tsirang	Mendrelgang Town	0.48	0.77	0.62	14
Trashiyangtse	Trashi Yangste Town	0.50	0.81	0.61	15
Lhuentse	Autsho Town	0.43	0.73	0.60	16
Monggar	Monggar Town	0.47	0.81	0.58	17
Pema Gatshel	Yalang Town	0.48	0.82	0.58	18
Pema Gatshel	Mongling Town	0.44	0.76	0.58	19
Wangdue	Nobding Town	0.44	0.76	0.58	20
Trashigang	Khaling Town	0.45	0.79	0.57	21
Trashigang	Wamrong Town	0.48	0.84	0.57	22
Samdrup Jongkhar	Sambdrupcholing Town	0.50	0.87	0.57	23
Paro	Paro Town	0.41	0.73	0.57	24
Paro	Betekhya Town	0.50	0.90	0.56	25
Punakha	Punakha Town	0.46	0.85	0.55	26
Wangdue	Wangdue Phodrang Town	0.45	0.83	0.55	27
Wangdue	Rurichu Town	0.42	0.78	0.54	28
Thimphu	Thimphu Thromde	0.44	0.81	0.54	29
Pema Gatshel	Nangkhor Town	0.42	0.78	0.54	30
Sarpang	Gelegphu Thromde	0.46	0.86	0.53	31
Samtse	Sipsu Town	0.42	0.79	0.53	32
Sarpang	Sarpang Town	0.40	0.75	0.53	33
Chhukha	Tsimasham Town	0.43	0.82	0.53	34
Monggar	Gyalposhing Town	0.44	0.85	0.52	35
Monggar	Lingmethang Town	0.42	0.81	0.52	36
Trashigang	Trashigang Town	0.45	0.86	0.52	37
Trashigang	Resarbu Town	0.45	0.88	0.51	38
Samtse	Samtse Town	0.44	0.87	0.51	39
Pema Gatshel	Old Pema Gatshel Town	0.42	0.83	0.51	40
Samdrup Jongkhar	Samdrup Jongkhar Thromde	0.41	0.82	0.50	41
Dagana	Dagana Town	0.41	0.82	0.50	42
Pema Gatshel	Nganglam Town	0.42	0.84	0.50	43
Chhukha	Chhukha Town	0.42	0.85	0.50	44
Samtse	Gomtu Town	0.40	0.81	0.49	45
Monggar	Yadi Town	0.45	0.92	0.49	46
Zhemgang	Zhemgang Town	0.42	0.85	0.49	47
Punakha	Lobaysa Town	0.44	0.90	0.49	48
Haa	Haa Town	0.35	0.72	0.49	49
Lhuentse	Lhuentse Town	0.31	0.63	0.49	50
Gasa	Damji Town	0.35	0.74	0.48	51
Zhemgang	Tingtibi Town	0.33	0.70	0.48	52
Tsirang	Tsirang Town	0.38	0.79	0.48	53

Dzongkhag	Town	Sensitivity	Adaptive Capacity	Vulnerability Index	Vulnerability Rank
Trashigang	Rangjung Town	0.37	0.80	0.47	54
Monggar	Dramedtse Town	0.40	0.86	0.47	55
Chhukha	Phuentsholing Thromde	0.37	0.82	0.45	56
Chhukha	Gedu Town	0.40	0.88	0.45	57
Trashiyangtse	Duksum Town	0.38	0.87	0.44	58
Gasa	Gasa Town	0.37	0.86	0.44	59
Trongsa	Trongsa Town	0.29	0.67	0.43	60
Bumthang	Chhumig Town	0.32	0.80	0.40	61
Trashigang	Kanglung Town	0.29	0.72	0.40	62
Pema Gatshel	Denchi Town	0.31	0.77	0.40	63
Dagana	Drukjeygang Town	0.29	0.77	0.38	64

Annexure 5: Gewog Level Vulnerability Index

Dzongkhag	Gewog	Sensitivity	Adaptive Capacity	Vulnerability Index	Vulnerability Rank
Gasa	Lunana	0.44	0.13	3.33	1
Thimphu	Naro	0.33	0.13	2.47	2
Chhukha	Getana	0.63	0.33	1.93	3
Monggar	Thang-Rong	0.62	0.37	1.67	4
Chhukha	Maedtabkha	0.60	0.37	1.64	5
Pema Gatshel	Chongshing	0.57	0.38	1.52	6
Chhukha	Doongna	0.60	0.39	1.51	7
Zhemgang	Barbo	0.55	0.37	1.50	8
Dagana	Khebisa	0.57	0.40	1.41	9
Monggar	Kengkhar	0.48	0.34	1.40	10
Monggar	Balam	0.57	0.41	1.39	11
Samdrup Jongkhar	Wangphu	0.48	0.35	1.39	12
Lhuentse	Jarey	0.55	0.40	1.38	13
Zhemgang	Goshing	0.58	0.42	1.37	14
Trashigang	Merag	0.42	0.31	1.35	15
Trashigang	Sagteng	0.46	0.35	1.34	16
Dagana	Dorona	0.52	0.39	1.33	17
Wangdue	Kazhi	0.56	0.43	1.32	18
Chhukha	Loggchina	0.55	0.42	1.30	19
Samtse	Duenchhukha	0.48	0.37	1.30	20
Samdrup Jongkhar	Lauri	0.42	0.33	1.28	21
Monggar	Jurmed	0.52	0.41	1.28	22
Tsirang	Pungtenchhu	0.52	0.40	1.28	23
Wangdue	Dangchhu	0.60	0.48	1.26	24
Monggar	Silambi	0.56	0.44	1.26	25
Dagana	Largyab	0.47	0.37	1.26	26
Trashiyangtse	Yalang	0.52	0.41	1.26	27
Bumthang	Tang	0.49	0.39	1.25	28
Zhemgang	Shingkhar	0.51	0.41	1.25	29
Samtse	Pemaling	0.57	0.46	1.24	30
Samtse	Namgyalchhoeling	0.56	0.45	1.24	31
Haa	Gakiling	0.44	0.36	1.23	32
Lhuentse	Gangzur	0.53	0.43	1.23	33
Tsirang	Semjong	0.52	0.42	1.23	34
Pema Gatshel	Dechhenling	0.53	0.43	1.23	35
Pema Gatshel	Chhimoong	0.47	0.38	1.23	36
Monggar	Shermuhoong	0.47	0.38	1.23	37
Zhemgang	Bjoka	0.49	0.40	1.22	38
Trashiyangtse	Yangtse	0.55	0.45	1.21	39
Samtse	Tading	0.53	0.44	1.21	40
Monggar	Na-Rang	0.47	0.39	1.21	41
Sarpang	Chhudzom	0.49	0.41	1.20	42
Bumthang	Ura	0.47	0.39	1.20	43
Monggar	Gongdue	0.50	0.42	1.19	44
Chhukha	Bongo	0.53	0.44	1.19	45
Trashiyangtse	Toedtsho	0.52	0.44	1.19	46
Tsirang	Doonglagang	0.54	0.45	1.19	47
Tsirang	Serigithang	0.51	0.43	1.18	48
Dagana	Karna	0.50	0.42	1.17	49
Pema Gatshel	Yurung	0.52	0.44	1.17	50
Trashigang	Shongphu	0.53	0.45	1.17	51
Monggar	Chagsakhar	0.47	0.41	1.14	52
Samtse	Norgaygang	0.51	0.45	1.13	53
Thimphu	Lingzhi	0.38	0.33	1.13	54
Trashigang	Udzorong	0.44	0.39	1.12	55

Dzongkhag	Gewog	Sensitivity	Adaptive Capacity	Vulnerability Index	Vulnerability Rank
Pema Gatshel	Khar	0.49	0.44	1.12	56
Wangdue	Nahi	0.58	0.52	1.11	57
Wangdue	Phobji	0.55	0.50	1.11	58
Monggar	Tsakaling	0.57	0.51	1.11	59
Trashigang	Kangpar	0.43	0.39	1.10	60
Pema Gatshel	Chhoekorling	0.46	0.42	1.10	61
Trashiyangtse	Tongmajangsa	0.55	0.50	1.10	62
Trashiyangtse	Boomdeling	0.52	0.48	1.08	63
Tsirang	Barshong	0.46	0.43	1.07	64
Pema Gatshel	Nanong	0.45	0.42	1.07	65
Lhuentse	Tsaenkhar	0.55	0.51	1.07	66
Trashiyangtse	Khamdang	0.52	0.48	1.07	67
Lhuentse	Maestsho	0.44	0.41	1.07	68
Dagana	Tashiding	0.49	0.47	1.06	69
Samtse	Doomtoed	0.42	0.40	1.06	70
Chhukha	Phuentshogling	0.50	0.48	1.05	71
Wangdue	Athang	0.48	0.45	1.05	72
Dagana	Nichula	0.44	0.42	1.05	73
Dagana	Tsangkha	0.51	0.49	1.04	74
Monggar	Saling	0.49	0.47	1.04	75
Trashigang	Phongmed	0.46	0.45	1.04	76
Trashigang	Radhi	0.50	0.49	1.03	77
Samdrup Jongkhar	Gomdar	0.43	0.42	1.03	78
Pema Gatshel	Zobel	0.43	0.41	1.03	79
Trongsa	Korphu	0.45	0.45	1.01	80
Gasa	Laya	0.37	0.37	1.01	81
Tsirang	Tsholingkhar	0.52	0.52	1.01	82
Thimphu	Soe	0.39	0.39	1.01	83
Punakha	Kabisa	0.54	0.53	1.01	84
Samtse	Dophuchen	0.45	0.46	0.99	85
Samtse	Sang-Ngag-Chhoeling	0.51	0.52	0.99	86
Monggar	Tsamang	0.51	0.51	0.99	87
Wangdue	Phangyuel	0.55	0.55	0.99	88
Trashigang	Khaling	0.42	0.43	0.99	89
Trashiyangtse	Jamkhar	0.43	0.44	0.98	90
Zhemgang	Nangkor	0.47	0.48	0.98	91
Bumthang	Chhumig	0.41	0.43	0.97	92
Punakha	Todewang	0.54	0.55	0.97	93
Haa	Samar	0.49	0.51	0.97	94
Zhemgang	Phangkhar	0.44	0.46	0.97	95
Paro	Nagya	0.44	0.46	0.96	96
Pema Gatshel	Dungmaed	0.40	0.42	0.95	97
Lhuentse	Kurtoed	0.43	0.45	0.94	98
Samdrup Jongkhar	Martshala	0.41	0.44	0.94	99
Bumthang	Chhoekhor	0.43	0.46	0.94	100
Punakha	Goenshari	0.47	0.50	0.94	101
Samtse	Yoeseltse	0.47	0.51	0.93	102
Trashigang	Thrimshing	0.44	0.48	0.93	103
Punakha	Shelnga-Bjemi	0.51	0.55	0.93	104
Wangdue	Saephu	0.47	0.51	0.92	105
Dagana	Drukjeygang	0.43	0.46	0.92	106
Sarpang	Jigme Chhoeling	0.44	0.47	0.92	107
Lhuentse	Maenbi	0.48	0.52	0.92	108
Dagana	Tsenda-Gang	0.45	0.49	0.92	109
Tsirang	Tsirang Toed	0.43	0.46	0.92	110
Monggar	Drepoong	0.47	0.51	0.91	111
Monggar	Ngatshang	0.45	0.49	0.91	112
Haa	Sangbay	0.34	0.38	0.91	113
Pema Gatshel	Shumar	0.50	0.55	0.90	114
Sarpang	Gakiling	0.44	0.49	0.90	115

Dzongkhag	Gewog	Sensitivity	Adaptive Capacity	Vulnerability Index	Vulnerability Rank
Lhuentse	Khoma	0.45	0.50	0.90	116
Chhukha	Samphelling	0.49	0.54	0.89	117
Punakha	Talog	0.48	0.54	0.89	118
Tsirang	Rangthangling	0.46	0.52	0.89	119
Tsirang	Gosarling	0.51	0.59	0.88	120
Tsirang	Patshaling	0.44	0.50	0.87	121
Zhemgang	Ngangla	0.46	0.53	0.87	122
Samdrup Jongkhar	Pemathang	0.46	0.53	0.87	123
Trashigang	Yangnyer	0.43	0.50	0.87	124
Trashigang	Lumag	0.41	0.48	0.87	125
Wangdue	Nyishog	0.52	0.59	0.87	126
Samtse	Norboogang	0.47	0.54	0.87	127
Chhukha	Chapchha	0.43	0.50	0.87	128
Dagana	Lhamoi Dzingkha	0.46	0.53	0.87	129
Samtse	Ugyentse	0.48	0.55	0.86	130
Trashigang	Samkhar	0.42	0.49	0.86	131
Samtse	Samtse	0.47	0.55	0.86	132
Pema Gatshel	Norboogang	0.43	0.50	0.85	133
Gasa	Khatoed	0.43	0.50	0.85	134
Trashigang	Bidoong	0.45	0.52	0.85	135
Samdrup Jongkhar	Langchenphu	0.43	0.51	0.84	136
Lhuentse	Minjey	0.46	0.55	0.84	137
Punakha	Chhubu	0.45	0.54	0.84	138
Samtse	Pheunsthogpelri	0.43	0.52	0.83	139
Zhemgang	Trong	0.46	0.56	0.82	140
Samdrup Jongkhar	Pheuntshogthang	0.49	0.60	0.82	141
Samdrup Jongkhar	Orong	0.41	0.50	0.82	142
Trashigang	Kanglung	0.43	0.52	0.82	143
Punakha	Dzomi	0.49	0.60	0.82	144
Chhukha	Geling	0.40	0.49	0.81	145
Sarpang	Senggey	0.43	0.53	0.81	146
Samdrup Jongkhar	Serthig	0.36	0.45	0.81	147
Wangdue	Ruebisa	0.44	0.55	0.80	148
Monggar	Chhaling	0.45	0.57	0.80	149
Chhukha	Darla	0.44	0.55	0.80	150
Punakha	Lingmukha	0.45	0.57	0.79	151
Dagana	Tseza	0.40	0.51	0.79	152
Gasa	Khamaed	0.41	0.52	0.78	153
Tsirang	Kikhorthang	0.45	0.57	0.78	154
Monggar	Dramedtse	0.52	0.67	0.78	155
Samtse	Tendruk	0.43	0.55	0.77	156
Thimphu	Ge-nyen	0.46	0.60	0.77	157
Sarpang	Umling	0.46	0.61	0.75	158
Trashigang	Bartsham	0.39	0.53	0.75	159
Trashiyangtse	Ramjar	0.35	0.47	0.75	160
Paro	Dokar	0.43	0.58	0.75	161
Sarpang	Serzhong	0.47	0.64	0.74	162
Dagana	Gozhi	0.40	0.54	0.74	163
Wangdue	Gangteng	0.43	0.58	0.74	164
Dagana	Karmaling	0.36	0.48	0.74	165
Paro	Doteng	0.45	0.62	0.72	166
Punakha	Toedpasia	0.42	0.58	0.72	167
Wangdue	Bjenag	0.39	0.54	0.72	168
Chhukha	Bjagchhog	0.39	0.55	0.70	169
Trongsa	Nubi	0.37	0.55	0.68	170
Sarpang	Chhuzanggang	0.42	0.62	0.68	171
Sarpang	Shompangkha	0.39	0.58	0.68	172
Sarpang	Samtenling	0.42	0.63	0.67	173

Dzongkhag	Gewog	Sensitivity	Adaptive Capacity	Vulnerability Index	Vulnerability Rank
Samtse	Tashichhoeling	0.44	0.65	0.67	174
Tsirang	Medndrelgang	0.40	0.61	0.66	175
Trongsa	Langthil	0.35	0.55	0.63	176
Dagana	Gesarling	0.34	0.54	0.63	177
Thimphu	Maedwang	0.39	0.64	0.61	178
Samdrup Jongkhar	Dewathang	0.36	0.59	0.61	179
Punakha	Guma	0.36	0.60	0.60	180
Monggar	Monggar	0.38	0.63	0.60	181
Paro	Loong-nyt	0.38	0.64	0.60	182
Wangdue	Gase Tshogongm	0.40	0.68	0.59	183
Haa	Kar-tshog	0.35	0.60	0.59	184
Paro	Dopshar-ri	0.37	0.64	0.58	185
Paro	Lamgong	0.37	0.64	0.58	186
Sarpang	Dekiling	0.38	0.65	0.58	187
Paro	Tsento	0.36	0.63	0.57	188
Haa	Bji	0.36	0.63	0.57	189
Wangdue	Thedtsho	0.35	0.63	0.56	190
Paro	Sharpa	0.35	0.63	0.56	191
Sarpang	Gelegphu	0.36	0.71	0.51	192
Thimphu	Kawang	0.32	0.63	0.50	193
Haa	Uesu	0.31	0.63	0.49	194
Thimphu	Chang	0.30	0.63	0.47	195
Samdrup Jongkhar	Samrang	0.24	0.52	0.46	196
Sarpang	Tareythang	0.25	0.54	0.46	197
Wangdue	Gase Tshowogm	0.26	0.61	0.44	198
Paro	Wanhchang	0.28	0.65	0.43	199
Thimphu	Darkarla	0.26	0.60	0.43	200
Punakha	Barp	0.34	0.82	0.41	201
Trongsa	Draagteng	0.23	0.60	0.39	202
Trongsa	Tangsibji	0.21	0.59	0.36	203
Wangdue	Darkar	0.12	0.56	0.21	204
Paro	Hoongrel	0.11	0.59	0.19	205

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