Community-based Climate Change Vulnerability and Capacity Assessment of the Protected Areas of Bhutan

Ugyen Wangchuck Institute for Conservation and Environment Research

June 2022

Community-based Climate Change Vulnerability and Capacity Assessment of the Protected Areas of Bhutan

Authors

Dawa Yoezer, Sr. Forestry Officer, UWICER

Kinley Choden, Sr. Environment Officer, National Environment Commission Secretariat

Dechen Wangdi, Statistician, Royal Monetary Authority

Sangay Pelzang, Sr. ICT Officer, UWICER

Kado Tshering, Specialist, UWICER

Shacha Dorji, Head Specialist, UWICER

Ugyen Wangchuck Institute for Conservation and Environment Research, Department of Forests and Park Services, Ministry of Agriculture and Forests.

Cover photo: Highland Cordyceps collection sites of the Wangchuck Centennial National Park. Courtesy: Dawa Yoezer, UWICER

Acknowledgement

We would like to sincerely acknowledge the generous contribution of following officials and offices for their support in undertaking this study.

First and foremost, we would like to thank the Bhutan for Life Fund Secretariat and the Project Coordination Unit for the financial support and technical guidance in implementing this study.

We would like to extend our sincere gratitude to the Chief Forestry Officers, and the focal officials (Annexure II) of the Bumdeling Wildlife Sanctuary, Jigme Dorji National Park, Jigme Khesar Strict Nature Reserve, Jigme Singye Wangchuck National Park, Jomotsangkha Wildlife Sanctuary, Phrumshingla National Park, Phibsoo Wildlife Sanctuary, Royal Manas National Park, Sakteng Wildlife Sanctuary, Wangchuck Centennial National Park, Bumthang Forest Division (for BC8), Mongar Forest Division (for BC7), Tsirang Forest Division (for BC3), Sarpang Forest Division (for BC3) and Zhemgang Forest Division (for BC4) for their contribution in the development of study framework and leading surveys in respective offices. Our sincere appreciations to all enumerators involved in undertaking the social survey.

We would like to offer our sincere gratitude to the management of the Ugyen Wangchuck Institute for Conservation and Environment Research (UWICER) for the guidance and facilitating the implementation of the study. Thank you to the participants of the UWICER and Protected Area Offices for contribution in the development and validation of the study framework, indicators and questionnaires which are critical component of the study. We would also like to thank Ryan Bartlett, Danielle Lein and Rebecca Snyder of the WWF-USA and Kunzang Choden (PhD) of Bhutan for Life Fund Secretariat for their inputs in the development of study framework and indicators.

Last but not least, we would like to thank the Hon’ble Director, Department of Forest and Park Services for support and according approvals for conduct of workshops, trainings and surveys for this study.

Contents

List of Figures

List of Tables

1 Executive Summary

Climate change is recognized as a global issue and is increasingly being acknowledged by the global community. Climate change impacts natural and human systems and these impacts are bound to no area and regions. Himalayan regions are found to have experienced an accelerated rate of climate change and future projections show even higher rates of increase in temperature. Fragile Himalayan mountain terrain and higher dependence of its inhabitants on climate sensitive sectors further exacerbates the situation. Bhutan being small, landlocked and least developed country located in the highly vulnerable eastern Himalayan region is highly susceptible to impacts of climate change. The country's dependence on climate sensitive sectors like rain-fed agriculture and hydropower coupled with low adaptive capacity, poor economy constrained by financial, technical and human capacity makes Bhutan highly vulnerable to climate change.

Bhutan is one of the first countries to recognize climate change as a threat to humanity and committed to remain carbon neutral for all times. Bhutan has made significant progress in taking climate change actions both at the national and international level. Bhutan adopted Climate Change Policy and is in the process of developing National Adaptation Plan to guide long-term national climate change adaptation strategies.

The Bhutan for Life (BFL) fund supported this study to assess climate change vulnerability of the communities living in the Protected Area (PA) networks of Bhutan with the aim to develop climate change adaptation plan and implement adaptation actions. The BFL envisions to increase resilience of communities living in the PAs to ensure their well-being as they form an integral part of Bhutan's biodiversity conservation strategy. The study was carried out in 14 PAs including all National Parks/Sanctuaries/Reserves and 4 of the 8 Biological Corridors with higher human settlements. Social questionnaire survey was conducted to assess community exposure, sensitivity and adaptation capacity to climate change. Vulnerability index for each PA was computed as a function of exposure, sensitivity and adaptive capacity.

The study surveyed 2020 households representing ~15% of households from each PA. The average age of respondents was 47 with ~85% of the respondents aged between 30 - 70 years. Women headed households constituted nearly 40% of the households interviewed. For all the PAs, men headed households had higher literacy rate. About 98% of the households have landholding and ~85% own livestock, indicating their dependency on agriculture and livestock farming as the primary source of income.

Landslides, flash floods, rainfall seasonality, windstorms and temperature extremes are the top contributors to exposure. Phibsoo Wildlife Sanctuary (PWS) was found to have highest exposure with higher percentage of households perceiving the observation of temperature extremes, increased occurrence of landslides, flash flood, seasonal droughts, and windstorms. The Jigme Khesar Strict Nature Reserve (JKSNR) has comparatively lower exposure than other PAs.

Issues concerning human-wildlife conflict (HWC), drinking and irrigation water availability, change in forest composition and shortage of pastureland were reported as the main contributors to sensitivity. Among all the PAs, PWS was found to have highest sensitivity with index score of 0.33, as compared with the least sensitive Sakteng Wildlife Sanctuary (SWS) having score of 0.09.

The adaptive capacity was assessed through measure of 5 asset types, namely; human asset, social asset, natural asset, financial asset and physical asset. The SWS has the highest adaptive capacity with higher contributions from indicators such as productive member, house type, distance to nearest school, distance to nearest health facility, distance to Gewog center and savings.

Overall, PWS was found to be most vulnerable with low vulnerability index of -0.27 and while SWS has the highest index of 0.56. PWS had the lower adaptive capacity coupled with highest exposure and sensitivity. With lowest adaptive capacity, BWS is the second most vulnerable along with JDNP due to lower sensitivity and exposure index. SWS had the highest adaptive capacity and lowest sensitivity and third lowest exposure making it the least vulnerable, followed by RMNP.

The study documented common issues and coping mechanisms currently being practiced. Common issues as a result of climate variability and extreme events are, decline or loss of crop yield, decrease in availability of freshwater, death of livestock, and decline in soil quality. The change in crop types and conservation agriculture, and land management were common coping mechanisms practiced. Local government offices are the main institutions that assisted people to cope with climate change impacts and disasters.

The study recommends to consider inclusion of these commonly practiced coping mechanisms in the climate change adaptation plans. Institutional capacities of local government and other relevant agencies should be built in order to assist communities in undertaking climate change mitigation and adaptation measures. The PA management plans and other area specific reports could provide vital information. The adaptation priorities identified in the National Adaptation Plan (NAP), the Third National Communication (TNC), sector specific climate risk assessments carried out as part of NAP formulation process and the Bhutan REDD+ strategy could be used as a guiding document to develop adaptation plan for respective PAs. The climate change adaptation priorities identified in these national documents, which are synthesized based on wider consultations and studies are very relevant for the communities of PAs and have greater chance of securing financial support.

2 Introduction

The global mean temperature has accelerated in the last four decades, and the observed changes in the atmosphere, oceans, cryosphere and biosphere provides the evidence of a world that is warmed (IPCC, 2021). Global surface temperature as a result of anthropogenic activity shows an increase of 0.8 °C to 1.3 °C from 1850 - 1900 to 2010 - 2019. The global mean temperature for the year 2020 was 1.2 ± 0.1 °C above the 1850 - 1900 baseline indicating 2020 as one of the three warmest on record with variation in temperature anomalies across the globe (WMO, 2021). The IPCC Sixth Assessment Report (AR6) summary for policy maker (SPM) predicts earth to be 1.4 - 4.4 °C hotter than pre industrial levels by the end of the century which depends on the rapid and substantial reduction in global greenhouse gas (GHG) emissions.

The climate change impacts on natural and human systems have been observed (IPCC, 2018) and these impacts are bound to no area and regions, and are particularly significant for rural communities of the least developed countries (UN-OHRLLS, 2009), that depend on natural resources for food and other needs. The reliance of rural communities on climate sensitive resources increases their vulnerability, having low resilience due to limited socio-economic resources (Choden et al., 2020). The resilience is developed when the assets and capacities to cope with the climate risk are strengthened (CARE International, 2019).

The Himalayan ecosystem is also changing rapidly and is expected to exacerbate with the predicted increase in mean temperature by 0.3 - 4.8 °C for 2100 (IPCC, 2013). The Himalayan communities are among the poorest and most vulnerable despite having abundant natural resources. The remoteness, unsustainable development and over exploitation of natural resources (Gerlitz et al., 2017; Nandy et al., 2011; Pandey et al., 2017; Shukla et al., 2016) lowers the resilience of the communities.

Bhutan is a Himalayan country with ~71% forest cover (DoFPS, 2016) and is globally acknowledged for being a net sequester of GHG. However, communities of the country are not spared from the negative impacts of climate change owing to its fragile mountainous ecosystem, and dependence of the country’s economy on climate-sensitive sectors such as agriculture and hydropower (NECS, 2020). The agriculture sector is highly vulnerable due to their total dependence on monsoon rains and shorter growing seasons (Chhogyel & Kumar, 2018). The topography and the effects of climate variability has highly exposed Bhutan to diversity of hazards such as extreme weather (NCHM, 2019a; NECS, 2020) that includes flash floods, GLOF (Glacial Lake Outburst Flood), landslides, cyclone induced storm, erratic rainfall and drought affecting the lives and livelihoods of the people (NCHM, 2021). This situation is further worsened by the country's low adaptive capacity, poor economic status constrained by financial, technical and human capacity (NECS, 2020).

The climate of Bhutan is exceptionally diverse. The climate in Bhutan is mainly contributed by topography that has vast differences in elevation, relative distance from the coast, and influence of the North Indian monsoon (NCHM, 2019a; NECS, 2020). Bhutan receives ~70% of the precipitation during monsoon season (NEC, 2016; NECS, 2011) and ~20% as pre-monsoon rainfall (NECS, 2020). It is difficult to identify general pattern and trend in precipitation due to regional specificity, and various factors affecting the rainfall pattern (NEC, 2011; Shahnawaz & Strobl, 2015; N. Wangdi & Kusters, 2012). The historical analysis of the rainfall data of Bhutan from 1996 - 2007 indicated marginal decrease in the rainfall with a larger variability (NCHM, 2019a).

The analysis of the trend in temperature over the 29 years (1976 - 2005) showed an increasing trend, and the mean annual temperature has increased by 0.8 degree Celsius (NCHM, 2019a). The warming trend of about 0.5°C from 1985 to 2002 during the non-monsoon season, increasing trends for both maximum and minimum temperature from 2000 - 2009 (NBC, 2011; NEC, 2011; N. Wangdi & Kusters, 2012), and wide range (mean=17.58 °C, max=34.85 °C, and min= -11.50 °C) of seasonal and spatial variation in temperature (D. Tshering & Sithey, 2008).

The warming is observed and predicted to be more rapid in high mountain areas than lower elevations (Shrestha & Devkota, 2010). The average temperature will not only increase but there is a probability of occurrence of extreme hot temperature conditions (UNDP, 2016). There are reports of increasing temperature (Lhendup et al., 2011), seasonal droughts and occurrences of temperature extremes (RSPN, 2012).

The IPCC mentions the increase in average temperature with an increase in daily minimum and maximum temperature in South Asia by 2100 (IPCC, 2014). This is in line with the detailed analysis conducted by NCHM that showed the increase of about 0.8 °C - 1.6 °C during 2021 - 2050, and about 1.6 ˚C -2.8 ˚C during 2070 - 2100 under RCP 4.5; and the projected increase of 0.8 ˚C to more than 3.2 ˚C under the RCP 8.5 scenario (NCHM, 2019a).

The mean annual rainfall showed an increase of about 10% - 30% on the mean annual scale with summer rainfalls between 5% to 15% under RCP 4.5 scenario. Increase of 10% to 20% during 2021-2050, and more than 30% for 2070 - 2100 in the mean annual rainfall was indicated under RCP 8.5 scenario (NCHM, 2019a).

Increasing number of communities are exposed to the risks of climate change effects making them vulnerable that ultimately causes huge impacts on their livelihood and their sustenance. Realizing the threats of climate change on sustainable development and the livelihood of the people, Bhutan is committed to taking all necessary measures to address climate change which includes integrating the potential impacts of climate change into national and local-level development plans using vulnerability assessment as recommended by IPCC (NECS, 2020). Building resilience to climate change is the priority objective for the climate change Policy of Bhutan, 2020.

Climate change adaptation is undertaken with the objective to reduce climate risk taking into account climate extremes and projected climate change (CARE International, 2019). Wide range of adaptive strategies were developed by the communities over the centuries (Macchi, 2011) owing to the old phenomenon of environmental change.

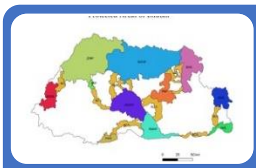
The climate vulnerability assessment is one of the critical steps in adaptation planning. Vulnerability assessments are required for effective planning of climate change adaptation of local vulnerabilities to bridge community needs at the local level with policy processes at a higher level (Burton et al., 2006). Vulnerability assessments are also conducted with the objective to identify current and potential hotspots, identifying key entry points for interventions, tracking changes in vulnerability and monitoring and evaluation of adaptation, developing climate adaptation proposals, and also to prioritize adaptation interventions (Macchi, 2011).

Vulnerability assessments are conducted either through top to bottom (Cutter et al., 2010; de Mello Rezende, 2016; Sajjad & Jain, 2014) or bottom-up approach (Chen et al., 2013; Holand et al., 2011; Mavhura et al., 2017) depending on the resources and expertise. Most vulnerability assessments are conducted at community level to generate specific information on vulnerabilities and capacities of the communities to climatic risk considering their experience and perceptions (Barsley et al., 2013; Declet-Barreto et al., 2020; Macchi, 2011). The outcomes of the assessments are commonly fed into local programmes or policies of adaptation in consultation with the stakeholder (Barsley et al., 2013). The assessments at the community level can be aggregated to identify vulnerability at larger scales.

There are limited studies conducted to study the community-based climate vulnerability assessments in Bhutan (Choden et al., 2020; ICIMOD & RSPN, 2017; Lhendup et al., 2011; RSPN, 2012; UNDP, 2016, 2021; T. Wangdi et al., 2019) that focus in either national scale (Dzongkhag or Gewog) or specific Protected Area (PA). This study assessed the vulnerability of PA networks (except four BCs) based on the community's perception and experience to provide information on identifying vulnerable PAs for development and implementation of adaptation activities.

2.1 Project Milestone

This assessment is part of the Bhutan for Life project (BFL) milestone 4 which is to "From year 7 onwards, all communities living within PAs use traditional knowledge, best available science, and technologies to increase their climate and disaster resilience". The activities under milestone 4 are shown below (Figure 1).



Community-based Climate Vulnerability and Capacity Assessment (CVCA) in the Protected Areas to develop adaptation plan.

2022 – 2023: (for five villages in Year 2, and six villages per year from Year 3 to Year 7), based on CVCA results, implement ecosystem-based adaptation and climate-smart, organic agriculture approaches and technologies, in priority demonstration sites in critical watersheds (representing 10% of the population living within PAs/BCs).

2022-2023: (for five villages in Year 2, and six villages per year from Year 3 to Year 7), based on CVCA results, design and implement storm-water management, disaster risk reduction, preparedness, and response measures in priority demonstration sites in critical watersheds (representing 10% of the population living within PAs/BCs) (This relates to Activity 12.3).

2022-2023: Every ten years, develop, raise awareness, and build capacity to implement community-based climate adaptation plans and green recovery and reconstruction.

Figure 1. Plan of activities under milestone 4 of the Bhutan for Life Project

2.2 Project Goal

The overall goal of this project is to develop climate change adaptation plans for the PA network of Bhutan through assessment of community-based climate vulnerability, adaptive capacity, and their responses to climate change.

2.3 Objective

The objective of this study are to;

- Assess vulnerability of Protected Area networks of Bhutan based on social vulnerability.
- Assess community-based capacities for coping and adaptation measures and identify key entry points for intervention.
- Prioritize and recommend adaptation strategies for enhancement of community resilience to climate change.

2.4 Conceptual Framework for Vulnerability Assessment

Vulnerability is defined in various ways and there is no single definition that could cover all the context of vulnerability (Buchir et al., 2019; Füssel & Klein, 2006). The definition of vulnerability revolves around the IPCC's (2001) definition of vulnerability as a function of exposure, sensitivity and adaptive capacity (Pandey & Jha, 2012; Vincent, 2007). According to IPCC (2001), Vulnerability is defined as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. This assessment adopts the concept of IPCC 2001 to assess the vulnerability which was used for such similar studies (Hahn et al., 2009; Kumar et al., 2016; Lung et al., 2013; Metzger et al., 2006; Simane et al., 2016).

Vulnerability (CV) is expressed as a function of exposure (E), sensitivity (S) and adaptive capacity (AC) (Brooks et al., 2005; IPCC, 2001; KC et al., 2015; Mendoza et al., 2012). It is used primarily to refer to the vulnerability of climate change impacts.

$$CV = f\,(E, S, AC)$$

Exposure is defined in these reports as the nature and degree to which a system is exposed to significant climatic variations. Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct such as change in crop yield in response to change in mean, range or variability of temperature, or indirect such as damages caused by an increase in the frequency of coastal flooding due to sea level rise (Brooks, 2003). Adaptive capacity is the flexibility of the system to adjust to climate change and cope with the consequences. The capacity of the system to adapt to the system depends on the ownership and access to assets (Piya et al., 2016). Vulnerability is influenced by adaptive capacity where the adaptive capacity has an inverse relation with vulnerability (Sharma & Rabindranath, 2019). The conceptual framework for assessment of vulnerability and developing adaptation measures is represented in Figure 2.

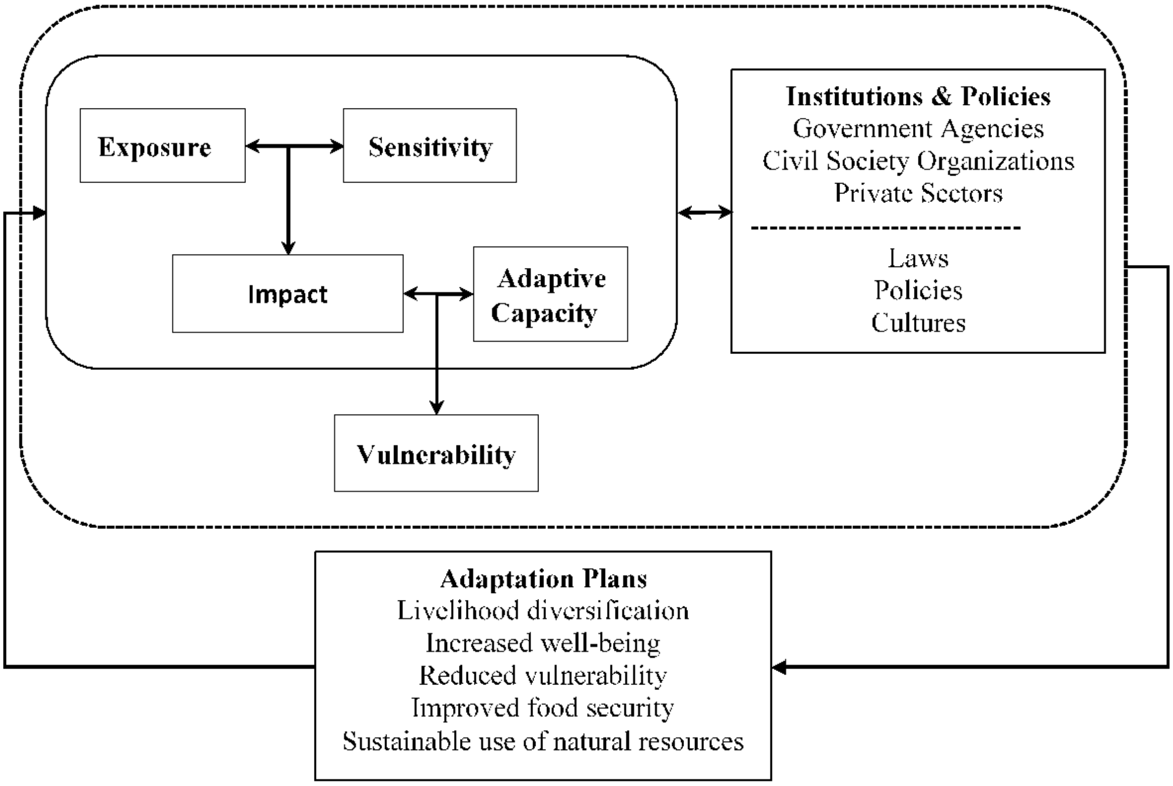


Figure 2. Conceptual framework for assessment of vulnerability and developing adaptation measures.

Three conceptual approaches of vulnerability are typically used; socio-economic (Adger, 1999), biophysical (Füssel & Klein, 2006) and integrated approaches (Nelson et al., 2010; O'Brien et al., 2004; Piya et al., 2016). The socio-economic approach involves analysis of social, political and economic aspects of the society (Choden et al., 2020), and is associated with the well-being of individuals, communities and society (UNISDR, 2004). Thus, this method was employed in this study in accordance with the project requirement.

3 Study Area and Methodology

3.1 Protected Areas of Bhutan

Bhutan is a small landlocked country located in the eastern Himalayas occupying an area of ~38,394 km^2 situated between China and India. Majority of the landscapes are of rugged terrain characterized by huge variation in elevation that ranges from ~160 meters to more than 7,000 masl (NSB, 202). The northern part of the country is occupied by glaciated mountain peaks and alpine pastures that provides pasturage for livestock tended by population practicing transhumance. The mid region of the country comprises valleys and gorges with temperate forest (NSB, 2021a). The sub-tropical forest dominates the southern foothills of alluvial plains with broad river valleys.

Bhutan is among the least populated countries in Asia with a total population of ~727, 145 with population growth rate of 1.3% per annum between 2005 and 2017 (NSB, 2017). About 49.2% of the Bhutanese people depend on agriculture for their livelihood (NSB, 2021a). Out of the total landscapes, only 2.75% or 112,556.2 ha constitutes cultivated agricultural land (RNR, 2019).

The forest dominates the country with ~70% of the total land area and ~51.44% of the total area is conserved as PA networks (DoFPS, 2016). PAs consists of five national parks, four wildlife sanctuaries, one strict nature reserve, and eight biological corridors (BC). The settlements within the PAs play an essential role in the conservation, making it a unique PA system (NECS, 2020). This study covered all parks/wildlife sanctuaries/reserves and four BCs (Figure 3). The four BCs assessed for this study are; BC3, BC4, BC7 and BC8 which are selected based on having comparatively higher settlements.

Jigme Dorji National Park (JDNP), Wangchuck Centennial National Park (WCNP) and Bumdeling Wildlife Sanctuary (BWS) are located in northern part of the country, whereas Phrumsengla National Park (PNP), Jigme Singye Wangchuck National Park (JSWNP), Sakteng Wildlife Sanctuary (SWS), and Jigme Khesar Strict Nature Reserve (JKSNR) occupy the central part of Bhutan. Phibsoo Wildlife Sanctuary (PWS), Royal Manas National Park (RMNP), and Jomotshangkha Wildlife Sanctuary (JWS) occupy the southern part of the country. These parks/wildlife sanctuaries/reserves spread across the country are interconnected by network BCs to allow for free movement of wildlife.

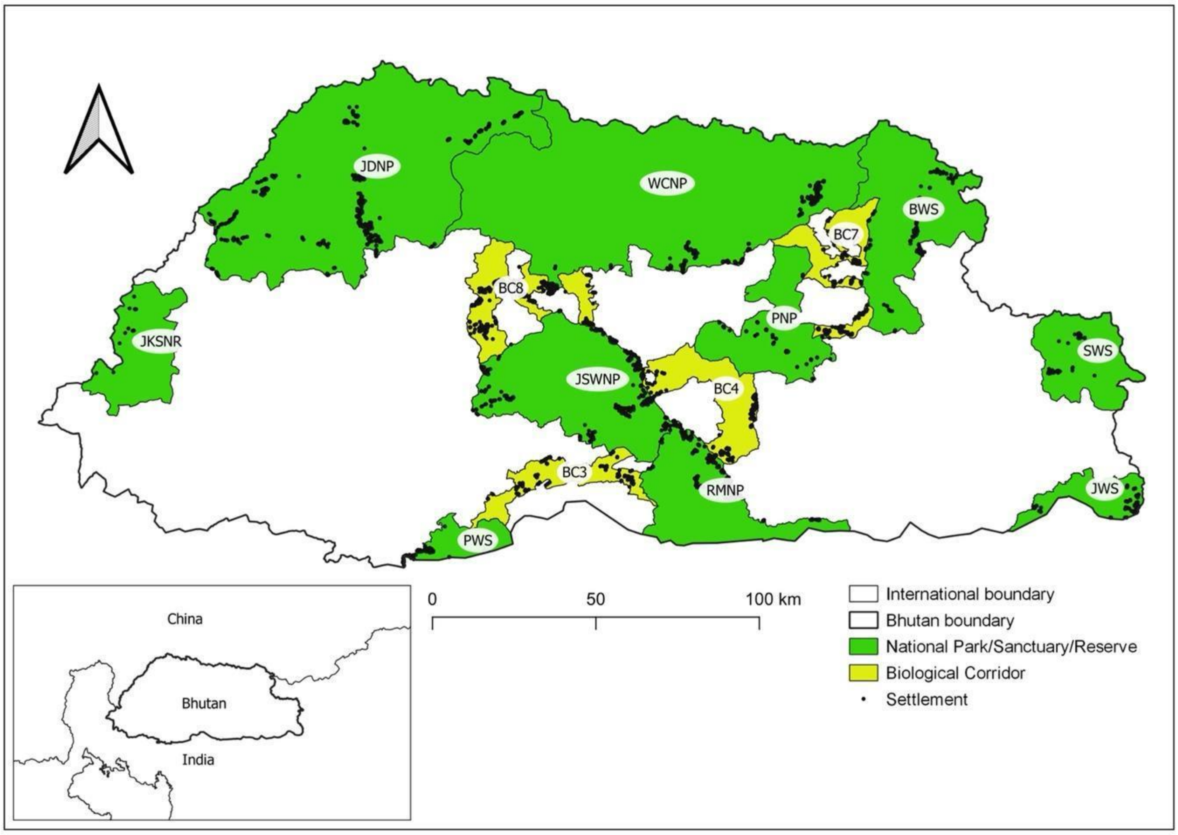


Figure 3. Overview of the study area covering Protected Area networks across the country.

3.2 Climate Data of the Study Area

The study of climate science and research is still a challenge for Bhutan despite the efforts made to generate observation data from 1990s. It is mainly attributed to paucity of historical climate data coupled by lack of robust observational network, resources, technology and capacity to undertake climate research (NCHM, 2019a). We use the freely available global datasets of WorldClim to understand the historical climate and future projections. The dataset includes the main climatic variables (monthly minimum, mean and maximum temperature, precipitation, solar radiation, wind speed and water vapor pressure) as well as 19 bioclimatic variables derived from the monthly temperature and rainfall values. In this study, we use bioclimatic variables BIO1 (annual mean temperature) and BIO12 (annual precipitation) to extract minimum, maximum and average temperature and precipitation respectively for the study areas.

3.2.1 Historical Temperature

WorldClim version 2.1 released in January 2020 contains average monthly climatic gridded data (in GeoTiff format) for the period 1970-2000 available under four spatial resolutions, between 30 seconds (~ 1km^2) to 10 minutes (~340 km^2). We used 30 seconds resolution for this our study to yield maximum accuracy.

The average annual mean temperature of the study sites varies accordingly with the average elevation of PAs and the BCs (Figure 4). JDNP with highest average elevation of 4313 masl has the lowest mean annual temperature of about 0.82°C and on the other hand PWS has the highest annual mean temperature of about 23°C with lowest average elevation (497 masl). Mean annual temperature is inversely proportional to the mean elevation of the study sites. The similar trend was observed for both mean minimum and maximum temperature.

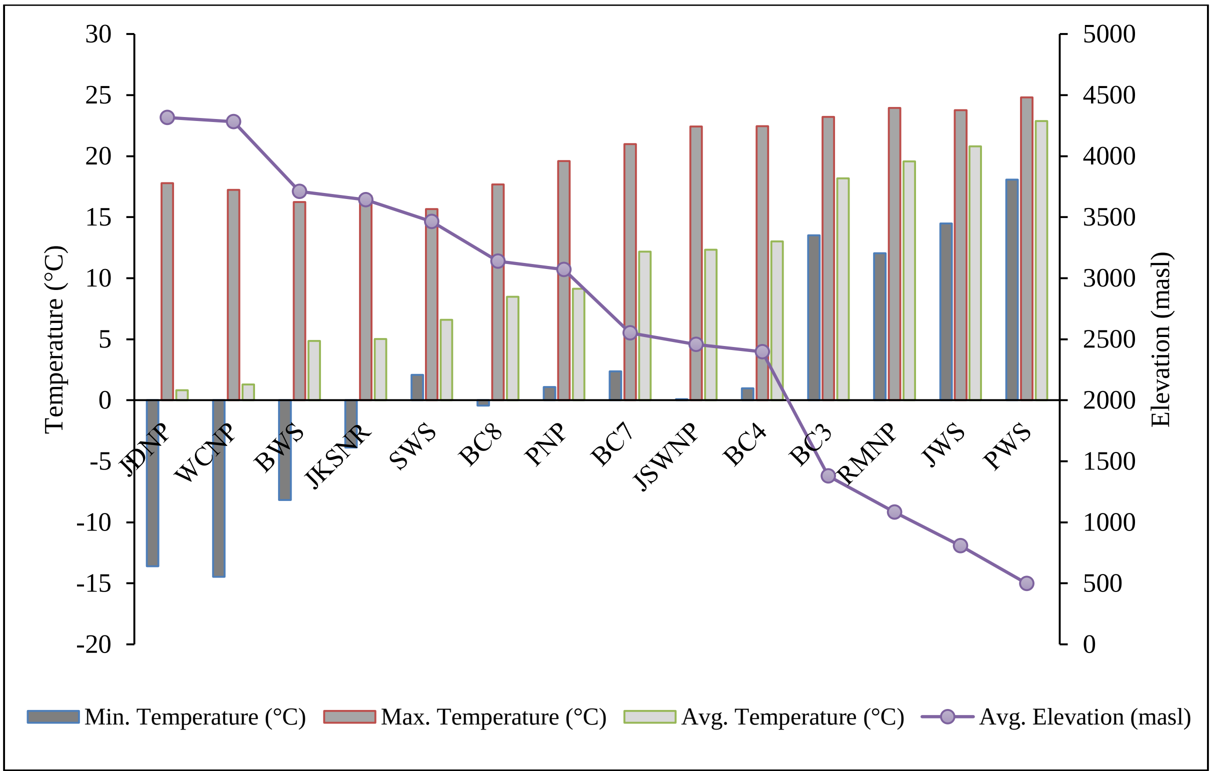


Figure 4. Historical minimum, maximum and average temperature (°C) and average elevation of the study area. (Data source: WorldClim version 2.1)

3.2.2 Historical Precipitation

The average precipitation of the study area decreases as it gains elevation (Figure 5). JDNP with the highest elevation has the least average precipitation of 424 mm whereas PWS received the highest average precipitation (3154 mm) over the year 1970-2000. PNP has the least precipitation variation (803 mm) with altitude difference of 3620 m between lowest (915

m) and highest (4535 m) altitude variation, where has RMNP has the highest precipitation variation across altitude difference of 33 m (lowest) and 2674 m (highest).

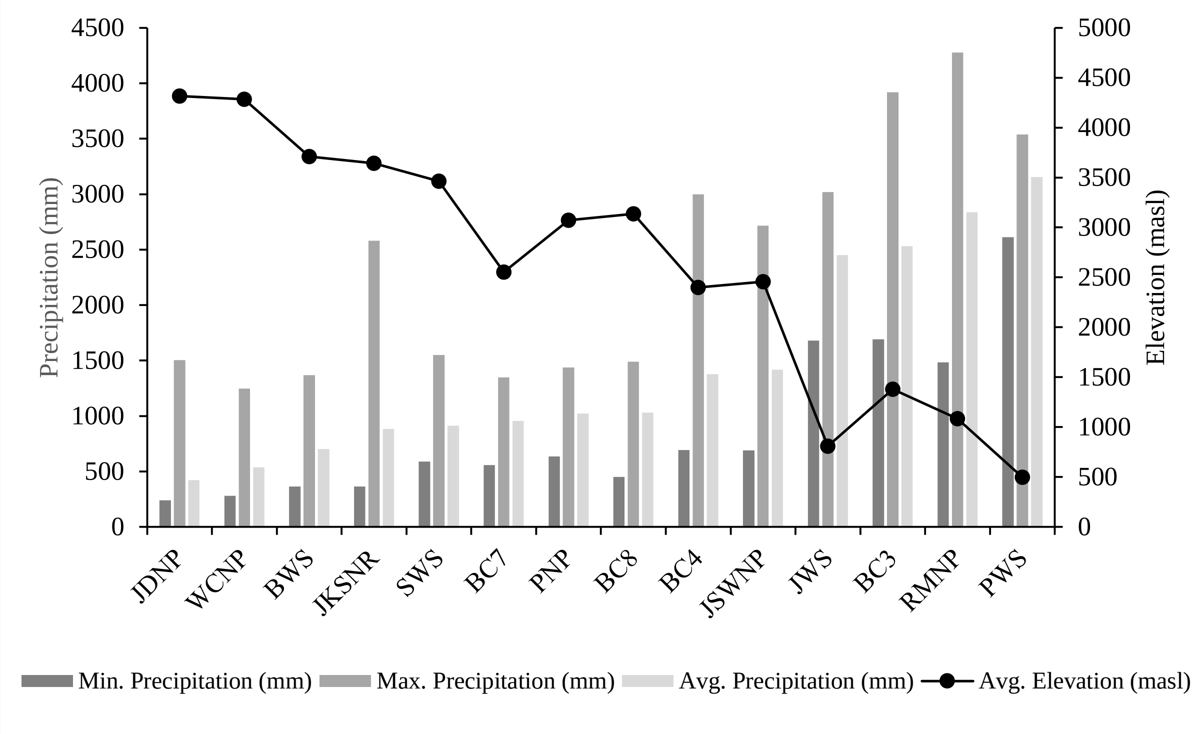


Figure 5. Historical minimum, maximum and average precipitation and average elevation of the study area. (Data source: WorldClim version 2.1)

3.2.3 Future Climate Projection

We used CMIP6 (Coupled Model Intercomparison Projects) downscaled future climate projected data from WordClim 2.1. This study considered 6 equivalent global climate models (GCM) at 30 seconds resolution for the SSP245 (Shared Socio-economic Pathways) scenario used by the National Center for Hydrology and Meteorology for studying historical climate and future projections (NCHM, 2019a). The new state-of-the-art CMIP6 models have been featured in IPCC's sixth assessment report (AR6). The global CMIP models are used by scientists to understand past climate and how it may change in future, hence CMIP serves as a framework to different modelling groups to avoid biasness, meet global climate modelling standards, and make results comparable. The National Center for Hydrology and Meterology (2019) used IPCC AR5 RCP (Representative Concentration Pathways) 4.5 and 8.5 for future climate projection.

The projected mean temperature of all 6 GCMs for SSP245 (2021-2040) range from 0.62°C (lowest of all 6 GCMs) to 1.65°C (highest of all 6 GCMs) as compared with historical mean temperature (Table 1). This indicates continued warming in the immediate future even under the

the medium pathway (SSP245).

Table 1. Projected mean temperature increase form historical mean temperature.

SSP245	Projected mean temperature increase from historical mean temperature						Historical mean temperature
PA/BC	**ACCESS-CM2**	**CNRM-CM6-1**	**IPSL-CM6A-LR**	**MIROC6**	**MPI-ESM1-2-LR**	**MRI-ESM2-0**	**Year (1970-2000)**
BC3	1.46	1.06	1.52	0.75	0.71	1.11	18.18
BC4	1.5	1.08	1.55	0.81	0.81	1.18	13.01
BC7	1.53	1.25	1.62	0.95	0.93	1.32	12.19
BC8	1.53	1.21	1.65	1	0.93	1.28	8.48
BWS	1.55	1.33	1.62	1	0.97	1.37	4.86
JDNP	1.56	1.4	1.63	1.24	1.06	1.49	0.82
JKSNR	1.48	1.17	1.5	0.88	0.84	1.25	5.01
JSWNP	1.49	1.1	1.58	0.85	0.82	1.19	12.33
JWS	1.44	1.05	1.44	0.66	0.7	1.07	20.80
PNP	1.52	1.15	1.59	0.87	0.87	1.25	9.12
PWS	1.4	1.03	1.48	0.7	0.62	1.05	22.89
RMNP	1.45	1.05	1.49	0.71	0.7	1.1	19.57
SWS	1.49	1.07	1.51	0.74	0.82	1.18	6.60
WCNP	1.57	1.37	1.67	1.14	1.03	1.43	1.30

3.3 Social Data Collection

The study was based on primary data collected through the household surveys conducted from January to May, 2022. About 15% of the total households residing within the PAs and those depend on the resources of the PAs were sampled for the survey in consultation with the Bhutan for Life (BFL) project secretariat and the project coordination unit. The final sample constitutes a total of 2020 households (Table 2). The indicators and questionnaire was developed referring to literatures, tested by conducting pilot surveys and finalized in consultation with the project focal from the study areas. The Epi-collect5 application (https://five.epicollect.net) was used for data collection to overcome the burden of manual data entry. About 179 surveyors from the study areas were trained on Epicollect5 usage and familiarized with questionnaires in-person and virtually from 1st January to 26th January, 2022. The survey focused on collecting demographic information, indicators for exposure, sensitivity and adaptive capacity in the last 10 years.

Table 2. Details of total dependent households and households sampled for each Protected Areas offices.

Sl. No.	Protected Area Offices	Total Households	Households Sampled
1	RMNP	1469	226
2	JDNP	975	174
3	JSWNP	604	90
4	BWS	1119	149
5	SWS	787	119
6	PWS	102	15
7	JKSNR	1192	183
8	PNP	1165	176
9	WCNP	814	125
10	JWS	638	54
11	BC3		
	Tsirang Forest Division	162	24
	Sarpang Forest Division	2140	325
12	BC4	525	80
13	BC7	214	140
14	BC8	889	140

3.4 Selection and Description of Indicators

Vulnerability assessments can be qualitative or quantitative which includes indicator based and the econometric based methods (Banerjee et al., 2019; Choden et al., 2020; Maiti et al., 2015). The 'econometric method' analyzes the level of vulnerability of different social group using household-level socio-economic survey data while the 'indicator method' selects the indicators from potential indicators and systematically combines to indicate the level of vulnerability (Deressa et al., 2008). Numerous studies used 'indicator method' to assess social vulnerability to climate change (Brooks et al., 2005; Choden et al., 2020; Deressa et al., 2008; Hahn et al., 2009; Kavi Kumar & Tholkappian, 2006; Maiti et al., 2015; Moreno & Becken, 2009; Nelson et al., 2010; Piya et al., 2016; Rama Rao et al., 2013; Ravindranath et al., 2011;

Seidl et al., 2011; Tambe et al., 2011). Similarly, the indicator-based method was applied for the present assessment.

The tentative indicators for exposure, sensitivity and adaptive capacity was identified and listed from literatures on similar studies. Series of consultations within the researchers from Ugyen Wangchuck Institute for Conservation and Environmental Research (UWICER) and experts from WWF-USA was held to discuss the relevancy of indicators. Indicators were finalized in consultation with the focal officials from the PAs in November, 2022.

Perception on historical changes in climate variables, and occurrence of extreme events were taken as the indicator for the exposure. The climatic variable includes temperature extremes, and shifts in rainfall seasonality. The climate related extreme events considered are; flash flood, GLOF, landslides, windstorm, and seasonal drought events.

Sensitivity is best measured by the change in income or livelihood pattern due to climate change (Maiti et al., 2015). The change in crop yield, crop pest and diseases, invasive weeds, availability of water for irrigation and drinking, time spent collecting drinking water, forest composition, wildlife population, pasture land, human diseases, impact on infrastructures, and loss of family member to natural disaster were used as an indicator for the sensitivity. The climate sensitive sectors; agriculture, water, livestock, forest, health and infrastructures were used to determine the sensitivity.

Adaptive capacity of the households was considered as the summation of five types of livelihood assets; physical, human, social, natural and financial assets (Banerjee et al., 2019; Maiti et al., 2015, 2017; Piya et al., 2016). Human assets are represented by literacy of the household head, vocational skill, and awareness on climate change adaptation. Literacy of the household head is useful for making household heads capable of taking climate adaptation related decision making. The vocational skill of the household member helps to generate income from off-farm activities. Membership of the household to the community group, and the number of productive group are used as social assets. There are four indicators under natural assets; household landholding, type of crops grown, availability of forest resources, and alternative sources of drinking water. Indicator of physical assets includes house type, availability of communication facilities, and distance to nearest essential facilities like market, health, and Gewog centers. Financial assets include livelihood diversity, proportion of off-farm income to total income, access to loan and saving. Total of 7 indicators for exposure, 12 indicators for sensitivity and 19 indicators for adaptive capacity were used to assess the vulnerability (Table 3).

Each finalized indicator was then quantified by providing and deciding on a measurable parameter. Most indicators were given a score of 0 to 2 based on the impacts caused to the communities. The scoring was decided jointly through consultation with focal officials representing respective PAs. Detailed indicator description in given in Table 3.

Table 3. Description of indicators used to assess exposure, sensitivity and adaptive capacity.

Component	Indicator	Description and scoring of the indicator	Unit	Hypothesized relation
Exposure	Temperature extremes	Occurrence of temperature extremes (0=No occurrence; 1=Occurred without any negative impact; 2=Occurred with negative impact)	Ordinal value	+
	Rainfall seasonality	Shift in rainfall seasonality (0=No occurrence; 1= occurred without any negative impact; 2=Occurred with negative impact)	Ordinal value	+
	Flash flood	Frequency of flash flood (0=No increase; 1=Increased without any negative impact; 2=Increase with negative impact)	Ordinal value	+
	Landslides	Incidence of landslides (0=No increase; 1=Increased without any negative impact; 2=Increase with negative impact)	Ordinal value	+
	Windstorm	Frequency of windstorm (0=No increase; 1=Increased without negative impact; 2=Increase with negative impact)	Ordinal value	+
	Seasonal drought	Occurrence of seasonal drought events (0=No occurrence; 1=Increased without negative impact; 2=Increased with negative impact)	Ordinal value	+
	GLOF	Frequency of GLOF (0=No increase; 1=Increased without any negative impact; 2=Increase and negative impact)	Ordinal value	+
Sensitivity	Crop yield	Decrease in crop productivity (0=No decrease; 1= Less than 50%; 2= More than 50%)	Ordinal value	+
	Pest and diseases	Occurrence of pest and diseases (0=No occurrence; 1= Less than 50%; 2= More than 50%)	Ordinal value	+
	Invasive plants	Occurrence of invasive plants (0=No occurrence; 1=Occurrence in agriculture or forest land; 2=Occurrence in both agriculture and forest land)	Ordinal value	+
	Drinking water	Availability of water for drinking (0=No decrease; 1=Decrease without any negative impact; 2=Decrease with negative impact)	Ordinal Value	+
	Irrigation water	Availability of water for irrigation (0=No decrease; 1=Decrease without any negative impact; 2=Decrease with negative impact)	Ordinal Value	+
	Forest composition	Change in forest composition (0=No change, 1=Change without negative impact; 2=Change with negative impact)	Ordinal Value	+

	Human-wildlife conflict (HWC)	Human wildlife conflict as a result of increase in wildlife population (0=No increase; 1=Increase without any HWC; 2=Increased with HWC)	Ordinal Value	+
	Pastureland	Shrinking of pastureland (0=No decrease; 1=Decrease without any negative impact; 2=Decrease with negative impact)	Ordinal Value	+
	Family member affected	Injury and mortality of family members due to climate related disasters (0=No injury/death; 1=Injury to one or more household member; 2=Fatality of one or more household member)	Ordinal value	+
	Water collection time	Drinking water collection time (0=No increase; 1=Increase by less than one hour; 2=Increase by more than one hour)	Ordinal value	+
	Functional infrastructures	Impact on functional infrastructures (0=No impact; 1=One infrastructure affected; 2=more than one infrastructure affected)	Ordinal Value	+
	Human diseases	Climate change related diseases (vector borne and water borne diseases) (0=No increase; 1=Increase without fatality; 2=Increase with fatality)	Ordinal Value	+

Component	Indicator	Description and scoring of the indicator	Unit	Hypothesized relation
Adaptive capacity	**Human asset**			
	Household-head literacy	Literacy of household-head (0=Illiterate; 1=non-formal education; 2=formal/ monastic education)	Ordinal value	+
	Vocational skill	Vocational skill of household member (0=No vocational skills; 1=one household member; 2=more than one household members)	Ordinal value	+
	Climate awareness	Awareness on climate change adaptation (1=No; 2=Yes)	Ordinal value	+
	Social asset			
	Community group	Membership to active social community group (0=No membership; 1=One community group; 2= Two or more community groups)	Ordinal Value	+

Productive member	Household member in working age group (15-64) (0=No household member; 1=One household member; 2=Two or more household member)	Ordinal value	+
Natural asset			
Landholding	Landholding per household (0=No landholding; 1=Less than 3.45 acres 2=More than 3.45acres). 3.45 acres was calculated as average national landholding per household.	Ordinal value	+
Forest resources	Utilization of forest resources (0=No forest resources; 1=Less than six forest resources; 2=Six or more forest resources)	Ordinal value	+
Water source	Availability of multiple sources of water (0=No alternative sources of water; 1=One alternative sources of water; 2= Two or more alternative sources of water)	Ordinal value	+
Crop types	Crop types grown (0=Only food crop is grown; 1=Only cash crop is grown; 2=Both food crop and cash crop grown)	Ordinal value	+
Financial asset			
Credit access	Access to credit (1=No; 2=Yes)	Ordinal value	+
Savings	Savings (1=No; 2=Yes)	Ordinal value	+
Off-farm contribution	Proportion of off-farm to total income (0=0%; 1=Less than or equal to 50%; 2=More than 50%)	Ordinal value	+
Livelihood diversity	Diversity of livelihood sources (agriculture, livestock and off-farm) (0=One livelihood sources, 1=Two livelihood sources; 2=Three livelihood sources)	Ordinal value	+
Physical asset			
House type	Types of houses (0=Temporary; 1=Semi-permanent (Erka walled); 2=Permanent (Stone-walled/mud walled)	Ordinal value	+
Communication medium	Availability of communication facilities (0=No facility, 1=Having at least one facility, 2=having more than one (Radio, cellular, TV, printed media)	Ordinal Value	+
Market facility	Distance to nearest market (0=more than 20 km, 1=10 km to 20 km, 2=Less than 10 km)	Ordinal Value	-
Health facility	Distance to nearest health facility (0=more than 10km; 1=5 km to 10 km; 2=Less than 5 km)	Ordinal value	-
Gewog center	Distance to Gewog (0=more than 10 km; 1=5 km to 10 km; 2=Less than 5 km)	Ordinal value	-
School facility	Distance to nearest school (0=more than 10 km; 1=5 km to 10 km; 2=Less than 5 km)	Ordinal value	-

3.5 Calculation of Vulnerability Index

The latent variables (Exposure, Sensitivity, and Adaptive capacity) were captured based on indicators by constructing confirmatory factor analysis (CFA) model using the lavaan package in R. CFA was used for this study as all the variables are categorical. One factor CFA was employed with the assumption that each latent variable associated with indicator variables are reliable estimate measures of respective latent variables. All the indicators which are used for estimating the latent variables are fundamental elements in a CFA and the covariance between the observed variables forms the fundamental components in the CFA. The observed population covariance matrix Σ is a matrix of bivariate covariance that determines how many total parameters can be estimated in the model. The model implied matrix $\Sigma(\theta)$ has the same dimensions as Σ. The model implied covariance is defined as;

$$\Sigma(\theta) = Cov(y) = \Lambda\Psi\Lambda' + \Theta_{\epsilon}$$

This means that theta Θ is composed of parameters Λ, Ψ, Θ, which corresponds to the loadings, the covariance of latent variables and the covariance of residual errors. For estimation of this model, marker method was used whereby it fixes variance of each factor to one but freely estimates all loadings.

The constructed model was diagnosed for robustness using RMSEA, and observed the value of 0.061 and P-value less than 0.001 indicating that model is robust. The robust model is used to predict latent variable values for each observation.

The predicted values are then normalized to bring the values within comparable range. The min- max method was used for data normalization where the formula (Value-Min)/(Max-Min) was used. The following formula was used to determine the vulnerability index;

$$Vulnerability\ (V) = Adaptive\ Capacity\ (AC) - (Exposure\ (E) + Sensitivity(S))$$

The overall vulnerability index facilitates inter protected area comparison. Higher value of the vulnerability index indicates lower vulnerability. Negative value of the index indicates the net effect of adaptive capacity, exposure and sensitivity was negative (Maiti et al., 2017). This index does not give an absolute measurement of the vulnerability but highlights the comparative among the PAs.

4 Results and Discussion

4.1 Demography and Socio-economic Status

Total of 2020 households representing ~15% of households from each PA was surveyed for the study. The average age of respondents was 47 with the youngest single respondent of 15 years and oldest of 89. About 85% of the total respondents aged between 30 - 70 years. Women headed households constitutes nearly 40% of the households interviewed. BC4 (68%), BC7 (63%), BWS (51%), PNP (60%) and WCNP (53%) have more women headed households (Figure 6). BC3 has the highest percentage (~82%) of households headed by male, followed by SWS (~80%), RMNP (68%) and JKSNR (66%).

JWS has the highest percentage (59%) of households headed with either formal, non-formal and monastic education. Except for JWS, PNP and PWS, all other PAs have a higher percentage of households headed by illiterate members (Figure 6). For all the PAs, men headed households have higher literacy rate as compared with women headed households. For instance, a total of 127 men headed households has monastic education as compared with only 3 female head households having monastic education.

About 98% of the households have landholding and 85% own livestock, indicating their dependency on agriculture and livestock farming as the primary source of income. Nearly 55% of the households generate income from off-farm activities such as wage and salaries, contract labour, business, collection of NWFPs, performing religious/cultural services etc.

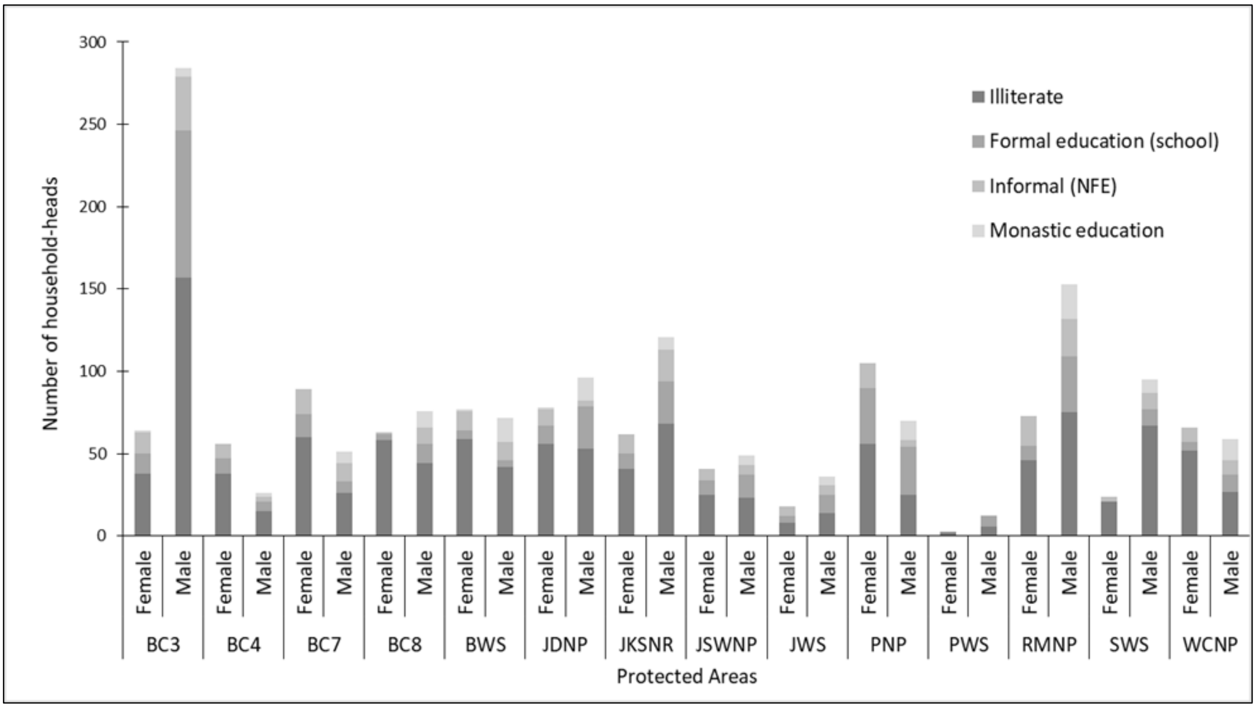


Figure 6. Literacy and gender representation of the head of households interviewed for respective Protected Areas

4.2 Exposure

The exposure is estimated by summation of 7 indicators. All 7 indicators showed positive contribution to exposure as hypothesized and were found to be significant (p value< 0.001). Thus, all indicators were used for the calculation of degree of exposure. The contribution of landslides, flash floods, rainfall seasonality, and windstorms to the overall exposure index was more compared with the contribution of temperature extremes. Seasonal drought and GLOF showed lesser contribution in comparison to temperature extremes (Table 3). The absolute values of model weights revealed that landslides contributed the most to the overall exposure index followed by rainfall seasonality and windstorms.

Landslides are ever-present, prominent and devastating natural hazards in Bhutan due to its steep geographical terrain triggered by intense and heavy rainfall (Dikshit et al., 2020; NECS, 2020). The damage caused by landslides includes loss of lives (Gyelmo, 2021), damage to infrastructures, and loss of agricultural lands. The third national communication of Bhutan, 2020 reported a decreasing trend in rainfall with high variability. Most studies in Bhutan reported fluctuations and erratic rainfall (Lhendup et al., 2011; NBC, 2011; NEC, 2016; Tshering et al., 2011; Wangdi & Kusters, 2012). According to the past records, there are frequent and widespread windstorm occurrences in Bhutan (NECS, 2020). The windstorms had mostly affected rural households and their livelihood.

The GLOF had the lowest contribution to the exposure index. This is because the increase in the incidences of the GLOF was reported in only three study areas (JDNP, WCNP and BC8) as compared with other indicators (Table 4). The future hazard (GLOF) risk in Gasa, Lhuentse and Bumthang was also reported in climate change vulnerability analysis study conducted as a part of National Adaptation Plan formulation process in Bhutan (UNDP, 2021). Change in the glacier is a key indicator of climate change, and glaciers in Bhutan are retreating at alarming rate poses increasing risk of the occurrence of GLOF (NECS, 2020). There are 17 potentially dangerous glacial lakes; 9 major lakes in 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 (NCHM, 2019b).

Table 4. Weights and significance of indicators on exposure and sensitivity.

Exposure Indicator	Weight	Std. Error	Z-value	Sig.
Temperature extremes	1.000			
Rainfall seasonality	1.312	0.122	10.743	***
Flash flood	1.105	0.093	11.902	***
Landslides	1.492	0.122	12.261	***
Windstorm	1.273	0.113	11.216	***
Seasonal drought	0.591	0.066	8.977	***
GLOF	0.214	0.025	8.553	***
Sensitivity Indicator				
Crop yield	1.000			
Pest and diseases	0.460	0.031	14.849	***
Invasive plants	0.382	0.028	13.488	***
Drinking water	0.643	0.068	9.520	***
Irrigation water	0.579	0.055	10.504	***
Forest composition	0.269	0.052	5.131	***
Wildlife population	0.316	0.057	5.559	***
Pastureland	0.046	0.053	0.879	
Family member affected	0.012	0.007	1.699	.
Water collection time	0.084	0.020	4.153	***
Functional infrastructures	0.037	0.022	1.680	.
Human diseases	0.077	0.023	3.321	**

Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

PWS has the highest exposure and JKSNR has comparatively lower exposure than other PAs (Figure 7). PWS has the highest percentage of households perceiving the observation of temperature extremes, increased occurrence of landslides, flash flood, seasonal droughts, and windstorms (Table 5). JKSNR has comparatively low percentage of households reporting the observation of temperature extremes, increased occurrence of landslides, flash floods, and windstorms. JDNP and BC4 are second and third most exposed PAs, respectively, after PWS.

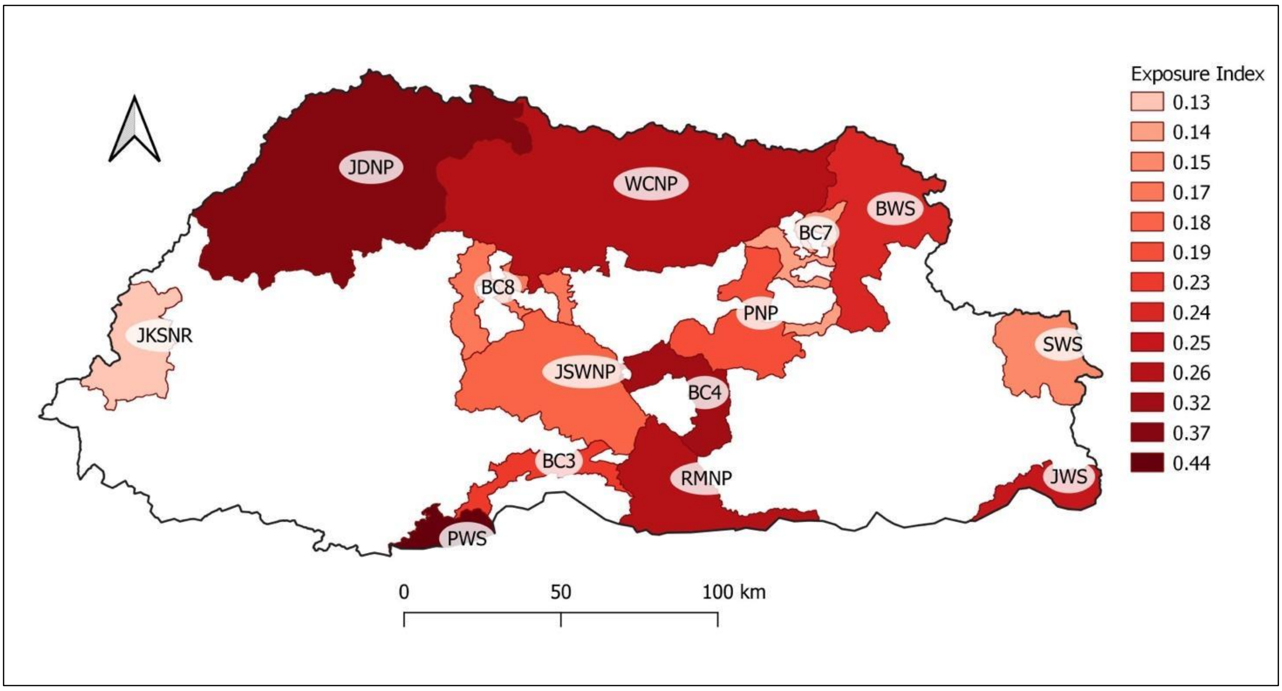


Figure 7. The normalized exposure index score map of Protected Areas. Higher index values indicate higher exposure and vice-versa.

Table 5. Actual number and percentage () of respondents perceiving unfavorable change or increase in exposure indicators.

Protected Areas	Temp. Extremes (%)	Rainfall Seasonality (%)	Landslide (%)	Flash flood (% Increased)	GLOF (%)	Drought (%)	Windstor (%)
BC3	296 (85)	222 (64)	60 (17)	33 (9)	0	55 (16)	89 (26)
BC4	53 (65)	72 (88)	25 (30)	7 (9)	0	16 (20)	46 (56)
BC7	79 (56)	60 (43)	6 (4)	2 (1)	0	5 (4)	28 (20)
BC8	110 (79)	68 (49)	15 (11)	19 (14)	2 (1)	12 (9)	12 (9)
BWS	110 (74)	88 (59)	29 (19)	13 (9)	0	2 (1)	65 (44)
JDNP	145 (83)	118 (68)	74 (43)	49 (28)	23 (13)	12 (7)	83 (48)
JKSNR	**98 (54)**	**105 (57)**	**13 (7)**	**6 (3)**	**0**	**13 (7)**	**16 (9)**
JSWNP	60 (67)	52 (58)	8 (9)	10 (11)	0	2 (2)	15 (17)
JWS	42 (78)	48 (89)	6 (11)	6 (11)	0	13 (24)	16 (30)
PNP	116 (66)	99 (57)	18 (10)	14 (8)	0	33 (19)	48 (27)
PWS	**15 (100)**	**14 (93)**	**7 (47)**	**4 (27)**	**0**	**7 (47)**	**10 (67)**
RMNP	160 (71)	161 (71)	43 (19)	45 (20)	0	42 (19)	68 (30)
SWS	94 (79)	41 (34)	14 (12)	8 (7)	0	6 (5)	13 (11)
WCNP	92 (74)	67 (54)	38 (30)	28 (22)	7 (6)	12 (10)	35 (28)

4.3 Sensitivity

Sensitivity components were considered as summation of twelve indicators. All indicators contributed to sensitivity positively though some indicators such as pasture land, family members affected, and functional structures were not significant (P>0.05). Weightage contribution of the crop yield to the sensitivity index was higher as compared with other indicators (Table 4). The family members affected due to climate change disasters contributed less to the overall sensitivity index. There are reports on crop loss to unusual outbreak of pest and diseases, erratic rainfalls, windstorms, hailstorms, droughts and flash floods annually in the country (Chhogyel et al., 2020; Chhogyel & Kumar, 2018).

Issues concerning human-wildlife conflict (HWC), drinking and irrigation water availability, change in forest composition and shortage of pastureland were listed as the main contributors to sensitivity for all PAs. These indicators featured as the top three sensitive indictors with score of 2 for all PAs (Figure 9). Except SWS, JWS and WCNP, all other PAs reported HWC as the primary issue, among the list of indicators. Decrease in drinking water availability and its associated impacts was reported as the main cause of concern for communities of JWS and SWS. Households of WCNP reported pastureland shortage (38%) and HWC (37%) as the main issue, among others.

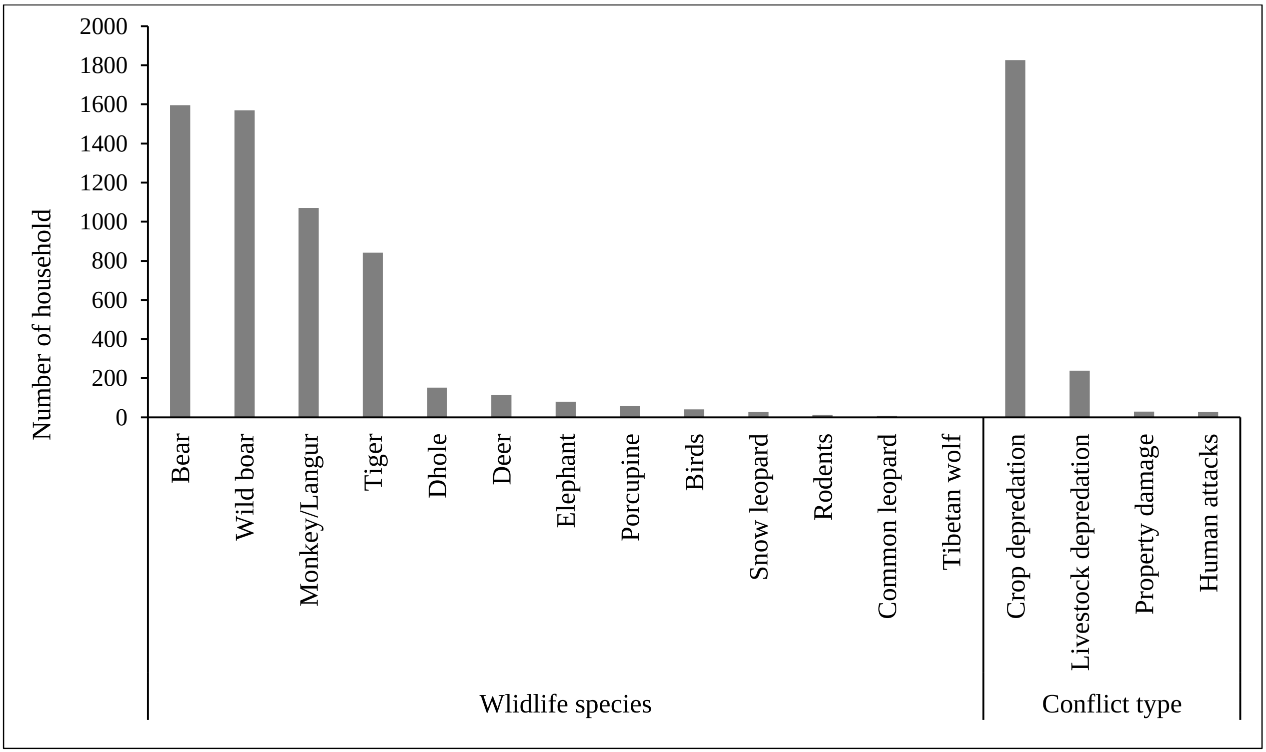


Figure 8. Common wildlife species causing human-wildlife conflict and main conflict types.

The crop depredation was reported as the main conflicting issues as a result of HWC and the common conflicting species across all PAs were bear, wild boar, monkey/langur, and tiger (Figure 8).

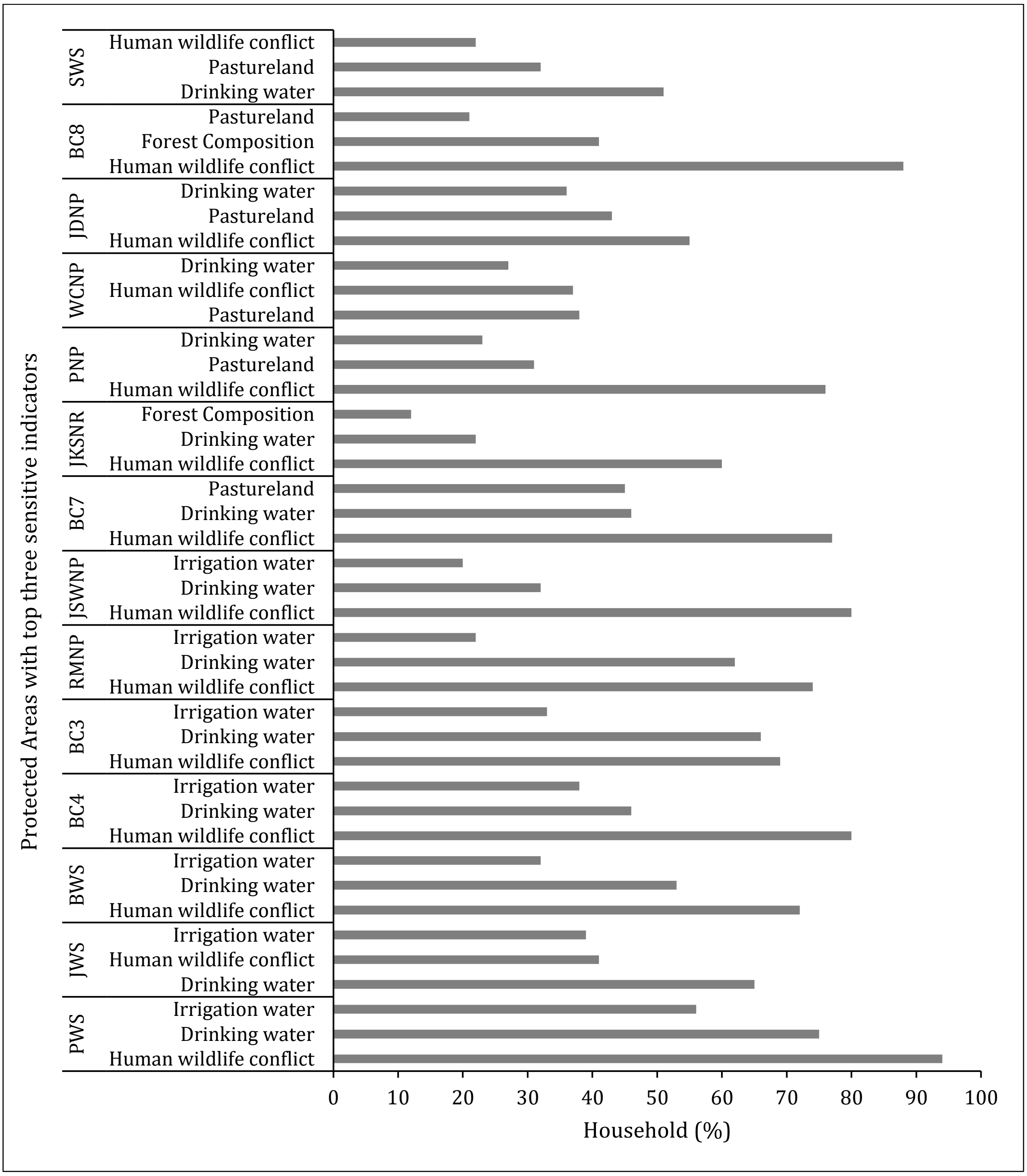


Figure 9. Top three sensitivity indicators with indicator score of 2 for each Protected Area. The indicators were given score 2 when there is unfavorable change in the indicator and has caused adverse impacts on the households.

Though there are not much studies on relationship between climate change and HWC, there are reports that highlights their interaction and complexity. A systematic literature review study on HWC in the Hindu Kush Himalayas (HKH) by Sharma et al. (2021) revealed that climate change is one of the drivers of HWC, causing change in plant phenology and shift in habitat. Abrahms B. (2021) highlighted that climate change impacts availability of resources, thereby causing congregation of wildlife and people to crowded spaces causing conflicts. According to the state of the environment report of Sikkim (Government of Sikkim, 2016), climate change directly or indirectly impacts the forest habitat, distribution and limits the food availability for wild animals leading to increased HWC incidences. There are also reports of the incidences of elephants encroaching the human settlements for food and water due to drought events in Namibia, Southern Africa (Lendelvo et al., 2021). Climate change causes socio-ecological impacts and any conflicts such as HWC reduces adaptation capacity and increases vulnerability (Gupta et al., 2017). Acknowledging the association between climate change and HWC, the third national communication (NEC, 2020a) proposed management of HWC as a climate change adaptation option. Apart from climate change, people perceived human encroachment, decreasing food, habitat degradation, increase in conflicting species, range shift, unsupervised grazing, and wrath of local deities to be the possible reasons for increasing HWC.

Issues of drinking and irrigation water availability can be directly linked to climate change, as water resource is one of the most impacted resources as a result of climate change. Forest composition is the least common indicator across the top three indicators of all protected areas. The negative impacts of change in forest compositions were scarcity/loss of forest products, habitat degradation, HWC, increase/emergence of forest pest and diseases, and range shift of plants and animals.

Among all the PAs, PWS was found to have highest sensitivity with index score of 0.33, as compared with the least sensitive SWS having score of 0.09 (Figure 10). The subsequent sensitive protected areas are BWS and BC4. PWS has the higher percentage of households reporting HWC, drinking water and irrigation water compared to other PAs. This is consistent with the report of intense crop and livestock depredation in the PWS (PWS, 2012). For SWS, livestock and crop depredation, inconsistent water availability, and decrease in pastureland due to invasion of unpalatable species, occurrence of landslide and flash floods were reported from Merak and Sakteng (SWS, 2019; Wangdi et al., 2019)

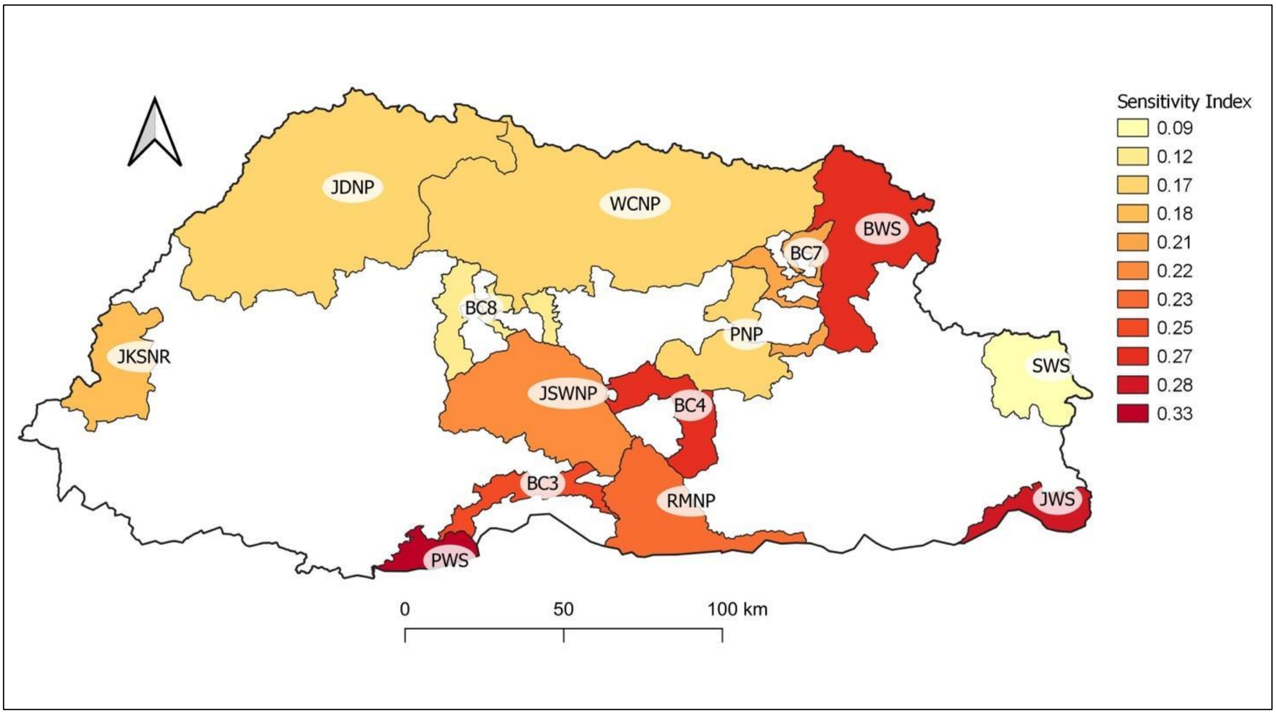


Figure 10. The normalized sensitivity index score map of the Protected Areas. Higher index values indicate higher sensitivity and vice-versa.

4.4 Adaptive Capacity

Table 6 represents the weights of each indicator to adaptive capacity. As compared with household-head literacy, indicators such as community group, land holdings, distance to market, health facility, Gewog center, and school facilities contributed more to the adaptive capacity index. The indicators of physical assets such as distance to nearest market, health facility, Gewog center and school showed comparatively higher contribution to adaptive capacity index. This may be attributed to the presence of school, and basic health facilities in most Gewogs, as education and health are the country's priority development sectors. Most indicators had no significant contribution to the overall adaptive capacity index, however, the insignificant indicators were not dropped since the model performance was robust ($P < 0.001$).

Table 6. Weights and significance of indicators for adaptive capacity.

Adaptive capacity indicator	Weight	Std. Error	Z-value	Sig.
Human asset				
Household-head literacy	1.000			
Vocational skill	0.393	0.352	1.116	
Climate awareness	0.046	0.259	0.179	
Social asset				
Community group	1.144	0.645	1.774	.
Productive member	-0.107	0.209	-0.509	
Natural asset				
Landholding	1.360	0.668	2.035	*
Forest resources	0.697	0.379	1.841	.
water source	-0.286	0.415	-0.688	
Crop types	-0.219	0.338	-0.649	
Financial asset				
Credit access	0.914	0.473	1.933	.
Savings	0.103	0.227	0.453	
Off-farm contribution	0.252	0.505	0.499	
Livelihood diversity	-0.341	0.371	-0.919	
Physical asset				
House type	0.688	0.405	1.697	.
Communication medium	0.398	0.461	0.863	
Market facility	7.645	3.450	2.216	*
Health facility	15.88	7.121	2.231	*
Gewog center	13.81	6.197	2.230	*
School facility	14.44	6.477	2.230	*

On the scale of 0 to 1, the normalized score of adaptive capacity does not show large variations. SWS scored the highest, in terms of adaptive capacity index, followed by RMNP, JWS, BC4, WCNP, PNP, BC3, JKSNR and PWS (Figure 11). BC7, JDNP, BC8, JSWNP and BWS had lower adaptive capacity to adapt to climate change. For SWS, the indicators such as productive member, house type, distance to nearest school, distance to nearest health facility, distance to Gewog center and savings contributed more to the adaptive capacity. For instance, more than 90% of the households had house type and productive member indicators with indicator score of 2.

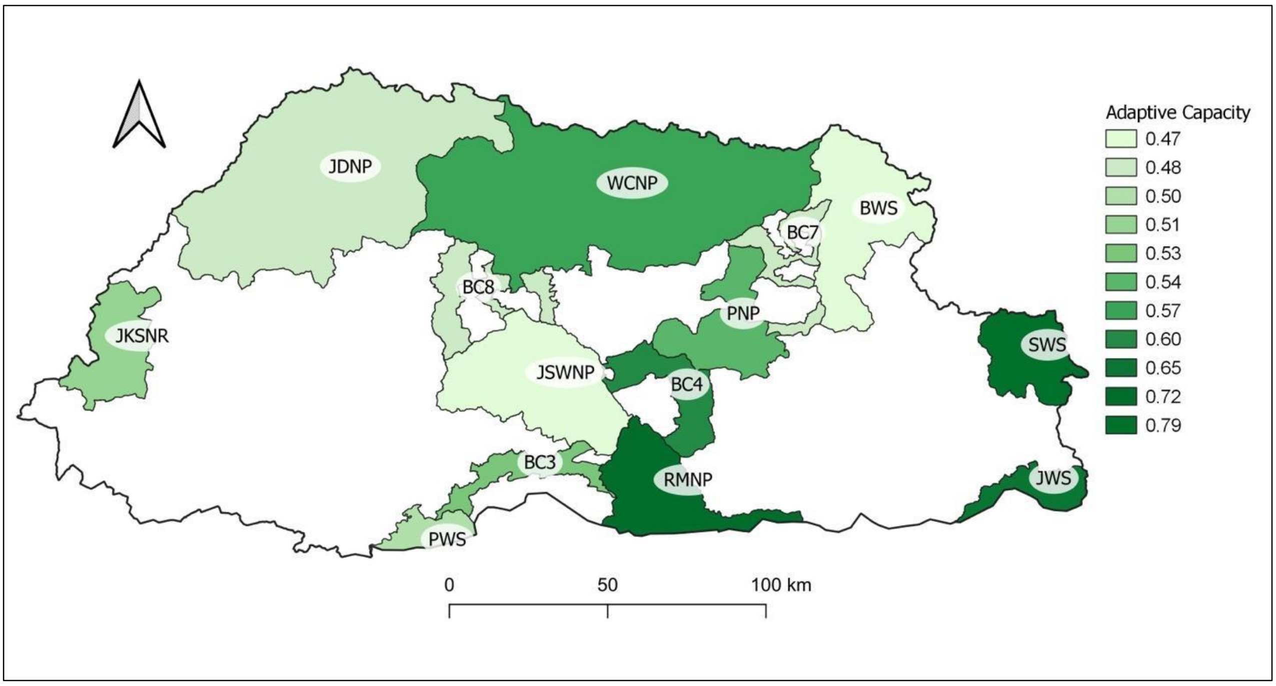


Figure 11. The normalized adaptive capacity index score map of the Protected Areas. Higher index values indicate higher adaptive capacity and vice-versa.

The Figure 12 shows the percentage of households with the indicator score of 2 for each assets. PNP and BWS has higher human assets. Similarly, PNP, BWS, JDNP, PWS and WCNP has higher percentage of households with indicator score of 2 for social assets. SWS has the lowest number of households with score of 2 for natural assets. This may be because of higher dependency of communities of SWS on livestock and limited availability of pastureland (forest resources) in the alpine region. The shortage of pastureland was also reported under sensitivity index. BWS, PWS, JDNP and WCNP indicated having higher financial asset as compared with other PAs. Higher financial assets of JDNP and WCNP can be attributed to additional income generated from harvesting of highly priced Caterpillar Fungus (*Ophiocordyceps sinensis*) and other priced high altitude aromatic and medicinal plants (MAPs).

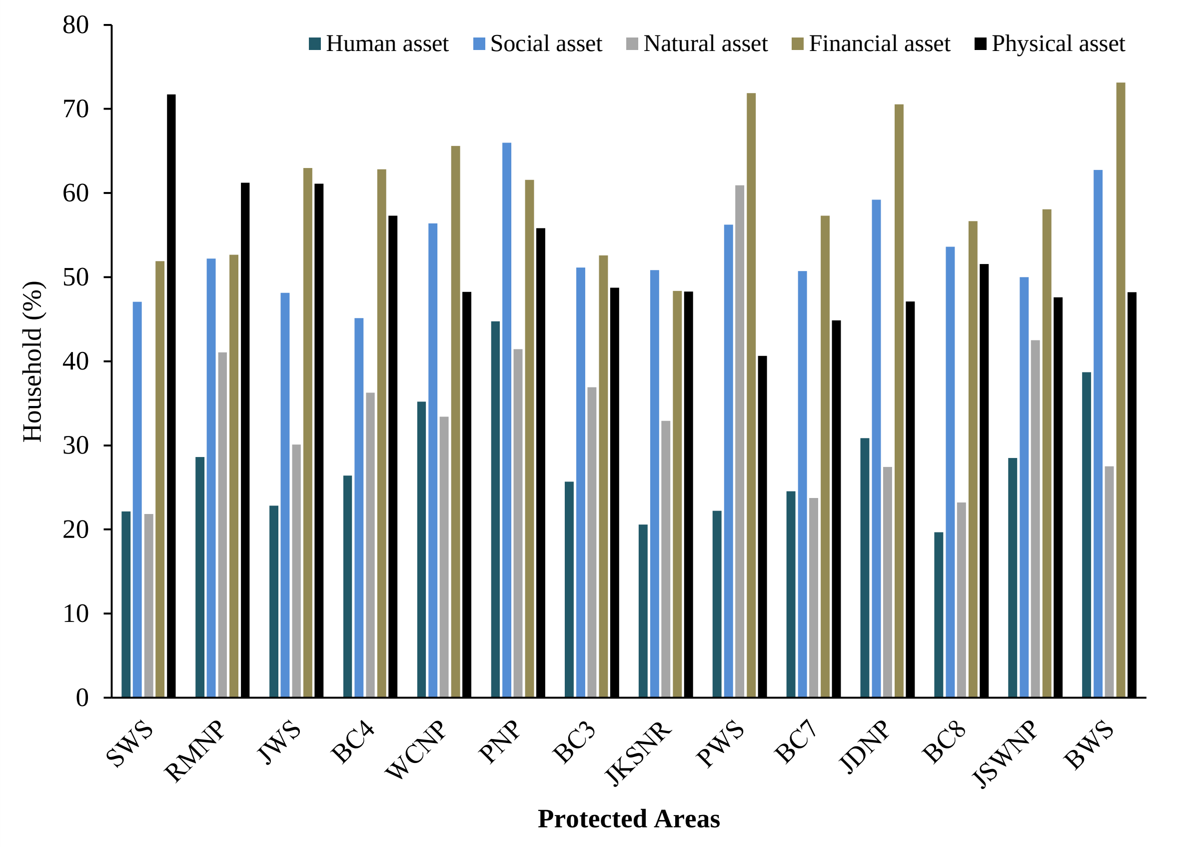


Figure 12. Percentage of households with the indicator score of 2 for each asset type.

4.5 Vulnerability Index

Overall vulnerability is calculated by subtraction of sum of exposure and sensitivity from the adaptive capacity. The vulnerability index scores of the PAs are presented in Table 7 and Figure 13. PAs with higher negative scores of vulnerability index were more vulnerable. However, a positive score of the vulnerability index don't mean that those PAs are not vulnerable, but they are comparatively less vulnerable.

Table 7. Exposure, sensitivity, adaptive capacity and vulnerability index scores of the Protected Areas.

Park	Adaptive Capacity	Exposure	Sensitivity	Vulnerability Index
PWS	0.50	0.44	0.33	-0.27
JDNP	0.48	0.37	0.17	-0.05
BWS	0.47	0.24	0.27	-0.05
BC4	0.60	0.32	0.27	0.01
BC3	0.53	0.23	0.25	0.04
JSWNP	0.47	0.18	0.22	0.07
JWS	0.65	0.25	0.28	0.12
BC7	0.48	0.14	0.21	0.13
WCNP	0.57	0.26	0.17	0.14
PNP	0.54	0.19	0.17	0.17
BC8	0.48	0.17	0.12	0.18
JKSNR	0.51	0.13	0.18	0.21
RMNP	0.72	0.26	0.23	0.23
SWS	0.79	0.15	0.09	0.56

According to the value of the vulnerability index, PWS was found to be most vulnerable with low vulnerability index of -0.27 and while SWS has the highest index of 0.56. PWS had the lower adaptive capacity coupled with highest exposure and sensitivity. With lowest adaptive capacity, BWS is the second most vulnerable along with JDNP due to lower sensitivity and exposure index. JDNP has higher exposure index and lower adaptive capacity. SWS had the highest adaptive capacity and lowest sensitivity and third lowest exposure making it the least vulnerable, among other PAs. RMNP showed higher adaptive capacity, making it the second least vulnerable.

The findings from this study is mostly in consistent with the nationwide climate vulnerability and capacity assessment conducted as a part of National Adaptation Plan (NAP) formulation process (NEC & UNDP, 2021), though there were differences in indicators and assessment methodology.

The study identified Samtse, Mongar, Sarpang, Dagana and Punakha as the Dzongkhags which are most at risk from climate impacts in the country. Further, the study listed Zhemgang, Dagana and Mongar Dzongkhags to be most vulnerable in 2005 and Gasa, Zhemgang, Trashiyangtse in 2017. A study on flood vulnerability assessment for the districts of Bhutan by Tempa (2022) found that the frequency of flood events in Bhutan have increased by three-fold in the recent years. The study ranked Chhukha, Punakha, Sarpang, and Trashigang Dzongkhags as more vulnerable with higher flood vulnerability index. The study used indicators such as historical flood events, fatalities, population affected, infrastructure damages, economic losses, highest annual rainfall and existence of flood map. The PAs that were found to be more vulnerable from this study mostly falls under these Dzongkhags. For instance, the survey respondents of PWS were from Dagana. The JDNP covers most parts of Gasa and Punakha; BWS in Tashiyangtse; BC4 in Zhemgang and BC3 in Sarpang Dzongkhag.

The Notre Dame Global Adaptation Index (ND-GAIN) published by the University of Notre Dame (gain-new.crc.nd.edu), USA which assesses country's vulnerability and readiness to adaptation, ranked Bhutan as the 32nd most vulnerable and 61st readiest country for the year 2019. It categories Bhutan as the being able to respond effectively to climate change but needs to heighten urgency in adaptation measures. For the year 2012, Bhutan ranked 143rd out of 178 countries as most exposed to climate risk (ADB, 2014). Therefore, it is critical that the climate change is taken seriously and integrated in the national development plans and polices.

Bhutan adopted the Climate Change Policy (CCP) in 2020 (NEC, 2020b) with a vision "A prosperous, resilient and carbon neutral Bhutan where the pursuit of gross national happiness for the present and future generations is secure under the changing climate". The CCP aims to pursue carbon neutral development, build resilience to climate change, ensure adequate means of implementation of mitigation and adaptation actions through enhanced coordination and collaboration. Consequently, the National Adaptation Plan (NAP) is currently being developed to build national adaptive capacity and resilience to climate change. The NAP, through exhaustive consultations listed priority adaptation measures for priority thematic areas such as water, agriculture and livestock, forest and biodiversity, human settlements and climate smart cities, health, energy, and climate services and disaster risk reduction. All these priority adaptation measures are very relevant to build adaptive capacity of communities residing within the PAs. Additionally, the policies and measures identified in the Bhutan REDD+ strategy (DoFPS, 2022) needs to be pursued to mitigate climate change and enhance ecosystem based adaptation.

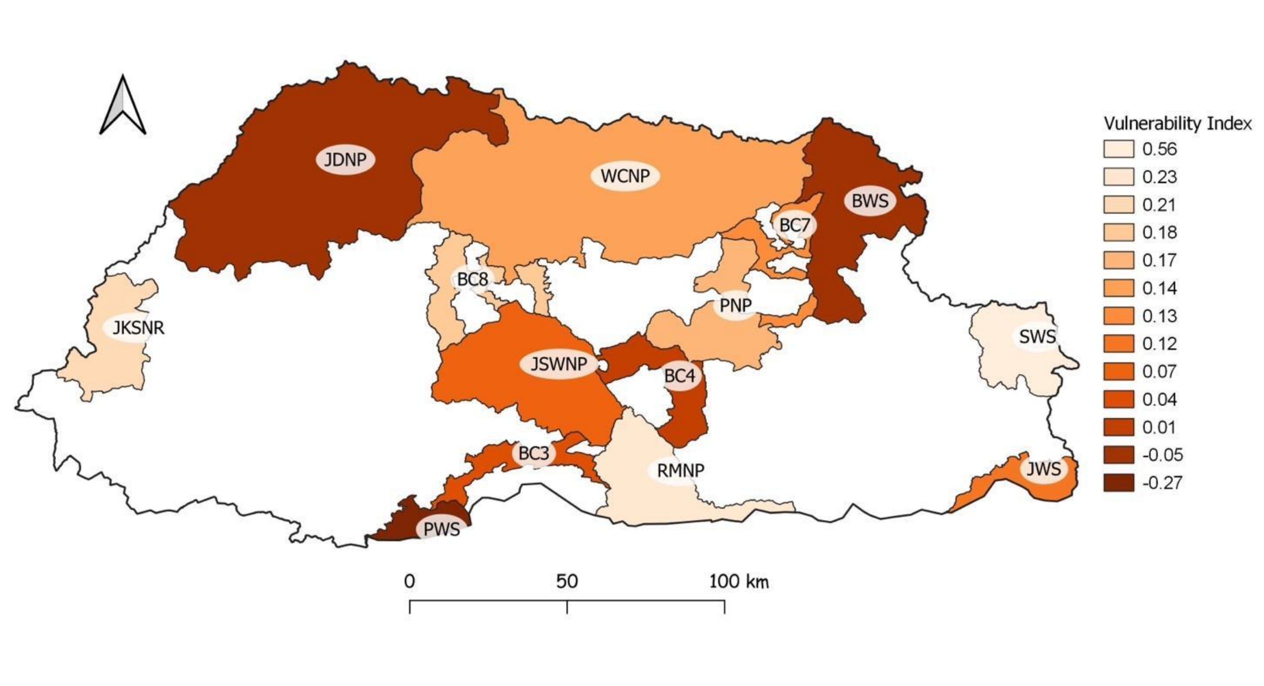


Figure 13. Vulnerability index map of Protected Areas.

Impacts and Coping Mechanisms

The common climate change impacts reported by communities and coping mechanisms practiced are summarized in Table 8. The common issues as a result of climate variability and extreme events are, decline or loss of crop yield, decrease in availability of freshwater, death of livestock, and decline in soil quality. The change in crop types and conservation agriculture, and land management were common coping mechanisms practiced.

The impacts of decrease in availability of drinking and irrigation water and the coping mechanism practiced are summarized in Table 9. Highest number of households reported sanitation issues as the main negative impact of decrease in availability of drinking water for which the coping mechanisms practiced were use of wells/pipes to source water, construction of tanks/dams and rainwater harvesting. In case of decrease in irrigation water, water related conflict and loss of crop yields were the negative impacts and use of wells and pipes, construction of dams/tanks, and introduction of new irrigation systems some of the main coping mechanism practiced.

Local government offices are the main institutions that assisted people to cope with climate change impacts and disasters. Communities reported that Dzongkhag disaster office, Dzongkhag kidu office, Gewog RNR extension offices (agriculture, livestock, and forestry), community center, and health offices assisted them in dealing with climate change impacts. Other agencies such as financial and insurance offices, non-government organizations (Tarayana Foundation and UNDP), department of Disaster Management (DDM), National Center for Hydrology and Meteorology (NCHM), department of Forest and Park Services (DoFPS), department of Agriculture (DoA), and department of Livestock (DoL) are also mentioned to have assisted communities in adapting to climate change.

These commonly practiced coping mechanisms could be considered while developing climate change adaptation plans. Institutional capacities of local government and other relevant agencies should be built in order to assist communities in undertaking climate change mitigation and adaptation measures.

Table 8. Summary of common climate related impacts reported by households (HHs) and coping mechanism currently being practiced.

Common impacts of temperature extremes	No.# HHs	Common coping mechanisms for temperature extremes	No.# HHs
Decline/loss of crop yield	1627	Change in crop types	268
Death of livestock	153	Conservation agriculture (crop rotation, cover cropping etc.)	73
Decline in milk/diary production	95	Change in grazing areas	70
Drying up of water sources	95	Use of irrigation/increased use of irrigation	48
Heat stress	91	Business	27
New/increase in number of pests and diseases	88	Change in livestock type (switching to heat tolerant livestock)	26
Cold stress	87	Harvest rainwater	19
Common impacts of shift in rainfall seasonality	**No.# HHs**	**Common mechanisms to cope with shifting rainfall seasonality**	**No.# HHs**
Decline/loss of crop yield	1713	Change of crop types	296
Decline in soil quality	180	Irrigation	172
Decrease in availability of freshwater	57	Change in cropping season	61
Range shift of wild animals/plants	12	Conservation agriculture (crop rotation, cover cropping etc.)	56
Plant phenology change	12	Perform rituals	28
New/increase in number of pests/diseases	12	Fertilizer application	7

Common impacts of flash floods	No.# HHs	Common mechanisms to cope with flash floods	No.# HHs
Decline/loss of crop yield	469	Land management/development	197
Damage of property	73	Construct check dams	13
Decline in soil quality	72	Rely on NGOs/government for aid/compensation	13
Death of livestock	39	Change of crop type	11
Decrease in availability and quality of freshwater	50	Construct wall/levee (to protection from flooding)	8

Common impacts of landslides	No.# HHs	Common mechanisms to cope with landslides	No.# HHs
Decline/loss of crop yield	566	Land management/development	200
Decline in soil quality	119	Change of crop type	26
Property damage	72	Practice agroforestry	23
Decrease in availability and quality of freshwater	71	Change in grazing area	12
Death of livestock	67	Use of wells/pipes	12
Habitat degradation	36	Rely on NGOs/government for aid/compensation	11

Common impacts of windstorm	No.# HHs	Common mechanisms to cope with windstorm	No.# HHs
Decline/loss of crop yield	873	Building modification	117

Property damage	285	Land management/development	116
Death of livestock	38	Rely on NGOs/government for aid/compensation	49
Decline in soil quality	16	Change of crop type	41
Decrease in availability of freshwater	12	Increased logging for rebuilding	30
Habitat degradation	10	Practice agroforestry	22
Common impacts of seasonal drought	**No.# HHs**	**Common mechanisms to cope with seasonal drought**	**No.# HHs**
Decline/loss of crop yield	786	Change of crop type	91
Decrease in availability and quality of freshwater	67	Use of wells/pipes	47
Death of livestock	40	Irrigation (introduce/increased use)	17
Decline in soil quality	34	Practice agroforestry	15
Common impacts of GLOF	**No.# HHs**	**Common mechanisms to cope with seasonal drought**	**No.# HHs**
Death of livestock	49	Land management/development	14
Property damage	43	Use of wells/pipes	8
Decline/loss of crop yield	36	Building modification	6
Decreased availability of freshwater	20	Practice agroforestry	4
Shrinkage of pastureland	13		

Table 9. Summary of common impacts reported by households (HHs) and coping mechanism currently being practiced to deal with issues concerning drinking and irrigation water shortage.

Common impacts of decreasing in drinking water	**No.# HHs**	**Common mechanisms to cope with decreasing drinking water**	**No.# HHs**
Sanitation issues	1590	Use of wells/pipes	496
Water related conflicts	211	Constructing dams/tanks	132
Decline in livestock productivity	75	Harvest rainwater	91
Health issues	65	Change in livestock type	61
Dehydration	34	Water access (traveling further/new location to access water)	54
Death of livestock	25	Conservation of key landscapes/ecosystem services	53
Common impacts of decreasing in irrigation water	**No.# HHs**	**Common mechanisms to cope with decreasing irrigation water**	**No.# HHs**
Water related conflicts	567	Use of wells/pipes	278
Decline/loss of crop yield	277	Constructing dams/tanks	101
Decline in soil quality	20	Irrigation (introduction of new irrigation system)	40
New/increased number of pests	7	Water access (traveling further/new location to access water)	20
Scarcity of pasture for livestock	1	Change in crop types	19

Conclusion and Recommendations

Bhutan is highly vulnerable to the adverse impacts of climate change being a landlocked and least developed country with a fragile mountain ecosystem, and dependence on climate sensitive sectors. Recognizing the global and national impacts of climate change, Bhutan has pledged to remain carbon neutral and has upped its efforts to address climate change. Bhutan adopted the Climate Change Policy in 2020 and is in process of developing comprehensive national adaptation plan. At the national level, key sector specific climate risk and vulnerability assessments were undertaken to guide the development of national adaptation plan.

This study assessed the vulnerability of communities residing in the PA networks of Bhutan with the aim to develop and integrate climate change adaptation strategies in the management plan of respective PAs. It provides a diagnostic tool to understand the resilience of communities of PAs based on key socio-economic parameters, and guide adaptation planning, implementation and investment. The index can be used as a baseline to monitor and track change in vulnerability and evaluation of adaptation in future. Vulnerability was calculated as the net effect of exposure and sensitivity on the adaptive capacity. This net effect was found to be negative for PWS, JDNP and BWS. The PWS was found to be most vulnerable, while SWS was the least vulnerable.

The adaptation strategies must focus on lowering the exposure and sensitivity index and increasing adaptive capacities. Climate change adaptation and mitigation measures must be taken to reduce climate induced events like landslides, flash floods, windstorms, change in rainfall seasonality and temperature extremes. Adaptation actions must focus on tackling HWC, securing drinking and irrigation water, managing forest resources including pastureland as these were found to be commonly reported indicators that raised the climate sensitivity of most PAs. Similarly, adaptive capacity of the communities must be strengthened to build climate resilience.

Common coping mechanisms and local knowledge already being practiced by communities to deal with climate change impacts could be incorporated in the adaptation plans. The PA management plans and other area specific reports could provide vital information. The adaptation priorities identified in the National Adaptation Plan (NAP), the Third National Communication (TNC), sector specific climate risk assessments carried out as part of NAP formulation process and the Bhutan REDD+ strategy could be used as a guiding document to develop adaptation plan for respective PAs. The climate change adaptation priorities identified in these national documents, which are synthesized based on wider consultations and studies are very relevant for the communities of PAs and have greater chance of securing financial support.

Based on the findings, following general recommendations are proposed;

- Implement adaptation measures to reduce exposure to climate induced events such as landslides, shift in rainfall seasonality, windstorms, flash floods and extreme temperatures. Prioritize the adaptation measures for respective PAs based on the prevalence and severity of impacts of such climatic events.
- Implement strategies to reduce HWC to mitigate impacts of crop and livestock depredation which are main livelihood activities of rural communities. HWC is reported as the primary cause of concern for all Protected Areas.
- Enhance climate smart agriculture and livestock farming through crop diversification, climate resistant breeds, sustainable land management and agroforestry development to better cope with climate uncertainties.
- Secure water for drinking and irrigation. Promote efficient use of water through use of water efficient technologies such as rain-water harvesting, storm-water management, and integrated water resources and watershed management.
- Promote effective coping mechanisms already being practiced by communities in dealing with climate related issues and impacts.
- Undertake measures to reduce forest fire, spread of invasive plants and outbreak of forest pest and diseases to promote healthy forest ecosystem to sustain natural resources.
- Develop capacity and awareness of communities, local government and relevant stakeholders.
- Enhance adaptive capacity of communities through setting up enabling conditions to build human, social, natural, financial and physical assets to build climate resilience.
- Develop climate change adaptation plan for respective PAs with the consideration of findings of this assessment report and other relevant documents.

.

References

Abrahms B. Human-wildlife conflict under climate change. Science. 2021 Jul 30;373(6554):484-485. doi: 10.1126/science.abj4216. PMID: 34326219.

ADB. (2014). Bhutan: Country partnership strategy (2014-2018). Asian Development Bank.

Adger, W. N. (1999). Social vulnerability to climate change and extremes in coastal Vietnam. World Development, 27(2), 249–269. https://doi.org/10.1016/S0305-750X(98)00136-3

Banerjee, S., Black, R., Mishra, A., & Kniveton, D. (2019). Assessing vulnerability of remittance-recipient and non-recipient households in rural communities affected by extreme weather events: Case studies from South-West China and North-East India. Population, Space and Place, 25(2). https://doi.org/10.1002/PSP.2157

Barsley, W., de Young, C., & Brugère, C. (2013). Vulnerability assessment methodologies: an annotated bibliography for climate change and the fisheries and aquaculture sector. In 2013. www.fao.org/icatalog/inter-e.htm

Brooks, N. (2003). Vulnerability, risk and adaptation: A conceptual framework (No. 38).

Brooks, N., Adger, W. N., & Kelly, P. M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environmental Change, 15(2), 151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006

Buchir, L. M. S. T., Detzel, D. H. M., Mine, M. R. M., Kishi, R. M. M., Detzel, D. H. M., Bessa, M. R., & Fernandes, C. V. S. (2019). Vulnerability and adaptation capacity of river basins to climate change: A different approach to climate vulnerability index. Simpósio Brasileiro de Recursos Hídricos. https://www.researchgate.net/publication/338083965

Burton, I., Diringer, E., & Smith, J. (2006). Adaptation to climate change: International policy options.

CARE International. (2019). Climate vulnerability and capacity analysis handbook. Version 2.0. https://careclimatechange.org/wp-content/uploads/2016/06/CARE-CVCA-Handbook-EN-v0.8-web.pdf

Chen, W., Cutter, S. L., Emrich, C. T., & Shi, P. (2013). Measuring social vulnerability to natural hazards in the Yangtze River Delta region, China. International Journal of Disaster Risk Science, 4(4), 169–181. https://doi.org/10.1007/s13753-013-0018-6

Chhogyel, N., & Kumar, L. (2018). Climate change and potential impacts on agriculture in Bhutan: A discussion of pertinent issues. Agriculture and Food Security, 7(1), 1–13. https://doi.org/10.1186/S40066-018-0229-6/TABLES/8

Chhogyel, N., Kumar, L., Bajgai, Y., & Sadeeka Jayasinghe, L. (2020). Prediction of Bhutan's ecological distribution of rice (Oryza sativa L.) under the impact of climate change through maximum entropy modeling. Journal of Agricultural Science, 158(1–2), 25–37. https://doi.org/10.1017/S0021859620000350

Choden, K., Keenan, R. J., & Nitschke, C. R. (2020). An approach for assessing adaptive capacity to climate change in resource dependent communities in the Nikachu watershed, Bhutan. Ecological Indicators, 114. https://doi.org/10.1016/J.ECOLIND.2020.106293

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 7(1). https://doi.org/10.2202/1547-7355.1732

de Mello Rezende, G. B. (2016). Social Vulnerability Index: A methodological proposal for application in the cities of Barra do Garcas-MT, Pontal Do Araguaia-MT and Aragarcas-GO, Brazil. Open Journal of Social Sciences, 4, 32–45. https://www.scirp.org/pdf/JSS_2016120615532244.pdf

Declet-Barreto, J., Marissa, J. R., & Fedinick, K. P. (2020). Guide to community climate vulnerability assessment. https://www.nrdc.org/sites/default/files/guide-community-climate-vulnerability-assessments-report.pdf

Deressa, T., Hassan, R., & Ringler, C. (2008). Measuring Ethiopian farmers' vulnerability to climate change across regional states [in Amharic] (No. 00806). https://www.researchgate.net/publication/46442194

Dikshit, A., Sarkar, R., Pradhan, B., Segoni, S., & Alamri, A. M. (2020). Rainfall induced landslide studies in the Indian Himalayan region: A critical review. Applied Sciences (Switzerland), 10(7). https://doi.org/10.3390/app10072466

DoFPS. (2016). National Forest Inventory: Stocktaking nation's forest resources. Volume I. Department of Forest and Park Services.

Füssel, H. M., & Klein, R. J. T. (2006). Climate change vulnerability assessments: An evolution of conceptual thinking. In Climatic Change (Vol. 75, Issue 3, pp. 301–329). https://doi.org/10.1007/s10584-006-0329-3

Gerlitz, J. Y., Macchi, M., Brooks, N., Pandey, R., Banerjee, S., & Jha, S. K. (2017). The Multidimensional Livelihood Vulnerability Index–an instrument to measure livelihood vulnerability to change in the Hindu Kush Himalayas. Climate and Development, 9(2), 124–140. https://doi.org/10.1080/17565529.2016.1145099

Government of Sikkim. (2016). State of Environment Report Sikkim.

Gupta, N., Rajvanshi, A. & Badola, R. (2017). Climate change and human-wildlife conflicts in the Indian Himalayan biodiversity hotspot. Current Science, 113(5), 846–847.

Gyelmo, D. (2021, July 14). Are Bhutan's monsoon landslides becoming more deadly? The Third Pole. https://www.thethirdpole.net/en/climate/bhutan-landslides-climate-change/

Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change- A case study in Mozambique. Global Environmental Change, 19(1), 74–88. https://doi.org/10.1016/J.GLOENVCHA.2008.11.002

Holand, I. S., Lujala, P., & Ketil Rød, J. (2011). Social vulnerability assessment for Norway: A quantitative approach. Norsk Geografisk Tidsskrift-Norwegian Journal of Geography, 65(1), 1–17. https://doi.org/10.1080/00291951.2010.550167

ICIMOD & RSPN. (2017). A Multi-dimensional assessment of ecosystems and ecosystem services in Barshong, Bhutan. International Centre for Integrated Mountain Development and Royal Society for Protection of Nature.

IPCC. (2001). Climate Change 2001: Impacts, adaptation, and vulnerability (J. McCarthy, O. Canziani, N. Leary, D. Dokken, & K. White, Eds.). Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC. (2013). Climate Change 2013: The Physical Science Basis. Intergovernmental Panel on Climate Change. Cambridge University Press. https://books.google.bt/books?hl=en&lr=&id=o4gaBQAAQBAJ&oi=fnd&pg=PR1&dq=ipcc+physical+science+basis&ots=Whoz6PIxTk&sig=yCXwh7Kf0fLeg11y6o4x2RUj36c&redir_esc=y#v=onepage&q=ipcc%20physical%20science%20basis&f=false

IPCC. (2014). Summary for policymakers. Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf

IPCC. (2021). Summary for policymakers. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), Climate Change 2021: The Physical Science Basis. Contribution of working group I to the sixth assessment report of the Intergovernmental Panel on Climate Change (pp. 3–32). Cambridge University Press. https://doi.org/10.1017/9781009157896.001

UNISDR. (2004). Living with Risk. A global review of disaster reduction initiatives. International Strategy for Disaster Reduction of United Nations.

Kavi Kumar, K. S., & Tholkappian, S. (2006). Relative vulnerability of indian coastal districts to sea-level rise and climate extremes. International Review for Environmental Strategies, 6(1), 3–22.

KC, B., Shepherd, J. M., & Gaither, C. J. (2015). Climate change vulnerability assessment in Georgia. Applied Geography, 62, 62–74. https://doi.org/10.1016/J.APGEOG.2015.04.007

Kumar, S., Raizada, A., Biswas, H., Srinivas, S., & Mondal, B. (2016). Application of indicators for identifying climate change vulnerable areas in semi-arid regions of India. Ecological Indicators, 70, 507–517. https://doi.org/10.1016/j.ecolind.2016.06.041

Lendelvo, S., Nghitevelekwa, R., & Pinto, M. (2021). Gendered climate change-induced human-wildlife conflicts (HWC) amidst COVID-19 in the Erongo Region, Namibia. In Negotiating Climate Change in Crisis (pp. 159–172). Open Book Publishers. https://doi.org/10.11647/obp.0265.12

Lhendup, P., Wikramanayake, E., Freeman, S., Sindorf, N., Gyeltshen, K., & Forrest, J. (2011). Climate change vulnerability assessment of Wangchuck Centennial Park. Bhutan

Lung, T., Lavalle, C., Hiederer, R., Dosio, A., & Bouwer, L. M. (2013). A multi-hazard regional level impact assessment for Europe combining indicators of climatic and non-climatic change. Global Environmental Change, 23(2), 522–536. https://doi.org/10.1016/J.GLOENVCHA.2012.11.009

Macchi, M. (2011). Framework for community-based climate vulnerability and capacity assessment in mountain areas. International Centre for Integrated Mountain Development: Kathmandu. Nepal.

Maiti, S., Jha, S. K., Garai, S., Nag, A., Bera, A. K., Paul, V., Upadhaya, R. C., & Deb, S. M. (2017). An assessment of social vulnerability to climate change among the districts of Arunachal Pradesh, India. Ecological Indicators, 77, 105–113. https://doi.org/10.1016/j.ecolind.2017.02.006

Maiti, S., Jha, S. K., Garai, S., Nag, A., Chakravarty, R., Kadian, K. S., Chandel, B. S., Datta, K. K., & Upadhyay, R. C. (2015). Assessment of social vulnerability to climate change in the eastern coast of India. Climatic Change, 131(2), 287–306. https://doi.org/10.1007/s10584-015-1379-1

Mavhura, E., Manyena, B., & Collins, A. E. (2017). An approach for measuring social vulnerability in context: The case of flood hazards in Muzarabani district, Zimbabwe. Geoforum, 86, 103–117. https://doi.org/10.1016/J.GEOFORUM.2017.09.008

Mendoza, R. U., Beja, E. L., Venida, V. S., & Yap, D. (2012). An empirical analysis of political dynasties in the 15th Philippine Congress. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.1969605

Metzger, M. J., Rounsevell, M. D. A., Acosta-Michlik, L., Leemans, R., & Schröter, D. (2006). The vulnerability of ecosystem services to land use change. Agriculture, Ecosystems and Environment, 114(1), 69–85. https://doi.org/10.1016/J.AGEE.2005.11.025

Moreno, A., & Becken, S. (2009). A climate change vulnerability assessment methodology for coastal tourism. Journal of Sustainable Tourism, 17(4), 473–488. https://doi.org/10.1080/09669580802651681

Nandy, S., Kushwaha, S. P. S., & Dadhwal, V. K. (2011). Forest degradation assessment in the upper catchment of the river Tons using remote sensing and GIS. Ecological Indicators, 11(2), 509–513. https://doi.org/10.1016/J.ECOLIND.2010.07.006

NBC. (2011). Climate summit for a living Himalayas – National Action Plan - Biodiversity persistence and climate change. National Biodiversity Centre. http://nbc.gov.bt/wp-content/uploads/2010/06/National-Paper-on-Biodiversity-and-Climate-Change-_Bhutan1.pdf

NCHM. (2019a). Analysis of historical climate and climate projection for Bhutan. National Centre for Hydrology and Meteorology. www.nchm.gov.bt

NCHM. (2019b). Reassessment of potentially dangerous glacial lakes in Bhutan. National Centre for Hydrology and Meteorology. www.nchm.gov.bt

NCHM. (2021). Bhutan State of the Climate 2020. National Centre for Hydrology and Meteorology. www.nchm.gov.bt

NEC. (2011). Second National Communication to the UNFCCC. National Environment Commission. www.nec.gov.bt/climate/snc/

NEC. (2016). Bhutan state of the environment report 2016. National Environment Commission. http://www.nec.gov.bt/nec1/wp-content/uploads/2016/07/Bhutan-State-of-Environment-Report-2016.pdf

NEC. (2020a). Third National Communication to the UNFCCC. National Environment Commission. Royal Government of Bhutan.

NEC. (2020b). Climate Change Policy of the Kingdom of Bhutan. National Environment Commission. Royal Government of Bhutan.

NEC & UNDP (2021). Climate change vulnerability analyses and mapping for national adaptation plan (NAP) formulation process in Bhutan. National Environment Commission and United Nations Development Programme -Bhutan.

Nelson, R., Kokic, P., Crimp, S., Martin, P., Meinke, H., Howden, S. M., de Voil, P., & Nidumolu, U. (2010). The vulnerability of Australian rural communities to climate variability and change: Part II-Integrating impacts with adaptive capacity. Environmental Science and Policy, 13(1), 18–27. https://doi.org/10.1016/j.envsci.2009.09.007

NSB. (2017). Population & housing census of Bhutan. National Statistics Bureau. www.nsb.gov.bt

NSB. (2021a). Labour force survey report. National Statistics Bureau. www.nsb.gov.bt

NSB. (2021b). Statistical yearbook of Bhutan 2021. National Statistics Bureau. www.nsb.gov.bt

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., & West, J. (2004). Mapping vulnerability to multiple stressors: Climate change and globalization in India. Global Environmental Change, 14(4), 303–313. https://doi.org/10.1016/j.gloenvcha.2004.01.001

Pandey, R., & Jha, S. K. (2012). Climate vulnerability index - measure of climate change vulnerability to communities: A case of rural Lower Himalaya, India. Mitigation and Adaptation Strategies for Global Change, 17(5), 487–506. https://doi.org/10.1007/s11027-011-9338-2

Pandey, R., Jha, S. K., Alatalo, J. M., Archie, K. M., & Gupta, A. K. (2017). Sustainable livelihood framework-based indicators for assessing climate change vulnerability and adaptation for Himalayan communities. Ecological Indicators, 79, 338–346. https://doi.org/10.1016/J.ECOLIND.2017.03.047

Piya, L., Joshi, N. P., & Maharjan, K. L. (2016). Vulnerability of Chepang households to climate change and extremes in the mid-hills of Nepal. Climatic Change, 135(3–4), 521–537. https://doi.org/10.1007/s10584-015-1572-2

PWS. (2012). Phibsoo Wildlife Sanctuary: Conservation management plan (2012-2017). Department of Forest and Park Services.

Rama Rao, C., Raju, B., Subba Rao, A., Rao, K., Rao, V., Kausalya R, Venkateswarlu B, & Sikka AK. (2013). Atlas on vulnerability of Indian agriculture to climate change.

Ravindranath, N. H., Rao, S., Sharma, N., Nair, M., Gopalakrishnan, R., Rao, A. S., Malaviya, S., Tiwari, R., Sagadevan, A., Munsi, M., Krishna, N., & Bala, G. (2011). Climate change vulnerability profiles for north east India. CURRENT SCIENCE, 101(3).

RNR. (2019). RNR census of Bhutan. Renewable Natural Resources Statistics Division. Directorate Services. Ministry of Agriculture and Forests.

RSPN. (2012). Assessment of climate change vulnerabilities in Kangpara Gewog, Trashigang. Royal Society for Protection of Nature.

Sajjad, H., & Jain, P. (2014). Assessment of Socio-Economic Vulnerabilities among Urban Migrants in South-East Delhi, India. Journal of Studies in Social Sciences, 7(1), 65–81. https://www.researchgate.net/publication/266378023

Seidl, R., Rammer, W., & Lexer, M. J. (2011). Adaptation options to reduce climate change vulnerability of sustainable forest management in the Austrian Alps. Canadian Journal of Forest Research, 41(4), 694–706. https://doi.org/10.1139/x10-235

Shahnawaz, & Strobl, J. (2015). A Zonal Analysis of the Climatic Conditions in Bhutan Shahnawaz and Josef Strobl. In Shahnawaz & U. Thinley (Eds.), Climate Change, Environment and Development in Bhutan (Issue 1, pp. 1–22). College of Natural Resources,Royal University of Bhutan (RUB). http://www.cnr.edu.bt/CCED/01_Shahnawaz-Strobl_ClimaticConditionsInBhutan_P_01-22.pdf

Sharma, J., & Ravindranath, N. H. (2019). Applying IPCC 2014 framework for hazard-specific vulnerability assessment under climate change. In Environmental Research Communications (Vol. 1, Issue 5). Institute of Physics. https://doi.org/10.1088/2515-7620/ab24ed

Sharma, P., Chettri, N. & Wangchuk, K. (2021). Human–wildlife conflict in the roof of the world: Understanding multidimensional perspectives through a systematic review. Ecology and Evolution, 11(17), 11569–11586. https://doi.org/10.1002/ece3.7980

Shrestha, A. B., & Devkota, L. P. (2010). Climate change in the eastern Himalayas: Observed trends and model projections; Climate change impact and vulnerability in the Eastern Himalayas – Technical report I. Environmental Science. doi:10.53055/icimod.520

Shukla, R., Sachdeva, K., & Joshi, P. K. (2016). Inherent vulnerability of agricultural communities in Himalaya: A village-level hotspot analysis in the Uttarakhand state of India. Applied Geography, 74, 182–198. https://doi.org/10.1016/J.APGEOG.2016.07.013

Simane, B., Zaitchik, B. F., & Foltz, J. D. (2016). Agroecosystem specific climate vulnerability analysis: application of the livelihood vulnerability index to a tropical highland region. Mitigation and Adaptation Strategies for Global Change, 21(1), 39–65. https://doi.org/10.1007/s11027-014-9568-1

SWS. (2019). Conservation management plan of Sakteng Wildlife Sanctuary. Sakten Wildlife Sanctuary. Department of Forest and Park Services.

Tambe, S., Arrawatia, M. L., Bhutia, N. T., & Swaroop, B. (2011). Rapid, cost-effective and high resolution assessment of climate-related vulnerability of rural communities of Sikkim Himalaya, India. Current Science, 101(2). www.worldclim.org.

Tempa, K. (2022). District flood vulnerability assessment using analytic hierarchy process (AHP) with historical flood events in Bhutan. *Plos One*, *17*(6). https://doi.org/10.1371/journal.pone.0270467

Tshering, D., & Sithey, G. (2008). Climate change and human health in Bhutan. https://doi.org/10.1093/ajae/aar006

Tshering, K., Sharma, E., Chettri, N., & Shrestha, A. (2011). Climate change impact and vulnerability in the eastern Himalayas – Synthesis Report (K. Tshering, E. Sharma, N. Chettri, & A. Shrestha, Eds.). ICIMOD. https://www.preventionweb.net/files/14744_climatechangevulnerabilityofmountai.pdf

UNDP. (2016). Climate change vulnerability assessment and adaptation planning: Enhancing sustainability and climate resilience of forest and agriculture landscape and community livelihoods in Bhutan. United Nation Development Program.

UN-OHRLLS. (2009). Impact of climate change on the development prospects of the Least Developed Countries and Small Island Developing States. Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States. https://www.un.org/ohrlls/sites/www.un.org.ohrlls/files/the_impact_of_cc_on_ldcs_and_sids_for_web.pdf

Vincent, K. (2007). Uncertainty in adaptive capacity and the importance of scale. Global Environmental Change, 17(1), 12–24. https://doi.org/10.1016/j.gloenvcha.2006.11.009

Wangdi, N., & Kusters, K. (2012). Loss & Damage: The costs of adaptation in Punakha, Bhutan: Loss and damage associated with changing monsoon patterns. http://loss-and-damage.net/download/6902.pdf

Wangdi, T., Tobgay, S., Dorjee, K., Dorji, K., Yangdon, N., & Wangyel, S. (2019). Report on building socio-ecological resilience: An adaptation to progressive climate change in Sakteng Wildlife Sanctuary. Department of Forest and Park Services. Ministry of Agriculture and Forests.

WMO. (2021). State of the Global Climate 2020. World Meteorological Organization. ISBN 978-92-63-11264-4. https://library.wmo.int/doc_num.php?explnum_id=10618

Annexures

Annexure I. Vulnerability Index of Gewogs under respective Protected Areas

The Gewogs are sequenced from being more vulnerable (lower/negative index value) to less vulnerable (high/positive index value). The vulnerability index was calculated separately for those Gewogs that fall under the jurisdiction of more than one Protected Area.

Gewog	Dzongkhag	Protected Area	Exposure	Sensitivity	Adaptive Capacity	Vulnerability Index
Nubi	Trongsa	WCNP	0.50	0.15	0.09	-0.56
Tangsibji	Trongsa	JSWNP	0.15	0.37	0.03	-0.49
Sherzhong	Sarpang	BC3	0.45	0.42	0.40	-0.47
Sephu	W/phodrang	WCNP	0.67	0.35	0.56	-0.45
Shermuhong	Mongar	BWS	0.43	0.44	0.42	-0.45
Gelephu	Sarpang	BC3	0.50	0.34	0.41	-0.42
Laya	Gasa	JDNP	0.65	0.20	0.45	-0.41
Langthel	Trongsa	JSWNP	0.17	0.28	0.07	-0.38
Gangzur	Lhuntse	BC7	0.21	0.41	0.24	-0.37
Metsho	Lhuntse	PNP	0.40	0.39	0.42	-0.37
Tendruk	Samtse	JKSNR	0.15	0.28	0.08	-0.36
Lunana	Gasa	JDNP	0.47	0.24	0.38	-0.33
Nichula	Dagana	PWS	0.47	0.35	0.51	-0.31
Shingkhar	Zhemgang	BC4	0.49	0.30	0.49	-0.30
Norgaygang	Samtse	JKSNR	0.06	0.28	0.06	-0.28
Samtenling	Sarpang	BC3	0.31	0.19	0.25	-0.25
Gakidling	Sarpang	BC3	0.22	0.29	0.27	-0.24
Pemathang	S/jongkhar	JWS	0.18	0.18	0.23	-0.13
Dangchu	W/phodrang	WCNP	0.50	0.11	0.49	-0.12
Tsento	Paro	JDNP	0.18	0.13	0.18	-0.12
Khoma	Lhuntse	BWS	0.18	0.29	0.35	-0.12
Patshaling	Tsirang	BC3	0.32	0.28	0.50	-0.11
Tangsibji	Trongsa	BC8	0.35	0.23	0.48	-0.09
Trong	Zhemgang	JSWNP	0.13	0.16	0.20	-0.09
Dunglagang	Tsirang	BC3	0.14	0.20	0.25	-0.09
Sergithang	Tsirang	JSWNP	0.36	0.29	0.62	-0.04
Khamaed	Gasa	JDNP	0.33	0.20	0.51	-0.02
Tsakaling	Mongar	BC7	0.30	0.09	0.36	-0.02
Phangkhar	Zhemgang	RMNP	0.19	0.25	0.45	0.00
Tang	Bumthang	WCNP	0.09	0.10	0.19	0.00
Lingzhi	Thimphu	JDNP	0.14	0.10	0.25	0.00
Goenshari	Punakha	JDNP	0.22	0.23	0.45	0.01
Chhudzom	Sarpang	BC3	0.18	0.23	0.45	0.03
Samrang	S/jongkhar	JWS	0.35	0.29	0.67	0.04
Nangkor	Zhemgang	BC4	0.35	0.25	0.64	0.04
Kazhi	W/phodrang	BC8	0.17	0.08	0.31	0.06

Langthel	Trongsa	BC4	0.21	0.29	0.57	0.07
Serthi	S/jongkhar	JWS	0.10	0.03	0.21	0.08
Trong	Zhemgang	RMNP	0.18	0.20	0.47	0.09
Chhume	Bumthang	PNP	0.08	0.02	0.21	0.11
Jigmecholing	Sarpang	BC3	0.19	0.26	0.57	0.12
Kurtoed	Lhuntse	WCNP	0.18	0.17	0.47	0.13
Langchenphu	S/jongkhar	JWS	0.24	0.29	0.68	0.15
Nyisho	W/phodrang	BC8	0.06	0.13	0.37	0.17
Tsamang	Mongar	PNP	0.03	0.17	0.39	0.19
Nubi	Trongsa	BC8	0.21	0.12	0.53	0.20
Umling	Sarpang	RMNP	0.40	0.26	0.87	0.22
Norbugang	Pemagatshel	RMNP	0.21	0.19	0.62	0.22
Dekiling	Sarpang	BC3	0.10	0.16	0.48	0.22
Tsamang	Mongar	BC7	0.06	0.07	0.36	0.22
Gangtey	W/phodrang	BC8	0.12	0.19	0.54	0.23
Tareythang	Sarpang	RMNP	0.26	0.35	0.86	0.25
Ura	Bumthang	PNP	0.20	0.13	0.59	0.25
Naro	Thimphu	JDNP	0.12	0.05	0.43	0.26
Gakiling	Haa	JKSNR	0.12	0.12	0.50	0.26
Tsenkhar	Lhuntse	BC7	0.14	0.25	0.65	0.26
Athang	W/phodrang	JSWNP	0.42	0.09	0.80	0.28
Jarey	Lhuntse	PNP	0.15	0.20	0.63	0.28
Khoma	Lhuntse	BC7	0.08	0.09	0.45	0.29
Khatoed	Gasa	JDNP	0.35	0.11	0.78	0.32
Umling	Sarpang	BC3	0.25	0.17	0.77	0.35
Senggey	Sarpang	BC3	0.25	0.25	0.87	0.38
Minjay	Lhuntse	BC7	0.08	0.06	0.53	0.39
Saling	Mongar	PNP	0.07	0.08	0.54	0.39
Bumdeling	T/yangtse	BWS	0.11	0.11	0.62	0.40
Sakteng	Trashigang	SWS	0.18	0.12	0.70	0.40
Sephu	W/phodrang	BC8	0.09	0.09	0.58	0.40
Menbi	Lhuntse	BC7	0.13	0.14	0.70	0.43
Chhoekhor	Bumthang	WCNP	0.14	0.11	0.70	0.45
Sangbay	Haa	JKSNR	0.11	0.12	0.68	0.45
Gangzur	Lhuntse	WCNP	0.06	0.09	0.62	0.47
Jigmecholing	Sarpang	JSWNP	0.02	0.12	0.61	0.47
Korphu	Trongsa	JSWNP	0.11	0.20	0.79	0.47
Bji	Haa	JKSNR	0.18	0.17	0.83	0.48
Ngangla	Zhemgang	RMNP	0.16	0.20	0.91	0.54
Soe	Thimphu	JDNP	0.19	0.06	0.90	0.64
Merak	Trashigang	SWS	0.10	0.04	0.92	0.78

Annexure II. Vulnerability Index of Chiwogs under respective Protected Areas

The Chiwogs are sequenced from being more vulnerable (lower/negative index value) to less vulnerable (high/positive index value). The vulnerability index was calculated separately for those Chiwogs that fall under the jurisdiction of more than one Protected Area.

Chiwog	Gewog	Protected Area	Exposure	Sensitivity	Adaptive Capacity	Vulnerability Index
Oonggar	Metsho	PNP	0.50	0.89	0.32	-1.07
Gangmoong	Shermuhong	BWS	0.28	0.70	0.08	-0.90
Rolmateng Tsanggo	Khoma	BWS	0.57	0.34	0.07	-0.85
Damzekesa	Nichula	PWS	0.55	0.67	0.41	-0.81
Yarphelling	Nichula	PWS	0.67	0.42	0.31	-0.78
Muhoong Shiling	Shermuhong	BWS	0.54	0.46	0.26	-0.73
Drakphel Tali	Nangkor	BC4	0.51	0.48	0.29	-0.70
Gagar Karzhong	Nubi	WCNP	0.54	0.22	0.06	-0.70
Langthel	Langthel	JSWNP	0.14	0.57	0.03	-0.68
Khailog Tashithang	Khamaed	JDNP	0.45	0.27	0.07	-0.64
Kela	Tangsibji	JSWNP	0.18	0.45	0.03	-0.60
Nakha	Sephu	WCNP	0.46	0.29	0.18	-0.58
Soenakhar Yarab	Shermuhong	BWS	0.43	0.37	0.23	-0.57
Soobdrang	Trong	RMNP	0.34	0.26	0.06	-0.54
Shang Threlga Wachey	Lunana	JDNP	0.56	0.24	0.25	-0.54
Zhongmaed	Metsho	PNP	0.33	0.27	0.06	-0.53
Barshong	Sherzhong	BC3	0.45	0.45	0.37	-0.53
Raminang Uesana	Lunana	JDNP	0.34	0.22	0.06	-0.51
Pazhi	Laya	JDNP	0.63	0.15	0.27	-0.51
Shawa Zhamling	Gangzur	BC7	0.22	0.32	0.03	-0.50
Jabang Trueling	Shermuhong	BWS	0.38	0.31	0.19	-0.50
Darbab Sinphoog	Nubi	WCNP	0.48	0.11	0.11	-0.48
Rolmateng Tsanggo	Khoma	BC7	0.42	0.12	0.07	-0.47
Gayza Lungo	Laya	JDNP	0.61	0.15	0.30	-0.46
Pangkhar	Khoma	BWS	0.17	0.33	0.06	-0.44
Neylug	Laya	JDNP	0.57	0.22	0.36	-0.44
Radhi	Shingkhar	BC4	0.37	0.24	0.18	-0.43
Buso Zeri	Sephu	WCNP	0.71	0.36	0.64	-0.43
Pelrithangkha Toed	Gelephu	BC3	0.50	0.34	0.41	-0.42
Dangdoong	Langthel	JSWNP	0.16	0.29	0.03	-0.42
Sherzhong	Sherzhong	BC3	0.44	0.40	0.43	-0.41

Kachhen Kuchhen	Tendruk	JKSNR	0.15	0.30	0.05	-0.40
Bamdhir Yurung	Metsho	PNP	0.30	0.16	0.06	-0.39
Jasabi Ugyenphoog	Kurtoed	WCNP	0.15	0.29	0.05	-0.38
Goomgang	Goenshari	JDNP	0.26	0.32	0.20	-0.38
Jang Ngar	Gangzur	BC7	0.19	0.40	0.22	-0.37
Tshozhong	Lunana	JDNP	0.53	0.19	0.36	-0.36
Dangreyboog	Nichula	PWS	0.65	0.28	0.57	-0.35
Thangza Toenchoe	Lunana	JDNP	0.43	0.26	0.34	-0.34
Jangbi	Langthel	JSWNP	0.18	0.24	0.09	-0.33
Obi Trongthrong	Metsho	PNP	0.39	0.51	0.57	-0.32
Rongchuthang	Langchenphu	JWS	0.27	0.37	0.31	-0.32
Gayza Zomina	Khamaed	JDNP	0.45	0.29	0.42	-0.32
Toedkor	Laya	JDNP	0.82	0.34	0.83	-0.32
Milamthang Thagzosa	Tendruk	JKSNR	0.16	0.27	0.12	-0.32
Dramchunang	Nichula	PWS	0.32	0.35	0.35	-0.32
Relangthang	Gakidling	BC3	0.19	0.30	0.18	-0.31
Choetenkhar	Jigmecholing	BC3	0.13	0.29	0.11	-0.31
Panabi	Phangkhar	RMNP	0.21	0.35	0.25	-0.31
Chongra Loobcha	Laya	JDNP	0.68	0.22	0.61	-0.29
Chongzhu Tshachu	Norgaygang	JKSNR	0.05	0.30	0.06	-0.29
Nyala Drangla	Tangsibji	BC8	0.24	0.26	0.22	-0.28
Barsha Panikong	Khamaed	JDNP	0.36	0.20	0.28	-0.28
Chhugoo Phendeygang	Norgaygang	JKSNR	0.08	0.25	0.05	-0.27
Chendebji	Tangsibji	BC8	0.39	0.23	0.35	-0.27
Khempagang	Samtenling	BC3	0.31	0.19	0.25	-0.25
Nyakha	Nangkor	BC4	0.31	0.36	0.42	-0.25
Chendebji	Tangsibji	JSWNP	0.09	0.19	0.04	-0.24
Khangkidyul	Lingzhi	JDNP	0.14	0.15	0.05	-0.24
Nimshong	Shingkhar	BC4	0.55	0.34	0.65	-0.23
Sangkha	Gakidling	BC3	0.17	0.24	0.18	-0.23
Dorjitse	Tareythang	RMNP	0.60	0.52	0.89	-0.23
Baling	Langthel	BC4	0.24	0.32	0.34	-0.22
Nimshong Tongling	Gangzur	BC7	0.22	0.54	0.54	-0.22
Nakha	Sephu	BC8	0.17	0.08	0.05	-0.20
Maenchulam	Gakidling	BC3	0.30	0.34	0.45	-0.19
Drangmaling Nanggor	Tsamang	PNP	0.02	0.22	0.06	-0.19
Tsanglajong Zurphel	Trong	RMNP	0.20	0.26	0.28	-0.18
Tandigang	Tang	WCNP	0.10	0.11	0.05	-0.17
Tangroong Wawel	Kurtoed	WCNP	0.11	0.16	0.12	-0.15

Dragchhu	Chhudzom	BC3	0.17	0.21	0.23	-0.15
Soe Yaktsa	Tsento	JDNP	0.12	0.08	0.05	-0.15
Patshaling Toed	Patshaling	BC3	0.28	0.33	0.47	-0.14
Pemathang	Pemathang	JWS	0.18	0.18	0.23	-0.13
Gangyuel	Lingzhi	JDNP	0.21	0.06	0.15	-0.13
Berpa Khoma	Khoma	BWS	0.18	0.40	0.46	-0.13
Rongchola Dadijong	Phangkhar	RMNP	0.30	0.28	0.46	-0.12
Artobaded Guendrang	Tsenkhar	BC7	0.08	0.19	0.15	-0.12
Godrang Tagsar	Dangchu	WCNP	0.50	0.11	0.49	-0.12
Singkhar	Ura	PNP	0.21	0.10	0.19	-0.11
Baptong Drakteng	Khoma	BWS	0.14	0.25	0.29	-0.10
Chhuzarkha	Lingzhi	JDNP	0.14	0.08	0.12	-0.10
Berti Tagma	Trong	JSWNP	0.13	0.16	0.20	-0.09
Norjangsa	Dunglagang	BC3	0.14	0.20	0.25	-0.09
Mitshig Shana	Tsento	JDNP	0.26	0.18	0.36	-0.09
Khiliphu	Merak	SWS	0.07	0.07	0.05	-0.08
Long Toed	Sephu	BC8	0.08	0.07	0.06	-0.08
Chengarzam	Phangkhar	RMNP	0.25	0.08	0.25	-0.08
Patshaling Maed	Patshaling	BC3	0.36	0.23	0.53	-0.07
Joenkhar Moorbi	Sakteng	SWS	0.39	0.35	0.68	-0.06
Zhomthang	Naro	JDNP	0.07	0.04	0.05	-0.06
Zhelngosa	Goenshari	JDNP	0.29	0.26	0.49	-0.06
Bji Saengbji	Nubi	BC8	0.25	0.10	0.29	-0.06
Thagthri	Sakteng	SWS	0.15	0.15	0.24	-0.06
Dorithasa	Gakiling	JKSNR	0.20	0.16	0.31	-0.06
Pagoed	Naro	JDNP	0.04	0.04	0.04	-0.04
Ngangtshothang Meod	Samrang	JWS	0.32	0.39	0.67	-0.04
Norbugang	Sergithang	JSWNP	0.36	0.29	0.62	-0.04
Agoorthang	Langchenphu	JWS	0.22	0.31	0.50	-0.03
Tshangkha	Tangsibji	BC8	0.49	0.30	0.77	-0.03
Malang Serzhong	Shermuhong	BWS	0.40	0.46	0.84	-0.02
Tagkhambi	Tsakaling	BC7	0.30	0.09	0.36	-0.02
Rimi	Khatoed	JDNP	0.56	0.22	0.76	-0.01
Tangsibi	Ura	PNP	0.20	0.15	0.36	0.01
Yumchhe	Jarey	PNP	0.39	0.21	0.61	0.01
Ngangtshothang Teod	Samrang	JWS	0.37	0.28	0.67	0.02
Baptong Drakteng	Khoma	BC7	0.03	0.14	0.20	0.03
Dragchukha	Goenshari	JDNP	0.16	0.27	0.46	0.03
Chagzom Chhusa	Kurtoed	WCNP	0.35	0.19	0.57	0.03
Norbugang Rinchenzoor	Norbugang	RMNP	0.24	0.26	0.53	0.03
Saidzong Thangdokha	Gakiling	JKSNR	0.12	0.17	0.33	0.04

Shingnyer	Ura	PNP	0.24	0.09	0.36	0.04
Bagochen Ueling	Nubi	BC8	0.62	0.11	0.78	0.05
Tsheringkha	Khatoed	JDNP	0.30	0.08	0.44	0.05
Phootsena Ngatse	Gakiling	JKSNR	0.13	0.26	0.44	0.05
Baedrog	Kazhi	BC8	0.17	0.08	0.30	0.05
Lhedi	Lunana	JDNP	0.50	0.25	0.81	0.06
Samtengang	Nyisho	BC8	0.00	0.02	0.08	0.06
Ladrong	Jarey	PNP	0.04	0.32	0.42	0.06
Amdrangchhu Zham	Minjay	BC7	0.10	0.08	0.24	0.07
Bomdir Wogmanang	Bumdeling	BWS	0.11	0.18	0.36	0.07
Khandrophoong Minjiwoong	Serthi	JWS	0.10	0.03	0.21	0.08
Saling	Saling	PNP	0.17	0.10	0.35	0.08
Lomtshokha	Athang	JSWNP	0.33	0.07	0.47	0.08
Baychu Tshepgang	Khatoed	JDNP	0.50	0.17	0.76	0.09
Jangchubling	Chhudzom	BC3	0.12	0.22	0.43	0.09
Khamaed	Jigmecholing	BC3	0.22	0.23	0.54	0.10
Damsagang Maed	Samrang	JWS	0.33	0.26	0.69	0.10
Choongphel	Chhume	PNP	0.08	0.02	0.21	0.11
Yorbo	Goenshari	JDNP	0.15	0.21	0.48	0.12
Gangtokha	Nichula	PWS	0.34	0.26	0.72	0.13
Shalingtoed Tashibi	Phangkhar	RMNP	0.14	0.27	0.54	0.13
Tsaidang	Nangkor	BC4	0.37	0.20	0.71	0.14
Lhayuel	Chhudzom	BC3	0.24	0.26	0.64	0.14
Tashithang	Umling	RMNP	0.30	0.36	0.81	0.15
Gongduegang	Jigmecholing	BC3	0.20	0.29	0.64	0.16
Gagar Karzhong	Nubi	BC8	0.26	0.17	0.59	0.17
Khangrab	Tang	WCNP	0.08	0.08	0.33	0.17
Nimshong Maed	Korphu	JSWNP	0.17	0.42	0.75	0.17
Artobi Ngangngae	Jarey	PNP	0.21	0.26	0.65	0.18
Duenmang	Nangkor	BC4	0.16	0.16	0.51	0.18
Mamong Trong Pantang	Phangkhar	RMNP	0.14	0.19	0.51	0.18
Ganglapong Maed	Tsamang	BC7	0.06	0.08	0.32	0.18
Gortshom	Metsho	PNP	0.48	0.22	0.88	0.18
Rejoog	Umling	RMNP	0.47	0.25	0.90	0.18
Maenjabi	Menbi	BC7	0.18	0.11	0.47	0.18
Ribati	Ngangla	RMNP	0.19	0.23	0.60	0.19
Goensar Rajawog	Nyisho	BC8	0.07	0.15	0.41	0.19
Shema Yaba	Sangbay	JKSNR	0.13	0.02	0.35	0.20
Gashari	Norbugang	RMNP	0.19	0.15	0.55	0.20
Shayuel	Lingzhi	JDNP	0.09	0.04	0.34	0.20

Thuenmong Tokari	Tsamang	PNP	0.04	0.20	0.45	0.20
Gogona	Gangtey	BC8	0.07	0.07	0.35	0.20
Langchenphu	Langchenphu	JWS	0.27	0.35	0.83	0.21
Dekaling Tshochen	Tsenkhar	BC7	0.17	0.28	0.66	0.21
Gangla Kholma	Khoma	BWS	0.13	0.16	0.51	0.22
Jigmeling	Dekiling	BC3	0.10	0.16	0.48	0.22
Dangling	Umling	RMNP	0.33	0.27	0.83	0.22
Lawa Lamga	Athang	JSWNP	0.56	0.15	0.93	0.22
Jigmecholing	Jigmecholing	BC3	0.22	0.48	0.93	0.22
Darbab Sinphoog	Nubi	BC8	0.15	0.08	0.45	0.23
Jangsa	Langchenphu	JWS	0.40	0.31	0.94	0.23
Yoedzergang	Tareythang	RMNP	0.28	0.38	0.89	0.23
Pemacholing	Tareythang	RMNP	0.26	0.40	0.90	0.23
Nyenyul	Senggey	BC3	0.24	0.22	0.70	0.23
Kamjong	Nangkor	BC4	0.31	0.09	0.65	0.24
Tashithang	Naro	JDNP	0.04	0.04	0.33	0.24
Gaden	Umling	RMNP	0.44	0.22	0.90	0.24
Nimshong Toed	Korphu	JSWNP	0.19	0.38	0.82	0.24
Gangtey	Gangtey	BC8	0.16	0.28	0.69	0.25
Tshaelshingzor	Norbugang	RMNP	0.21	0.19	0.66	0.26
Marangduet	Ngangla	RMNP	0.31	0.39	0.96	0.26
Lophokha Pagtakha	Athang	JSWNP	0.16	0.05	0.50	0.28
Chagphu	Lingzhi	JDNP	0.13	0.19	0.61	0.29
Pangkhar Taphel	Bumdeling	BWS	0.02	0.03	0.35	0.30
Yarpheling	Senggey	BC3	0.33	0.28	0.94	0.32
Sechaednang	Goenshari	JDNP	0.22	0.07	0.62	0.33
Doongmin	Umling	RMNP	0.42	0.16	0.91	0.33
Nasiphel Zangling Zhabjethang	Chhoekhor	WCNP	0.21	0.14	0.69	0.34
Tashithang	Umling	BC3	0.25	0.17	0.77	0.35
Tsenka Taloong	Bji	JKSNR	0.18	0.21	0.76	0.37
Khatoed	Jigmecholing	BC3	0.22	0.23	0.82	0.37
Dangdoong	Langthel	BC4	0.17	0.27	0.82	0.38
Tangsibji	Tangsibji	BC8	0.35	0.15	0.88	0.38
Baanjar	Tsamang	PNP	0.01	0.04	0.45	0.39
Kazhi	Kazhi	BC8	0.13	0.06	0.58	0.40
Gangkhardong Tshaling	Bumdeling	BWS	0.18	0.18	0.75	0.40
Autsho Charbi	Tsenkhar	BC7	0.12	0.21	0.73	0.40
Tashicholing	Tareythang	RMNP	0.14	0.23	0.78	0.41
Rukha	Athang	JSWNP	0.48	0.07	0.97	0.42
Mochu	Sangbay	JKSNR	0.07	0.13	0.62	0.42
Rangtse Tanga Yokha	Gakiling	JKSNR	0.10	0.04	0.57	0.43
Bemji Chela	Nubi	BC8	0.13	0.10	0.66	0.43

Anakha Shepji	Sangbay	JKSNR	0.18	0.30	0.91	0.43
Choompa Jamgoen	Bji	JKSNR	0.18	0.19	0.80	0.43
Gyensa Tokey	Bji	JKSNR	0.23	0.21	0.88	0.43
Rishong	Senggey	BC3	0.15	0.18	0.77	0.43
Sangyethang	Senggey	BC3	0.18	0.23	0.86	0.45
Tozotoen	Soe	JDNP	0.37	0.08	0.90	0.45
Jabisa	Khamaed	JDNP	0.20	0.13	0.78	0.46
Gomphu	Trong	RMNP	0.12	0.13	0.72	0.46
Ney	Gangzur	WCNP	0.06	0.09	0.62	0.47
Gongduegang	Jigmecholing	JSWNP	0.02	0.12	0.61	0.47
Buli	Nangkor	BC4	0.33	0.17	0.97	0.48
Chenpa Gyechukha	Bji	JKSNR	0.18	0.14	0.80	0.48
Sombay Ama	Sangbay	JKSNR	0.15	0.14	0.78	0.49
Gongtsekha	Jigmecholing	BC3	0.12	0.24	0.86	0.49
Thridangbi	Saling	PNP	0.03	0.06	0.59	0.50
Masangdaza	Saling	PNP	0.06	0.11	0.67	0.50
Dhur Lusibee	Chhoekhor	WCNP	0.12	0.09	0.72	0.51
Ngalimang Phanteng	Bumdeling	BWS	0.16	0.10	0.77	0.51
Kharsa Thangbi	Chhoekhor	WCNP	0.10	0.09	0.69	0.51
Korphu Toed	Korphu	JSWNP	0.06	0.12	0.69	0.51
Nyingshingborang	Norbugang	RMNP	0.21	0.18	0.91	0.52
Pusa Tenmang	Sakteng	SWS	0.10	0.04	0.67	0.53
Phagidoong	Menbi	BC7	0.01	0.06	0.61	0.53
Jampani	Langchenphu	JWS	0.14	0.13	0.81	0.53
Mentsiphug	Naro	JDNP	0.29	0.05	0.89	0.56
Tabi	Kurtoed	WCNP	0.19	0.18	0.94	0.56
Yabi Zangkhar	Jarey	PNP	0.03	0.14	0.73	0.56
Kharchung	Jarey	PNP	0.01	0.03	0.62	0.57
Fentena Sertena	Gakiling	JKSNR	0.08	0.05	0.71	0.58
Damji	Khamaed	JDNP	0.23	0.11	0.93	0.58
Barshong Nango	Naro	JDNP	0.18	0.07	0.84	0.59
Nakha Tashigang	Sangbay	JKSNR	0.11	0.04	0.74	0.60
Borangmang	Sakteng	SWS	0.19	0.09	0.88	0.60
Korphu Maed	Korphu	JSWNP	0.07	0.06	0.74	0.60
Damgochong	Soe	JDNP	0.24	0.06	0.90	0.60
Ura Dozhi	Ura	PNP	0.20	0.16	0.96	0.60
Sakteng	Sakteng	SWS	0.14	0.06	0.82	0.61
Mani	Khatoed	JDNP	0.26	0.07	0.94	0.62
Gangla Kholma	Khoma	BC7	0.03	0.05	0.70	0.62
Dungkar	Kurtoed	WCNP	0.16	0.12	0.90	0.62
Beteng Pangkhar Soomthrang	Ura	PNP	0.18	0.14	0.97	0.64
Ganglapong Toed	Tsamang	BC7	0.01	0.03	0.69	0.65

Bumilog	Sephu	BC8	0.06	0.10	0.82	0.66
Khashateng	Merak	SWS	0.02	0.07	0.76	0.67
Yangthang	Bji	JKSNR	0.13	0.10	0.90	0.68
Ganglapong	Tsamang	PNP	0.01	0.03	0.73	0.68
Toed Khamdar	Menbi	BC7	0.09	0.18	0.96	0.70
Moormo Pangbang	Ngangla	RMNP	0.11	0.13	0.96	0.72
Sonamthang Rukubji	Sephu	BC8	0.11	0.11	0.94	0.72
Dotabithang	Soe	JDNP	0.12	0.05	0.90	0.72
Jomphu	Soe	JDNP	0.11	0.05	0.89	0.73
Jangothang	Soe	JDNP	0.10	0.06	0.90	0.74
Gyengo	Merak	SWS	0.18	0.05	0.97	0.74
Dragong Jalang	Minjay	BC7	0.07	0.04	0.87	0.76
Nabi	Korphu	JSWNP	0.08	0.11	0.95	0.77
Chhogley Phulakha	Khatoed	JDNP	0.09	0.05	0.91	0.78
Betshemang	Bumdeling	BWS	0.11	0.05	0.96	0.80
Merak Toed	Merak	SWS	0.10	0.04	0.97	0.83
Merak Maed	Merak	SWS	0.08	0.04	0.97	0.84
Gakidling	Jigmecholing	BC3	0.06	0.02	0.96	0.88

Annexure III. List of Participants of Consultation Workshop

Three consultation workshops were conducted for the development and validation of framework, indicators and questionnaires for the climate vulnerability and capacity assessment study.

Following are the list of participants:

1. Mr. Jigme Dorji, Chief Forestry Officer, Zhemgang Forest Division
2. Mr. Yonten Norbu, Chief Forestry Officer, Phrumshingla National Park
3. Mr. Norbu Wangdi, Principal Forestry Officer, Mongar Forest Division
4. Mr. Yonten Jamtsho, Forestry Officer, Jigme Dorji National Park
5. Mr. Bal Ram Mafchan, Forestry Officer, Phrumshingla National Park
6. Mr. Karma Wangdi, Forestry Officer, Wangchuck Centennial National Park
7. Mr. Karma Gyeltshen, Forestry Officer, Royal Manas National Park
8. Ms. Khandu Tshomo, Forestry Officer, Phibsoo Wildlife Sanctuary
9. Mr. Tshering Dorji, Forestry Officer, Sarpang Forest Division
10. Mr. Sonam Tobgay, Senior Forestry Officer, Sakteng Wildlife Sanctuary
11. Mr. Abir Man Sinchuri, Forestry Officer, Jigme Singye Wangchuck National Park
12. Ms. Kezang Choden, Forestry Officer, Bumthang Forest Division
13. Mr. Sangay Wangchuk, Forest Ranger, Jigme Khesar Strict Nature Reserve
14. Mr. Kharananda Ghimeray, Senior Forest Ranger, Tsirang Forest Division
15. Mr. Tenzin Rabgay, Forestry Officer, Phrumshingla National Park
16. Mr. Jangchub Gyeltshen, Senior Forest Ranger, Phrumshingla National Park
17. Mr. Pema Thinley, Forest Ranger, Phrumshingla National Park
18. Mr. Pema, Senior Forest Ranger, Phrumshingla National Park
19. Mr. Pema Tshewang, Senior Forest Ranger, Phrumshingla National Park
20. Mr. Kado Tshering, Specialist, Ugyen Wangchuck Institute for Conservation and Environment Research (UWICER)
21. Mr. Kinzang Namgay, Senior Forestry Officer, UWICER
22. Mr. Kelly Tobden Dorji Tamang, Senior Forestry Officer, UWICER
23. Mr. Sonam Wangdi, Senior Librarian, UWICER
24. Mr. Tashi Dhendup, Senior Forestry Officer, UWICER
25. Mr. Jigme Wangchuk, Senior Ranger, UWICER

Annexure IV. List of Focal Officials of Protected Area Offices

List of the focal officials for climate vulnerability and capacity assessment study of respective Protected Areas Offices. Focal officials were involved in development of the assessment framework and coordinating field surveys.

SI.No.	Office	Name	Designation	Email ID
1	Jigme Dorji National Park	Yonten Gyamtsho	Sr. Forestry Officer	zyamtshok@gmail.com
2	Jigme Singye Wangchuck National Park	Abir Man Sinchuri	Forestry Officer	amsinchuri@moaf.gov.bt
3	Jigme Khesar Strict Nature Reserve	Sangay Wangchuk	Forest Ranger	sangay88@gmail.com
4	Royal Manas National Park	Karma Gyeltshen	Forestry Officer	karmag@moaf.gov.bt
5	Phrumsengla National Park	Bal Ram mafchan	Forestry Officer	brmafchan@moaf.gov.bt
6	Wangchuck Centennial National Park	Karma Wangdi	Forestry Officer	karmawangdi1@moaf.gov.bt
7	Phibsoo Wildlife Sanctuary	Tashi Phuntsho	Forest Ranger	phuntshotashi9@gmail.com
8	Bumdeling Wildlife Sanctuary	Sonam Choidup	Forest Ranger	sonamchoidup@gmail.com
9	Sakteng Wildlife Sanctuary	Sonam Jamtsho	Forest Ranger	sonamdupthop@gmail.com
10	Jomotshangka Wildlife Sanctuary	Lekey Chaida	Forestry Officer	lchaida@moaf.gov.bt
11	Zhemgang Forest Division (BC4)	Phub Dorji	Forestry Officer	phubdorji@moaf.gov.bt
12	Tsirang Forest Division (BC3)	K.N. Ghimeray	Forest Ranger	Ghimeray@hotmail.com
13	Bumthang Forest Division (BC8)	Ugyen Namgay	Forestry Officer	u_namgyel@hotmail.com
14	Sarpang Forest Division (BC3)	Tshering Dorji	Forestry Officer	tsheringdorji1@moaf.gov.bt
15	Mongar Forest Division (BC7)	Norbu Wangdi	Principal Forestry Officer	nwangdi@moaf.gov.bt