Ecosystem and Socioeconomic Resilience Analysis and Mapping of High-Altitude Wetland Areas of Bhutan

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This report has been prepared by the Royal Society for Protection of Nature (RSPN) in collaboration with the Royal Government of Bhutan (RGoB) under the project **"Strengthening capacities and enhancing climate data and services in Bhutan to scale-up climate financing from multiple sources."** The initiative aims to strengthen ecosystem-based approaches for biodiversity conservation and climate change adaptation.

The project is supported by the **Green Climate Fund (GC) Readiness and Preparatory Support Program (RPSP)**, which supports developing countries in strengthening institutional capacities, enhancing national arrangements for climate finance access, and enabling effective programming of climate investments aligned with national priorities.

Through this support, the project contributes to strengthening Bhutan's institutional and technical capacity to integrate climate change considerations into biodiversity and ecosystem management. It facilitates the generation of scientific knowledge, development of decision-support tools, and enhancement of enabling frameworks to promote climate-resilient and sustainable development pathways.

The project focuses on the development and promotion of **ecosystem-based solutions (EbS)** for managing biodiversity landscapes by integrating climate change adaptation, ecosystem conservation, and community resilience. It supports improved understanding of climate risks and vulnerabilities affecting ecosystems and communities while promoting practical approaches for ecosystem restoration, conservation, and adaptive management.

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The outcomes and knowledge generated through this project will contribute to Bhutan's climate commitments under the Paris Agreement, biodiversity conservation objectives, and national priorities for long-term environmental sustainability and ecosystem resilience.

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Acronym

AWQC:
BDWQS:
BNC:
BWS: **CC**:
CF:
CI:
CNR:
CVI:
CVM:
DBDC:
DBH: **DD**:
DO:
DoFPS:
EC:
EN:
EPA:
ESRAM:
FEMD:
FFG:
FGD:
FPOM:
GCF:
GNH:
GNHC:
HH:
ICIMOD:
IPCC:
IUCN:
LC:
LDCs:
LVI:
MC:

Ambient Water Quality Criteria
Bhutan Drinking Water Quality Standard
Black-Necked Crane
Bumdeling Wildlife Sanctuary
Climate Change
Contributing Factor
Confidence Interval
College of Natural Resources
Climate Change Vulnerability Index
Contingent Valuation Method
Double bounded dichotomous choice
Diameter at Breast Height
Data Deficient
Dissolved Oxygen
Department of Forest and Park Services
Electrical Conductivity
Endangered
Environment Protection Agency
Ecosystem and Socio-economic Resilience Analysis and Mapping
Flood Engineering and Management Division
Functional feeding group
Focus group discussions
Fine particulate organic matter
Green Climate Fund
Gross National Happiness
Gross National Happiness Commission
Households
International Centre for Integrated Mountain Development
Intergovernmental Panel on Climate Change
International Union for Conservation of Nature
Least Concerned
Least Developed Countries
Livelihood Vulnerability Index
Major Component

MoAF:	Ministry of Agriculture and Forestry
NDCs:	Nationally Determined Contributions
NEC:	National Environment Commission
NMDS:	Non-metric multidimensional scaling
NSB:	National Statistics Bureau
NT:	Near Threatened
Nu.	Ngultrum
NWFPs:	Non-Wood Forest Products
Parameters:	Parameters
PCoA:	Principal Coordinates Analysis
PES:	Payment for ecosystem service
pH:	Potential of Hydrogen
RA:	Relative Abundance
RSPN:	Royal Society for Protection of Nature
RUT:	Random Utility Theory
SBDC:	Single Bounded Dichotomous Choice
SWS:	Sakteng Wildlife Sanctuary
TDS:	Total Dissolved Solids
TSS:	Total Soluble Solids
UNDP:	United Nation Development Program
UNFCC:	United Nations Framework Convention on Climate Change
V:	Vulnerable
WCN:	Weather and Climate Network
WPI:	Water Poverty Index
WTP:	Willingness to Pay
WWF:	World Wildlife Fund
masl:	meters above sea level
hh:	Household

Glossary

Chhu	Stream/River
Chiwog	Refers to the basic electoral precinct
Drukpa Kagyu	Subset of Buddhist religion in Bhutan
Dzongkhag	District
Gewog	An administrative block composing a group of villages in Bhutan
Lhakhangs	Temple
Ngalop	Dzongkha speaking Bhutanese ethnic group dominant in Western and Northern Bhutan
Ngultrum	Currency of Bhutan
Sharchops	Sharchop (meaning "easterner"), are Tshangla speaking populations of mixed Tibetan, South Asian and Southeast Asian descent that mostly live in the eastern districts of Bhutan
Throm	Town/City
Tsechu	Buddhist festival usually celebrated on important days that are marked in the lunar/Buddhist calendar.

1 Introduction

1.1 Background

Climate change is profoundly affecting Bhutan's high-elevation ecosystems, with high-altitude wetlands among the most vulnerable. These wetlands are ecologically significant, contributing to biodiversity conservation, maintaining hydrological balance, and delivering key ecosystem services such as carbon sequestration and water regulation (International Centre for Integrated Mountain Development (ICIMOD, 2015). However, rising temperatures and changing precipitation patterns are accelerating glacial retreat, degrading permafrost, and altering seasonal water flows—posing serious threats to these fragile habitats (National Environment Commission (NEC, 2020). High-altitude wetlands also provide critical habitat for rare and endangered species such as the Black-necked Crane (*Grus nigricollis*) and support unique alpine vegetation. In addition to their ecological value, these systems are closely linked to the livelihoods of local communities, particularly those engaged in traditional practices such as yak herding, subsistence farming, and the collection of medicinal plants (RSPN, 2019). Therefore, the preservation and sustainable management of high-altitude wetlands are essential—not only for biodiversity and climate regulation, but also for enhancing the socio-economic resilience of mountain communities in the face of accelerating climate change.

RSPN, has a longstanding engagement in wetland conservation in Bhutan especially in Gangtey-Phobji valley in Wangduephodrang, Gaytsa-Domkhar under Chummig Gewog in Bumthang and Bumdeling in Trashiyangtse. The organization's approach to conservation is guided by the principle of harmonious co-existence and the need to make conservation relevant to the socioeconomic way of life of the local communities. With increasing evidence of climate change and its impacts on ecosystems and livelihoods of communities, RSPN recognizes the importance of integrating climate dimensions into formulating and implementing plans towards conservation and sustainable livelihood objectives. In 2019, RSPN adopted the Ecosystem and Socio-economic Resilience Analysis and Mapping (ESRAM) approach to assessing and addressing ecosystem and community vulnerability to climate change impacts. Recognizing the implications of climate change on high-altitude wetlands species, ecosystems, and communities dependent on them, RSPN fielded another ESRAM study to assess risks and vulnerabilities of high-altitude wetland ecosystems and communities.

This report is the technical output of the project "Ecosystem and Socio-economic Resilience Analysis and Mapping Study in High-altitude Wetlands of Bhutan" commissioned by RSPN. The overall objective of the ESRAM study is to:

- ✔️ understand the climate vulnerability and impact of high-altitude wetland ecosystems.
- ✔️ outline interventions together with climate financing scope.

ESRAM is a systematic approach designed to evaluate the ability of ecosystems and human communities to endure, adapt, and recover from various environmental and socioeconomic pressures. This method integrates environmental science with socio-economic considerations to identify vulnerabilities and opportunities for resilience enhancement. By analyzing factors such as ecosystem health, biodiversity, community livelihoods, and climate risks, ESRAM provides a framework for sustainable management and policy development.

This **ESRAM** study was fielded by RSPN to assess the vulnerabilities of communities and ecosystems in high-altitude wetland areas of Bhutan through the **GCF Readiness and Preparatory Support Program (RPSP)**. Through this study, RSPN expects to bridge the data and planning gap for enhanced understanding of how ecological vulnerability, climate risks, and socio-economic conditions of the high-altitude wetland areas interact.

1.2 Importance of High-Altitude Wetlands

Wetlands play a pivotal role in the global climate system, acting as natural carbon sinks while regulating hydrological processes. Their ability to capture and store carbon in peat soils, vegetation, and sediments makes them crucial in mitigating greenhouse gas emissions. Furthermore, wetlands provide resilience against climate change-induced events by buffering floods, maintaining groundwater levels, and stabilizing ecosystems under fluctuating climatic conditions. High-altitude wetlands are among the most ecologically significant and climate-sensitive ecosystems in the world. They are particularly important for biodiversity conservation, water regulation, and carbon storage (Groot et al., 2018; Jacobsen & Dangles, 2017). They serve as critical habitats for various species, including migratory birds, and play a vital role in maintaining regional ecological balance (Keddy et al., 2009). Preserving these landscapes is not only vital for ecological health but also for sustaining the livelihoods of communities dependent on their resources.

In mountain countries like Bhutan, local communities depend heavily on wetland ecosystem services for water supply, livestock grazing, subsistence farming, medicinal plant collection, and eco-tourism (ICIMOD, 2015; RSPN, 2019). Mountain wetlands of Bhutan, though small and dispersed, are vital to downstream water security and regional climate resilience. These regions are not only biodiversity hotspots—home to Black-necked Cranes, alpine flora, and endemic fauna—but also support traditional livelihoods based on yak herding, subsistence agriculture, and seasonal migration (RSPN, 2019). However, these fragile ecosystems are under increasing threat from climate change impacts such as glacial retreat, altered precipitation patterns, permafrost degradation, and drying of wetland systems (NEC, 2020; WWF Bhutan, 2022). These environmental changes directly affect community livelihoods and ecosystem stability.

1.3 National Policies and Global Climate Goals

Bhutan has gained international acclaim for its innovative environmental policies and its constitutional commitment to conservation. As the world's only carbon-negative country, Bhutan absorbs more carbon dioxide than it emits, a feat largely attributed to its extensive forest cover. According to the National Environment Commission (NEC, 2020), over 60% of Bhutan's land area is required by the Constitution of the Kingdom of Bhutan (Article 5-Section 3) to remain forested, ensuring the preservation of crucial carbon sinks and biodiversity hotspots.

Bhutan's climate policies, strategies and actions reflect a strong alignment with global climate objectives, particularly the goals of the United Nations Framework Convention on Climate Change (UNFCCC). The country has been a vocal advocate for climate justice, emphasizing the disproportionate vulnerabilities of Least Developed Countries [LDCs] to climate impacts, despite their minimal contributions to global emissions (UNDP, 2019). By leveraging international partnerships such as those under the NDC Partnership and accessing financial aid from mechanisms like the Green Climate Fund (GCF), Bhutan has significantly enhanced its capacity to scale up mitigation and adaptation efforts (WWF Bhutan, 2022).

The Climate Change Policy of the Kingdom of Bhutan 2020 underscores the nation's unwavering commitment to environmental conservation and its status as one of the carbon-negative countries in the world. Towards a "prosperous, resilient and carbon neutral Bhutan" the policy integrates sustainable development with environmental conservation and Gross National Happiness (GNH), emphasizing harmony between human well-being and ecological health (MoAF, 2021). Further, the policy strengthens Bhutan’s advocacy for climate justice, focusing on the disproportionate vulnerabilities faced by LDCs and aligning with global frameworks like the UNFCCC to secure international technical and financial support.

As part of its Nationally Determined Contributions (NDCs) under the Paris Agreement (2015), Bhutan has reiterated its commitment to carbon neutrality, supported by initiatives such as hydropower-driven clean energy production, extensive reforestation programs, and climate-resilient agricultural practices (NEC, 2020). It highlights Bhutan’s 70% forest cover against the constitutional mandate to maintain a minimum 60%, ensuring robust carbon sinks and biodiversity hotspots.

The conservation of high-altitude wetlands is paramount for both regional and global ecological resilience, further reinforcing Bhutan’s leadership in environmental stewardship (ICIMOD, 2015). Bhutan’s commitment is exemplified by its designation of critical wetlands as Ramsar sites, including Bumdeling in 2012, Khotokha and Gangtey-Phobji in 2016, underscoring their national and international ecological significance. The implementation of Ramsar site management plans, such as those in Gangtey-Phobji (RSPN, 2019), demonstrates Bhutan’s proactive approach to sustainable wetland conservation, balancing biodiversity protection with community needs.

The National Biodiversity Strategies and Action Plan (NBSAP, 2025) states that while Bhutan’s protected areas are globally renowned, its wetlands including the Gangtey-Phobji, Khotokha, and Bumdeling Ramsar sites are equally vital. These marshlands provide essential habitats for endemic and threatened species. Beyond biodiversity, these high-altitude wetlands are cornerstones of Bhutan's nature-based tourism, proving that conservation importance extends well beyond protected area networks.

The country has designated three Ramsar sites, namely Gangtey-Phobji, Khotokha and Bumdeling, collectively covering an area of approximately 1,225 hectares (ha) to conserve the ecologically important wetlands with diverse biodiversity and as wintering grounds for the Near Threatened, black-necked crane (Grus nigricollis) (Birdlife International, 2025).

1.4 About the ESRAM Report

The ESRAM Report for High Altitude Wetland Areas of Bhutan presents a holistic and integrated assessment of the resilience and vulnerability of both wetland ecosystems and the communities who depend on them. This technical report synthesizes scientific research, field observations, and community insights to offer a detailed understanding of how ecological, socioeconomic, and climatic factors interact in these high-altitude landscapes.

The ESRAM study was conducted across four critical high-altitude wetland sites Gangtey-Phobji in Wangdue Phodrang, Gaytsa-Domkhar under Chummig Gewog in Bumthang, Bumdeling in Trashiyangtse, and Sakteng in Trashigang. The report aims to assess vulnerabilities of both ecosystems and communities to climate change and socioeconomic pressures, map the status of biodiversity and ecosystem services, evaluate socioeconomic conditions, livelihood strategies, and local resilience, and provide actionable recommendations for adaptation, conservation, and climate financing opportunities.

The ESRAM framework adopts a multi-disciplinary methodology. This includes ecological assessments through systematic sampling and analysis of vegetation, aquatic life, avifauna, and mammals/reptiles to document biodiversity, ecosystem health, and habitat conditions.

Socioeconomic and livelihood analysis is conducted using structured household surveys and focus group discussions to capture community demographics, income patterns, livelihood activities, resource dependence, and adaptive strategies. The valuation of ecosystem services is carried out using the Contingent Valuation Method to quantify the value local people place on provisioning, regulating, and cultural services provided by wetlands, incorporating their willingness to pay for conservation. Community perceptions of climate change are explored through gender- and education-disaggregated analysis of knowledge and attitudes, focusing on local awareness, causal understanding, and observed climate impacts. Livelihood and climate vulnerability assessment employs adapted indices (such as the Livelihood Vulnerability Index and IPCC-LVI) to measure vulnerability across multiple dimensions—exposure, adaptive capacity, and sensitivity—to climate change. Water quality monitoring assesses physical and chemical water quality parameters and benchmarks them against national standards to gauge ecological status and human usability. Finally, the report includes a policy context and recommendations section that situates findings within Bhutan's national policies, global climate goals, and conservation frameworks, providing evidence-based recommendations for targeted interventions and sustainable management.

The key features of the report include comprehensive site profiles, which offer detailed descriptions of each wetland covering physical geography, ecological uniqueness, socioeconomic and cultural contexts, and major ecosystem services. It combines quantitative and qualitative analysis, involving rigorous statistical evaluation of survey data with rich qualitative insights from local communities. The report also provides a comparative analysis, comparing results across sites to highlight regional variations in vulnerability, resilience, ecosystem value, and adaptation needs. The outcomes are action-oriented, not only diagnosing vulnerabilities but also outlining practical actions for conservation, community engagement, and climate change adaptation and mitigation, supporting Bhutan's pursuit of resilience and climate finance.

2 Methodological Framework

2.1 Overview of ESRAM Approach

To understand climate vulnerability and the impacts on high-altitude wetland ecosystems, as well as to identify suitable interventions and climate financing opportunities, the ESRAM study applied an integrated approach. The methodology combined social surveys and focus group discussions (FGDs) to capture local knowledge, perceptions, and livelihood dependencies. Ecological assessments included vegetation surveys, aquatic surveys, and bird surveys to document biodiversity, habitat conditions, and ecosystem health. Overall, these methods provided a comprehensive picture of both ecological and socio-economic resilience, supporting the planning of targeted adaptation measures and investment priorities.

2.2 Socioeconomic and Livelihood Analysis

To assess community livelihoods and socio-economic conditions, a household survey was conducted using a structured set of interview questions. The sample size was determined using the Yamane formula[1] as shown in the equation below (detailed calculation provided in the annex), ensuring statistically sound representation. Households were selected through simple random sampling to reduce bias.

The resulting sample size per Chiwog under each of the study sites are provided in **Table 2.1**. Interviews were carried out face-to-face with household respondents using the EpiCollect5 mobile data collection tool, which enabled efficient and consistent recording of responses in the field. The collected data were then exported to Microsoft Excel for cleaning and sorting to ensure accuracy and completeness.

Subsequent data analysis was performed using R software. The analysis focused on key themes including:

- ✔️ Community awareness of climate change
- ✔️ Local perspectives on the causes of climate change
- ✔️ Socio-economic and income analysis
- ✔️ Ecosystem services analysis

This approach provided a robust understanding of local socio-economic conditions, community perceptions, and their links to ecosystem resilience and climate vulnerability.

1

Where:

n = Sample size

$$n=\frac{N}{1+N(e^2)}$$

N= Population size

e = Level of precision (margin of error), usually 0.05 (5%)

Table 2.1: Chiwog, villages and sample size for household socio-economic surveys

Site	Gewog	Chiwog	Household	
			Total Population (HH)	**Sample Size**
Gangtey-Phobji Wetland	Gangtey Gewog	Jangchen Kumboo	80	21
		Gangtey	80	26
		Yaekorwog Mole	85	73
		Eusa Tabading	85	73
		Site Total	**330**	**193**
	Phobji Gewog	DoksenaGorphoog	40	20
		DrangpaPangsar	43	19
		KhemdroNyemphel	130	55
		TalachenTawa Taphu	150	70
		DamchhoeGangphel	85	39
		Site Total	**448**	**203**

Site	Gewog	Chiwog	Household	
			Total Population (HH)	**Sample Size**
Gaytsa-Domkhar Wetland	Gaytsa-Domkhar Gewog	Gaytsa	78	58
		Domkhar	69	61
		Site Total	**147**	**119**
Bumdeling wetland	Bumdeling Gewog	PangkharTaphel	87	8
		BetsamangLamdrak	86	39
		NgalimangPhanteng	90	40
		Site Total	**263**	**87**
Sakteng wetland	Sakteng Gewog	Borangmang	78	35
		Pusa Tengma	130	68
		Sakteng	120	57
		Total	**328**	**160**
Grand Total			**1,516**	**762**

2.3 Biodiversity Assessment Techniques

2.3.1 Vegetation

2.3.1.1 Sampling Design

Vegetation biodiversity was quantified through inventories of randomly located plots distributed in forest and wetland habitat. To ensure unbiased and comprehensive data collection, the sampling design was adjusted based on stakeholder recommendations, particularly to include upstream wetland areas. Keeping this in mind, the following buffer zones were established around key sites to obtain the sampling area:

- ✔ 2500m around the RAMSAR boundaries of Gangtey-Phobji and Bumdeling
- ✔ 1000m around the Chamkhar Chhu and Uruk Chhu
- ✔ 1000m on the right and 1500m on the left of Gamri Chhu

A 1000m x 1000m grid (using fishnet tool) was overlaid across the sampling areas. Every second point in the grid was then selected for survey, eliminating points that fell in agricultural land, non-vegetated land (e.g. built-up, bare ground) or which we determined were too remote to access efficiently. Based on the sampling design, a total of 86 upland plots were inventoried and 13 wetland plots, totaling 3.44 ha for trees, 0.22 for shrubs/herbs, and 0.005 ha for wetland herbs (Fig 2.1). This method allowed for sufficient coverage of upstream forests, meadows, and wetland areas, ensuring a representative and unbiased assessment of vegetation.

Data Collection

A nested quadrat approach was implemented to systematically assess vegetation across the study sites. At each sampling point, a primary 20m × 20m quadrant was established for tree enumeration. Within this main quadrant, a smaller 5m × 5m sub-quadrat was positioned for shrub assessment, and nested within this, a 2m × 2m quadrant was designated for herbaceous plants. To maintain standardization across all sampling locations, the northeast corner of each quadrant was consistently aligned with the predefined sampling point, as illustrated in Figure 2.2. This spatial consistency was crucial for ensuring comparability of data across different sites.

Data collection followed a rigorous protocol to ensure comprehensive and accurate documentation. Within each quadrat size category, all plant species were identified and recorded according to established botanical references. For trees meeting the DBH threshold, both diameter and height measurements were taken following the methodology outlined by Kaka et al. (2014). Simple counts of individuals were made for shrubs and herbs. In addition to vegetation data, several environmental variables were documented, including elevation, slope, aspect, canopy cover, and human impact levels. All field data were recorded digitally using the SW Map application, which enhanced data accuracy and facilitated efficient data management. This systematic approach ensured the collection of ecologically representative data while minimizing sampling bias across the study area.

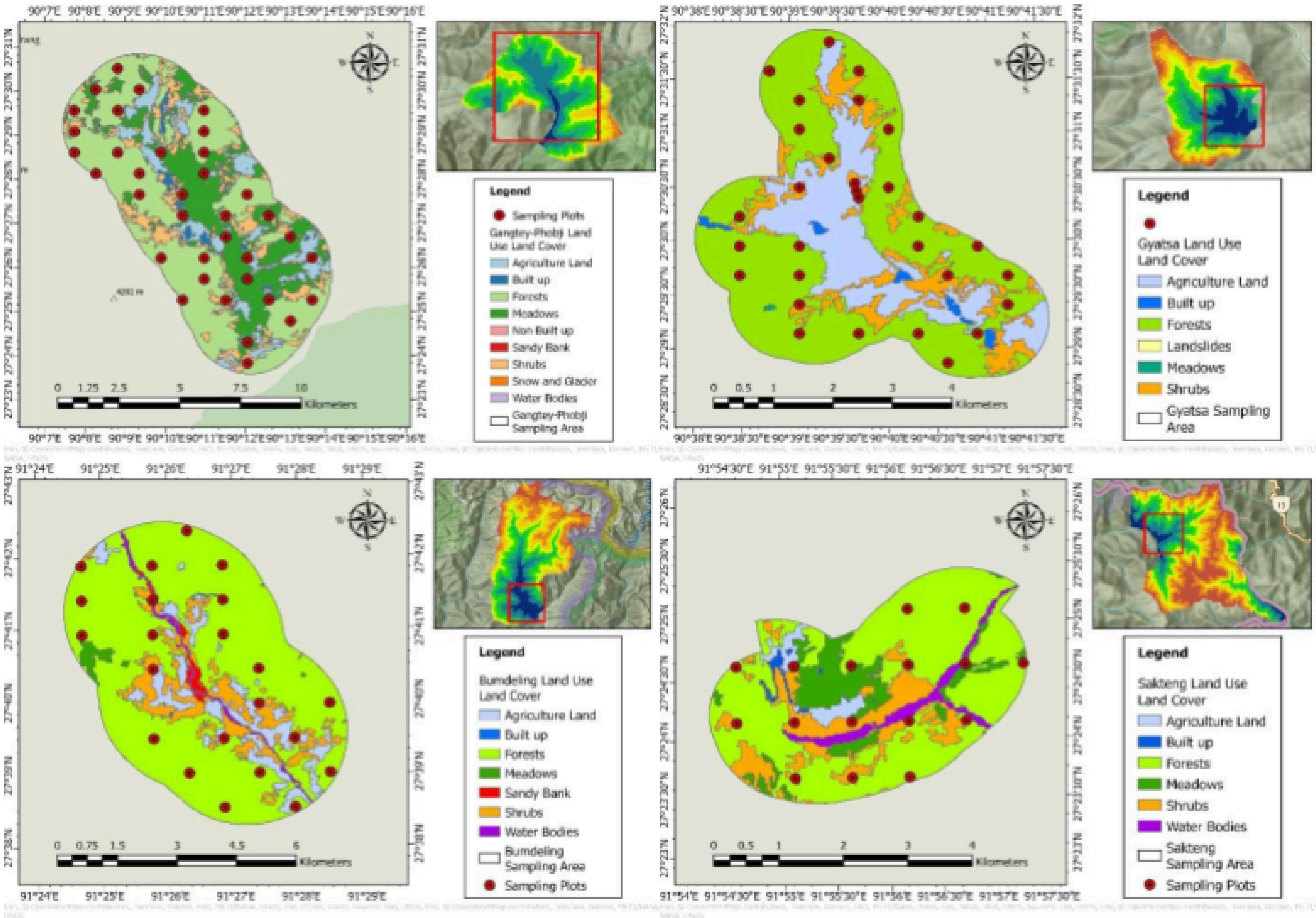


Figure 2.1.
Vegetation study site maps and vegetation plots in Gangtey-Phobji, Gaytsa-Domkhar, Bumdeling, and Sakteng.

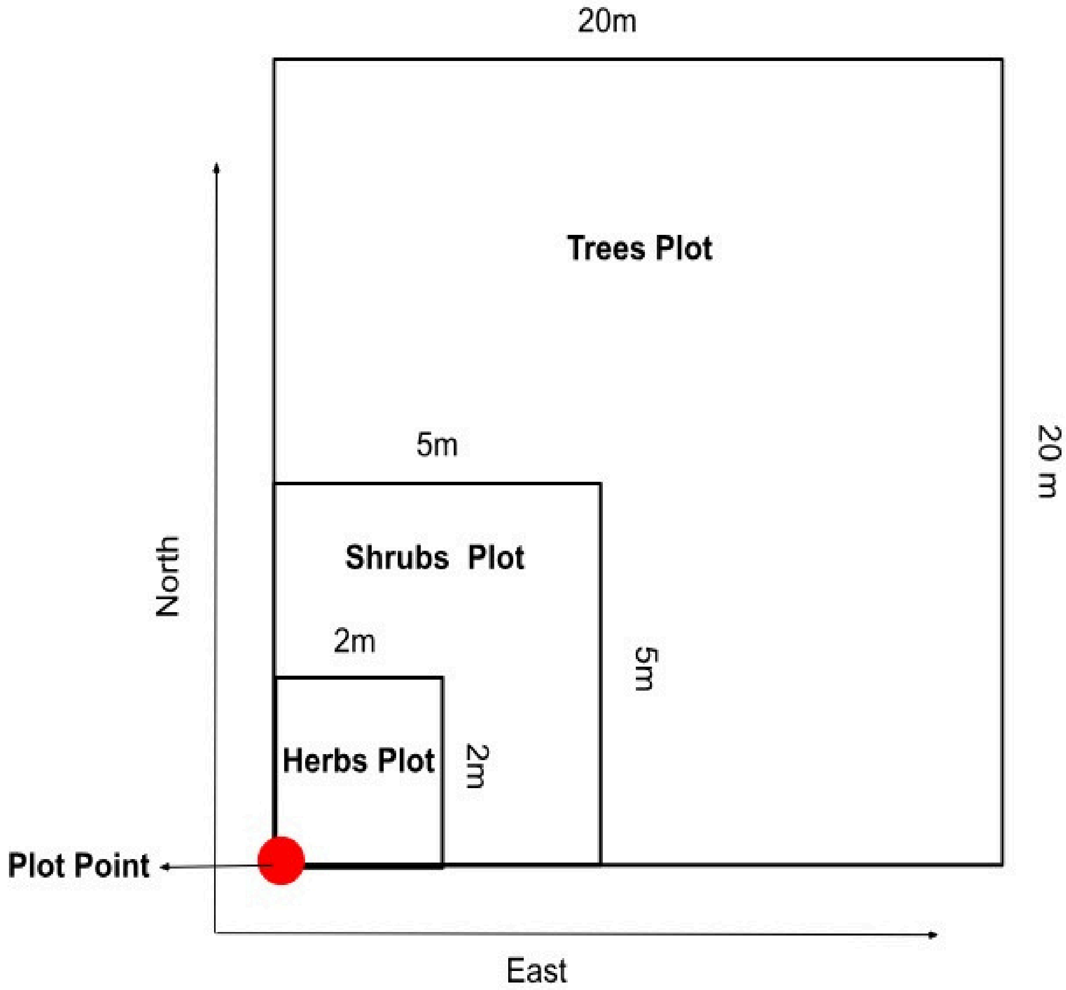


Figure 2.2: ESRAM vegetation plot design

2.3.2 Avifauna

2.3.2.1 Sampling Design

The study implemented a mixed-method approach to comprehensively assess bird diversity in the study area. Opportunistic observations were recorded throughout all field activities, documenting avian species encountered anytime. This approach proved particularly valuable for detecting rare/elusive species that might otherwise be missed through fixed sampling methods. Complementing this, the study established systematic observation points coinciding with the vegetation sampling plots. These fixed locations served as standardized observation stations, while transects between plots functioned as linear survey routes. This integrated design allowed us to:

- ✔️ Maximize species detection across different habitats
- ✔️ Maintain methodological consistency with parallel vegetation studies
- ✔️ Effectively utilize field time and resources
- ✔️ Generate comparable biodiversity metrics

The combination of systematic point counts and opportunistic observations provided robust data on avian community composition while offering behavioral insights for key species. This approach proved particularly effective for rapid biodiversity assessment, balancing scientific rigor with practical field logistics.

2.3.2.2 Sampling Method

Bird surveys were conducted along transects covering major habitat types, including forests, wetlands, ecotones, farmlands, settlements, and riversides. Observations occurred primarily during early morning hours, with additional surveys during daytime and evening while moving between vegetation and aquatic sampling plots. The study recorded all birds seen or heard using binoculars and field guides. For each observation, the study noted the species, number of individuals, behavior, and exact location using GPS. Photos were taken, when possible, to confirm identifications. This approach efficiently documented bird diversity across different habitats while complementing other ecological surveys. The data provides reliable records of species presence and habitat use patterns.

2.3.3 Aquatic

2.3.3.1 Sampling Design

For both fish and macroinvertebrates, a systematic sampling was adopted across all study sites. However, due to differences in the size of the wetlands and the length of rivers and their tributaries, a uniform distance between sampling sites was not achieved. For Gangtey-Phobji wetland, the sampling sites were spaced 2 km apart, with one sampling site established on each of the seven major tributaries. Similarly, in the main river in Gaytsa, Bumthang, the plot-to-plot distance was 1 km and at least one sampling site was established per tributary depending on the length.

Using this sampling design, 23 sites in the Gangtey-Phobji, 10 in Gaytsa-Domkhar, and seven each in Bumdeling and Sakteng were surveyed (**Figure 2.3**). However, it is important to note that, of the 23 sampling sites in Gangtey-Phobji, fish were recorded at 19 sites, while macroinvertebrates were found across all sites, while in Gaytsa-Domkhar, all the sites recorded fishes as well as macroinvertebrates. However, in Bumdeling, fish were recorded from five sites only while no fish species was found in Sakteng.

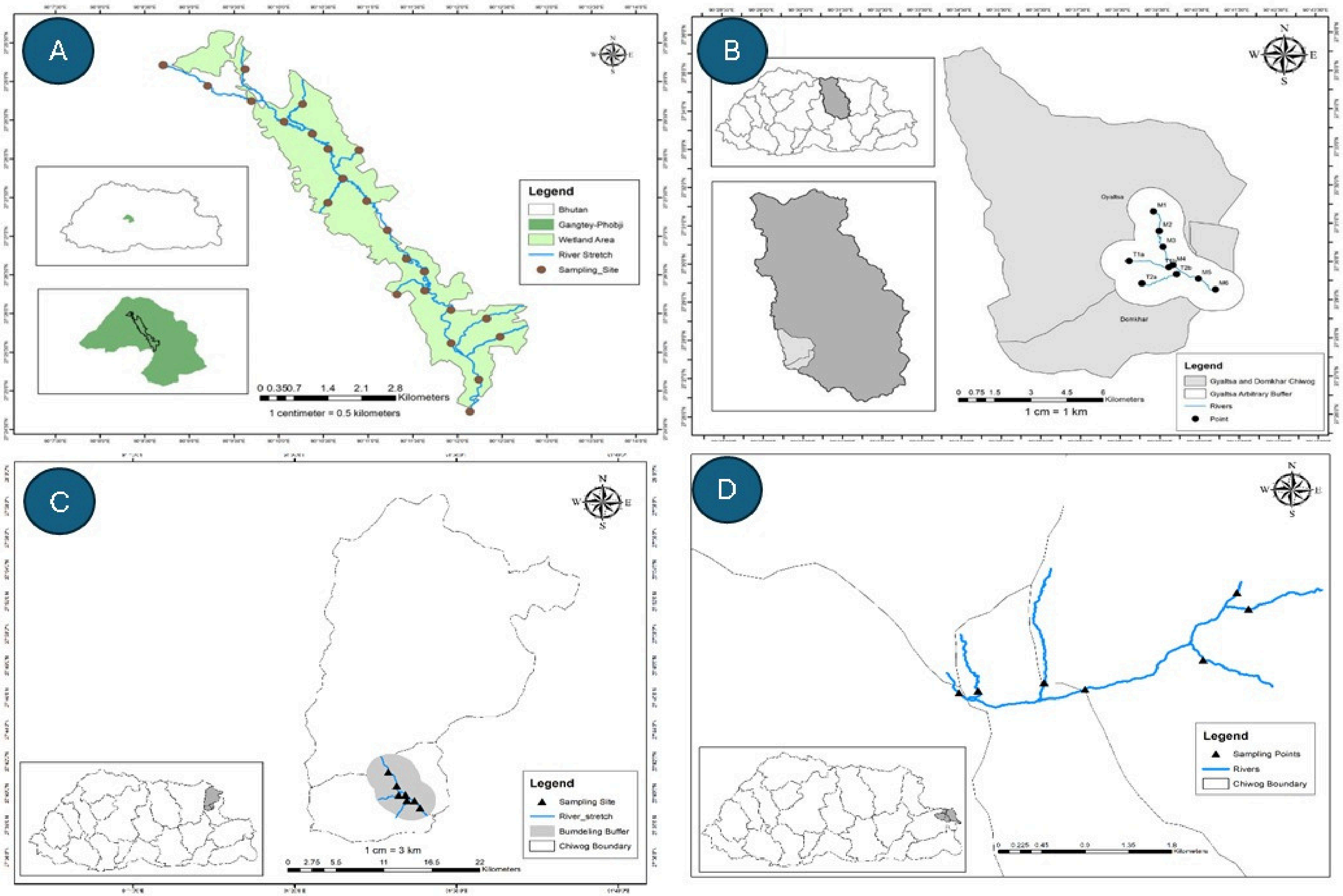


Figure 2.3. Aquatic sampling in Gangtey-Phobji, Gaytsa-Domkhar, Bumdeling, and Sakteng.

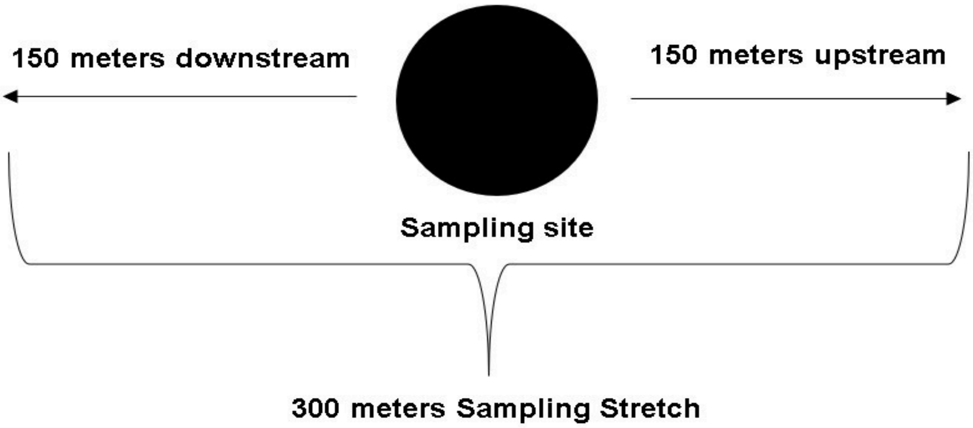


Figure 2.4. Sampling design for aquatic biodiversity

2.3.3.2 Data collection

2.3.3.2.1 Fish

Within each sampling plot, a 300 m sampling stretch was identified, and sampling was conducted in multiple habitats, including pool, riffle, and run (Changlu et al., 2021; Wangchuk & Tshering, 2022; Wangmo & Rai, 2019). This stretch was evenly divided into 150 m upstream and 150 m downstream (**Figure 2.4**). Various fishing gears were used to facilitate effective sampling across these aquatic habitats. Cast nets of varying mesh size were used to capture fish species present in shallow water. Fishing rods and lines were employed for targeted sampling of elusive and larger species, allowing for precise capture in specific microhabitats. Additionally, an electro-shocker (Honda GCV 160cc, Honda, Tokyo, Japan) was also used to temporarily stun fish species, aiding in the collection for closer examination and measurements.

Fish captured at each sampling site were identified using (Gurung & Thoni, 2015; Thoni & Gurung, 2018) and measured for length and weight. Following (Dorji & Sagar, 2025) substrate type was recorded and environmental parameters including water depth and velocity, were measured using YSI flow probe (Xylum Inc., Ohio, USA).

2.3.3.2.2 Macroinvertebrates

Benthic macroinvertebrates were sampled using a multi-habitat sampling approach. Microhabitat coverage considering flow types at 5% intervals was assessed within the 300 m river stretch with twenty sub-samples proportionately collected from identified microhabitats (pool, riffle, and run). Kick nets (25 cm × 25 cm frame with a 500 µm mesh) were used to collect benthic samples by disrupting the river bottom to dislodge sediments and organisms, which were transported into the net by the water current. This method resulted in composite samples representing 1.25m² of the riverbed surface. Macroinvertebrates were cleaned, sorted, and identified (Merritt et al., 2008; Thorp & Covich, 2010).

2.3.3.2.3 Physico-chemical Water Parameters

A total of six physico-chemical water parameters (**Table 2.2**) were measured on site across all the sampling plots. However, additional testing of eight physicochemical water parameters was conducted only for the

Table 2.2: Water quality parameters measured in the study, including corresponding units and methods or instruments used for analysis

Parameters	Unit	Method/Instrument
Temperature	℃	PC Testr
pH		PC Testr
DO	mg/L	DO Meter
Conductivity	mS/s	PC Testr
TDS	ppm	PC Testr
Salinity	ppt	PC Testr
Ammonia	mg/L	4500-NH_3 Phenate Method
Turbidity	NTU	Nephelometric Method
Total Suspended Solid	mg/L	Gravimetric Method EDTA
Magnesium Hardness	mg/L	Titrimetric
Total Hardness ($CaCO_3$)	mg/L	EDTA Titrimetric
Iron	ppm	Phenanthroline Method
Total Chlorine	mg/L	Chlorine meter

Gangtey-Phobji wetland, as it was easier to store and transport the samples within the presentation timeframe. Conducting similar tests for other areas was practically not feasible. The water parameters were compared with Ambient Water Quality Criteria (National Environment Commission, 2020) and Bhutan Drinking Water Quality Standard (NEC, 2016).

2.4 Valuation of Ecosystem Services

There are several techniques that can be employed to assess the value people place on non-market goods such as environmental resources and ecosystem services. While it is fundamentally impossible to derive the actual monetary value of ecosystems and ecosystem services, valuation is useful for better understanding of the extent to which communities acknowledge the importance of their surrounding natural resources and the goods and services that they appropriate for livelihood needs. From among the many methods available, this study employed Contingent Valuation Method [CVM] for the valuation of wetland ecosystems and services.

2.4.1 Contingent Valuation Method

Wetlands are an environmental feature which deliver a variety of market and non-market goods and services. Non-market ecosystem services valuations provide more insight into the trade-offs between market activities and environmental quality. As the extent of the contribution ecosystems services make to well-being is better understood, there is an increasing demand for methods that make ecosystems values more explicit and allow for better inclusion in the decision- making process. For example, studies based on benefit transfer in Bhutan found that wetland generates economic value on the average of US $50,034,833 per year from provisioning, regulating and cultural services (Ida Kubiszewski et al., 2013). This study therefore adopted the contingent valuation method to place a value on the non-use attributes of wetlands in Bhutan.

A big challenge to do cost-benefit analysis is the need to place monetary values on non- marketed goods and services. Valuation methods for non-marketed goods such as CVM can be used. Contingent valuation involves asking a sample of the population about their willingness to pay (WTP) towards protection or conservation. One of the most common ways to elicit WTP using contingent valuation is to use a dichotomous choice question. In its simplest form the individual is asked: will you be willing to pay “t” for the program that I just described? Hanemman et al. (1991) suggested the double bounded dichotomous choice [DBDC] method for estimating WTP efficiently.

2.4.1.1 Contingent Valuation Survey Design: Development and Structure

The CV survey instrument used in this study was developed based on the results of a pilot study and literature search. The design of the survey instrument followed recommendations from influential literature (e.g., Hanemman et al., 1991; Gunatilake, 2003). The CV survey instrument consisted of a survey questionnaire booklet. The survey was designed to be administered in person with households randomly selected based on the second household after the first household is selected. The first part of the survey questionnaire provided the introduction and background information. This included a definition of a wetland, and a list of ecosystem services provided by a fully functional wetland. The second part of the survey questionnaire was designed to collect information on respondents’ awareness of the existence of the wetland. The third section built on the previous sections and provided a list of reasons for valuing existing wetlands such as, protecting wildlife and wildlife habitat, providing scenic beauty, commercial income, recreational opportunities, flood control, water purification, and non- use value considerations such as option, existence and bequest values. Respondents were asked to indicate, by a tick, the importance of each reason on a three-point scale from ‘‘Not sure’’ (1) to ‘‘Highly dependent’’ (3). Respondents’ attitude towards environmental protection was tested by presenting them with land uses for the site — agricultural development versus preservation of ecosystem services and asking them if they would support an environmental program that seeks to preserve and conserve the site. In addition, once respondents had expressed their WTP, they were asked to distribute this value over the items which they would like it to be used for. People could choose to pay, to secure the source of water for drinking and agriculture (provisioning value), to secure the source of income (cultural value), to secure the existence of the lake (existence value), to secure the existence of wildlife (wildlife value), to retain the option for them to enjoy the lake in the future (option value), to ensure that future generations would be able to enjoy the lake (bequest value), to ensure the use of the lake for themselves (use value) or to ensure that other people could use the lake (altruistic value), and others.

2.4.1.2 Valuation question and payment vehicle

The valuation question consists of a DC question with a closed-ended follow-up. In the contingent scenario, one of 30 bid amounts (referred to as 'Seed' as this was the seed bid) representing the annual amount to be paid was presented to each respondent (Nakatani et al., 2025). Respondents were reminded before answering the valuation question: to consider their income and other financial commitments (income constraints); of the benefits they derive from the site (value). It was important to remind respondents in this manner to ensure that realistic valuations that conform to the utility theory were stated. Two possible answers to the valuation question were provided. The first option provided for a ''YES'' or "No" answer to the DC question and a provision for the respondent to again respond to a follow-up bidding with similar response "Yes" or "No". If the respondent selects the "Yes" option, a higher closed-ended WTP bid will be offered. Alternatively, if the respondent selects the "No" option, a lower closed-ended WTP bid will be offered.

2.5 Livelihood and Climate Vulnerability

2.5.1 The LVI and its structure

The Livelihood Vulnerability Index [LVI] is a derivative of the Water Poverty Index (Sullivan, 2002), which was first applied to non-water resource interactions by Hahn (Hahn et al., 2009). The LVI represents the overall vulnerability of the community, i.e. it is a community-level index. The LVI consists of a set of Major Components [MC] which are themes representing critical dimensions of livelihood in the study area. The study structured the MCs following Hahn et al: socio-demographic, livelihood, social networks, health, food, water and natural disasters and climate variability. Each MC consists of Subcomponents (S), i.e. variables of specific aspects of the MC that contribute to livelihood vulnerability or security. Each S is then indexed at the community level according to the range of possible responses for each SC question:

$$Index\ S_d = \frac{S - Sd_{min}}{S_{max} - S_{min}}$$

Where, S_d is the indexed sub-component for location d, and S_{min} and S_{max} are the minimum and maximum values obtained across the entire data set, respectively. In caseswhere the question is yes/no, the S_d value is calculated as the percent of respondents in that communityanswering either yes or no (depending on the directionality of the response in terms of vulnerability).For example, variables measured in frequencies such as the 'percent of experiencing shortage of waterin day-to-day life,' the minimum value is set at 0 and the maximum at 100. For other S values, thequestion may have required an inverse function of the variable value to maintain the proper directionality of the variable. The maximum and minimum values would then also be transformed and standardizethe sub-component.

Subcomponent scores (S_d) are then consolidated into MC scoresinthe following manner:

$$MC_d = \sum_{i=1}^{n} s_{di} / n$$

Where, MC_d is the MC in question for specific location d, the s_{di} represents the sub-components, indexed by i, that make up the major component, and n is the number of sub-components in each major

The LVI for a site is calculated as the weighted mean of MC scores:

$$LVI_d = \sum_{i=1}^{8} W_{mi} MC_{di} \Big/ \sum_{i=1}^{8} W_{mi}$$

Where, LVI_d, is the Livelihood Vulnerability Index for the specific location d and W_{mi}, is determined by the number of sub-components for each major component.

across sites for which the same variable questions were used, thus making cross-study comparisons

2.5.2 The IPCC-LVI and its structure

The Climate Vulnerability Index [IPCC-LVI] restructures the MCs of the LVI in a manner that emphasizes the vulnerability of communities to climate change issues (Hahn et al., 2009). The sub-components are rearranged into three Contributing Factors [CF] (analogous to Major Components), namely Exposure, Sensitivity and Adaptive Capacity (Hahn et al., 2009).

Table 2.3: Restructuring of the LVI MCs into IPCC contributing factors to calculate the CVI.

Table from Hahn et al. (2009).

IPCC Contributing Factors (CF)	LVI Major Components
Exposure	Natural disasters and climate vulnerability
Adaptive capacity	Socio-demographics
	Livelihood strategies
	Social Networks
Sensitivity	Health
	Food
	Water

The contributing factors are calculated as the weighted mean of their constituent MCs, i.e.:

$$CF_d = \sum_{i=1}^{n} W_{mi} M_{di} \Big/ \sum_{i=1}^{n} W_{mi}$$

Where, CF_d is the contributing factor for the site d, M_{di} is the major component for site d, indexed by i, W_{mi} is the weightage of each major component, and n is the number of major components in each contributing factor.

Once Exposure, Sensitivity and Adaptive capacity are calculated, the IPCC-LVI is calculated as:

$$LVI - IPCC = (Exposure - AdaptiveCapacity) \times Sensitivity$$

IPCC-LVI can rangefrom0.0(leastvulnerable)to1.0(mostvulnerable).

3 Study Area Overview

3.1 Description of ESRAM Study Sites

The four selected ESRAM sites of this study fall in the high-altitude wetlands known for cool climates, beautiful valleys, rich biodiversity, and farming communities that rely on forests, pastures, rivers and wetlands for their livelihoods. Moreover, Bumdeling and Gangtey-Phobji wetlands were designated as RAMSAR sites in May 2012 and June 2016 respectively. The following sections provide detailed descriptions of each site, covering their location, vegetation, topography, climatic conditions, and socio-economic and cultural contexts.

3.2 Gangtey-Phobji, Wangdue Phodrang Dzongkhag

3.2.1 Location

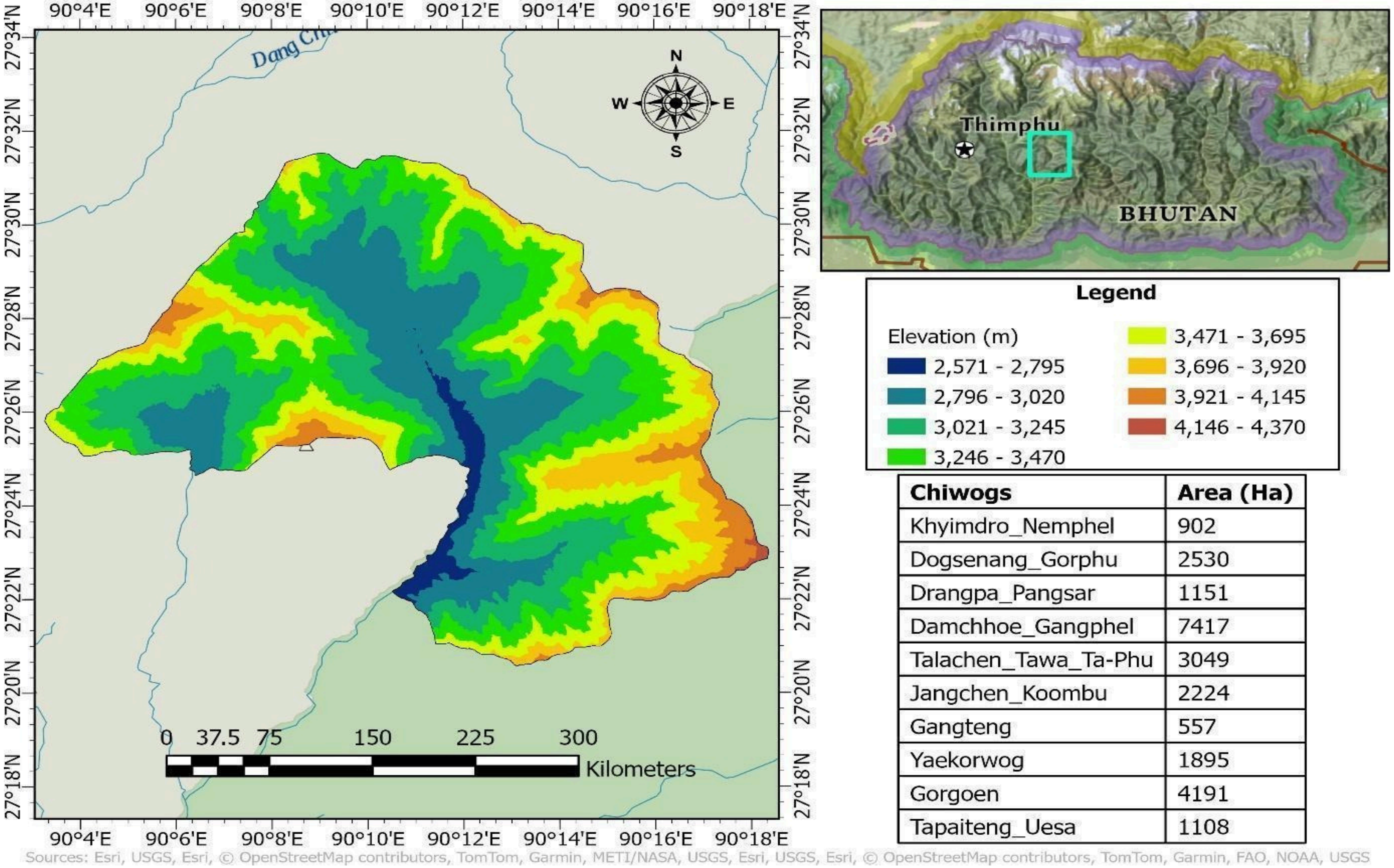
Gangtey-Phobji is a high-altitude glacial valley located in Wangdue Phodrang Dzongkhag in central Bhutan. Geographically, it lies within the coordinates 27.503° to 27.589° N latitude and 89.872° to 89.878° E longitude. Elevations within the valley typically range around 2500 masl, extending up to 4300 masl in surrounding areas. The valley is surrounded by the Black Mountains, *Jowo Durshing*, with high peaks rising above 5,000 masl. These mountains form a natural barrier, which affects the local weather and water flow in the area (Hart, 2020). The valley is accessible via the *Lawa La* Pass and is about 45 km east of *Bajo Throm*.

3.2.2 Vegetation, Topography, and Climatic Conditions

The vegetation in Gangtey-Phobji is a mix of cool temperate forests and open wetland meadows. The surrounding slopes are covered with conifers such as blue pine, while the valley floor has grasses, bamboos, and scattered shrubs. The valley has 41 plant families with 135 known species (RSPN, 2014). These include one bamboo species (*Yushania microphylla*), seven types of shrubs, and three ground orchids such as *Chusua pauciflora, Satyrium nepalense*, and *Spiranthes sinensis*. There are also four kinds of ferns and mosses such as *Pteridium aquilinum*, *Selaginella sp*, *Sphagnum palustre*, and *Sphagnum sp*. Additionally, two plant species (*Eriocaulon bhutanicum* and *Euphrasia bhutanica*) endemic to Bhutan have been recorded in the study area (RSPN, 2014).

The valley is a wide, U-shaped glacial valley surrounded by high mountains. The valley floor is mostly flat and open, making it ideal for wetlands and farming. Gentle rolling hills and forested slopes rise on all sides, creating a natural bowl-like shape. Small streams and rivers meander through the valley, draining water from the surrounding mountains. The marshy wetlands are fed by more than 93 springs. Some springs such as *Tokha Menchhu*, *Bjagi Menchhu*, *Eusa Menchhu*, *Mang Menchhu*, and *Phala Menchhu*, are culturally significant, with local communities attributing therapeutic properties to them (Dorji, 2024).

The valley has a cool mountain climate with clear seasonal changes. Winters, especially from December to February, are very cold. The average yearly temperature is about 8.3 °C, with the hottest month, July, averaging 15.3 °C and the coldest month, January, dropping to around -0.3 °C. Annual precipitation varies between 1,100 mm and 2,200 mm (Dorji, 2024). South Asian monsoons influence the hydrological cycles of the valley (Power *et al*., 2021). According to FGD data, there's an indication of climatic pattern changes such as rise in temperature, decrease in snowfall, incidences of frost, hailstorms, and unpredictable rainfall, which impact crop yield and water availability. Similar observations were recorded by Wangmo et al. (2022), where it indicates a concerning trend of reduced snow cover and drying wetlands, suggesting



Chiwogs	Area (Ha)
Khyimdro_Nemphel	902
Dogsenang_Gorphu	2530
Drangpa_Pangsar	1151
Damchhoe_Gangphel	7417
Talachen_Tawa_Ta-Phu	3049
Jangchen_Koombu	2224
Gangteng	557
Yaekorwog	1895
Gorgoen	4191
Tapaiteng_Uesa	1108

Figure 3.1. Study area of Gangtey-Phobji with its elevation profile and Chiwog details.

shifts in precipitation patterns and increased climate vulnerability. This trend directly threatens the valley's hydrological balance, which is crucial for its unique biodiversity and the livelihoods highlighting a critical adaptation challenge for Bhutan.

3.2.3 Socio-economic and Cultural Contexts

According to the Population and Housing Census of Bhutan (National Statistics Bureau [NSB], 2017), Gangtey Gewog consists of 235 households with a total population of 1,109, while Phobji Gewog comprises 412 households housing a population of 1,911. The economy of Gangtey-Phobji is primarily agrarian, characterized by traditional subsistence agriculture and livestock rearing. The main crops cultivated include potatoes, turnips, and barley, and livestock rearing especially yaks and cattle which are an important livelihood activity. Based on the survey, most of the households own less than 2 acres of land, with only a portion under active cultivation. Farming remains the primary occupation, supplemented by seasonal labors, monastic services, and small-scale ecotourism including homestays and nature guiding. The median household income is Nu.200,000 derived from agricultural produce, dairy products, and tourism services.

The cultural and spiritual life of people revolve around the Gangtey Monastery, a significant spiritual, and historical landmark in the region (RSPN, 2021). Annual religious festivals such as Gangtey *Tshechu* not only serve spiritual purposes but also reinforce social cohesion and traditional knowledge systems. The local architectures, dialects, and agricultural practices reflect a deep-rooted cultural identity shaped by centuries of human environment interaction.

3.3 Gaytsa-Domkhar, Bumthang Dzongkhag

3.3.1 Location

Gyatsa-Domkhar is located within Bumthang Dzongkhag featuring narrow valleys, gentle slopes, and cool highland conditions typical of the region. Geographically, it lies within the coordinates 27.462° to 27.552° N latitude and 90.662° to 90.742° E longitude. The region is characterized by a wide altitudinal range from 2,800 masl to 4,200 masl (Flood Engineering and Management Division [FEMD], 2019). The area is shaped by narrow valleys and gentle hills, with forested slopes and river systems feeding into the Chamkhar Chhu. The area is accessible by road from Jakar *Throm.*

3.3.2 Vegetation, Topography, and Climatic Conditions

The region falls within Bhutan's cool temperate agro-ecological zone. The dominant vegetation types in this region are characterized by coniferous forests, specifically Blue Pine and Mixed Conifer forests. These forests are interspersed with various broadleaf species, and the higher elevations support alpine flora such as rhododendrons, fir, and spruce. The diverse microclimates resulting from the varied terrain contribute to a rich variety of plants and trees, including species that yield non-timber forest products (Gurung *et al*., 2021). The presence of temperate forests and alpine zones is not solely an ecological characteristic but also a direct economic asset. These ecosystems provide valuable Non-Wood Forest Products [NWFPs] such as Cordyceps *(Yartsaguenbub)* and Matsutake mushrooms *(Sangay Shamu)*, highlighting a crucial link between natural vegetation and local income generation, which requires sustainable management.

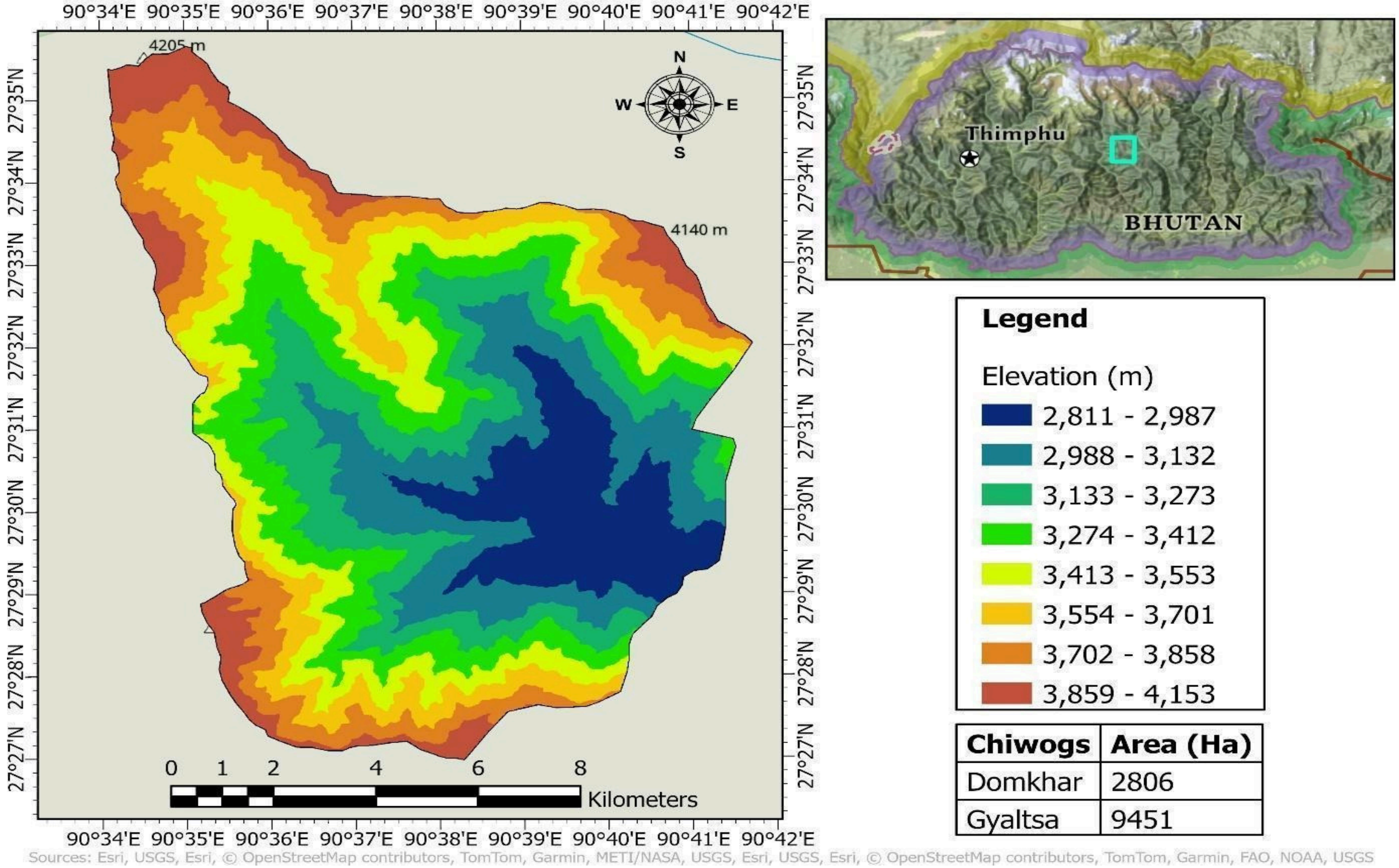


Figure 3.2. Study area of Gyatsa-Domkhar with its elevation profile and Chiwog detai

The topography of Gyatsa-Domkhar is marked by narrow valleys and gentle mountain slopes. River valleys carve through the landscape, creating fertile floodplains for farming. Forested ridges and surrounding highlands rise on all sides, giving the area a varied and scenic terrain with both flat valley bottoms and sloping uplands. The riverine topography, particularly the floodplains, makes the region inherently susceptible to hydrological hazards. The concentration of human settlements and agricultural activities within the floodplains of the Chamkhar Chhu valley directly translates the region's riverine topography into a significant hazard exposure (FEMD, 2019; Lhamo *et al*., 2023). This highlights a critical human-environment interaction where land use patterns, driven by the fertile valley bottom, increase vulnerability to climate-induced events like floods and flash floods, leading to the loss of cultivable land (Chhogyel & Kumar, 2018; FEMD, 2019).

The region experiences a temperate highland climate with dry winters (Köppen classification: Cwb) (Weather and Climate Network [WCN], 2025). The average annual temperature is around 9.61°C. The climate exhibits distinct seasonality: winters (December-February) are cold, with mean daily minimum temperatures dropping to - 3.9 °C and snowfall occurring at higher elevations (Tshering *et al*., 2019). Summers (June-September) are warmer and wet, characterized by the monsoon, with mean daily maximum temperatures reaching 22.7 °C and significant rainfall, averaging 95.9 to 152.6 mm per month during peak monsoon (WCN, 2025). The annual precipitation is approximately 71.39 mm spread over 142 rainy days, with July being the wettest month (WCN, 2025). According to FGD data of this study, there’s an indication of climatic pattern changes such as increasing delay in cropping schedules and crop damage caused by armyworm infestations, both linked to rising temperatures and shifting rainfall patterns. Additionally, reduced snowfall and untimely precipitation have disrupted traditional farming calendars, particularly affecting wheat cultivation. Similar patterns have been noted by Penjore, (2025) where the seasonal pattern dictates the agricultural calendar and influences the natural vegetation.

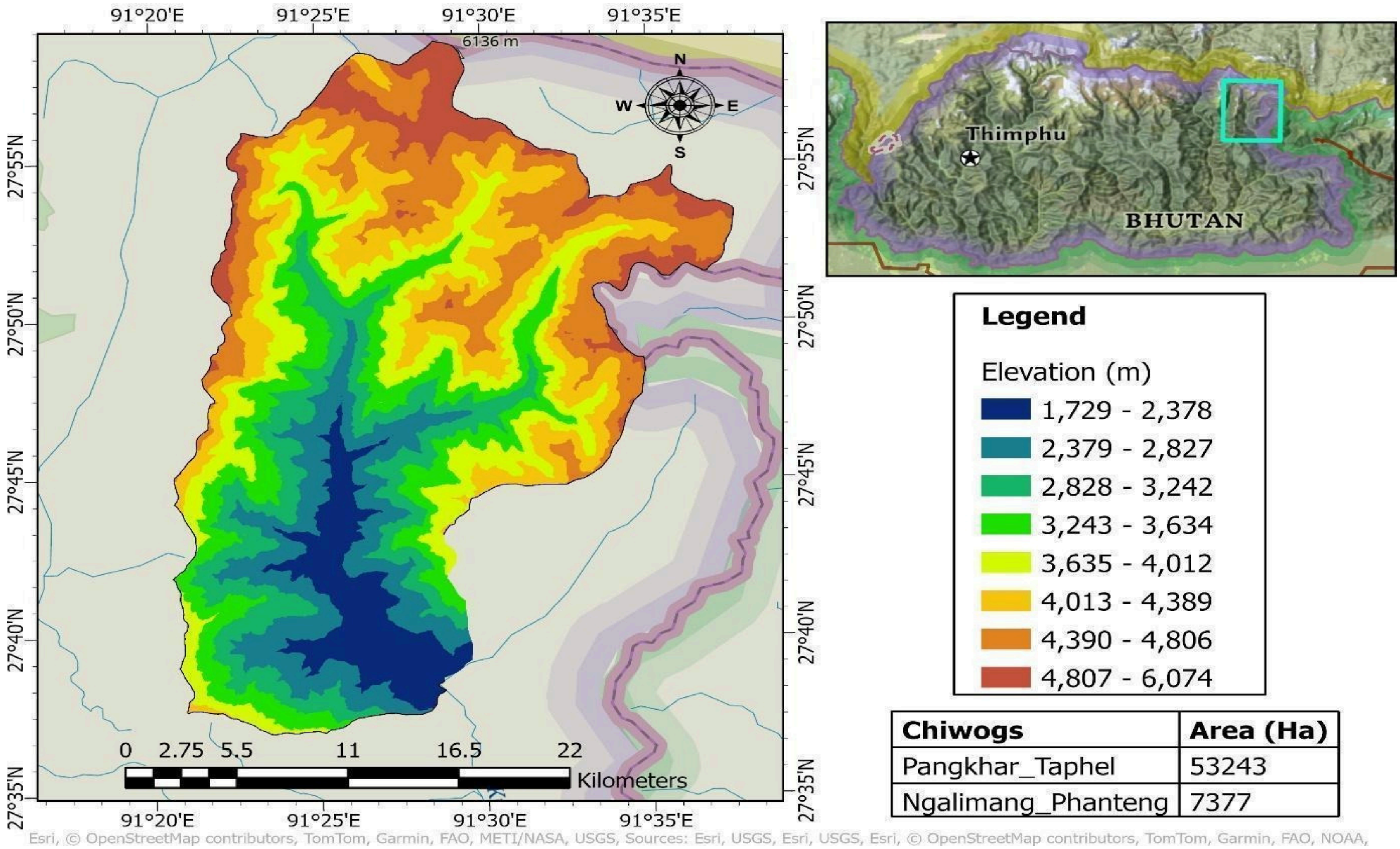
3.3.3 Socio-economic and Cultural Contexts

According to national census data, Chhumig Gewog has approximately 402 households and a population of 1,674 (NSB, 2017). The primary economic activity in the region is subsistence and commercial farming, especially of potatoes, wheat, and buckwheat. Households typically own between 1–2 acres of land, with cultivation adapted to high-altitude agro-climatic conditions. Based on ESRAM social data, median household income is Nu. 50,000, sourced from crop sales, livestock products, and remittances. Occupation profiles reveal that most individuals are engaged in farming, with very few in formal employment. A growing number of residents also participate in rural tourism, including homestays and handicrafts, although such ventures remain small-scale. Religious festivals (*tshechus*), *lhakhangs* (temples), and household rituals are integral to community life and guide many agricultural and seasonal practices.

3.4 Bumdeling, Trashiyangtse Dzongkhag

3.4.1 Location

Bumdeling Gewog is in Trashiyangtse District in north-eastern Bhutan. This area falls in a cool, mid-altitude zone and is known for its forested valleys and mountain slopes. It is home to the Bumdeling Wildlife Sanctuary (BWS), which covers about 1,520 square km and stretches from 1,700 to 6,100 masl (Namgyel & Singh, 2021; Thinley et al., 2020). The landscape includes snowy mountains, glaciers, glacial lakes and river valleys. The Bumdeling valley, drained by Kholongchhu is especially important because it serves as the winter home for around 158 near threatened, Black-necked Cranes (*Grus nigrocollis*) that migrate from the Tibetan Plateau.



Chiwogs	Area (Ha)
Pangkhar_Taphel	53243
Ngalimang_Phanteng	7377

Figure 3.3. Study area of Bumdeling with its elevation profile and Chiwog details.

3.4.2 Vegetation, Topography, and Climatic Conditions

Bumdeling forms a crucial part of the Eastern Himalayan Eco-region, supporting a wide range of ecosystems from warm broadleaved forests in lower elevations to alpine meadows at higher altitudes (World Wildlife Fund Bhutan [WWF], 2025). The vegetation types present include Alpine scree slopes, Alpine pastures and meadows, Fir, Hemlock, Mixed conifer, Pine, Oak, Bamboo and Alnus. The area is particularly notable for its high floral diversity, including several endemic species such as the East Himalayan Pine *(Pinus bhutanica)* and various *Rhododendron* species *R. kesangii*, *R. bhutanense*, *R. flinckii*. It also hosts protected plants like Himalayan yew *(Taxus baccata)* and the national flower, blue poppy *(Meconopsis grandis)* (BWS, 2020). This rich and varied vegetation provides critical habitat for a diverse array of fauna, underscoring the ecological significance of the area.

Bumdeling experiences a range of climates due to its varied elevation, from warm temperate conditions in the south to cold alpine zones in the north. Temperatures in the lower areas can reach up to 30 °C, while higher regions remain cold and snow-covered. Rainfall is heaviest during the monsoon season (May to September), with annual precipitation between 1,000 mm and 3,500 mm (BWS, 2020). These changing weather patterns, especially rising temperatures and increased rainfall, have led to flash floods that damage farmland and homes, shifts in crop cultivation, and the spread of invasive species. Such climate-related impacts, along with human activities like pollution, road construction, and land use changes, are affecting local biodiversity.

3.4.3 Socio-economic and Cultural Contexts

Bumdeling Gewog is home to around 547 households and a population of 2,367 (NSB, 2017) in eastern Bhutan. Community life is deeply connected to nature, notably the seasonal arrival of the Black-necked Crane, which winters in the Bumdeling Wildlife Sanctuary (RSPN, 2021). The local economy is largely agrarian, with households growing crops like maize, paddy, millet, barley, potatoes, and the local chili variety (*Urka Bangla*), alongside rearing cattle and poultry with median income of Nu. 50,000.

The community faces several challenges, including limited market access, unstable crop prices, and increasing environmental stress. Climate-related issues such as delayed monsoons, unseasonal hailstorms, flash floods, and invasive species have affected agriculture, while eutrophication of *Dungtsho* Lake and human-wildlife conflict also pose serious concerns. Socially, a lack of awareness regarding the importance of wetlands and key bird species like the White-bellied Heron (*Ardea insignis*) persists. In response, households have begun adopting adaptive strategies, including the use of climate-resilient agriculture (CNR, 2025; GNHC, 2020).

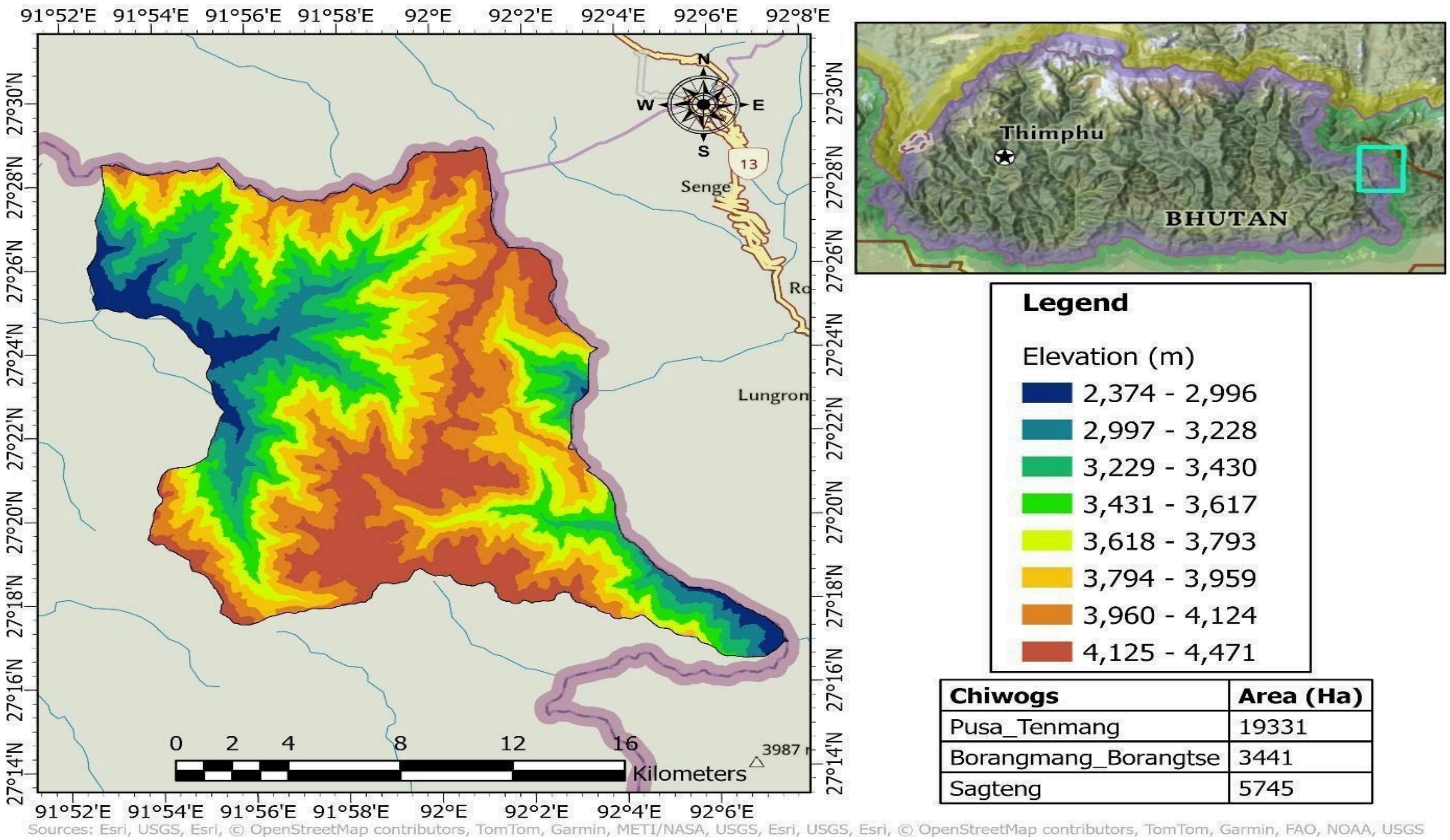
3.5 Sakteng, Tashigang Dzongkhag

3.5.1 Location

Sakteng is in the easternmost part of Bhutan. It has a total area of approximately 740.60 km². The study area exhibits a significant elevation range, from 2,300 masl to 4,500 masl. The Gamri Chhu flows through Sakteng valley, characterized by wide areas with gentle slopes, harbouring numerous alpine lakes.

3.5.2 Vegetation, Topography, and Climatic Conditions

Sakteng study site which is located in Sakteng Wildlife Sanctuary is known for its incredible plant diversity, especially its wide range of forests and flowering plants. It is famously called the "Paradise of



Chiwogs	Area (Ha)
Pusa_Tenmang	19331
Borangmang_Borangtse	3441
Sagteng	5745

Figure 3.4. Study area of Sakteng with its elevation profile and Chiwog details.

Rhododendrons" because it is home to 41 out of the 46 rhododendron species found in Bhutan, including some rare types such as *Rhododendron kesangiae* and *R. bhutanense* (Dorji, 2020). The sanctuary's forests vary by altitude, starting with warm broadleaf forests and chir pine in the lower areas, moving up to cool broadleaf forests, hemlock, and fir trees in the mid-region, and finally giving way to alpine scrub and grassy meadows at the highest points. Beautiful alpine flowers like the national flower Blue Poppy (*Meconopsis grandis*), *Primula* and *Gentiana* species grow in the upper pastures. The area is also rich in orchids, with 131 species recorded here, and is home to many valuable medicinal plants. This rich variety of vegetation supports a wide range of wildlife and is a key part of Bhutan's natural heritage.

Sakteng landscape is characterized by steep hills, deep valleys, rocky cliffs, and high mountain passes. The sanctuary also has open alpine pastures where yaks graze and remote wetlands scattered across the upper slopes. Rivers and streams like the Gamrichhu and others cut through the valleys, shaping the land and providing water for people and wildlife. This varied landform not only adds to the beauty of the sanctuary but also plays an important role in the lives of local communities, especially the Brokpas, who rely on the land for grazing and farming.

Sakteng has three types of climates based on elevation: warm and humid in the low valleys (subtropical), cool in the middle areas (temperate), and cold in the high mountains (alpine). Most of the sanctuary falls under the temperate zone, which experiences warm summers, cold winters, and heavy rainfall during the monsoon months of June to August (SWS, 2019). Snowfall is common from mid-October to early April. The average yearly rainfall in the area ranges from 1,000 mm to 2,000 mm (Trashigang Dzongkhag Administration, 2024). Due to climate change, local people have noticed several problems, such as shrinking pastures for yaks, forest growth into grazing areas, irregular snowfall, water shortages, and changes in the flowering patterns of plants like rhododendrons. These changes are affecting both the natural environment and the traditional lifestyles of the Brokpa community who live in the sanctuary.

3.5.3 Socio-economic and Cultural Contexts

Sakteng Gewog is home to about 498 households and a population of 2,240 (NSB, 2017), mostly belonging to the Brokpa community, semi-nomadic highlanders known for their distinct language, traditional dress, and unique cultural practices that differ from mainstream Bhutanese society (Wangchuk, 2017). While they follow Buddhism, they also hold strong beliefs in mountain spirits and sacred natural sites. The main source of income for most Brokpa families is cattle herding, particularly through the sale of dairy products and livestock, which contributes to about 83% of their household income (SWS, 2016). Farming is limited and only practiced in the lower parts, with crops like barley and buckwheat grown in small, scattered plots. Median household income is Nu. 60,000 and livelihood options remain few.

The community faces several challenges, including poor access to clean drinking water in nomad camps, overharvesting of medicinal plants, and degradation of wetlands due to infrastructure projects like hydropower. Market access is poor, and prices for livestock products often fluctuate. Environmental issues such as floods, erratic snowfall, frost, and increased pests have been worsened by climate change, which has pushed yak pastures higher up, reducing available grazing land. In response, locals are turning to climate-resilient agriculture, building infrastructure, and using traditional knowledge to adapt (GNHC, 2020; DoFPS, 2021).

3.6 Livelihood Activities across the Sites

The analysis of economic activities across the four sites reveals that farming remains the primary livelihood for most households. In Bumdeling, a significant majority of residents (over 86%) are

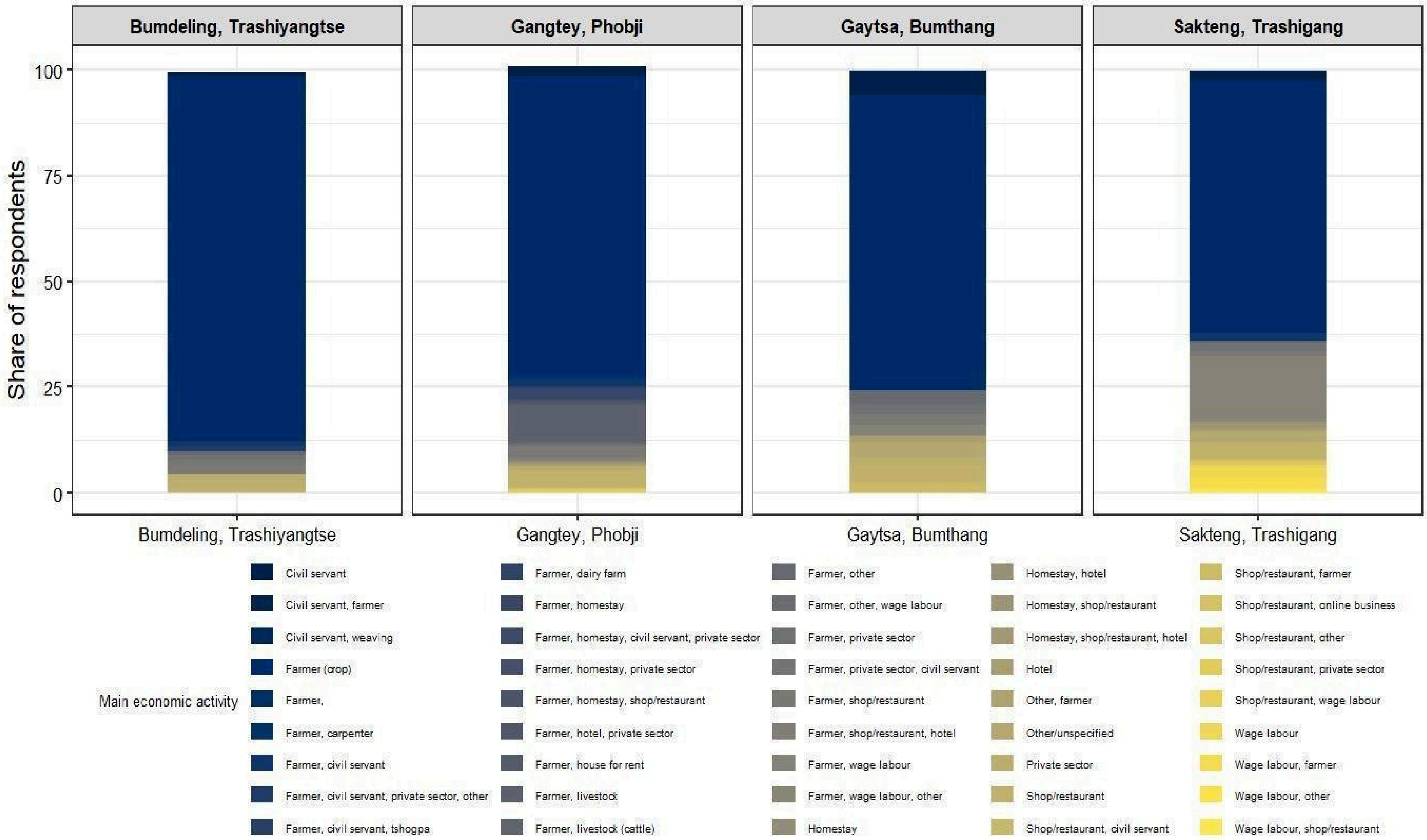


Figure 3.5. Main livelihood activities across the four sites.

engaged in agriculture. A few individuals combine farming with other occupations such as civil service, shop keeping, or private-sector employment, but overall, the area remains heavily reliant on agriculture with limited diversification in livelihoods.

In contrast, Gangtey-Phobji also shows farming as the dominant activity (over 70%), but with greater economic diversity. Many households combine farming with homestays, livestock rearing, shop/restaurant operations, or civil service jobs. This suggests that tourism and service-based opportunities may be supplementing farm income in this region, making Gangtey more economically varied than Bumdeling.

Similarly, Gaytsa-Domkhar shows a farming-dominated economy, with around 70% of residents engaged in agriculture. However, there is a small but notable presence of civil servants, wage laborers, and shopkeepers, indicating a gradual shift toward mixed-income strategies. Though farming is still the backbone, households are increasingly seeking additional income sources.

Sakteng, Trashigang, while also reliant on farming (nearly 60%), displays a unique pattern with a notably higher proportion of farming and livestock. About 15% of individuals engage in both farming and wage labor, and there are also households involved in homestays, restaurants, and other small businesses. This suggests a growing trend of livelihood diversification, possibly influenced by the area's remoteness, changing economic needs, or seasonal work availability.

Overall, while farming is the foundation of livelihoods across all sites, the degree of economic diversification varies. Bumdeling remains mostly agricultural with little change, whereas Gangtey-Phobji and Sakteng are showing increasing signs of mixed livelihoods, incorporating elements of tourism, private-sector work, livestock and informal labor. These variations highlight the different levels of economic opportunity and adaptation in rural Bhutanese communities.

3.7 Ecosystem Services

Ecosystem services are the benefits that people obtain from nature. These services support human well-being, livelihoods, and cultural traditions. In the ESRAM data collection, community members in the four study sites shared their knowledge of how they benefit from these services from the nearby wetland ecosystem during Focus Group Discussions (FGDs) and a separate social survey.

The services discussed were grouped into three broad categories:

- ✔ **Provisioning Services:** These include direct products from nature such as food, water, genetic resources, raw materials, and fuel wood that support daily needs and local economies.
- ✔ **Regulating Services:** These are natural processes that help maintain environmental balance and reduce risks, such as biodiversity protection, climate regulation, erosion prevention, water regulation and purification, biological control, soil formation, pollination, and protection against natural disturbances.
- ✔ **Cultural Services:** These include the spiritual, recreational, aesthetic, and cultural values people attach to landscapes, including tourism, recreation, heritage sites, and local traditions.

3.7.1 Types of Ecosystem Services

During FGDs, participants described the types of services they rely on under each category and discussed their importance. The data collected also recorded the relative percentage allocation of these services as recognized and valued by the community in each site.

The four ESRAM sites offer a wide range of ecosystem services valued by local communities. Provisioning services include medicinal plants such as *Picrorhiza kurroa* and *Aconitum*, timber species, firewood, mushrooms such as *Bjilli Namcho* and matsutake, drinking and irrigation water, and grazing pasture. Regulating services cover erosion control, water purification, water retention, and biodiversity protection, particularly habitats for species such as the Black-necked Crane. Cultural services include local and religious festivals, aesthetic landscape values, and tourism linked to sites and trails. Among these, water resources and water-related regulating services are the most universally important, sustaining livelihoods and environmental stability across all four sites.

3.7.2 Ecosystem Services Allocation

Across all sites, regulatory services were valued the most, with an overall average allocation of about 37.4%. This means people widely recognize and appreciate the role of nature in maintaining a clean, safe, and stable environment. For example, in Gaytsa-Domkhar, nearly 47% of the ecosystem value was attributed to regulatory services, the highest among all locations. This suggests that residents place a strong emphasis on how nature helps regulate floods, air quality, and other environmental conditions. Gangtey-Phobji also showed high appreciation for regulatory services, assigning about 41% to this category.

Following regulatory services, provisioning services were the second-most valued, with an overall average of 26.6%. This reflects the importance of natural resources like firewood, water, and food in people's daily lives. Interestingly, Sakteng, Trashigang showed the strongest reliance on provisioning services, allocating about 43%, the highest among the four sites likely indicating a more direct dependence on nature for basic livelihood needs. In contrast, Gaytsa and Gangtey-Phobji allocated about 20% to provisioning services, while Bumdeling placed it slightly higher at 33.6%, showing moderate dependence.

Cultural services, which include spiritual practices, local traditions, and recreational uses of nature, were valued the least across all sites, averaging just 20.2%. However, Sakteng gave the highest cultural value (around 24.9%), suggesting stronger spiritual or cultural ties with their natural surroundings. Other sites such as Gangtey and Gaytsa gave roughly 19% each, while Bumdeling valued cultural services the least at just 16%, indicating that cultural aspects of ecosystems may not be as strongly emphasized there.

In summary, while there are differences between communities, the overall trend is clear: people most value nature's role in regulating their environment, followed by its role in providing direct materials and resources, and finally, its cultural and spiritual contributions. These differences highlight the unique ways each community interacts with and depends on nature, shaped by their local environment, livelihood practices, and cultural background.

Table 3.1: Types of ecosystem services accessed by the local people across the sites

Ecosystem service type	Gangtey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
Provisioning	Bjilli Namcho (*Auricularia auricula*), *Picrorhiza kurroa,* Timber (*Abies densa*, *Tsuga dumosa*, and *Pinus wallichiana*. Drinking water, irrigation water, and pasture.	Leaf litter (manure), Bjilli Namcho (*Auriculariaauricula*), *Pinus wallichiana*, Junipers, Balu sulu (*Rhododendron anthopogon*) for incense, *Parispolyphylla,Tricholoma matsutake, Aconitum* sp, water, and firewood.	Cordyceps, Hemlock, firewood, drinking water, irrigation water, Mushroom, Daphne (paper), Fern, Rubia cordifolia and Paris pollyphylla.	(*Rhododendron anthopogon*) for incense, water, pasture, *Picrorhiza kurroa,* junipers, *Aconitum* sp and timber (*Quercus semicarpifolia*
Regulating	Erosion control, water purification, water retention, biodiversity protection (BNC habitat).	Water retention, water purification, and erosion control.	Water retention, water purification, and biodiversity protection (BNC habitat).	Erosion control, water retention, and water regulation.
Cultural	Crane festival, Khewang tshechu, and aesthetic value (tourism opportunity).	Aesthetic value (Tourism opportunity both domestic and international).	Domestic tourism (linked to Chorten kora), and crane festivals.	Rhododendron festival (link to Merak), International and domestic tourism (link to Merak Sakteng trail.

4 Local Perceptions of Climate Change, Impacts, and Issues

Local knowledgeandperceptions about climate change are critically important for formulating effective, inclusive, and sustainable climate responses. Communities at the frontline—such as smallholder farmers, herders, and indigenous group—are often the first to observe and experience environmental changes. Local experiences and observations of altered rainfall patterns, temperature shifts, and biodiversity loss provide valuable, place-based insights that may not be captured by scientific models (Adger et al., 2013). Integrating local perceptions also increases the legitimacy and effectiveness of climate policies by aligning interventions with ground realities. The process of soliciting information and perspectives from local people serves to strengthen community ownership, facilitates participation, and ensures that adaptation efforts address actual, rather than assumed, vulnerabilities (Ensor & Berger, 2009). In communities with strong linkages between socio-ecological systems and cultural practices, local insights are indispensable for building resilience and ensuring that climate action supports both ecosystems and livelihoods (UNDP Bhutan, 2019).

This chapter captures the community awareness and knowledge, experiences and perceptions about climate change, its impacts and issues in the study area. Information for this study was gathered through individual and collective responses queries through household interviews and focus group discussions conducted for each site.

4.1 Methodology

Data and information contained in this chapter were derived from two sources i) household survey self-reported level of awareness about climate change and ii) Focus Group Discussions (FGDs).

4.1.1 Level of awareness about climate change

Information on awareness levels were obtained during a survey that included a set of questions eliciting self-assessed levels of awareness about climate change and their perspective about the causes of climate change. Responses on level of climate change awareness were classified as Low, Moderate, and High. Responses to the question about respondent's perspective on causes of climate change were categorized into 'Human activities', 'Natural Causes', and 'Don't know'.

4.1.2 Focus Group Discussion Methodology

FGDs were employed to gather in-depth local knowledge about climate change and community conditions. FGDs participants with strong understanding of climate change, local weather patterns, environmental issues, and rural livelihoods, were selected. These participants include individuals with practical experience and insights, such as village elders, farmers, community leaders, and those locally recognized for their knowledge about environmental changes, were prioritized for FGDs. This process ensures gathering of commonly shared and reliable information that represent the views of the wider community. Each FGD session was structured in three parts:

- ✔ Socio-economic and Environmental Status – Discussing the community's livelihoods, farming practices, natural resources, and environmental conditions.
- ✔ Climate Change and Its Impacts – Exploring observed climate patterns, local perceptions of change, and impacts on farming, water, and forests.
- ✔ Mitigation and Adaptation Ideas – Gathering community suggestions and traditional knowledge on ways to reduce risks, adapt to changes, and improve resilience.

The discussions were facilitated in local language for better understanding and participation, with notetaking and recordings (when agreed) to capture all responses accurately. Data were later transcribed, sorted, and analyzed thematically to identify key issues and solutions shared by participants.

4.2 Awareness about Climate Change

Analyses on the level of awareness among respondents about climate change were disaggregated by gender and further analyzed for different perceived causes of climate change and education. Frequency tables were generated to capture the proportion of respondents.

Variations in local perspectives about causes of climate change were captured using bar plot. Overall analysis reveals varying patterns in awareness, and associations between awareness levels and the perceived causes of climate change. Findings are presented for each site.

4.2.1 Gangtey-Phobji

Local communities of Gangtey-Phobji showed variedlevelsofclimatechange awareness across gender, education level, and location. Overall, 64.30% ofrespondentsreportedamoderate level of awareness, 29.37% indicated low awareness, and 6.33% demonstratedhighawareness.Within gender groups, female respondents showed 4.74% high, 62.07% moderate,and33.19%lowawareness of climate change. Male respondents reported 8.59% high, 67.48% moderate,and23.93%lowawareness. In the high awareness category, males accounted for 56% while femalesrepresented44%.Interms of moderate awareness, females accounted for 56.69% and male 43.31%.Inthelowawarenesscategory, females accounted for 66.37%. (**Table 4.1**)

Table4.1: Gangtey-Phobji:Level of climate changeawarenesswithingender

	High		Moderate		Low		Grand Total	
Gender	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Female	11	4.74	144	62.07	77	33.19	232	100
Male	14	8.59	110	67.48	39	23.93	163	100
Total	25	6.33	254	64.30	116	29.37	395	100

When analyzed based on perceived causes of climatechange,clearpatterns emerged.Among the respondents, only a few (19.49%) selected “Don’t know”,andmostrespondents selectedthe low and moderate categories. This group had very few individualswithhighawareness, and a greaterproportion of female respondents appeared in the low and moderatelevels.Forthose who identified “Human activities” as the primary cause (66.58% of all respondents),moderateawareness dominated for both genders. Lastly, in the “Natural causes” category (13.93%),thepatternresembled that of the “Don’t know” group, with low and moderate awareness levels dominatingandhighawareness among a very few. (**Figure 4.1**)

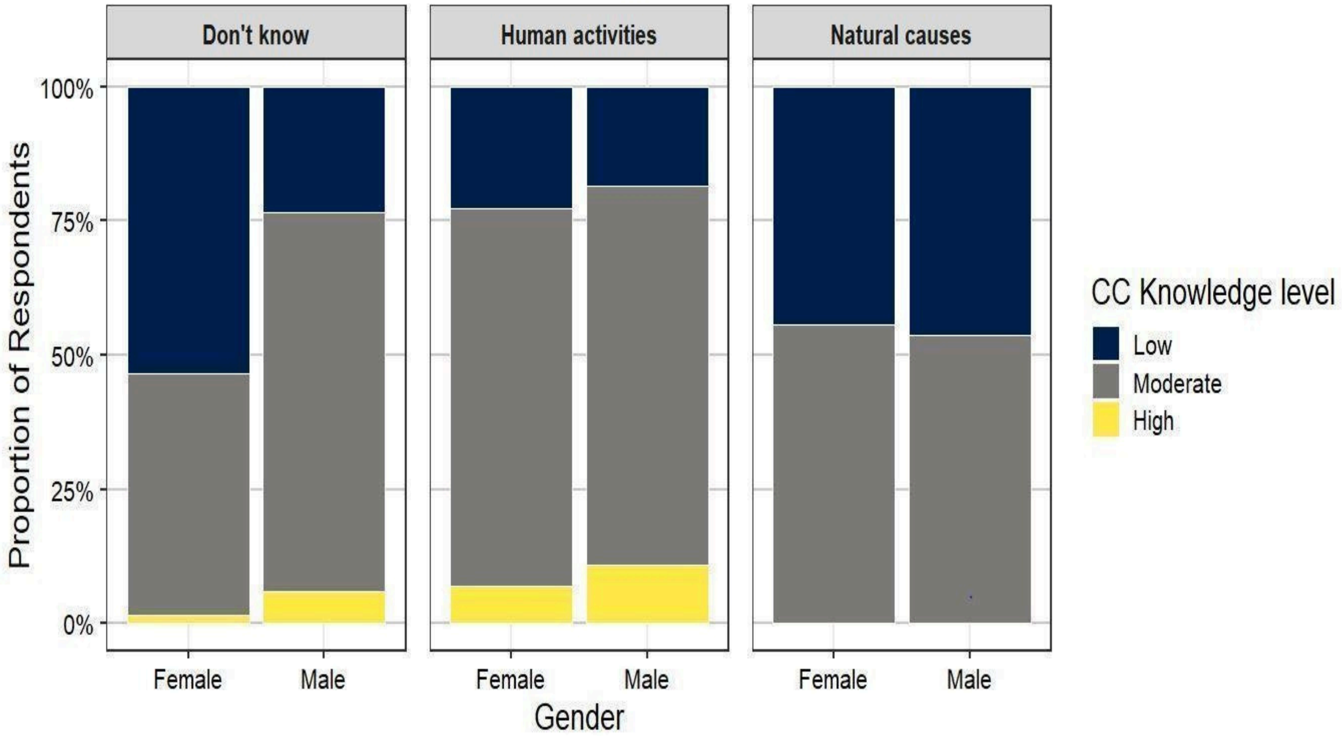


Figure 4.1: Awareness of causes of climate change by gender in Gangtey-Phobji

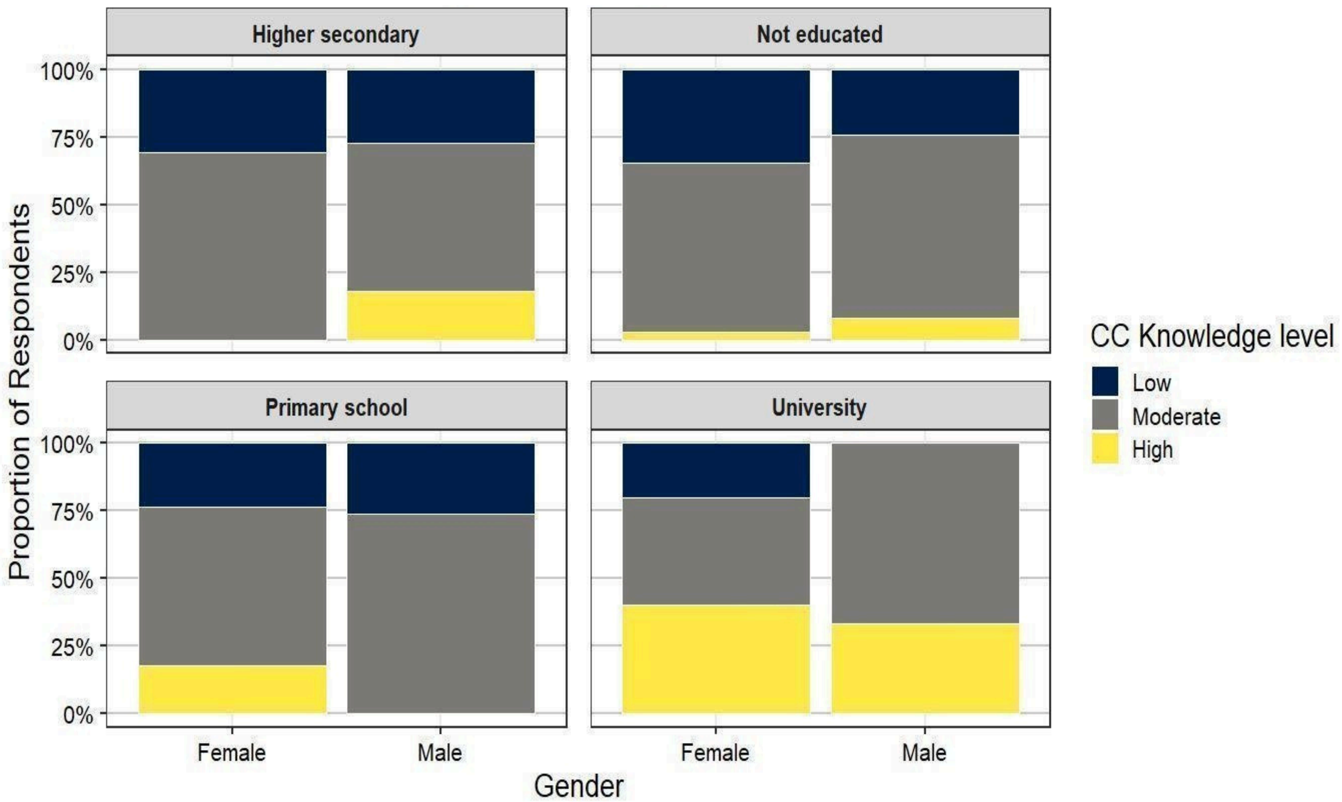


Figure 4.2. Climate change knowledge level by education level in Gangtey-Phobji.

Educational attainment was positively correlated with awareness levels. Respondents without formal education predominantly exhibited low (30.62%) to moderate (64.38%) awareness with only 5%

indicating high awareness. Those with primary education followed a similar pattern, although with slightly higher awareness (7.5%). High school graduates demonstrated an increase in high awareness (8.33%), while those with a university-level education exhibited the highest portion of high level of awareness (36.37%), alongside 54.54% moderate and only 9.09% low awareness as shown (**Figure 4.2**).

4.2.2 Gaytsa-Domkhar

Local communities of Gaytsa-Domkhar demonstrated varied levels of awareness about climate change. Overall, 57.14% of respondents reported a moderate level of awareness, 31.09% indicated low awareness, and 11.76% demonstrated high awareness. Within gender groups, female respondents showed 8.75% high, 55.0% moderate, and 36.25% low awareness of climate change. Male respondents reported 17.95% high, 61.54% moderate, and 20.51% low awareness. (**Table 4.2**)

Table 4.2: Gaytsa-Domkhar: Level of climate change awareness within gender.

	High		Moderate		Low		GrandTotal	
Gender	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Female	7	8.75	44	55.00	29	36.25	80	100
Male	7	17.95	24	61.54	8	20.51	39	100
Total	14	11.76	68	57.14	37	31.09	119	100

In terms of perceived causes of climate change, most respondents (74.78%) attributed climate change to human activities, while 15.96% expressed uncertainty by responding “don’t know,” and 9.26% attributed climate change to natural causes. Notably, those who attributed climate change to anthropogenic causes

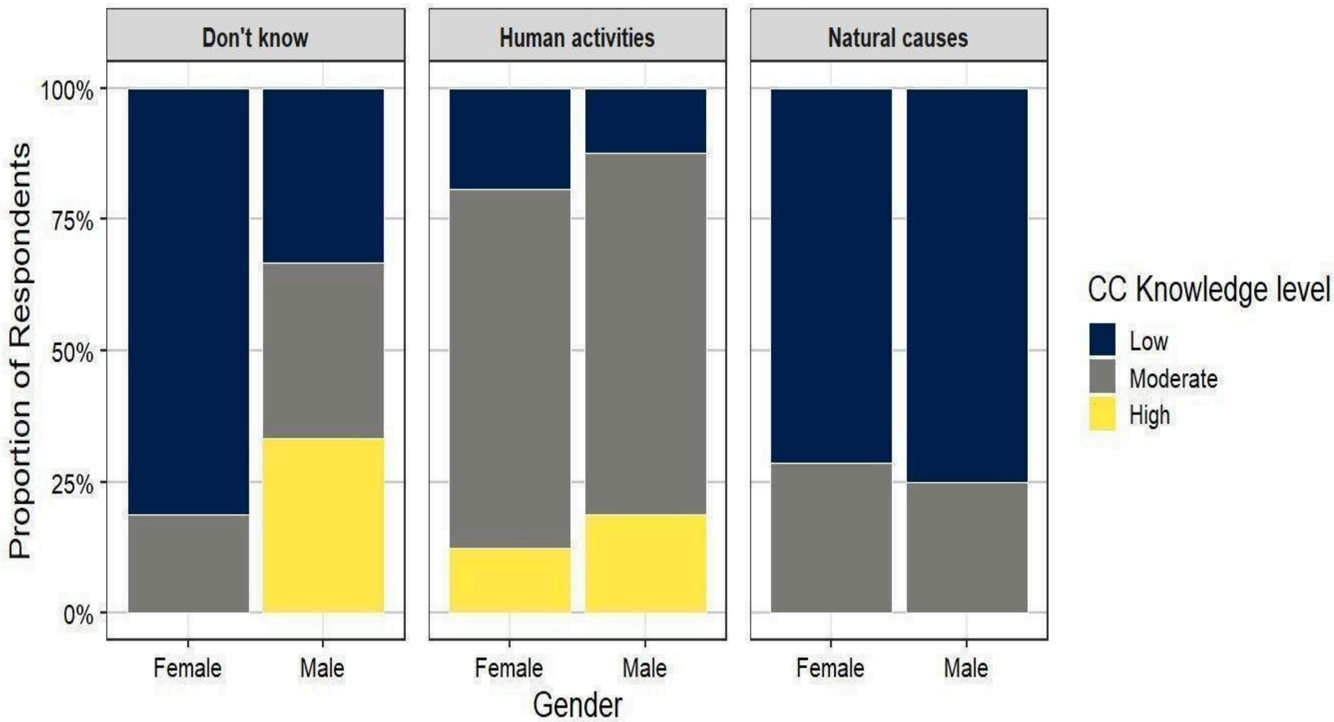


Figure 4.3: Awareness of causes of climate change by gender in Gaytsa-Domkhar.

were also more likely to be found in the moderate or high awareness categories, whereas respondents expressing uncertainty or attributing changes to natural causes were more concentrated in the low awareness group (**Figure 4.3**).

Educational attainment emerged as a significant determinant of climate change awareness. Among respondents with no formal education, 36.58% had low awareness, 53.65% had moderate awareness, and only 9.77% had high awareness. This distribution illustrates the general pattern of lower climate literacy among individuals lacking basic education. In contrast, those with a primary school education demonstrated higher climate awareness, with 72.72% showing moderate awareness, although high awareness remained low at 4.56%, and 22.72% still fell in the low category. Respondents with a university-level education exhibited the highest levels of awareness: 50.01% were categorized as high awareness, 33.33% moderate, and only 16.66% low. Similarly, respondents with high school education exhibited a strong concentration in the moderate category (62.51%), with 29.16% in low and 8.33% in high awareness categories. (**Figure 4.4**)

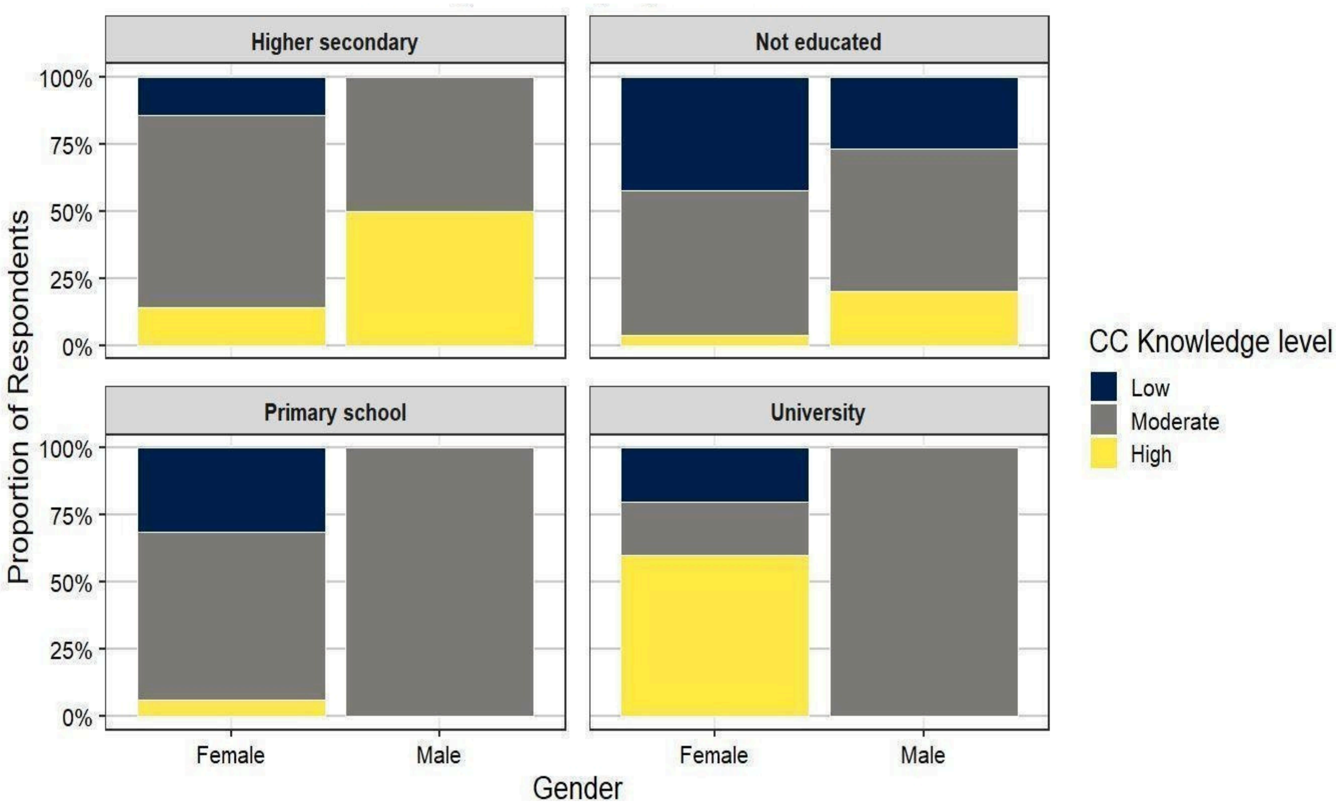


Figure 4.4. Climate change knowledge level by education level in Gaytsa-Domkhar.

4.2.3 Bumdeling

Local communities of Bumdeling demonstrated varied levels of awareness about climate change. Overall, 65.12% of respondents reported low awareness, 31.40% indicated moderate awareness, and only 4.65% demonstrated high awareness. Within gender groups, female respondents showed 2.04% high, 18.37% moderate, and 79.59% low awareness of climate change. Male respondents reported 7.89% high, 47.37% moderate, and 44.74% low awareness, showing different patterns within each gender. (**Table 4.3**)

Table 4.3: Bumdeling: Level of climate change awareness within gender

	High	Moderate	Low	Grand Total

Gender	n	%	n	%	n	%	n	%
Female	1	2.04	9	18.37	39	79.59	49	100.00
Male	3	7.89	18	47.37	17	44.74	38	100.00
Total	4	4.65	27	31.40	56	65.12	86	100.00

In terms of perceived causes of climate change, a substantial proportion of respondents (42.52%) indicated that they did not know the causes of climate change. This uncertainty was nearly equal to those who attributed climate change to human activities (44.82%), while 12.66% believed that natural causes were responsible. The high proportion of respondents expressing uncertainty about the causes of climate change corresponds closely with the high incidence of low awareness. (**Figure 4.5**)

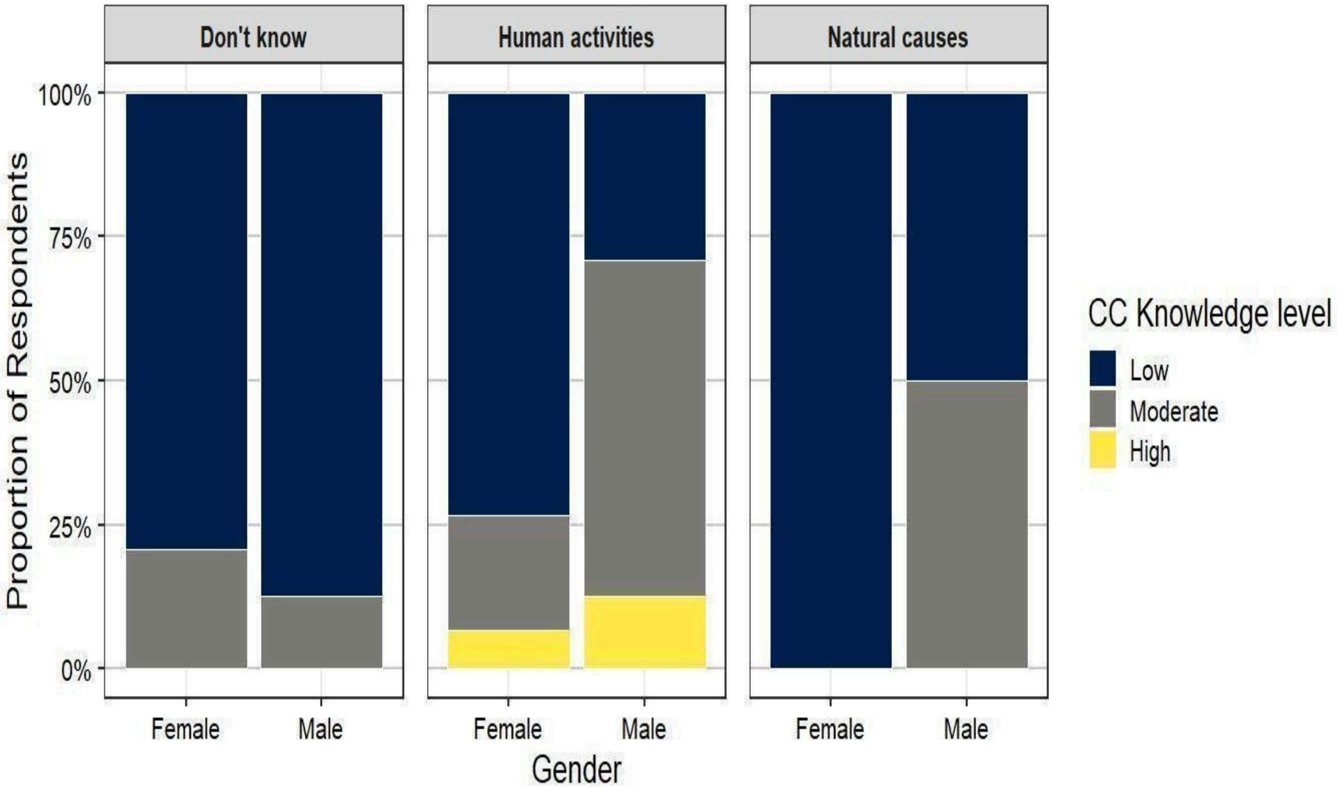


Figure 4.5: Awareness of causes of climate change by gender in Bumdeling.

When examined across educational backgrounds, the results underscore a strong association between educational attainment and climate change awareness. Among respondents with no formal education, a majority (65.82%) exhibited low awareness, 30.37% moderate, and only 3.81% high awareness. For those with primary school education, both low and moderate awareness were equally reported at 42.85%, with 14.3% achieving high awareness. Notably no respondents with university-level education were recorded in the sample, and among those with high school education, all respondents (100%) fell within the low awareness category, with no representation in moderate or high awareness levels. (**Figure 4.6**)

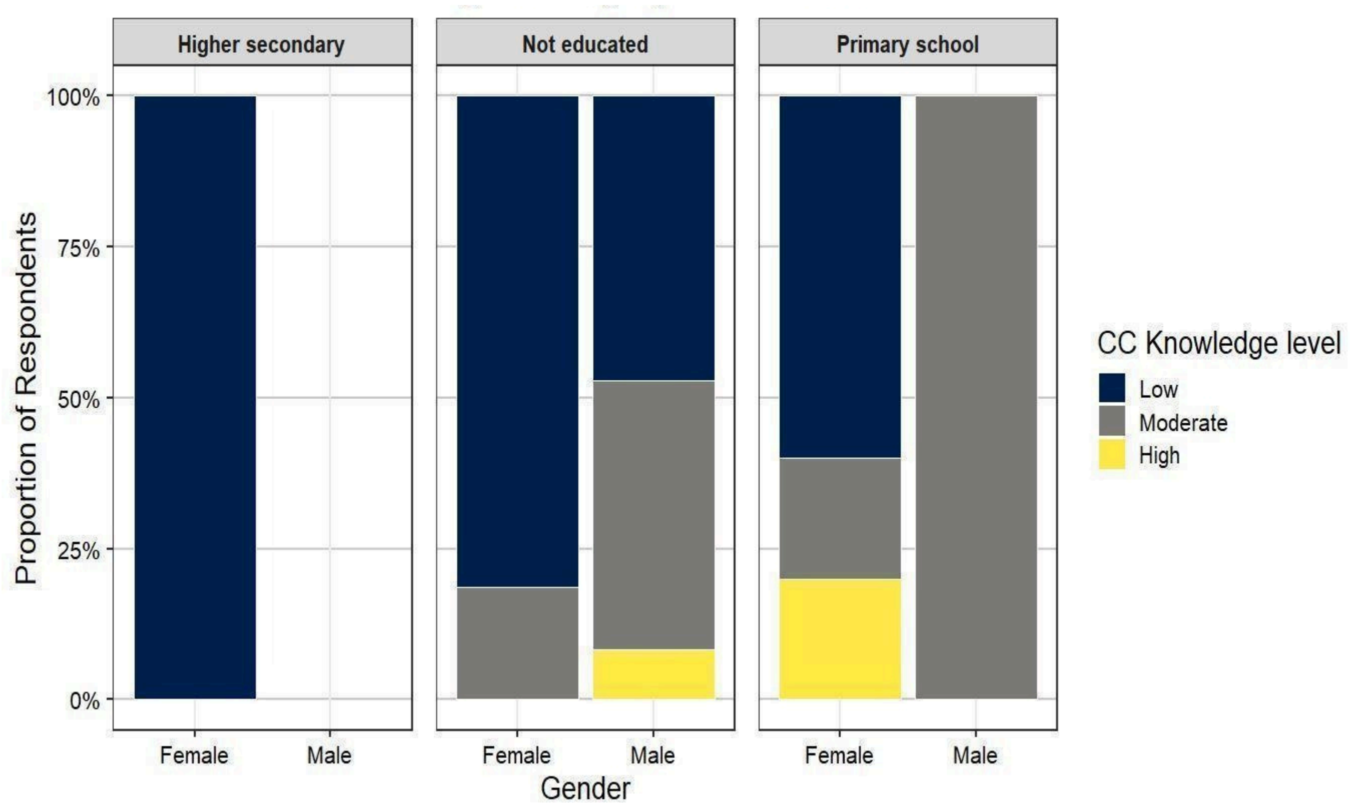


Figure 4.6: Climate change knowledge by education level, Bumdeling

4.2.4 Sakteng

The analysis of climate change awareness in Sakteng shows that low awareness is the most common level, with 60.12% of respondents in this category. Within gender groups, 67.33% of males and 32.67% of females reported low awareness. Moderate awareness was seen in 31.55% of respondents, with 45.28% of males and 58.49% of females within their respective groups showing this level. High awareness accounted for 8.33% overall, evenly split between males and females at 50% each. (**Table 4.4**)

Table4.4: Sakteng:Levelofclimate changeawareness withingender

Gender	High		Moderate		Low		Grand Total	
	n	%	n	%	n	%	n	%
Female	7	9.86	31	43.66	33	46.48	71	100.00
Male	7	7.22	22	22.68	68	70.10	97	100.00
Total	14	8.33	53	31.55	101	60.12	168	100.00

In terms of perceived causes of climate change, the majority of respondents (66.87%) attributed climate change to human activities, while 14.38% cited natural causes, and 18.75% reported that they did not know the cause. The comparatively high proportion of respondents recognizing anthropogenic factors as the driver of climate change is generally aligned with a higher representation of moderate awareness levels. However, the persistence of uncertainty and misattribution among a notable segment of the population may partially explain the limited prevalence of high awareness. (**Figure 4.7**)

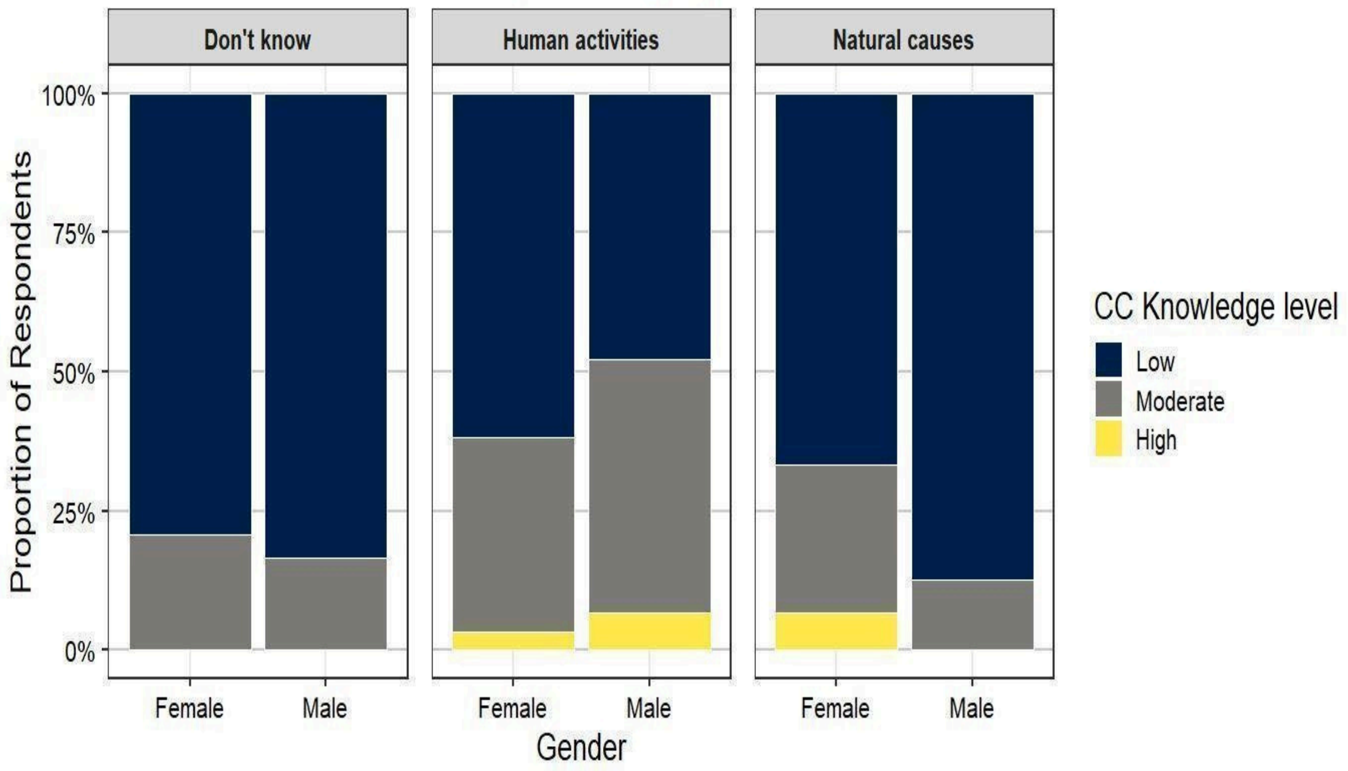


Figure 4.7: Awareness of causes of climate change by gender in Sakteng.

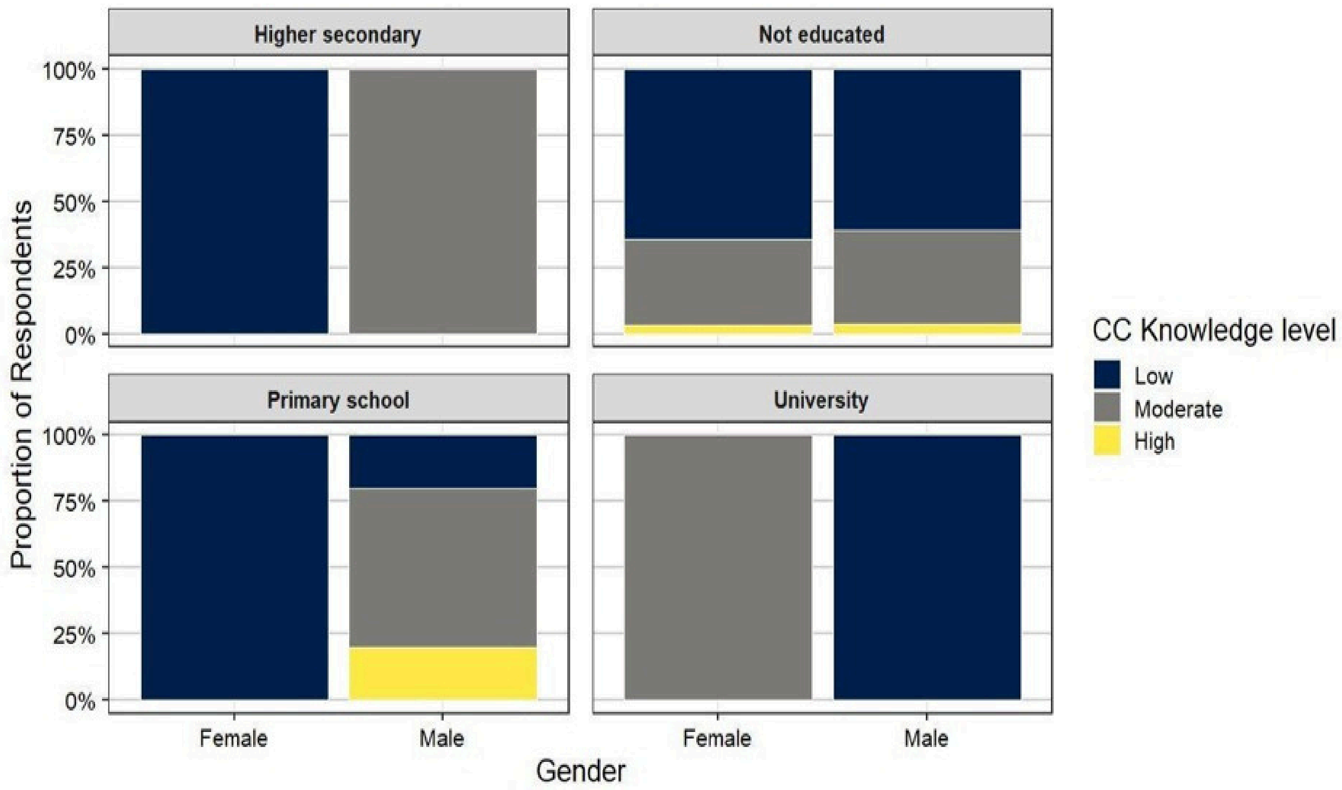


Figure 4.8: Climate change knowledge by education level, Sakteng

An analysis for educational attainment further illustrates the critical influence of education on climate change awareness. Among respondents with no formal education, 63.12% demonstrated low awareness, 33.33% moderate awareness, and only 3.55% were categorized as having high awareness. For those with
a primary school education, low awareness remained high at 63.63%, moderate awareness was observed at 27.27%, and 9.10% attained high awareness. Respondents with university-level education comprised a small portion of the sample, with 33.33% exhibiting low awareness and 66.67% moderate awareness; notably, no respondents from this category reported high awareness. Among those with a high school education, the distribution was heavily skewed, with 80% demonstrating low awareness and 20% moderate awareness, and no individuals attaining high awareness. (**Figure 4.8**)

4.2.5 Overall Climate Change Awareness across Sites

In Bumdeling, over three-quarters of females exhibited a low level of CC knowledge. Gangtey-Phobji displayed a relatively balanced distribution in the low and moderate levels of climate change knowledge. Similarly, in Gaytsa, males more often selected the moderate level for the CC knowledge. However, Gaytsa recorded the highest proportion of respondents with high levels of CC knowledge, especially elevated awareness level among the male respondents. In Sakteng, most reported low CC knowledge, among both males and females.

Overall, low to moderate levels of climate change knowledge were reported across the four study sites, with only few respondents in the high awareness category. Across the sites, male respondents demonstrated better levels of CC knowledge. (**Figure 4.9**)

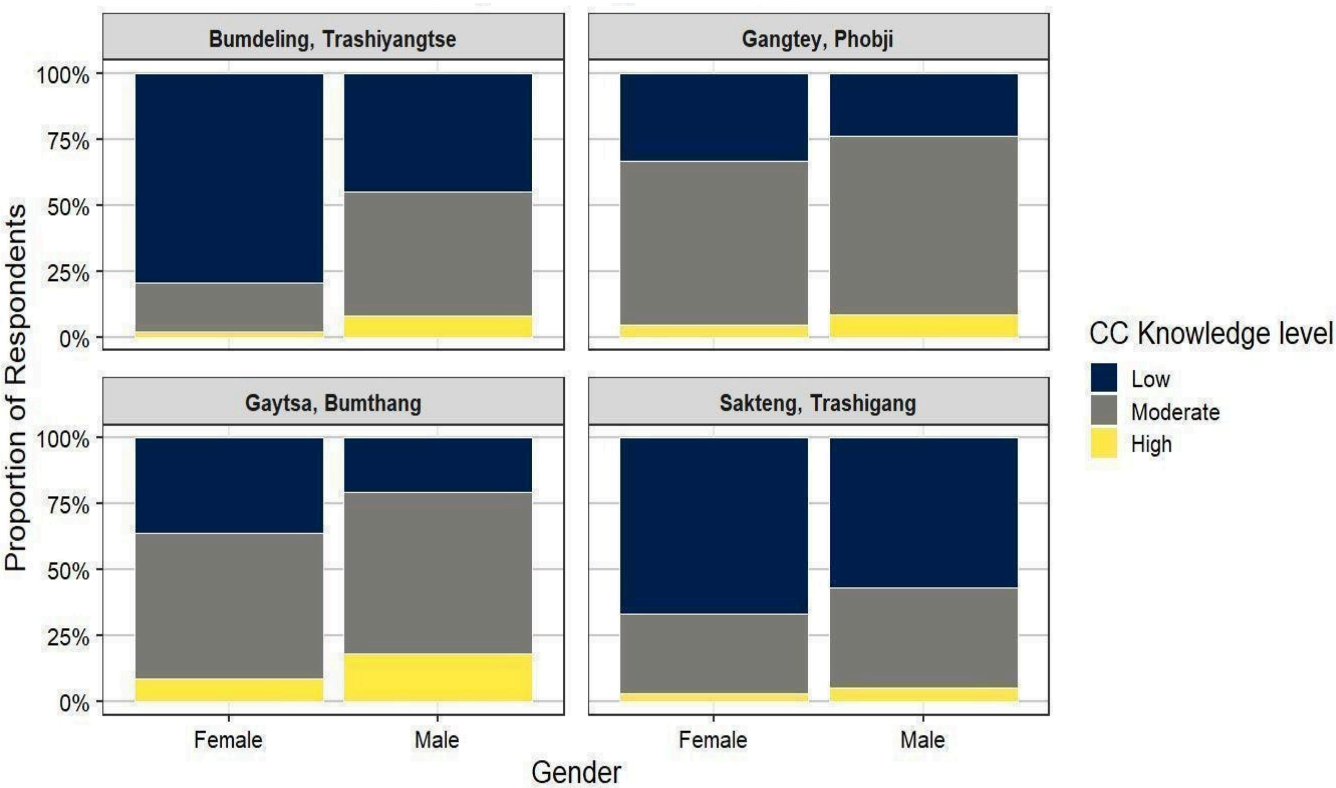


Figure 4.9. Overall climate awareness by gender across the four sites.

4.3 Local Perspectives about the Causes of Climate Change

The level of awareness among respondents in the four study sites shows variation in understanding of climate change causes from anthropogenic or natural drivers. Results were further presented by gender to assess potential differences in knowledge levels.

A clear trend emerged in the attribution of climate change causes across all sites. Most respondents believe human activities are the primary drivers of climate change, reflecting a strong awareness of anthropogenic influences on the climate system. Local people, particularly those in Bumdeling and Sakteng perceived that increase in temperature is the result of increasing use of electricity.

A smaller proportion attribute climate change to natural causes, while some admitted to having no knowledge on the subject. This suggests that while general awareness is relatively high, gaps persist in understanding the specific mechanisms behind climate change. Gender-based analysis revealed minimal differences in climate change knowledge between male and female respondents. Both groups demonstrated similar levels of awareness regarding the causes of climate change, indicating that gender does not play a significant role in shaping climate literacy in these communities. This finding aligns with broader literature suggesting that environmental knowledge is often influenced more by education and exposure to information than by gender alone.

Site-specific comparisons showed that Bumdeling and Gangtey-Phobji exhibited nearly identical patterns in climate change awareness, with a strong consensus on human activities as the leading cause. In contrast, Gaytsa and Sakteng displayed slightly higher variability, with a modest increase in the proportion of respondents who were uncertain or cited climate change as a natural process. These subtle regional differences may stem from variations in local education programs, media exposure, or community engagement with environmental issues. (**Figure 4.10**)

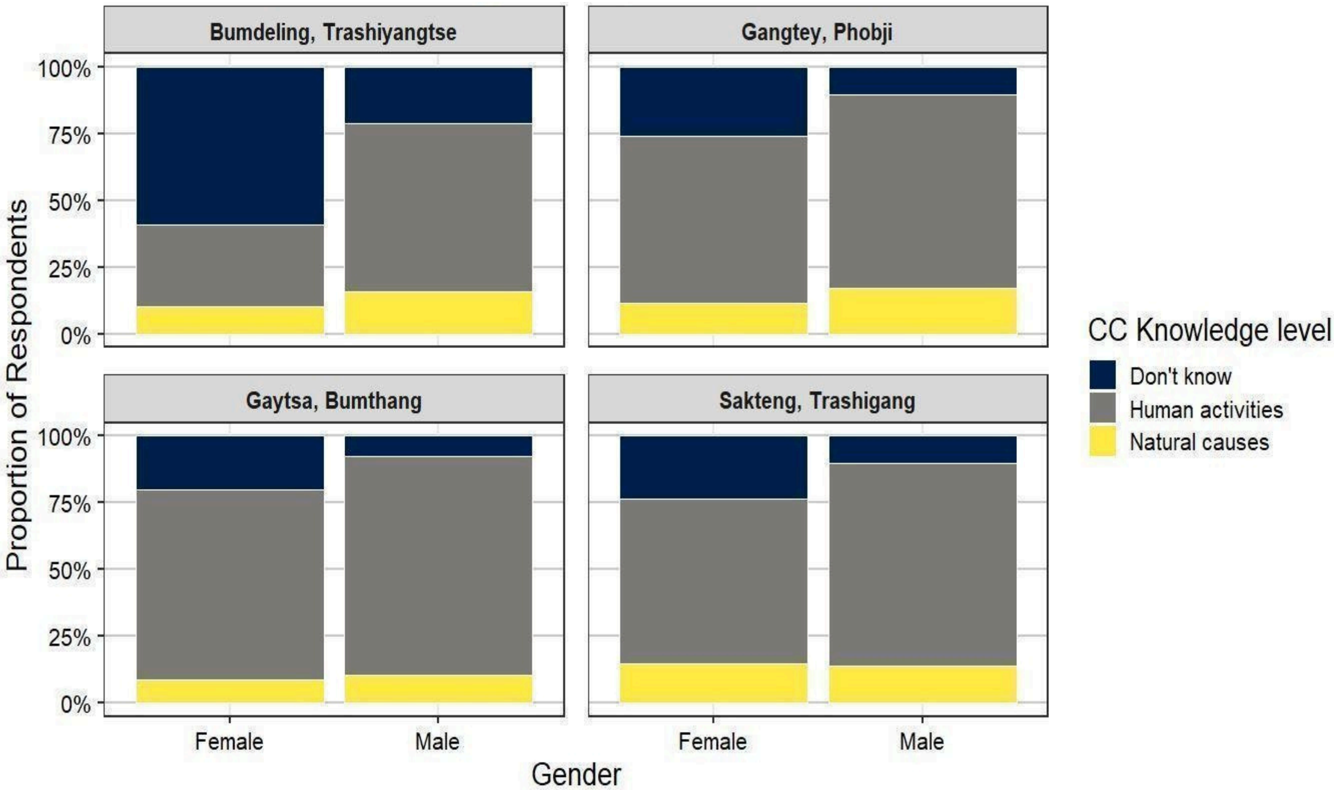


Figure 4.10: Causes of climate change: Local knowledge by gender across all sites

4.4 Perceptions of Climate Change Impacts

Respondents across all sites report experiences of climate change, particularly through shifts in rainfall patterns, rising temperatures, and an increase in extreme weather events such as floods, storms, and droughts. Among respondents from the four study sites, 42% noted rising temperatures, more erratic and intense rainfall, and a decline in snowfall. Over 15% observed warmer temperatures compared to the past, while 11% reported that rainfall has become less predictable and more intense, accompanied by reduced snowfall during winter. Additionally, 21% indicated they have experienced a combination of unpredictable, intense rainfall, higher temperatures, and a rise in extreme events such as flash floods and windstorms. Communities in all four study sites are convinced of climate change as a present-day reality. Climate change evidence commonly observed and experienced by communities across the study sites were captured through FGDs and household interviews. (**Table 4.5**).

4.4.1 Rising Temperatures

All communities across the study sites consistently report experiencing warmer temperatures compared to the past. Summers in Gangtey-Phobji, Gaytsa, and Sakteng are now noticeably hotter, while winters are no longer as harsh as they once were. In Gangtey-Phobji and Gaytsa, respondents recall playing with icicles and frozen streams during their childhood—features that are now rarely seen. Farmers in Bumdeling also observe that winters have become milder, while summers are significantly warmer. Residents of Gaytsa specifically noted the absence of snowfall over the past three years, with snow in higher elevations beginning to melt earlier in the year. Additionally, occurrences of winter frost have noticeably declined.

4.4.2 Changes in Precipitation Patterns

Communities in all sites have pointed to the noticeable changes in precipitation particularly in terms of unpredictability, amount, and intensity of rain and snow.

4.4.2.1 Unpredictable and Increased Rainfall Intensity

Respondents and participants in focus group discussions across all sites have consistently pointed out the increasing unpredictability of rainfall. Some have opined that there have been times when rain arrived early in the season while at other times rain arrives late and sometimes with prolonged dry spells in between rainfall making it highly unpredictable. Another notable aspect of rainfall pattern has been the increasing intensity. There is general agreement among respondents and FGD participants that rainfalls have become more intense with heavier downpours of shorter duration unlike gentle and prolonged rainfall in the past.

4.4.2.2 Reduced Frequency and Amount of Snowfall

A decline in both the frequency and intensity of snowfall has been observed across all sites. Locals are confident in their observation that snowfall has become increasingly rare and, when it does occur, it is brief and melts within a few hours. In Gangtey-Phobji and Gaytsa, older respondents recall that snowfall in the past used to be more regular and substantial compared to what they experience today. They remember winters from past decades being marked by consistent and heavy snowfall, making snow a defining feature of the winter landscape. Some residents vividly recall snow reaching knee height during

Table 4.5: Local perspectives on evidence of climate change

	Bumdeling		Chhumig		Gangtey		Phobji		Sakteng		TOTAL	
Climate events	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Extreme events	0	0.00	1	0.84	13	6.77	3	1.48	2	1.25	19	2.50
Rainfall	4	4.60	6	5.04	34	17.71	34	16.75	4	2.50	82	10.78
Rainfall, Extreme events	9	10.34	4	3.36	16	8.33	11	5.42	3	1.88	43	5.65
Rainfall, Temperature	28	32.18	59	49.58	68	35.42	91	44.83	74	46.25	320	42.05
Rainfall, Temperature, Extreme events	28	32.18	32	26.89	36	18.75	43	21.18	20	12.50	159	20.89
Temperature	14	16.09	15	12.61	19	9.90	19	9.36	51	31.88	118	15.51
Temperature, Extreme events	4	4.60	2	1.68	6	3.13	2	0.99	6	3.75	20	2.63
Grand Total	87	100	119	100	192	100	203	100	160	100	761	100

their childhood, a phenomenon that has gradually disappeared. In Gaytsa, women remember winters when wetlands and streams were frozen—something that no longer occurs.

In fact, they note that there has been no snowfall in the past three winters. The most significant snowfall in recent memory was during the winter of 2021, coinciding with the COVID-19 pandemic.

4.5 Impacts of Climate Change

The impacts associated with the changes in climate variables has had major impacts on ecosystems and socioeconomic way of life of the communities in the study sites. Many of the issues and perceived impacts identified by local communities are not easily relatable to climate change. Below we discuss some of the pertinent impacts that are clearly attributable to climate change.

4.5.1 Shift in Cropping Calendar

Communities in Gangtey-Phobji, Gaytsa, and Bumdeling shared observations about the impacts of climate change on agriculture and livestock farming. In response to rising temperatures, local farmers have gradually adjusted their farming practices by adjusting their cropping schedules. Below are examples of how cropping calendars have shifted across these sites.

Gangtey-Phobji are primarily known for their potato production although other crops like wheat, buckwheat, turnip are also grown. Although, with the rise in temperature, it has now become feasible to grow maize and vegetables like chili, carrot, tomato etc... However, the practice of growing wheat has drastically reduced owing to two factors. In the fast, moist soil from melting snow provided good conditions for sowing and germination of seeds. But, with reduced quantity and frequency of winter snowfall, post winter soils are much drier making it more difficult to grow wheat, barley and buckwheat. Similarly, locals used to sow potato seeds in March and harvest in July, but with the changing climate, potatoes are sown in April and harvested around the same time.

In Gaytsa, agriculture has become more feasible with a warmer climate. Earlier, agriculture was limited to livestock rearing and cultivation of wheat, barley, and buckwheat. With warmer climate, the area has become conducive for growing paddy, chili, and a variety of vegetables.

In Bumdeling, locals also have adjusted their paddy sowing schedule. In the past, they used to sow paddy seeds prior to the religious festival in Chorten Kora. Now, paddy seeds are sown after the festival in May. They attribute this to warmer climate because of crops having shorter growing seasons.

4.5.2 Reduced Crop Yield

Communities in the study sites also experience reduction in crop yields caused by invasive species, diseases, pests, and flash floods.

4.5.2.1 Invasive Species

Locals believe that a warmer climate created conditions for new species to grow. Invasive species in particular hamper agriculture productivity. Respondents in Gaytsa-Domkhar have witnessed the emergence of two types of invasive weeds locally named *Pangla tew* and *Toh yongmi tewa*. While both are observed to be invasive, *Toh yongmi tewa* is known to damage potatoes by penetrating and damaging tubers resulting in lower yields.

4.5.2.2 Increasing Incidence of Pest and Diseases

Farmers in the study sites point to climate change induced pests and diseases that hamper agricultural productivity and income. Communities in Gaytsa-Domkhar associate the never seen before pest infestation with rising temperature. Army worm infestation had occurred consecutively for the last two years damaging vegetables. Farmers suspect that the increase in temperature causes the land to dry, which creates favorable conditions for army worms.

In Bumdeling, farmers are witnessing a chili disease that hampers proper growth and productivity of a popular chili locally known as '*Urka Bangla*' (wrinkled chili). The disease causes the pedicel of the fruiting chilies to rot and prematurely fall.

4.5.2.3 Flash Floods

Communities across all sites consistently report about the impact of intense precipitation. Respondents of Gangtey-Phobji reported significant damage to potato fields caused by increased runoff caused by intense rainfall, which has become more common compared to the past. Swollen streams and rivers are cutting deeper and destabilizing slopes from creased soil erosion and landslides.

Bumdeling has suffered most from flooding events. Kholongchhu and its tributaries often burst their banks due to cloudbursts and incessant rainfall. A number of flooding events in the past have resulted in loss of life, agricultural land, and infrastructure. For instance, Barigang Chhu (a tributary near Pangkhar Taphel chiwog) triggered a landslide in 1997, followed by recurring floods from 2003 to 2007, submerging 50–60 acres of paddy fields across the Bumdeling plain and downstream areas. Similarly, Nakpola Chhu flooded in 1994, destroying 40 acres of paddy fields—which remain unusable—and claiming two lives along with 14 cattle. While 14–15 acres were later revived for cultivation, the damage underscores the persistent vulnerability of the region. Once regarded as the rice bowl of Tashiyangtse, Bumdeling's farmers continue to be deprived of the opportunity to produce rice annually. Although reclamation efforts are underway, the threat of flooding looms large as the site experiences more frequent and intense rainfall.

4.5.3 Reduced NWFPs

In Gangtey-Phobji, certain plant species, such as bamboo, *thoksampa* (*Paris polyphylla*), and *dungshing shamu* (*Cortinarius caperatus*) have declined due to decreased snowfall during the winter, but with drastic reduction in winter snow, this mushroom is not easily available while foraging.

4.5.4 Shrinking Temporal and Spatial Range for Yaks

The people of Sakteng are particularly concerned about the vulnerability of yaks to temperature rise. Climate change has affected migration patterns of the nomads and their livestock. With warmer temperatures, nomads are having to move their yaks to higher elevations about a month earlier than they used to earlier. Traditionally, yak herders of Sakteng migrate with their livestock and spend the entire winter and spring season in lower areas like Thakthri and move back up to pastures in higher elevation around May when warmer season sets in. With rise in average temperatures, which yaks are unable to cope with, they are now migrating early to higher elevations by about a month i.e., in April. This reduced stay in lower elevations is further hampered by shrinking of high elevation pastures resulting from expanding tree lines and traditional pasture lands. With Yak populations already declining, some suspect that continuing rise in temperature may be detrimental to the survival of yak species.

4.5.5 Emergence and Disappearance of Species

4.5.5.1 Emergence of Species

Species that did not exist in the past are being observed by residents across the study sites. People of Gangtey-Phobji have observed the emergence of invasive weeds (*Rumex acetosella*) and Watercress (*Nasturtium officinale*). Likewise, farmers have also observed the presence of mosquito, wild dogs, and tiger (*Panthera tigris*) – animal species that were not known to inhabit the area in the past.

In Gaytsa-Domkhar, a number of plant species which were not seen earlier have been observed now. They include both naturally occurring and those adopted for agriculture purposes. Naturally occurring plants include two invasive weeds locally named *Pangla Tewa* and *Toh Yongmi Tewa*. Although, with warmer climate, the locals can also grow paddy, millet, chili, cucumber, brinjal, maize, oats (*Chungma*) and strawberries that they believe could not be grown in the past.

Respondents of Bumdeling also reported emergence of a poisonous plant (name unknown), two bird species namely White-bellied Heron (*Ardea insignis*) and Cuckoo (*Cuculus conorus*), and butterfly species such as *Bhutanitis ludlowi*. Considering that the white-belled heron (WBH) and the butterfly *Bhutanitis Ludlowi* are both highly treasured species, their existence indicates pristine habitats.

Respondents in Sakteng have also noted the emergence of one plant species called *Ngawang shing meto*. In addition, they also cited the existence of three bird species (Great barbet, Eurasian hoopoe, and the Ibisbill) that were not observed in the past. However, with warmer temperatures, residents are taking up kitchen gardening as the climate becomes more favorable for potatoes and vegetables such as chili, radish, spinach, etc., which were not grown earlier.

4.5.5.2 Declining or Disappearing Species

Respondents in the study sites also described the disappearance of various species over time. FGD participants and village elders in Gangtey-Phobji reported NWFP products such as *Dungshing Shamu* (*Cortinarius caperatus*) and *Thoksampa* (*Paris polyphylla*) have now disappeared. Locals further observed that a particular bamboo species that previously existed has likewise disappeared. Further, community members expressed concern that wildlife species such as the white-collared blackbird (*Turdus albocinictus*), Kalij pheasant (*Lophura leucomelanos*), musk deer (*Moschus moschiferus*), barking deer (*Muntiacus*), and sambar deer (*Rusa unicolor*) appear to be declining or disappeared.

Gaytsa-Domkhar respondents reported that a yellow-colored bird locally known as *Khangkhu* is no longer sighted in the site. Local farmers have not sighted and therefore suspect wildlife such as Leopard (*Panthera pardus*), Yellow throated marten (*Martes flavigula*), Barking deer (*Muntiacus),* Sambar deer (*Rusa unicolor*), and Fox (*Vulpes vulpes*) have declined. Further, the number of Black-necked cranes (Grus nigricollis) that used to visit every winter are now on decline.

Respondents in Bumdeling recalled that a flowering plant known locally as *Kargen meto* and the medicinal plant *Thoksampa* (*Paris polyphylla*), which once grew in the area, have not been observed in recent times. A particular concern is the dramatic decline in the population of the Black-necked cranes (BNC), an iconic species in Bumdeling, with numbers plummeting from an estimated 200-300 in the past to 59 in 2024. Locals attribute the steady decline in population of the near threatened BNC to a combination of factors that resulted in loss of habitat from rising temperatures, intense rainfall and increased frequency of flash floods that have devastated the entire stretch of paddy fields along the Kholongchhu and Nagpolachhu. The loss of irrigated paddy land not only affected household food security but also destroyed the winter habitat of the BNCs. Another intriguing observation is the unexplained decline in the local leech population.

4.5.5.3 Declining water resources

Respondents have observed reduced quantities and drying of water sources. Deforestation and decline in forest resources are reported to further exacerbate the impacts of climate change. Gangtey-Phobji respondents also assert that the policy of timber allotment to communities outside their site remains a major concern, especially in terms of degrading watersheds and their impact on future water availability.

5 Biodiversity Assessment

5.1 Vegetation

All analyses were conducted in the R environment. For each site, completeness of the survey was evaluated based on the rarefaction curves, i.e. individual-based species accumulation curves. Abundance and relative abundance of each species was compiled, along with the Shannon's H' and Simpson's (1-λ) indices and the Evenness index. Rarefaction curves with the 95% confidence interval were constructed for each site to compare species accumulation across sites.

Commonly used indices–Shannon diversity index (Shannon & Wiener, 1949), Simpson's diversity index (Simpson, 1949), Pielou evenness index (*J*) (Pielou, 1966), Margalef's richness index (Margalef, 1958), Menhinick richness index (D_{Mn}) (Menhinick ,1964),areusedfortheanalyses: [2]

The Shannon and Simpson's diversity index measures diversity of species with higher values (typically ranging from 1.5 to 3.5 for Shanon and closer to 1 for Simpson's) indicates greater diversity and more equitable abundance distributions, and values closer to 0 suggest dominance by few species. Pielou evenness index measures how species are equally distributed, with 0 indicating highly uneven distribution and 1 perfect evenness. Margalef's richness index evaluates species richness with higher values indicating greater richness, and existence of rare species increasing the richness index. Menhinick index also

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$$H' = -\sum_{i=1}^{n} p_i \ln p_i$$

Where *H'*= Shannon diversity

pi= The proportion of individuals belonging to the i^{th} species

ln= Natural logarithm

$$D = 1 - \sum_{i=1}^{s} \frac{n_i(n_i - 1)}{N(N-1)}$$

Where*D* = Simpson's diversity

ni = The number of organisms that belong to species *i* *N* = The total number of organisms in the community

$$J' = \frac{H'}{\ln S}$$

Where: *J'* = Pielou evenness index

H '= Shannon Diversity Index.

S = Species richness

$$DMg = \frac{S-1}{\ln N}$$

Where: DMG: Margalef's richness index

S = Species richness

N = Total number of individuals

$$DMn = \frac{S_R}{\sqrt{n}}$$

Where: D_{Mn} = Menhinick's index

S_R = species richness

N = Total number of individuals

measures species richness but provides meaningful comparisons when sample size varies among the plots. By addressing the different aspects of composition and structure of the species, these indices offer a comprehensive understanding of biodiversity. In addition, Functional Feeding Group (FFG) of the macroinvertebrates were identified to understand the energy flow and ecosystem functioning of aquatic environments (Merritt et al., 2008).

5.1.1 Results

To compare differences in species composition across sites, Principal Coordinates Analysis (PCoA) was used to plot the locations of sites in two dimensions, based on calculation of Jaccard distance between plots. Calculation of the Jaccard distance is based on presence/absence of species at each site. This method was chosen because non-metric multidimensional scaling (NMDS) failed to converge, likely due to the large number of zeroes (absences) across sites. PCoA analysis was conducted in the R package *vegan* (Oksanen et al. 2022), on trees, shrubs, and herbaceous communities.

The elevation of the plots spanned a wide range (<2000 to >3500 *masl)*. Bumdeling forest plots were laid at elevations <2500 *masl*, whereas Gangtey-Phobji, Gaytsa-Domkhar and Sakteng plots were mostly located between 2900-3350 masl (**Figure 5.1**). In total, 1,552 trees were inventoried, of which 1,530 (99.1%) were identified to species or in a unique genus and retained in the analysis. In total, 45 tree species were recorded across the four sites. Bumdeling had 25, Gangtey-Phobji had 20, and both Gaytsa-Domkhar and Sakteng had eight tree species.

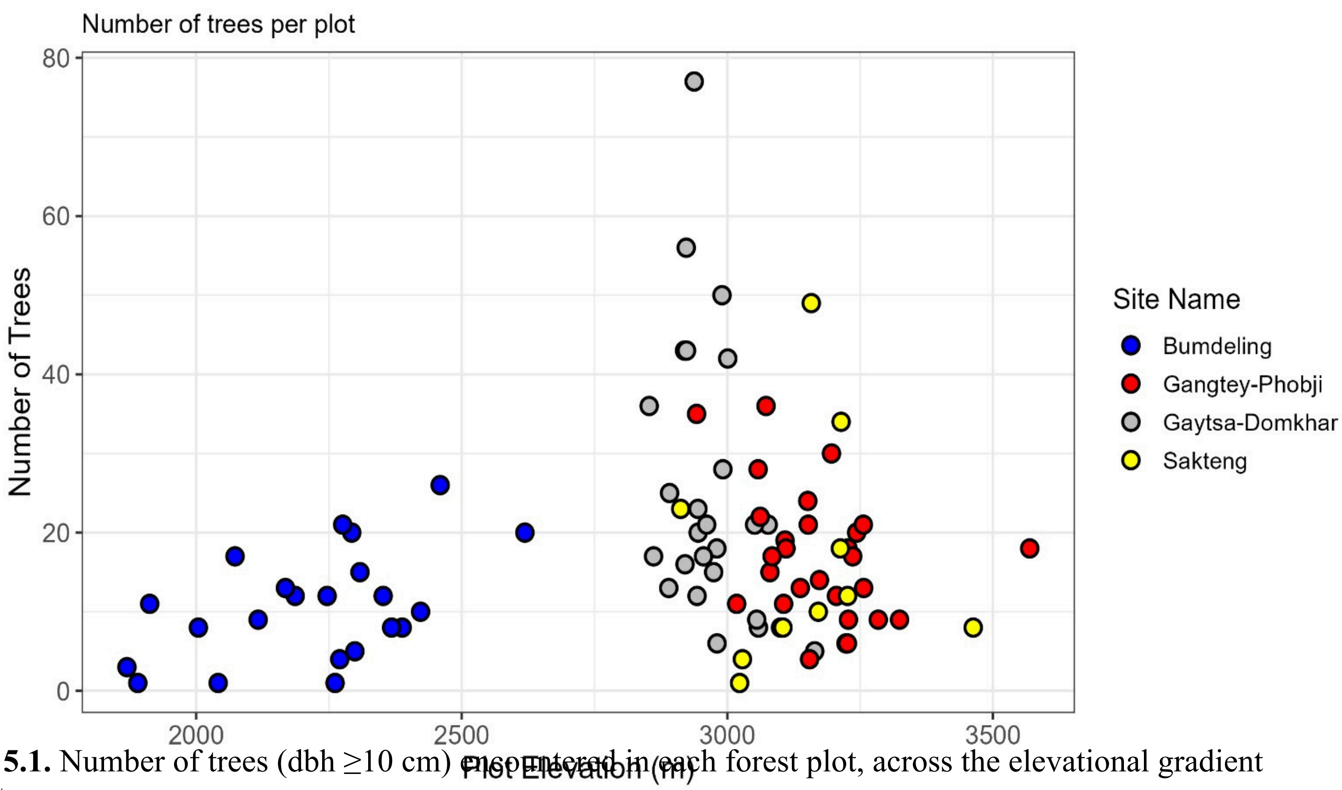

Figure 5.1. Number of trees (dbh ≥10 cm) encountered in each forest plot, across the elevational gradient at all sites.

Table 5.1: Diversity indices for the vegetation communities at four sites.

	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng	Total
Number of plots	**22**	**28**	**26**	**10**	**86**
Forest trees					
Area surveyed (ha)	0.88	1.12	1.04	0.4	3.44
Richness	25	20	8	8	45

Shannon Index (H')	2.7	2.2	0.26	1.7	2.2
Simpson Index (1-λ)	0.9	0.83	0.087	0.77	0.72
Evenness (E)	0.84	0.73	0.13	0.82	0.58
Forest shrubs					
Area surveyed (ha)	0.06	0.07	0.07	0.03	0.22
Richness	27	32	26	17	70
Shannon Index (H')	2.8	2.7	2.8	2.5	3.5
Simpson Index (1-λ)	0.92	0.9	0.93	0.9	0.95
Evenness (E)	0.85	0.78	0.86	0.88	0.82
Forest herbs					
Area surveyed (ha)	0.08	0.01	0.01	0.04	0.03
Richness	66	38	35	47	127
Shannon Index (H')	3.6	2.5	2.8	3.2	3.8
Simpson Index (1-λ)	0.96	0.84	0.92	0.94	0.96
Evenness (E)	0.86	0.69	0.79	0.83	0.78
Wetland herbs					
No. of plots		6	3	4	13
Area surveyed (ha)		0.002	0.001	0.002	0.005
Richness		27	3	22	38
Shannon Index (H')		2.8	0.92	2.8	3.2
Simpson Index (1-λ)		0.91	0.55	0.92	0.95
Evenness (E)		0.85	0.84	0.91	0.88

Rarefaction curves indicate that sampling adequately captured most of the expected tree species (**Figure A5.2, see appendix**). Diversity of the tree communities was far greater in Bumdeling and Gangtey-Phobji as indicated by both the total species richness. Diversity indices and eveness show lack of diversity and eveness at Gaytsa-Domkhar site. Both Simpson's H' and Simpson's Index show high diversity and evenness for the other three sites. Overall, the sites were heavily dominated by *Pinus wallichiana* (blue pine) which accounted for 788 (51.5%) of all stems (**Figure A5.3, see appendix**). However, this numerical dominance came because of its high abundances at Gaytsa-Domkhar and Gangtey-Phobji (**Table A5.1, see appendix**). Bumdeling forests were mixed broadleaf, co-dominated by *Quercus* sp (*oak*) and *Lyonia ovalifolia* (Angeri). Plots in Sakteng fall largely in Rhododendron Forest, which was dominated by *R. argipeplum*, *R. kesangiae*, and *R. arboretum*.
For shrubs, a total of 1906 individuals were encountered, of which 1,842 (96.6%) were identified to species or a unique genus (**Table A5.2, see appendix**) A total of 70 species were recorded, with Gangtey-Phobji having 32, followed by Bumdeling and Gaytsa-Domkhar with 27 and 26, respectively (**Table 5.1**). The shrub community was represented by a wide range of species that were evenly distributed overall (E = 0.82) with high species diversity according to Simpson's and Shannon's indices (**Table 5.1**). The most abundant species overall were *Daphne bhoula* (paper plant), *Yushinia microphylla* (mountain bamboo) and *Berberis hookeri* (Hooker's barberry) (**Table A5.3, see appendix**).

A total of 8,917 herbs were encountered, of which 7,662 (85.9%) were identified to species or unique genus (**Table A5.3, see appendix)**. A total of 127 species or unique genera were recorded. Across all sites, *Rubus fockeanus* (wild himalayan raspberry) had the highest abundance, although it was completely absent from the lowest elevation site, Bumdeling. Otherwise, *R. fockeanus* was an important component of the other three sites. Across all sites, species diversity and evenness are high.

5.2 Aquatic

Microsoft Excel and R Statistical Package were used for data curation and analyses. Two stream types, Tributary (T) and Main River (MR) were used to define plots.

5.2.1 Fish

The study recorded 283 individuals of three distinct freshwater fish species, each belonging to a different family. *Salmo trutta* (brown trout) was the most dominant species (*n* = 239, Relative Abundance [RA] = 84.45%) followed by *Schizothorax richardsonii* (snow trout) (*n* = 40, RA = 14.13%) while *Creuteuchiloglanis bumdhelingensis* (bumdeling catfish) was the least dominant species (*n* = 4, RA = 1.41%) (**Table 5.2**).

Table 5.2: Taxonomic composition of freshwater fish recorded from the study area, showing Order, Family, Species, Count (n), and Relative Abundance (RA%)

Sl. No.	Order	Family	Species	Count (n)	RA (%)
1	Salmoniformes	Salmonidae	*Salmotrutta*	239	84.45
2	Cypriniformes	Cyprinidae	*Schizothorax richardsonii*	40	14.13
3	Siluriformes	Sisoridae	*Creuteuchiloglanis bumdhelingensis*	4	1.41

Note: Sl. No = Serial Number, RA = Relative Abundance

5.2.1.1 Gangtey-Phobji

The fish community assessment conducted in the Gangtey-Phobji wetland revealed a relatively low species richness, which is consistent with the high-altitude cold-water environment of the region. The site is dominated by Brown Trout (*Salmo trutta*), a non-native species introduced in Bhutan for recreational purposes (Subedi et al., 2024).

The biodiversity indices of the Gangtey-Phobji site revealed an extremely low species diversity across all sampled plots and the study area as a whole. Plot-wise analyses showed that the Shannon diversity index was uniformly zero, indicating the exclusive presence of a single species, *Salmo tuttra*, with no measurable species diversity or evenness. This was corroborated by Simpson's diversity index values consistently reaching the maximum of 1, reflecting absolute dominance by *S. tuttra* at every sampling location. Species richness was consistently 1 across plots, confirming the monospecific composition of the community. Pielou's evenness and Margalef's richness indices were uniformly zero, further emphasizing the absence of species diversity and even distribution. Menhinick's index exhibited slight variability (ranging from 0.24 to 1) across plots likely attributable to differences in sample size rather than any real variation in biodiversity. (**Figure A5.10, see appendix**)

The overall diversity patterns of the study area persisted, with the Shannon index remaining at zero and Simpson's index at 1, reaffirming the overwhelming dominance of a single species. Species richness remained at 1, while both Pielou's evenness and Margalef's richness indices were 0, collectively indicating a lack of diversity and evenness at the landscape level (**Figure A5.3**). The low Menhinick's index value (.09) for the overall site further reflects the limited species richness and abundance structure observed.

Table 5.3: Diversity indices for the fish and macroinvertebrate communities at four sites.

	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng*
Fish				
Shannon Index	.31	0	0	na
Simpson Index	.17	1	1	na
Pielou's evenness	.45	0	0	na
Margalef's richness	.27	0	0	na
Menhinick's richness	.30	.09	0.09	na
Macroinvertebrates				
Shannon Index	3.23	2.64	2.54	2.70
Simpson Index	.95	.91	.89	.92
Pielou's evenness	6.37	3.16	3.95	3.36
Margalef's richness	.84	.56	.92	.63
Menhinick's richness	.81	.82	.76	.83

*Note: No fish species were encountered during the survey duration

5.2.1.2 Gaytsa-Domkhar

The diversity documented in Gaytsa-Domkhar exhibited similar patterns to those observed at Gangtey-Phobji, characterized by low species diversity and pronounced dominance of a single aquatic species (brown trout) across all the sampling sites. Plot-wise analyses showed that the Shannon diversity index was uniformly 0, indicating the exclusive presence of a single species, *Salmo trutta*, with no measurable species diversity or evenness. This was corroborated by Simpson's diversity index values consistently reaching the maximum of 1 (**Table 5.3**), reflecting absolute dominance by *S. trutta* at every sampling location. Species richness was consistently 1 across plots, confirming the monospecific composition of the community. Pielou's evenness and Margalef's richness indices were uniformly 0, further emphasizing the absence of species diversity and even distribution. Menhinick's index exhibited slight variability (ranging from .19 to .05) across plots, likely attributable to differences in sample size rather than any real variation in biodiversity.

The overall diversity patterns of the study area persisted, with the Shannon index remaining at 0 and Simpson's index at 1, highlighting the dominance of brown trout. Species richness was 1, while both Pielou's evenness and Margalef's richness indices were 0, collectively indicating a lack of diversity and evenness across the entire study area (**Table 5.3**). The low Menhinick's index value (.09) for the overall site further reflects the limited species richness and abundance structure observed.

5.2.1.3 Bumdeling

Overall, the diversity indices for Bumdeling (Shannon = .31; Simpson = .17; Margalef = .27; Menhinick's = .30) (**Table 5.3)**, suggest a more complex and heterogeneous aquatic community than that observed at Gangtey-Phobji and Gaytsa-Domkhar, indicating improved habitat conditions and the absence of invasive alien species.

5.2.2 Macroinvertebrates

The study recorded 8,722 individuals of macroinvertebrates under 14 orders, 42 families, and 59 genera (**Figure 5.2**). Of these, 4,090 individuals were recorded from Gangtey-Phobji, 1,987 from Gaytsa-Domkhar, 932 from Bumdeling, and 1,714 from Sakteng. The highest count in Gangtey-Phobji can be attributed to larger wetland area and higher number of sampling sites compared to other wetlands. *Diptera* (true flies) was the most dominant order (*n* = 387) followed by *Ephemeroptera* (mayflies) (*n* = 377), while *Gordioidea* (horsehair worms) and *Lepidoptera* (butterflies and moth) were the least dominant order with only one individual each. Likewise, *Chironomidae* (nonbiting midges) and *Heptageniidae* (flatheaded mayflies) were the most dominant family (*n* = 133), followed by *Siphlonuridae* (minnow mayflies) (*n* = 104), while *Athericidae* (water snipe flies), *Crambidae* (grass moths), Gordiidae, Leptoceridae (long-horned caddisflies), and *Libellulidae* (skimmer dragonflies) were the least dominant families with only one individual each. The most dominant genus was *Siphlonurus* (minnow mayflies) (*n* =961, RA = 11.02%), followed by *Probezzia* (biting midges) (n = 766, RA = 8.78%), while rare genera *Atherix* (water snipe flies), *Chematopsyche* (net spinning caddisfly), *Parapoynx* (aquatic moth), and *Sympetrum* (darter dragonfly) each contributed 0.01% to the total abundance (**Table 5.4**).

The macroinvertebrate community structure observed in the present study highlights a moderately diverse but unbalanced aquatic ecosystem. The dominance of *Siphlonurus* (Ephemeroptera), *Probezzia, Chironomus*, and *Simulium* (Diptera, black fly) suggests that the system is influenced by both naturally occurring conditions and possible moderate anthropogenic impacts (Srisuka et al., 2017). These taxa are typically tolerant of variable water quality, and their abundance may indicate organic enrichment or sedimentation (Lencioni et al., 2012).

The presence of *Trichoptera* (caddisflies), particularly *Hydropsyche* (net spinning caddisfly) and *Rhyacophila* (green caddisfly), suggest relatively clean, well-oxygenated, flowing water with structurally complex habitats. However, the comparatively low abundance of more sensitive groups such as Plecoptera (*Neoperla sp*, *Alloperla sp*) and some ephemeroptera such as *Ameletus sp* (mayfly) and *Hexagenia sp* (giant mayfly) may indicate localized habitat degradation or reduced ecological heterogeneity (Elias, 2021).

The steep dominance-abundance curve, with a few genera contributing a large portion of the total count, and many genera represented by few individuals, suggests a community under mild stress or transitional ecological conditions. This pattern, often seen in systems experiencing disturbance, highlights the need for continued ecological monitoring to assess long-term trends in water quality and habitat health.

Table 5.4: Taxonomic composition of aquatic macroinvertebrates recorded from the study area, showing Order, Family, Genus, Count (n), and Relative Abundance (RA%).

Sl.No.	Order	Family	Genus	Count	RA (%)
1	Ephemeroptera	Siphlonuridae	*Siphlonurus*	961	11.02
2	Diptera	Ceratopogonidae	*Probezzia*	766	8.78
3	Diptera	Chironomidae	*Chironomus*	690	7.91
4	Diptera	Simuliidae	*Simulium*	640	7.34
5	Ephemeroptera	Heptageniidae	*Epeorus*	604	6.93
6	Ephemeroptera	Baetidae	*Baetis*	486	5.57
7	Trichoptera	Hydropsychidae	*Hydropsyche*	384	4.40
8	Ephemeroptera	Ephemerellidae	*Ephemerella*	362	4.15
9	Diptera	Ceratopogonidae	*Culicoides*	349	4.00
10	Plecoptera	Perlidae	*Neoperla*	331	3.80
11	Ephemeroptera	Heptageniidae	*Leucrocuta*	285	3.27
12	Trichoptera	Rhyacophilidae	*Rhyacophila*	279	3.20
13	Tricladida	Planariidae	*Dugesia*	223	2.56
14	Trombidiformes	Hydrachnidae	*Hydrachna*	222	2.55
15	Trichoptera	Limnephilidae	*Pycnopsyche*	205	2.35
16	Ephemeroptera	Heptageniidae	*Heptagenia*	197	2.26
17	Ephemeroptera	Baetidae	*Acentrella*	171	1.96
18	Diptera	Tabanidae	*Tabanus*	167	1.91
19	Plecoptera	Capniidae	*Allocapnia*	157	1.80
20	Coleoptera	Elmidae	*Stenelmis*	154	1.77

Sl.No.	Order	Family	Genus	Count	RA (%)
21	Trichoptera	Calamoceratidae	*Heteroplectron*	144	1.65
22	Coleoptera	Hydrophilidae	*Hydrophilus*	119	1.36
23	Coleoptera	Psephenidae	*Ectopria*	75	0.86
24	Trichoptera	Philopotamidae	*Chimarra*	74	0.85
25	Ephemeroptera	Ephemerellidae	*Drunella*	65	0.75
26	Diptera	Tipulidae	*Dicronata*	64	0.73
27	Haplotaxida	Lumbricidae	*Lumbricus*	63	0.72
28	Trichoptera	Limnephilidae	*Dicosmoecus*	49	0.56
29	Coleoptera	Ptilodactylidae	*Anchytarsus*	48	0.55
30	Rhynchobdellida	Glossiphoniidae	*Placobdella*	40	0.46
31	Diptera	Tipulidae	*Tipula*	35	0.40
32	Ephemeroptera	Ephemeridae	*Hexagenia*	30	0.34
33	Coleoptera	Psephenidae	*Psephenus*	29	0.33
34	Plecoptera	Chloroperlidae	*Alloperla*	29	0.33
35	Diptera	Limoniidae	*Hexatoma*	26	0.30
36	Plecoptera	Perlidae	*Acroneuria*	26	0.30
37	Ephemeroptera	Ameletidae	*Ameletus*	25	0.29
38	Trichoptera	Limnephilidae	*Limnephilus*	20	0.23
39	Rhynchobdellida	Glossiphoniidae	*Helobdella*	16	0.18
40	Plecoptera	Perlodidae	*Isoperla*	13	0.15
41	Coleoptera	Dryopidae	*Helichus*	10	0.11
42	Diptera	Chironomidae	*Procladius*	10	0.11

Sl.No.	Order	Family	Genus	Count	RA (%)
43	Coleoptera	Hydrophilidae	*Berosus*	9	0.10
44	Haplotaxida	Almidae	*Glyphidrilus*	9	0.10
45	Trichoptera	Limnephilidae	*Apatania*	9	0.10
46	Trichoptera	Philopotamidae	*Dolophilodes*	9	0.10
47	Megaloptera	Corydalidae	*Nigronia*	8	0.09
48	Plecoptera	Taeniopterygidae	*Taeniopteryx*	7	0.08
49	Odonata	Gomphidae	*Ophiogomphus*	5	0.06
50	Coleoptera	Dytiscidae	*Agabus*	4	0.05
51	Odonata	Cordulegastridae	*Cordulegaster*	4	0.05
52	Gordioidea	Gordiidae	*Gordius*	3	0.03
53	Hemiptera	Gerridae	*Gerris*	3	0.03
54	Trichoptera	Leptoceridae	*Triaenodes*	3	0.03
55	Trichoptera	Limnephilidae	*Hesperophylax*	2	0.02
56	Diptera	Athericidae	*Atherix*	1	0.01
57	Lepidoptera	Crambidae	*Parapoynx*	1	0.01
58	Odonata	Libellulidae	*Sympetrum*	1	0.01
59	Trichoptera	Hydropsychidae	*Chematopsyche*	1	0.01
	Total			8,722	100.00

Note: Sl. No = Serial Number, RA = Relative Abundance

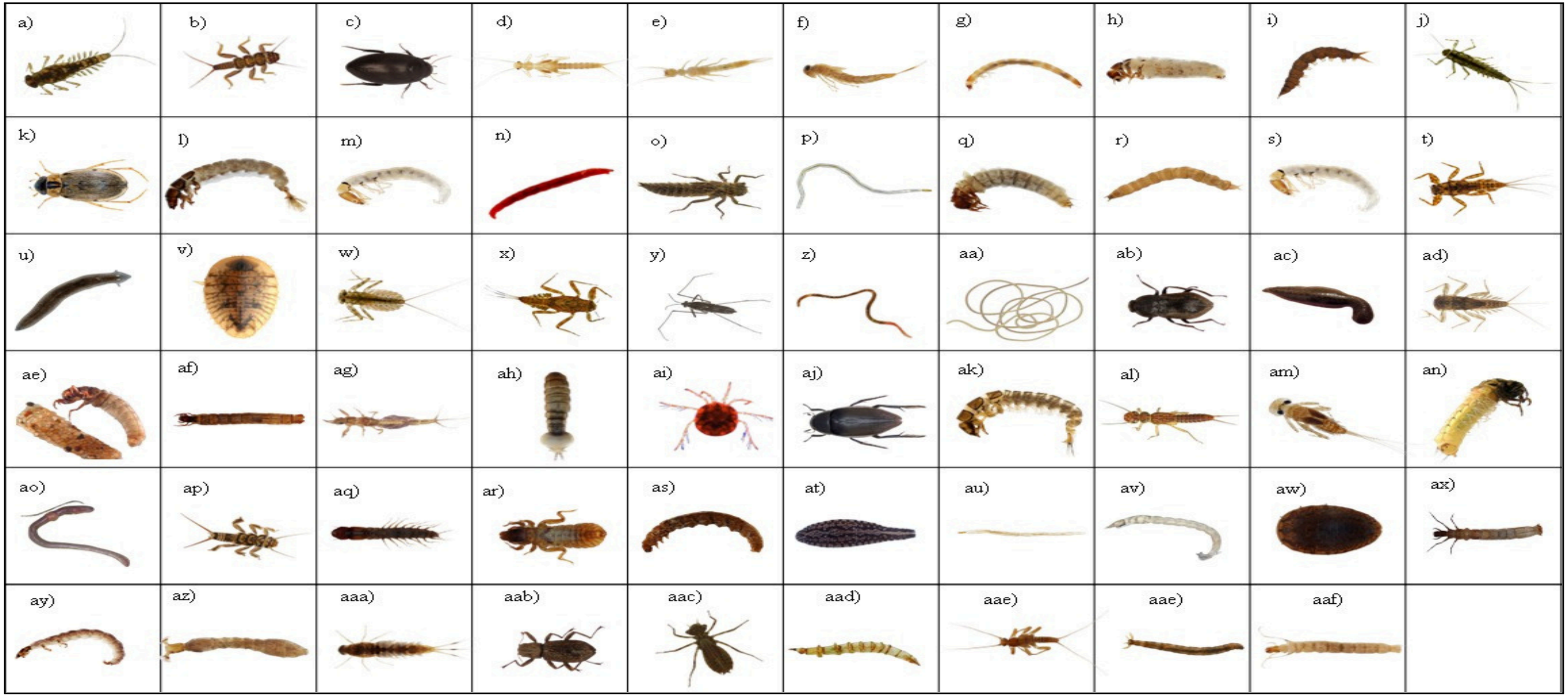

Figure 5.2: Macroinvertebrates recorded in the study area.

Accentrella a); Acroneuria b); Agabus c); Allocapnia d); Alloperla e); Ameletus f); Anchytarsus g); Apatania h); Atherix i); Baetis j); Berosus k); Chematopsyche l); Chimirra m); Chironomus n); Cordulegaster o); Culicoides p); Discosmoecus q); Dicronata r); Dolophilodes s); Drunella t); Dugesia u); Ectopria v); Epeorus w); Ephemerella x); Gerris y);Glyphidrilus z); Gordius aa); Helichus ab); Helobdella ac); Heptagenia ad); Hesperophylax ae); Heteroplectron af); Hexagenia ag); Hexatoma ah); Hydrichnida ai); Hydrophilus aj); Hydropsyche ak); Isoperla al); Leucrocuta am); Limnephilus an); Lumbricus ao); Neoperla ap); Nigronia aq);Ophiogomphus ar); Parapoynx as); Placobdella *at); Probezzia au); Procladius av); Psephenus aw); Pycnopsyche ax); Rhyacophila ay); Simulium az); Siphlonurus aaa); Stenelmis aab); Sympetrum aac); Tabanus aad); Taeniopteryx aaae); Tipula aae); Traenodes aaf).*

5.2.2.1 Gangtey-Phobji

The overall macroinvertebrate diversity in the Gangtey-Phobji wetland was also notably high. The Shannon index was 3.233, Simpson's index .94, and species richness 54 taxa, with high Margalef (6.37) and Pielou values (0.81) **(Table 5.3)**. These values indicate a diverse and well-balanced aquatic macroinvertebrate community in the study area.

5.2.2.1.1 Functional Feeding Group Composition of Macroinvertebrates in Gangtey-Phobji

A total of seven functional feeding groups (FFG) were identified in the study area (**Figure 5.3**). Gathering collectors (35.26%) was the most dominant group, which fed on fine particulate organic matter (FPOM) deposited on the streambed, highlighting the importance of decomposed organic material as a primary energy source (Merritt et al., 2008). The second most abundant group, scrapers (25.33%), consumes algae growing on submerged surfaces, indicating stable substrates and sufficient light for algal productivity. Similarly, filtering collectors, which filter suspended particles from flowing water, also contributed significantly (17.19%), suggesting well-oxygenated riffle areas with active water movement (Merritt et al., 2008). Predators (17.97%) formed an important functional component, reflecting a complex food web with effective prey availability and ecological balance. In contrast, detrital shredders (2.93%) were rare, suggesting limited input or breakdown of coarse organic matter, possibly due to riparian conditions or stream disturbance. Herbivore shredders (0.02%) and other minor groups (1.3%) occur in minimal numbers, representing specialized or less common feeding strategies.

5.2.2.2 Gaytsa-Domkhar

The overall community in Gaytsa-Domkhar recorded 25 taxa, with a Shannon index of 2.64 and Simpson's index of .91, indicating high diversity and low dominance across the site **(Table 5.3)**. This diversity profile suggests a healthy aquatic system supported by heterogeneous habitats, intact riparian zones, and minimal pollution or hydrological stress.

5.2.2.2.1 Functional Feeding Group Composition of Macroinvertebrates in Gaytsa-Domkhar

In Gaytsa-Domkhar wetland, filtering collectors was the most dominant group, comprising 31.61% of the community (**Figure 5.4**). This abundance indicates strong current velocity and high levels of suspended fine particulate organic matter (FPOM), likely supported by riffle habitats and good oxygenation. Scrapers were the second most abundant group (26.12%), suggesting the availability of stable substrates and algal biofilms, typically associated with clean water and moderate light conditions. Likewise, gathering collectors followed scrapers (25.67%), which feed on deposited FPOM, implying a mix of depositional areas and sediment retention within the stream channel. Detrital shredders accounted for 5.89%, highlighting the presence of coarse organic matter (leaf litter), likely from intact riparian zones and conifer needles. Predators made up 10.42% of the community, indicating a relatively complex trophic structure with sufficient prey availability and a functioning top-down regulatory mechanism in the food web. The category labelled "others" was minimal (0.30%), representing rare or functionally ambiguous taxa.

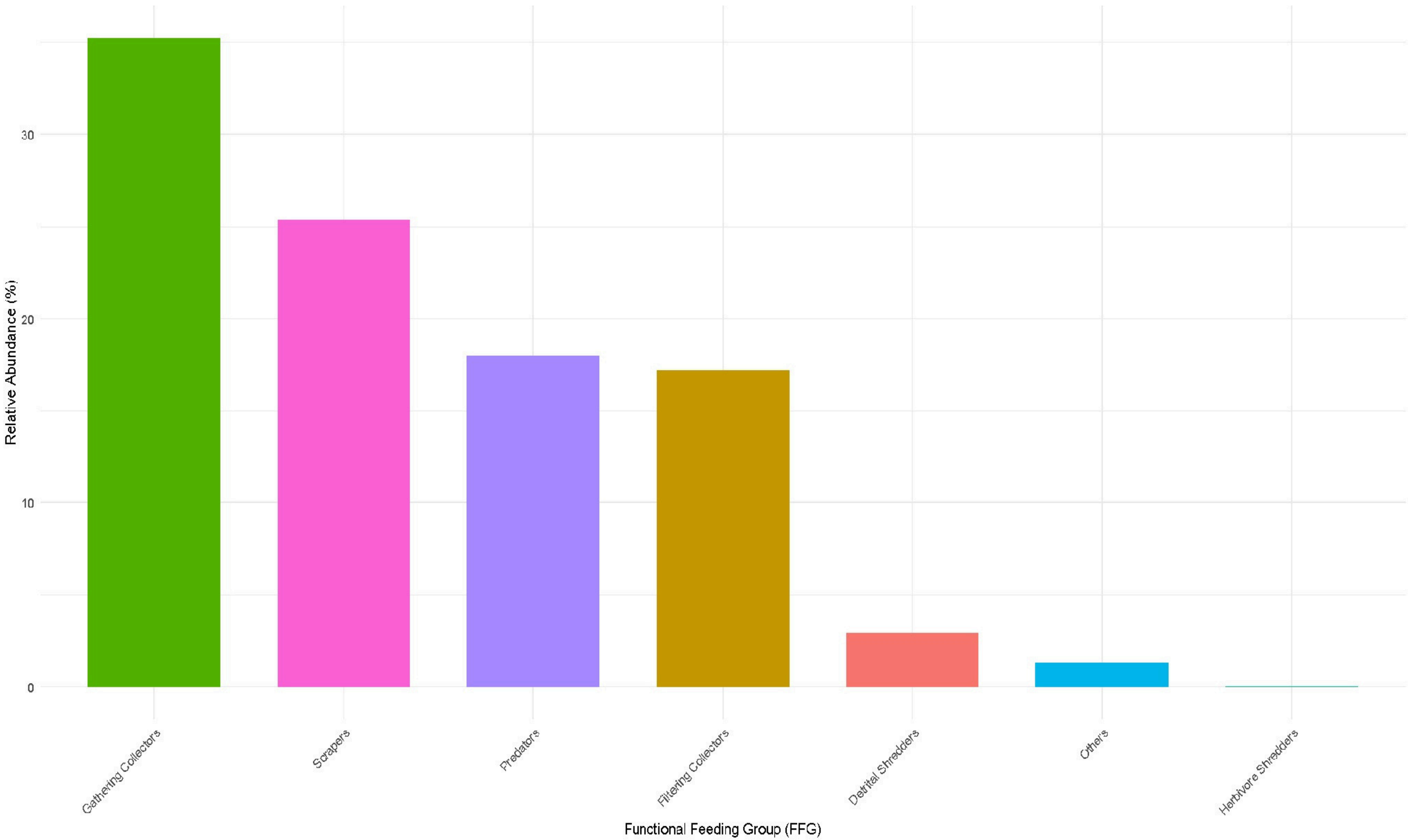

Figure 5.3. Relative Functional Feeding Group (FFG) Composition of Macroinvertebrates in Gangtey-Phobji (Retain)

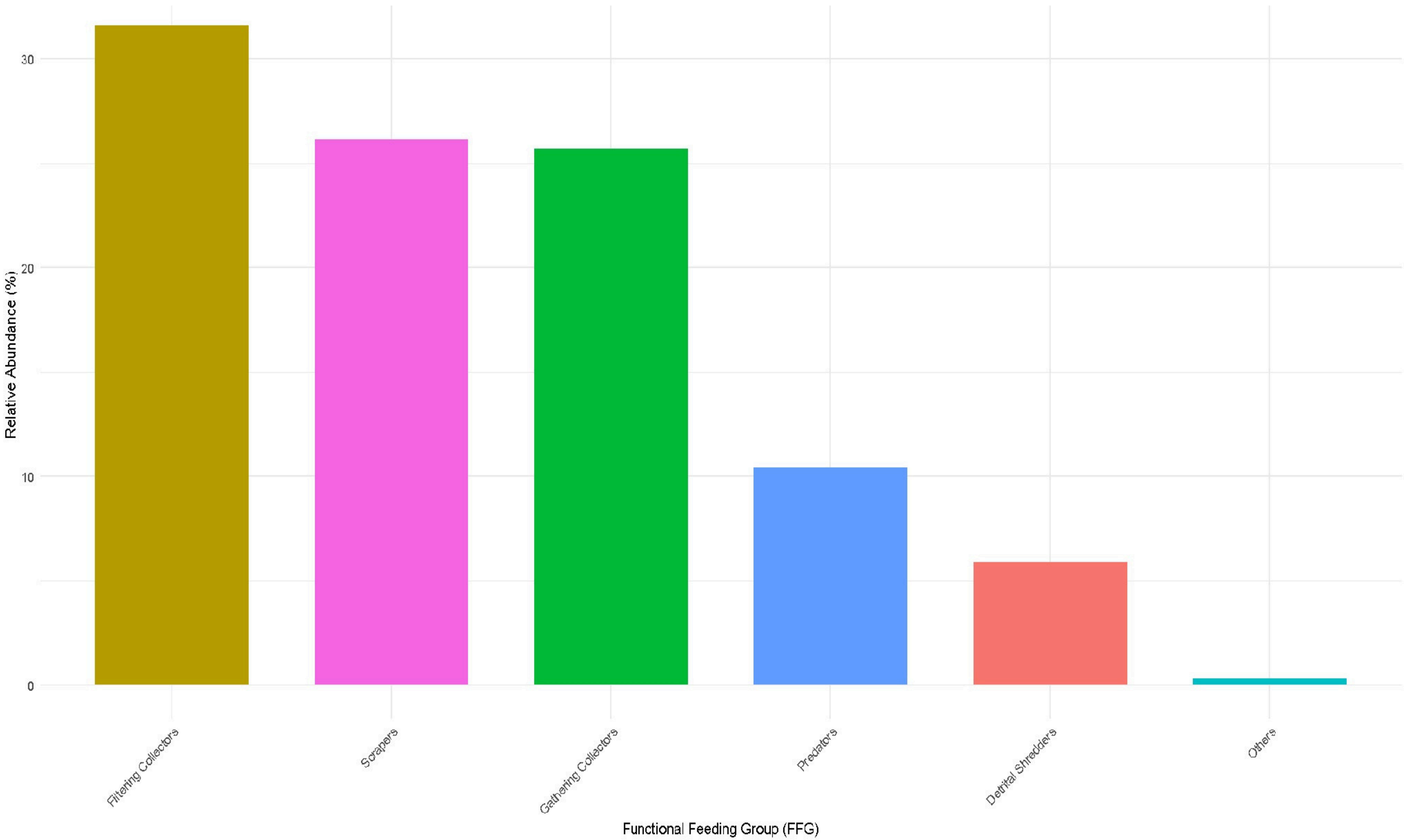

Figure 5.4. Relative Functional Feeding Group (FFG) composition of macroinvertebrates in Gaytsa-Domkha.

5.2.2.3 Bumdeling

Bumdeling recorded 28 genera of macroinvertebrates, with a Shannon index of 2.54 and Simpson's index of .89 (**Table 5.3**). These values suggest a robust aquatic assemblage, shaped by heterogeneous microhabitats, favorable environmental conditions, and minimal anthropogenic stress. The high diversity and evenness indices suggest that the area supports a structurally complex and resilient macroinvertebrate community, a key indicator of stream health and ecological health in high altitude freshwater ecosystems.

5.2.2.3.1 Functional Feeding Group Composition of Macroinvertebrates in Bumdeling

The macroinvertebrate community in Bumdeling was dominated by gathering collectors (45.22%), indicating a strong reliance on fine organic matter in sediments. Scrapers (18.90%) were the second most abundant, suggesting good algal availability on stable substrates. Filtering collectors (14.07%) reflected well-oxygenated flow habitats, while detrital shredders (12.89%) pointed to the presence of coarse organic inputs like leaf litter. Predators (8.92%), though the least common, contributed to trophic complexity (**Figure 5.5**).

5.2.2.4 Sakteng

In Sakteng, the Shannon index was 2.70 and Simpson's index of .92, indicating high diversity and low dominance across the site **(Table 5.3)**. This diversity profile suggests a healthy aquatic system supported by heterogeneous habitats, intact riparian zones, and minimal pollution or hydrological stress.

5.2.2.4.1 Functional Feeding Group Composition of Macroinvertebrates in Sakteng

In Sakteng, the macroinvertebrate community is primarily composed of gathering collectors (27.13%), indicating abundant fine particulate organic matter in the benthic zone. Predators (24.45%) and scrapers (21.00%) were also well represented, reflecting a complex food web with significant algal grazing activity. Filtering collectors (20.19%) suggest the presence of flowing habitats with suspended organic material, while detrital shredders (7.23%) contributed to the breakdown of coarse organic matter (**Figure 5.6**).

5.2.3 Water Quality

5.2.3.1 Gangtey-Phobji Physical Parameters

The physical water quality parameters across all sampling sites were largely within national standards (**Table 5.5**). Parameters such as temperature, Total Dissolved Solids (TDS), Total Suspended Solid (TSS), Turbidity (T), and Electrical Conductivity (EC) reflected excellent water clarity and low levels of particulate and mineral content. However, pH values at most sampling sites slightly exceeded the upper limit of 8.5, indicating mild alkaline conditions, may affect taste and treatment efficiency but are not harmful to health. Overall, the physical quality of the water suggests, clean, low in sediment and mineral load, and suitable for most uses with minimal treatment

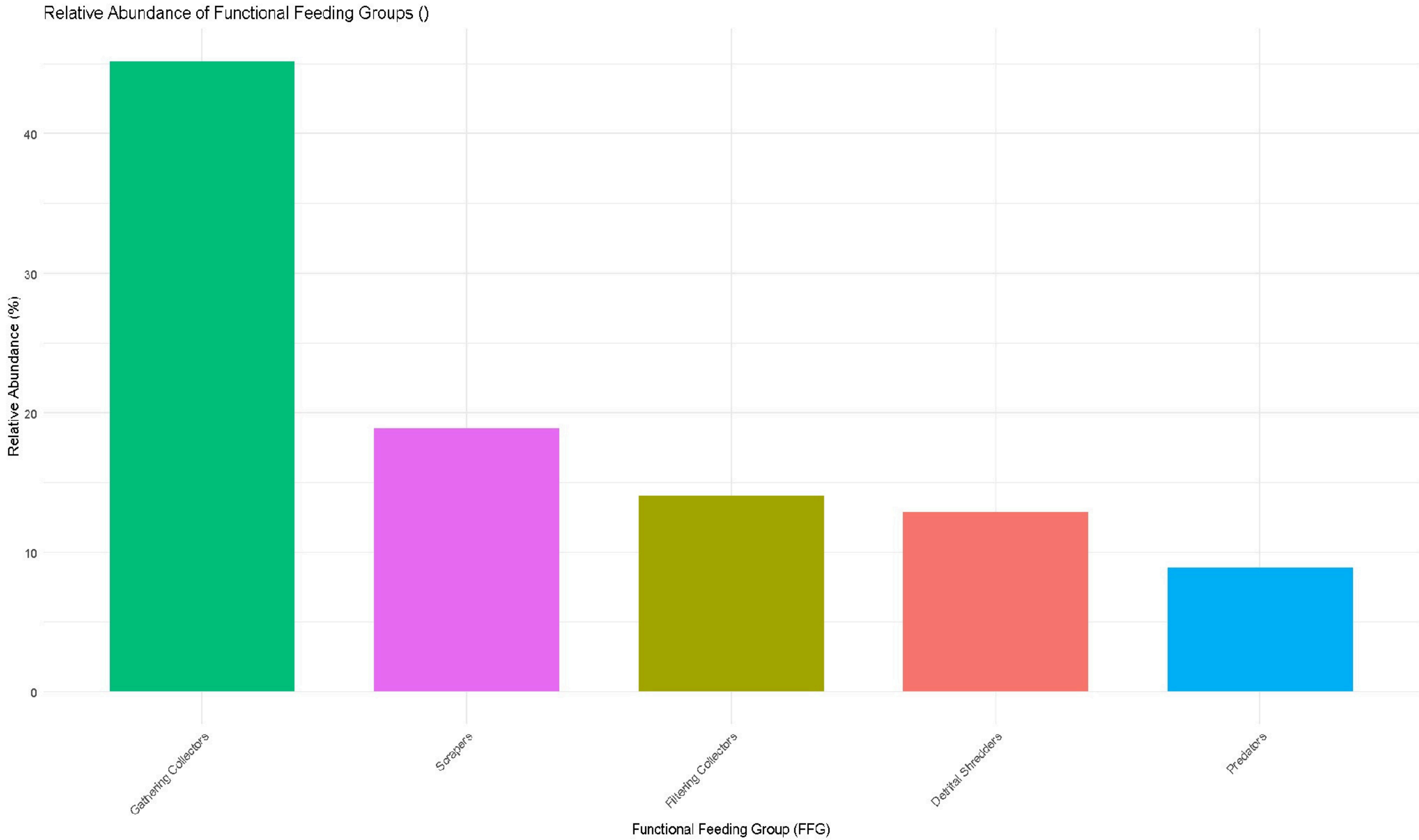

Figure 5.5: Relative Functional Feeding Group (FFG) composition of macroinvertebrates in Bumdeling

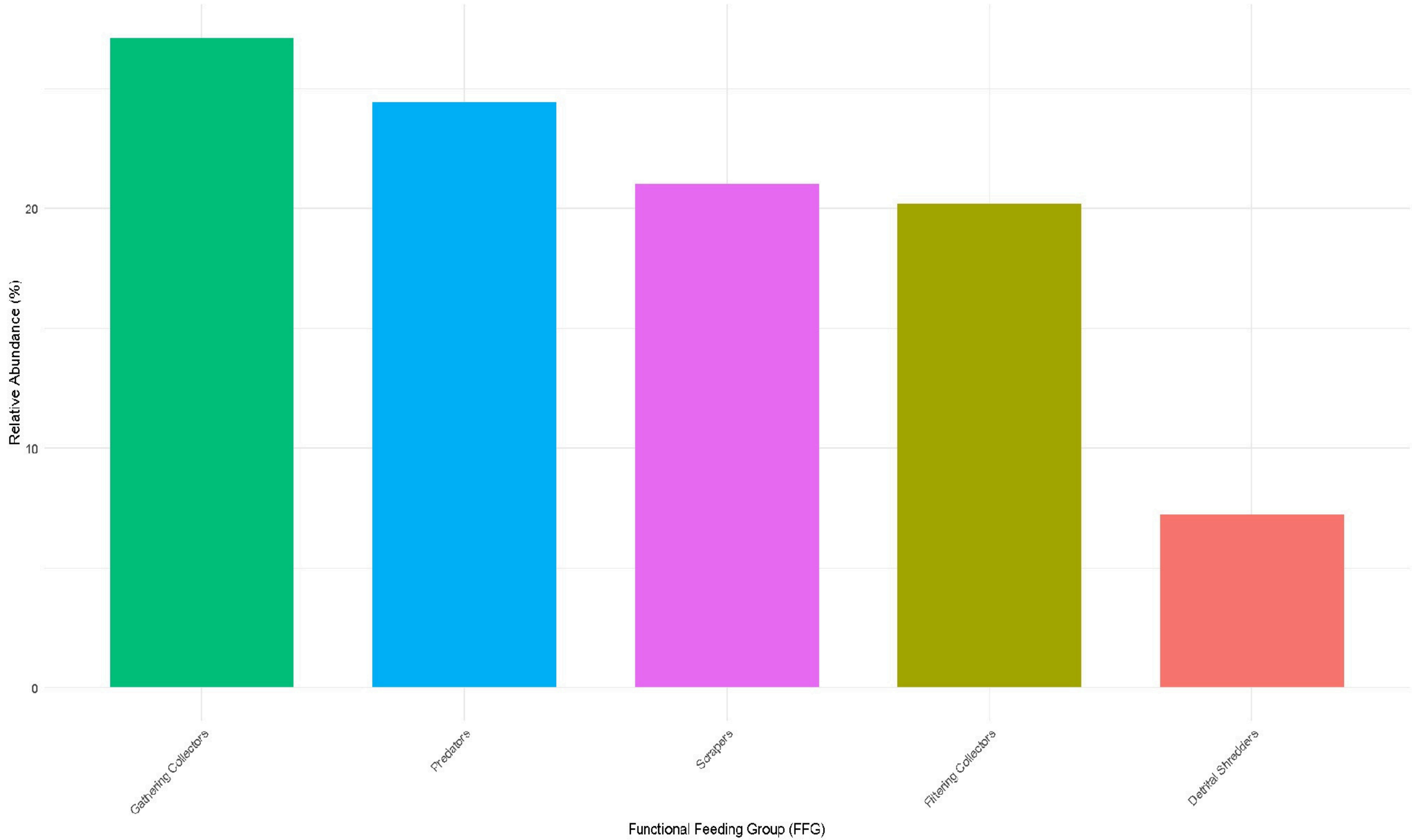

Figure 5.6: Relative Functional Feeding Group (FFG) composition of macroinvertebrates in Sakteng

Table 5.5: Gangtey-Phobji: Physical Water Parameters against national Ambient and drinking water quality standards

Parameters		pH (scale)	Turbidity (NTU)	Temp (oC)	TDS (mg/L)	TSS (mg/L)		EC (µS/cm)
Standards	**AWQC**	6.5-8.5[a]	5	-	24.3	25[a]		800[a]
		6.0-9.0[b]				100[b]		1000[b]
		6.0-9.0[c]						2000[c]
	BDW	6.5-8.5		-	20.7	-	5	-
Sampling Sites	M1	8.9		11.6	23.7	0.89	1.07	27
	M2	8.9		9.5	20.9	0.61	1.28	32
	M3	8.8		10.5	24.3	0.19	1.29	33
	M4	9.1		12	18.7	2.67	3.22	32
	M5	9.5		9.2	18.5	3.46	5.74	31
	M6	9.6		8.5	30.4			45
	M7	8.8		10.9	21.1			24
	M8	8.9		13.2	18.7			25
	M9	9.3		11.3	19.6			28
	M10	9.3		9.3	21			28
	M11	9.5		11.3	21.5			47
	M12	9.5		13.1	25.1			42
	M13	9.1		14.5	17.2			32
	M14	8.6		13.4	20.5			50
	M15	9.2		13.9	13.4			50
	M16	9		15.2	14.6			20

Parameters	pH (scale)	Temp (oC)	TDS (mg/L)	TSS (mg/L)	Turbidity (NTU)	EC (µS/cm)
T1	8.5	15.5	18.7			29
T2	9.1	7.8	12.6			55
T3	9.4	12.6	32.1			82
T4	9.5	13.2	17.7			74
T5	9.5	7.7	39.4			76
T6	8.9	7.4	24.3			102
T7	9.6	17.3	20.7			38

Notes: Sampling sites (M = Main River, T = Tributary,)

STANDARDS*:* (AWQC: Ambient Water Quality Criteria, 2020; BDW: Bhutan Drinking Water Quality Standard, 2016).

[a]Very Good, Drinking water source without conventional treatment, but after disinfection whenever necessary;

[b]Good, drinking water source with conventional treatment; [3]Moderate, Uses for irrigation, industrial cooling etc.

[c]Desirable limit; [b]maximum permissible limit

(-) No reference available

Table 5.6: Water Chemical parameters for Gangtey-Phobji against Ambient Water Quality Standards

Parameters		DO (mg/L)	Total Hardness (mg/L) as $CaCO_3$	Cl (mg/L)	NH_3 (mg/L)	Fe (ppm)	Mg (mg/L)	Salinity (ppm)
Standards	**AWQC**	6a 4b	200[a]	50[a] 200[b]	0.05[a] 0.5[b]	0.05[a] 0.5[b]	0.05[a] 0.5[b]	-
Sampling Sites	M1	5.81	30	0.62	0.02	0.06	14	19.5
	M2	5.45	26	0.70	0.01	0.5	16	17.9
	M3	4.94	28	0.63	0.01	0.05	14	18.9
	M4	4.79	24	0.5	0.01	0.49	18	15.6
	M5	4.67	22	0.8	0.01	0.09	16	18.4
	M6							15.5
	M7							16
	M8							23.8
	M9							18.2
	M10							17.1
	M11							17
	M12							16.5
	M13							21.6
	M14							19.7
	M15							15.4
	M16							16.6
	T1							12.2

	T2	13.7
	T3	13.9
	T4	11.5
	T5	25.1
	T6	14.1
	T7	32.6

Notes: Sampling sites (Site 1: 1 to 2 km upstream of Main Dam; Site 2: Main Dam; Site 3: Stretch 1 between Regulating and Main Dam; Site 4: Stretch 2 between Regulating and Main Dam; Site 5: Regulating Dam; Site 6: 1-2 km downstream of Regulating Dam)

STANDARDS*:* (AWQC: Ambient Water Quality Criteria, 2020; BDW: Bhutan Drinking Water Quality Standard, 2016; EPA Human Health Ambient Water Quality Criteria, 2015; WHO Guidelines for Drinking Water Quality, 2017).

*Maximum concentration limits

[1]Very Good, drinking water source without conventional treatment, but after disinfection whenever necessary; [2]Good, drinking water source with conventional treatment; [3]Moderate, Uses for irrigation, industrial cooling etc.

[a]Desirable limit; [b]maximum permissible limit

(-) No reference available

5.2.3.2 Gangtey-Phobji Chemical Parameters

The chemical water quality across different sampling sites showed good conditions when compared to Ambient Water Quality Criteria (AWQC) (**Table 5.6**). Dissolved oxygen (DO) levels range from 4.67 to 5.81 mg/L (below the ideal 6 mg/L but above the minimum permissible 4 mg/L) which are sufficient oxygen for aquatic life. Total hardness was low (22–30 mg/L $CaCO_3$), reflecting soft water, while chloride and ammonia concentrations remained very low (well under their respective limits), suggesting minimal pollution. Iron levels vary, but in some sites, levels are close to the maximum permissible limit of 0.5 ppm and may require monitoring of water quality. Magnesium levels correspond with the soft water profile, and salinity across sampling sites was consistently low (11.5–32.6 ppm), well below the 200ppm threshold. Overall, the river exhibits good chemical quality, suitable for ecological health and potential water use, though monitoring of iron and DO is recommended.

5.2.3.2 Gaytsa-Domkhar, Bumdeling, and Sakteng

In Gaytsa-Domkhar, Bumdeling, and Sakteng, only three water physicochemical parameters (one physical and two chemical parameters) were measured (**Table 5.7**). Analyses show that pH levels across all sampling sites mostly fall within acceptable range, with a few values slightly exceeding the BDW's limit. Temperatures varied considerably across study sites. Electrical conductivity remained well below the maximum permissible levels, indicating low mineral and ion content across all sites.

Table 5.7: Physicochemical water quality parameters for Gyatsa-Domkhar, Bumdeling, and Sakteng against national Ambient and Drinking Water Quality standards

Parameters		pH (scale)	Temp (oC)	EC (µS/cm)
Standards	**AWQC**	6.5-8.5[a]	-	800[a]
		6.0-9.0[b]		1000[b]
		6.0-9.0[c]		2000[c]
	BDW	6.5-8.5	-	-
Gaytsa-Domkhar	M1	11.6	8.9	27
	M2	9.5	8.9	32
	M3	10.5	8.8	33
	M4	12	9.1	32
	M5	9.2	9.5	31
	M6	8.5	9.6	45
	T1a	10.9	8.8	24
	T1b	13.2	8.9	25
	T2a	11.3	9.3	28
	T2b	9.3	9.3	28

Parameters		EC (µS/cm)	pH (scale)	Temp (oC)
Bumdeling	M1	47	11.3	9.5
	M2	42	13.1	9.5
	M3	32	14.5	9.1
	M4	50	13.4	8.6
	M5	50	13.9	9.2
	T1	20	15.2	9
	T2	29	15.5	8.5
Sakteng	M1	55	7.8	9.1
	M2	82	12.6	9.4
	M3	74	13.2	9.5
	T1	76	7.7	9.5
	T2	102	7.4	8.9
	T3	38	17.3	9.6
	T4	102	13.8	9.2

Notes: Sampling sites (M = Main River, T = Tributary, T1a = Upstream of Tributary 1, T1b = Downstream of Tributary 2, T2a = Upstream of Tributary 2, T2b = Downstream of Tributary 2)
STANDARDS*:* (AWQC: Ambient Water Quality Criteria, 2020; BDW: Bhutan Drinking Water Quality Standard, 2016). Does not apply to temperature.

[a]Very Good, Drinking water source without conventional treatment, but after disinfection whenever necessary;

[b]Good, drinking water source with conventional treatment; [3]Moderate, Uses for irrigation, industrial cooling etc.

[c]Desirable limit; [b]maximum permissible limit

(-) No reference available

5.2 Avifauna

The study documented a total of 133 bird species, encompassing both resident and migratory populations, distributed across 48 families (**Table 5.8**). Most of these species (130) were classified as Least Concern by the International Union for Conservation of Nature (IUCN), with only a few listed as Near Threatened [NT] or Vulnerable [VU]. The consolidated species list underscores Bhutan’s rich avian diversity, reinforcing its reputation as a key birding hotspot.

Table 5.8: List of bird species recorded across all sites with their common name, family, scientific name, and IUCN status. The green box indicates presence and red indicates the absence of bird species recorded during thestudyat eachspecificsite.

List of Birds	Family	Scientific Name	IUCN Status	Gangtey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
AshyDrongo	Dicruridae	*Dicrurusleucophaeus*	LC	Red	Red	Green	Green
Ashy-throated Warbler	Phylloscopidae	*Phylloscopus maculipennis*	LC	Red	Red	Red	Green
Bar-headed Goose	Anatidae	*Anser indicus*	LC	Green	Red	Red	Red
Barred-Cuckoo Dove	Columbidae	*Macropygia unchall*	LC	Red	Red	Green	Red
Bar-winged Flycatcher-shrike	Platylophidae	*Hemipus picatus*	LC	Red	Green	Red	Red
Bhutan Laughingthrush	Leiothrichidae	*Trochalopteron imbricatum*	LC	Red	Red	Red	Red
Black Bulbul	Pycnonotidae	*Hypsipetes leucocephalus*	LC	Red	Red	Green	Red
Black Eagle	Accipitridae	*Ictinaetus malayensis*	LC	Red	Red	Green	Red
Black Redstart	Muscicapidae	*Phoenicurus ochruros*	LC	Green	Red	Red	Red
Black-faced Laughingthrush	Leiothrichidae	*Trochalopteron affine*	LC	Green	Green	Red	Green
Black-necked Crane	Gruidae	*Grus nigricollis*	NT	Green	Red	Red	Red
Black-rumped Magpie	Corvidae	*Pica bottanensis*	LC	Green	Green	Red	Red
Black-throated Sunbird	Nectariniidae	*Aethopyga saturata*	LC	Red	Red	Green	Red
Black-throated Thrush	Turdidae	*Turdus atrogularis*	LC	Green	Red	Red	Red
Blood Pheasant	Phasianidae	*Ithaginis cruentus*	LC	Red	Green	Green	Red
Blue Whistling-Thrush	Muscicapidae	*Myophonus caeruleus*	LC	Green	Green	Green	Red
Blue-capped Rock Thrush	Muscicapidae	*Monticola cinclorhyncha*	LC	Red	Red	Green	Red
Blue-fronted Redstart	Muscicapidae	*Phoenicurus frontalis*	LC	Green	Red	Red	Red
Blyth's Leaf Warbler	Phylloscopidae	*Phylloscopus reguloides*	LC	Red	Green	Red	Green

List of Birds	Family	Scientific Name	IUCN Status	Gangtey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
Blyth's Swift	Apodidae	*Apusleuconyx*	LC				
Brown Dipper	Cinclidae	*Cinclus pallasii*	LC				
Brownish-flanked Bush Warbler	Cettiidae	*Horornis fortipes*	LC				
Brown-throated Fulvetta	Alcippeidae	*Alcippe ludlowi*	LC				
Buff-barred Warbler	Phylloscopidae	*Phylloscopus pulcher*	LC				
Chestnut-crowned Laughingthrush	Leiothrichidae	*Garrulax erythrocephalus*	LC				
Chestnut-tailed Minla	Leiothrichidae	*Minla strigula*	LC				
Coal Tit	Paridae	*Periparus ater*	LC				
Collared Owlet	Strigidae	*Glaucidium brodiei*	LC				
Common Buzzard	Accipitridae	*Buteo buteo*	LC				
Common Cuckoo	Cuculidae	*Cuculus canorus*	LC				
Common Kingfisher	Alcedinidae	*Alcedo atthis*	LC				
Crested Serpent-Eagle	Accipitridae	*Spilornis cheela*	LC				
Dark-sided Flycatcher	Muscicapidae	*Muscicapa sibirica*	LC				
Eurasian Hoopoe	Upupidae	*Upupa epops*	LC				
Eurasian Jay	Corvidae	*Garrulus glandarius*	LC				
Eurasian Kestrel	Falconidae	*Falco tinnunculus*	LC				
Eurasian Sparrowhawk	Accipitridae	*Accipiter nisus*	LC				
Eurasian Tree Sparrow	Passeridae	*Passer montanus*	LC				
Eurasian Wern	Troglodytidae	*Troglodytes troglodytes*	LC				

List of Birds Fire-	Family	Scientific Name	IUCN Status	Gangtey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
breastedFlowerpecker	Dicaeidae	*Dicaeum ignipectus*	LC				
Goldcrest	Regulidae	*Regulus regulus*	LC				
Great Barbet	Megalaimidae	*Psilopogon virens*	LC				
Greater Yellownape	Picidae	*Chrysophlegma flavinucha*	LC				
Green Sandpiper	Scolopacidae	*Tringa ochropus*	LC				
Green-backed Tit	Paridae	*Parus monticolus*	LC				
Green-crowned Warbler	Phylloscopidae	*Phylloscopus coronatus*	LC				
Greenish Warbler	Phylloscopidae	*Phylloscopus trochiloides*	LC				
Green-tailed Sunbird	Nectariniidae	*Aethopyga nipalensis*	LC				
Gray Bushchat	Muscicapidae	*Saxicola ferreus*	LC				
Gray Treepie	Corvidae	*Dendrocitta formosae*	LC				
Gray Wagtail	Motacillidae	*Motacilla cinerea*	LC				
Gray-backed Shrike	Laniidae	*Lanius tephronotus*	LC				
Gray-bellied Tesia	Cettiidae	*Tesia cyaniventer*	LC				
Gray-crested Tit	Paridae	*Lophophanes dichrous*	LC				
Gray-headed Canary-Flycatcher	Stenostiridae	*Culicicapa ceylonensis*	LC				
Gray-headed Woodpecker	Picidae	*Picus canus*	LC				
Gray-hooded Wabbler	Phylloscopidae	*Phylloscopus xanthoschistos*	LC				
Gray-winged Blackbird	Turdidae	*Turdus boulboul*	LC				
Hen Harrier	Accipitridae	*Circus cyaneus*	LC				

List of Birds	Family	Scientific Name	IUCN Status	Gangtey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
Hill partridge	Phasianidae	*Arborophila torqueola*	LC				
Himalayan Beautiful Rosefinch	Fringillidae	*Carpodacus pulcherrimus*	LC				
Himalayan Bluetail	Muscicapidae	*Tarsiger rufilatus*	LC				
Himalayan Griffon	Accipitridae	*Gyps himalayensis*	NT				
Himalayan Monal	Phasianidae	*Lophophorus impejanus*	LC				
Himalayan Owl	Strigidae	*Strix nivicolum*	LC				
Hogsons Redstart	Muscicapidae	*Phoenicurus hodgsoni*	LC				
Hogson's Treecreeper	Certhiidae	*Certhia hodgsoni*	LC				
House sparrow	Passeridae	*Passer domesticus*	LC				
Indian White-eye	Zosteropidae	*Zosterops palpebrosus*	LC				
Kalij Pheasant	Phasianidae	*Lophura leucomelanos*	LC				
Large Hawk-Cuckoo	Cuculidae	*Hierococcyx sparverioides*	LC				
Large-billed Crow	Corvidae	*Corvus macrorhynchos*	LC				
Large-billed Leaf Warbler	Phylloscopidae	*Phylloscopus magnirostris*	LC				
Lemon-rumped Warbler	Phylloscopidae	*Phylloscopus chloronotus*	LC				
Little Bunting	Emberizidae	*Emberiza pusilla*	LC				
Little Forktail	Muscicapidae	*Enicurus scouleri*	LC				
Long-billed Plover	Charadriidae	*Charadrius placidus*	LC				
Long-tailed Minivet	Campephagidae	*Pericrocotus ethologus*	LC				
Long-tailed Shrike	Laniidae	*Lanius schach*	LC				

List of Birds	Family	Scientific Name	IUCN Status	Gangtey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
Long-tailedSibia	Leiothrichidae	*Heterophasiapicaoides*	LC				
Mallard	Anatidae	*Anas platyrhynchos*	LC				
Maroon Oriole	Oriolidae	*Oriolus traillii*	LC				
Mrs. Gould's Sunbird	Nectariniidae	*Aethopyga gouldiae*	LC				
Nepal House-Martin	Hirundinidae	*Delichon nipalense*	LC				
Olive-backed Pipit	Motacillidae	*Anthus hodgsoni*	LC				
Oriental Skylark	Alaudidae	*Alauda gulgula*	LC				
Oriental Turtle-Dove	Columbidae	*Streptopelia orientalis*	LC				
Paddyfield Pipit	Motacillidae	*Anthus rufulus*	LC				
Plumbeous Redstart	Muscicapidae	*Phoenicurus fuliginosus*	LC				
Pygmy Cupwing	Pnoepygidae	*Pnoepyga pusilla*	LC				
Red Crossbill	Fringillidae	*Loxia curvirostra*	LC				
Red-billed Chough	Corvidae	*Pyrrhocorax pyrrhocorax*	LC				
Red-billed Leiothrix	Leiothrichidae	*Leiothrix lutea*	LC				
Red-tailed Minla	Leiothrichidae	*Minla ignotincta*	LC				
Red-throated Thrush	Turdidae	*Turdus ruficollis*	LC				
Red-vented Bulbul	Pycnonotidae	*Pycnonotus cafer*	LC				
Red-wattled Lapwing	Charadriidae	*Vanellus indicus*	LC				
Ruddy Shelduck	Anatidae	*Tadorna ferruginea*	LC				
Rufous Sibia	Leiothrichidae	*Heterophasia capistrata*	LC				
Rufous-bellied Niltava	Muscicapidae	*Niltava sundara*	LC				

List of Birds	Family	Scientific Name	IUCN Status	Gangtey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
Rufous-bellied Woodpecker	Picidae	*Dendrocopos hyperythrus*	LC				
Rufous-breasted Accentor	Prunellidae	*Prunella strophiata*	LC				
Rufous-capped Babbler	Timaliidae	*Stachyridopsis ruficeps*	LC				
Rufous-fronted Tit	Paridae	*Sittiparus castaneiceps*	LC				
Rufous-gorgeted Flycatcher	Muscicapidae	*Ficedula strophiata*	LC				
Rufous-vented Tit	Paridae	*Parus rubidiventris*	LC				
Rufous-vented Yuhina	Zosteropidae	*Yuhina occipitalis*	LC				
Russet Sparrow	Passeridae	*Passer rutilans*	LC				
Rusty-cheeked Scimitar-Babbler	Timaliidae	*Erythrogenys erythrocercus*	LC				
Rusty-flanked Treecreeper	Certhiidae	*Certhia nipalensis*	LC				
Satyr Tragopan	Phasianidae	*Tragopan satyra*	NT				
Scarlet Finch	Fringillidae	*Haematospiza sipahi*	LC				
Scarlet Minivet	Campephagidae	*Pericrocotus speciosus*	LC				
Siberian Stonechat	Muscicapidae	*Saxicola maurus*	LC				
Small Niltava	Muscicapidae	*Niltava macgrigoriae*	LC				
Snow Pigeon	Columbidae	*Columba leuconota*	LC				
Southern Nutcracker	Corvidae	*Nucifraga caryocatactes*	LC				
Spotted Forktail	Muscicapidae	*Enicurus maculatus*	LC				
Streak-breasted Scimitar -Babbler	Timaliidae	*Erythrogenys gravivox*	LC				
Stripe-throated Yuhina	Zosteropidae	*Yuhina gularis*	LC				

List of Birds	Family	Scientific Name	IUCN Status	Gangtey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
UltramarineFlycatcher	Muscicapidae	*Ficedula superciliaris*	LC				
Verditer Flycatcher	Muscicapidae	*Eumyias thalassinus*	LC				
Whistler's Warbler	Phylloscopidae	*Phylloscopus whistleri*	LC				
White Wagtail	Motacillidae	*Motacilla alba*	LC				
White-browed Fulvetta	Leiothrichidae	*Fulvetta vinipectus*	LC				
White-browed Shrike-Babbler	Vireonidae	*Pteruthius aeralatus*	LC				
White-browed Wagtail	Motacillidae	*Motacilla maderaspatensis*	LC				
White-capped Redstart	Muscicapidae	*Chaimarrornis leucocephalus*	LC				
White-collared Blackbird	Turdidae	*Turdus albocinctus*	LC				
White-tailed Nuthatch	Sittidae	*Sitta himalayensis*	LC				
White-throated Laughingthrush	Leiothrichidae	*Pterorhinus albogularis*	LC				
Yellow-billed Blue Magpie	Corvidae	*Urocissa flavirostris*	LC				
Yellow-browed Tit	Paridae	*Sylviparus modestus*	LC				

Notes: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Deficient

5.3 Mammals

The study documented a total of 49 mammal species representing 20 families. Data were compiled from field observations (both direct and indirect), FGDs, and secondary sources. All records consisted of presence-absence data, and based on IUCN Red List classifications, the recorded species included 20 categorized as LC, 13 as Data Deficient [DD], 8 as VU, 7 as Endangered [EN], and 1 as NT. (**Table 5.9**)

5.4 Reptiles

The study sites of Gangtey-Phobji, Gaytsa-Domkhar, and Sakteng were found to be suboptimal for reptile observations. Data collection methods in this area included direct and indirect field observations, FGDs, and secondary sources . The study documented 38 snake species representing 3 families (**Table 5.10**), including eight species identified only to family level in previous work (Wangyal & Tenzin, 2009). Among these, the study confirmed field observations of ecologically significant species including the False Cobra (*Pseudoxenodon macrops)* and King Cobra (*Ophiophagus hannah)*. The survey also documented seven lizard species across three families (**Table 5.11**).

Table 5.9: List of mammals' species recorded across all sites with their common name, family, scientific name, and IUCN status. The green box indicates presence and red indicates the absence of mammal species recorded duringthe studyat eachspecificsite.

Family	List of Mammals	Scientific Name	IUCN Status	Gangatey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
Cercopithecidae	AssameseMacaque	*Macacaassamensis*	VU	Green	Green	Green	Green
Cercopithecidae	Capped Langur	*Trachypithecus pileatus*	EN	Red	Red	Green	Green
Cercopithecidae	Gray Langur	*Semnopithecus entellus*	LC	Green	Green	Red	Red
Canidae Canidae	Golden or Common Jackal	*Canis aureus*	LC	Green	Green	Green	Red
Canidae Ursidae	Red Fox	*Vulpes Vulpes*	LC	Green	Green	Green	Green
Ursidae	Dhole or Wild Dog	*Cuon alpinus primaevus*	EN	Green	Green	Green	Green
Ailuridae	Sloth Bear	*Melursus ursinus*	VU	Red	Red	Green	Red
Mustelidae	Himalayan Black Bear	*Ursus thibetanus*	EN	Green	Green	Green	Green
Mustelidae	Red Panda	Ailurus Fulgens	EN	Green	Green	Green	Green
Mustelidae	Himalayan Weasel	*Mustela sibirica*	LC	Green	Green	Green	Green
Mustelidae	Pale Weasel	*Mustela altaica*	DD	Green	Green	Green	Green
Mustelidae	Yellow Bellied Weasel	*Mustela kathiah*	LC	Green	Green	Green	Green
Mustelidae	Beech or Stone Marten	*Martes foina*	LC	Green	Green	Green	Green
Viverridae	Himalayan Yellow Throated Marten	*Martes flavigula*	LC	Green	Green	Green	Green
Viverridae	Common Otter	*Lutra Lutra*	LC	Green	Green	Green	Green
	Small Indian Civet	*Viverricula indica*	VU	Red	Red	Green	Red
	Common Palm Civet	*Paradoxurus hermaphroditus*	LC	Red	Red	Green	Red

Family	List of Mammals	Scientific Name	IUCN Status	Gangatey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
Viverridae	HimalayanPalm Civet	*Paguma larvata*	LC				
Prionodontidae	Spotted Linsang Common	*Prionodon pardiclor*	EN				
Herpestidae	Mongose	*Herpestes edwardsii*	LC				
Felidae	Tiger	*Panthera tigris*	EN				
Felidae	Common Leopard	*Panthera pardus*	LC				
Felidae	Snow Leopard	*Uncia Uncia*	EN				
Felidae	Clouded Leopard	*Neofelis nebulosa*	VU				
Felidae	Asiatic Golden Cat	*Catopuma temmincki*	VU				
Felidae	Himalayan Lynx Marbled	*Lunx lynx*	LC				
Felidae	Cat	*Pardofelis marmorata*	VU				
Felidae	Leopard Cat	*Prionailurus bengalensis*	LC				
Felidae	Juncle Cat	*Felis chaus*	LC				
Felidae	Pallas Cat	*Otocolobus manul*	NT				
Suidae	Wild Pig	*Sus scrofa*	LC				
Moshchidae	Himalayan Musk Deer	*Moschus chrysogaster*	VU				
Cervidae	Sambar	*Cervus unicolor*	LC				
Cervidae	Muntjac or Barking Deer	*Muntiacus muntjak*	LC				
Bovidae	Brown Goral	*Nemorhaedus goral*	LC				

Family	List of Mammals	Scientific Name	IUCN Status	Gangatey-Phobji	Gaytsa-Domkhar	Bumdeling	Sakteng
Bovidae	Himalayan Serow	*Capricornis sumatraensis*	VU				
Leopridae	Wolly Hare	*Lepus osostolus*	DD				
Ochotonidae	Common Pika	*Ochotona roylei*	DD				
Rhinolophidae	Intermediate Horseshoe Bat	*Rhinolophus affinis*	DD				
Rhinolophidae	Dobson Horshoe Bat	*Rhinolophus yunanensis*	DD				
Rhinolophidae	Pearson Horshoe Bat	*Rhinolophus pearsonii*	DD				
Hystricidae	Himalayan Crestless Procupine	*Hysterix bracyhura*	DD				
Hystricidae	Indian Procupine	*Hysterix indica*	DD				
Sciuridae	Orange Bellied Squirrel	*Dremomys lokriah*	DD				
Sciuridae	Himalayan Striped Squirrel	*Tamiops macclellandi*	DD				
Cricetidae	Sikkim Vole	*Microtus sikimensis*	DD				
Muridae	House Mouse	*Mus musculus*	LC				
Muridae	Turkestan Rat	*Rattus turkestanicus*	DD				
Cricetidae	Himalayan Vole	*Alticola stoliczkanus*	DD				

Notes: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Defic

Table 5.10: Listofsnake species found in Bumdeling extracted from Wangyal & Tenzin (2009) and confirmed via field observations and FGD.

Common Name	Family	Scientific Name
Striped Trinket Snake	Colubridae	*Orthriophis taeniturus*
Eastern Trinket Snake	Colubridae	*Orthriophis cantoris*
Banded Trinket Snake	Colubridae	*Elaphe porphyracea*
Green Rat Snake	Colubridae	*Ptyas nigromarginata*
White-barred Kukri Snake	Colubridae	*Oligodon albocinetus*
Spot-tailed Kukri Snake	Colubridae	*Oligodon dorsalis*
Black-barred Kukri Snake	Colubridae	*Oligodon cihereus*
Russel's Kukri Snake	Colubridae	*Oligodon taeniolatus*
Slender Snake	Colubridae	*Trachischium* Spp
Olive Oriental Slender Snake	Colubridae	*Trachischium* Spp
False Wolf snake	Colubridae	*Cf. Dinodon* SPP
Bridal Snake	Colubridae	*Cf. Dryocalamus* Spp
Collared Black-headed Snake	Colubridae	*Sibynophis collaris*
Boulenger's Striped Keelback	Colubridae	*Amphisema parallelum*
Keelback sp	Colubridae	*Cf. Amphisema ssp*
False Cobra	Colubridae	*Pseudoxenodon macrops*
Tawny Cat Snake	Colubridae	*Boiga ochracea*
Green Cat Snake	Colubridae	*Boiga cyanea*
Many-banded Cat Snake	Colubridae	*Boiga multifasciata*

Short-nosed Vine Snake	Colubridae	*Ahaetulla prasina*
Green Bronze-back Tree Snake	Colubridae	*Dendrelaphis cyanochloris*
Macclelland's Coral Snake	Elapidae	*Sinomicrurus macclellandi*
Branded Krait	Elapidae	*Bungarus fasciatus*
Black Krait	Elapidae	*Bungarus niger*
Himalayan Krait	Elapidae	*Bungarus bungaroides*
Monocled Cobra	Elapidae	*Naja kaouthia*
King Cobra	Elapidae	*Ophiophagus hannah*
Mountain Pit Viper	Viperidae	*Ovophis monticola*
Jerdon's Pit Viper	Viperidae	*Protobothrops jerdonii*
False Wolf snake	Colubridae	*Cf Dinodon Spp*
-	Elapidae	
-	Elapidae	
-	Colubridae	*Oligodon* Spp
-	Colubridae	
-	Colubridae	
-	Colubridae	
-	Colubridae	
-	Colubridae	*Trachischium Spp*

Table 5.11: List of snake species found in Bumdeling extracted from Wangyal & Tenzin (2009) and confirmed via field observations and FGD.

Common Name	Family	Scientific Name
Flat-tailed Gecko	Gekkonidae	*Cosymbotus playurus*
Blood sucker	Agamidae	*Calotes versicolor*
Jerdon's Forest Lizard	Agamidae	*Calotes jerdoni*
Variegated Mountain Lizard	Agamidae	*Japalura variegata*
Agama Species	Agamidae	*Calotes Spp*
Sikkimese Rock Skink	Scincidae	*Asymblepharus sikkimensis*
Himalayan Litter Skink	Scincidae	*Sphenomorphus indicus*

6 Ecosystem Services Valuation

6.2 Summary

A considerable number of rural households obtain various direct and indirect use goods and services from wetland ecosystems. Using the Contingent Valuation [CV] method, we estimate the value of goods and services for which there is no market price. The study employed the Double Bounded Dichotomous model [DBDC], and estimated willingness to pay [WTP] for 721 households across four high-altitude wetland sites in Bhutan. The annual median financial contribution to support conservation efforts is Nu.3,386.26/HH/year. The willingness of households to allocate financial resources toward conservation initiatives shows they are dependent on these ecosystem services, which can be inferred from how they distribute their WTP bid across a range of provisioning, regulatory, and cultural ecosystem services. Positive willingness-to-pay estimates from our CV model demonstrate why individuals are willing to contribute financially to mitigate losses from wetland degradation associated with climate change.

6.3 Introduction

A considerable number of rural households obtain various direct and indirect use goods and services from wetland ecosystems. In numerous countries including Bhutan, these ecosystems are of paramount importance to the livelihoods of the rural population. However, the extent to which wetlands contribute to the economic well-being of society at the household, community, and national levels remains to be thoroughly examined.

High-altitude wetlands directly provide a variety of goods to the wetland users in Sakteng, Bumdeling, Gaytsa, and Gangtey-Phobji. The households derive more provisioning services which include food, water and raw materials that significantly contributes to the socio-economic livelihoods for wetland users. In addition, wetland ecosystem provides regulating[3] services which include pollination, soil formation, climate regulation etc. Further, wetlands also provide important cultural services like tourism, recreation, and cultural values.

However, the management of these wetlands frequently does not remain a priority and is not recognized as economically viable land due to a lack of awareness regarding the economic value of wetlands (Baral et al., 2005). In view of the above, the objective of this valuation exercise is to calculate the WTP for the conservation of high-altitude wetlands. To this end, the study will consider the values generated from the provisioning, regulating, and cultural services from the wetland ecosystem, and study whether wetland ecosystem services are important and local benefactors are willing to conserve them.

The estimation of the value of environmental goods and services in the context of wetland ecosystems in high-altitude regions of Bhutan can be obtained through two distinct approaches. Firstly, preference parameters can be estimated as "revealed" through behavior related to some aspect of the amenity or features of the wetland ecosystem. Secondly, stated information concerning preferences for the good can be used. In the valuation of high-altitude wetland ecosystem services, the stated preference approach, particularly CV, was adopted. CV refers to the valuation estimated from a given stated preference in which a respondent is said to be "contingent" on the details of the "constructed market" for the environmental good or service specified in the survey. The market is constructed as a form of willingness to pay for wetland protection by way of asking households to assign or choose some bid values

[3] In this document, when referring to regulating services, we also include supporting services of the wetland.

according to their perceived usefulness of the wetland ecosystem. In other words, this allocation of bids indicates the extent to which the households value the ecosystem services for which they are willing to conserve and pay.

The CV method is a valuable and practical tool for estimating the non-market benefits of wetland ecosystems. In Bhutan's context, CV is critical for informed policymaking, of community-supported conservation values, which enables the quantification targeted interventions, and securing long-term investments in high-altitude wetland preservation. The study adopted CV for assessing the value of wetland ecosystem for several reasons:

✔️ Wetlands Provide Critical, Non-Market Ecosystem Services: Bhutan's high-altitude wetlands offer essential services such as water regulation, biodiversity habitat, carbon storage, and eco-tourism opportunities. These services have no market price, yet they hold significant economic and cultural value.

✔️ Lack of Market-Based Evidence for Policy: In Bhutan, wetlands are typically public goods with unclear or non-existent market mechanisms. CV allows us to generate evidence of the economic value communities place on wetlands, which can inform conservation policy and funding decisions.

✔️ Supports Conservation Planning and Budget Justification: The WTP estimates from CV provide concrete, community-backed data that can be used to justify public investments in wetland management, guide budget allocations for conservation programs and demonstrate economic losses avoided through preventive action.

✔️ Captures Community Perceptions and Regional Differences: Bhutan's wetland sites vary in terms of dependency, awareness, and service use. CV helps capture this site-specific heterogeneity in value, allowing for more targeted and effective intervention strategies.

CV can be useful as it:

✔️ Captures Non-Market Values: Many vital ecosystem services—like clean water, biodiversity, flood control, and cultural or recreational benefits—are not traded in markets. CV is specifically designed to estimate the monetary value of non-market goods and services, which are otherwise excluded from cost-benefit analyses.

✔️ Elicits WTP: CV directly asks people how much they would be willing to pay to maintain or improve an environmental good. This allows policymakers to quantify public support or demand for conservation—especially when no observable market prices exist.

✔️ Flexible and Adaptable: CV surveys can be tailored to specific local contexts, policy scenarios, or conservation interventions. This makes it a versatile tool for evaluating a broad range of ecosystem services.

✔️ Empowers Public Participation: By involving communities in expressing their preferences, CV aligns with participatory and inclusive environmental planning, giving a voice to local stakeholders.

✔️ Globally Recognized Methodology: CV is widely used by institutions such as the World Bank, Organization for Economic Cooperation and Development (OECD), and United Nations Environment Program (UNEP) and extensively employed in environmental economics for water resources, forest management, protected areas, and more.

6.4 Model estimation

The CV method is used to estimate the value of goods and services that lack a market price (Carson & Hanemann, 2005). In a typical CV study, respondents are asked questions such as: “Would you be willing to pay a specific amount each year to protect wetlands?” Responses to this question are either yes or no, and this format is known as a single-bounded dichotomous choice [SBDC] survey question. Following the initial SBDC question, participants are often presented with a follow-up question that uses the same structure but proposes a different amount. For example, if a respondent agreed to pay Nu.100 for wetland conservation, they would then be asked: “Would you be willing to pay Nu.150 each year to help protect wetland ecosystems?” Conversely, if the respondent declined the initial Nu.100 bid, the follow-up question might be: “Would you pay Nu.50 per year to protect wetlands?”

Random Utility Theory [RUT] is the basic idea behind most models of discrete choice. This includes models used in contingent valuation and DBDC/SBDC. RUT is an economic framework used to explain and model how individuals make choices among discrete alternatives. According to this theory, when people must choose between two options, they choose the option that gives them the most utility. But because we can't always see every factor that influences a person's decision, part of that value is considered random. These models are based on certain assumptions. Utility maximization: People choose the option that gives them the most benefits; Partial observability: we only observe some part of the utility (covariates), and the rest is random noise. Probability of choice: Because of the random component, we can only model the probability of choosing an option[4].

In contingent valuation, the deterministic part of utility is written as:

$$V_i = \beta_0 + \beta_1 * BID + \beta_2 * Age + \beta_3 * Gender + \beta_4 * Educated + \beta_5 * Income + \beta_6 * Activity\_Ec \quad (I)$$

We don’t observe utility V, but we do observe choices (yes/no), and we estimate parameters β by maximizing the likelihood of observed choices using logistic regression. Random Utility Theory is powerful because it formalizes choice under uncertainty, accounts for heterogeneity

[4] The RUT model can be expressed as:
$U_{ij} = V^{ij} + e^{ij}$; Where U^{ij} = total utility that individual i gets from option j; V^{ij} = systematic (observable) component (depends on price, income, covariates); and e_{ij} = random (unobserved) component.

In a binary choice setting (e.g., yes/no to a bid) such as the contingent valuation, the acceptance or rejection of a bid falls under two options:

- Accept bid → $U^{yes} = V^{yes} + e^{yes}$
- Reject bid → $U^{no} = V^{no} + e^{no}$

The respondent says yes if:

Uyes Uno Vyes Vno eno- eyes

in preferences, and allows estimation of WTP as the monetary equivalent of utility differences.

The data set includes information from a DBDC CV survey, but for now, we're only using the information from the first WTP question. In other words, we treat the data set as if it were a SBDC CV study. To prepare the model for analysis, we need a column that has a 1 if the respondent answered "yes" to the first WTP question and a 0 if the respondent answered "no" to the first WTP question. Let's start by using a very basic model to analyze the data. For now, we're going to set aside information about gender, income, age, and so on. The model we used shows that the response value we see (which is either a '0' for a response of 'no,' I am not willing to pay this amount, or a '1' for a response of 'yes,' I am willing to pay this amount) can be explained by the bid value. We have a model with only one explanatory variable, which is the bid amount, also known as the "price. "Then we continue with the SBDC model, but we work through the process in a way that is more consistent with the typical modelling approach. This approach is usually termed "general to specific." In practice, a general to specific modelling approach means that we consider all the explanatory variables. The results are presented in (**Table 6.1**).

This analysis is based on 757 observations from four wetland sites in Bhutan. The most important thing to know about the coefficients is the negative sign on the bid variable. No matter what the code in the source file says, this will always appear as BID in the output summary. The BID coefficient shows what we expected: as the bid price goes up, the number of people willing to pay that amount goes down. The other information in the coefficient table also shows that the finding is "not statistically significant" in the simple SBDC model (Part A), but "statistically significant" at 10% significance level in the full SBDC model (Part B). The first thing to know about the results is that most of the variables we included in the model are not statistically significant. This means that, in addition to the bid price, only the age variable can explain whether a person said "yes" to the WTP question. When trying to understand the estimates, it's helpful to look at the sign of the variable instead of the exact value.

Since the SBDC did not conform to the implied demand curve, it is not appropriate to consider a DBDC. This presents a significant problem for this section because the bid values were too low to register sufficient “no” responses. Or is there another way to interpret a null result with the bid1 and bid2 SBDC analyses? Could it reflect an actual dynamic in the communities?

We are using the same approach for the DBDC model as we did for the SBDC model (**Table 6.2**). This analysis is based on 721 observations from four wetland sites in Bhutan, after 36 observations were removed due to inconsistency with monotonic assumption. The coefficients table shows that the DBDC model's results are like the SBDC model, but there are some important differences. In the DBDC model, the education variable is also statistically significant at 5% significance level, in addition to Age variable which is statistically significant at 1% significance level. The BID coefficient shows that when the bid price goes up, the number of people willing to pay that amount goes down. The BID coefficient is statistically significant in both the Simple DBDC and Full DBDC models. It may be noted that the z value associated with the BID variable is different between the SBDC question and the DBDC question. The DBDC question has made the z value bigger indicating:

- ✔ When prices go up, the number of people willing to pay that amount goes down.
- ✔ Older people are willing to pay less money.

- ✔ Educated people are willing to pay less money.
- ✔ People in Gaytsa-Domkhar are willing to pay less money compared to people in Gangtey-Phobji.
- ✔ There is no difference in the willingness to pay people with farming professions compared to people with other economic activities.

Table 6.1: RegressionSummary for SBDC Models

Variable	Coefficient	Std. Error	Z-value	P-value
Part A. Simple SBDC				
Intercept	1.5128	0.1443	10.4832	0.0000
BID	-0.0002	0.0001	-1.6427	0.1004
Part B. Full SBDC				
Intercept	2.7586	0.4691	5.8802	0.0000
BID	-0.0002	0.0001	-1.7778	0.0754
Age	-0.0218	0.0071	-3.0794	0.0021
Gender	-0.0345	0.1884	-0.1832	0.8546
Educated	-0.2729	0.2855	-0.9558	0.3392
Income	0.0339	0.1163	0.2913	0.7708
Economic activity				
Civil servant	0.3961	0.6628	0.5976	0.5501
Employee	1.0464	1.0650	0.9825	0.3258
Farmer +	-0.2560	0.3438	-0.7446	0.4565
Homestay	-0.2034	1.1380	-0.1788	0.8581
Hotel	-0.5089	1.1768	-0.4324	0.6654
Shop	-0.4672	0.4202	-1.1116	0.2663
Other	0.4670	1.1216	0.4164	0.6771
Wetland sites				
Bumdeling -0.23710.2798-0.84760.3967				
Gaytsa 0.15110.27380.55190.5810				
Sakteng 0.31440.25041.25590.2092				

Note: SBDC-Single Bounded Dichotomous Choice. The simpleSBDC modelincludes only the intercept. The full SBDC model includes other socio-economic and site variables. Farmer + means farmer who has other economic activities. Other includes economicgroups other than those listed here but relevant to remote areas.

Table 6.2: Regressionsummary for DBDC Models

Variable	Coefficient	Std. Error	Z-value	P-value
Part A. Simple DBDC				
Intercept	1.0351	0.0758	13.6528	0.0000
BID	-0.0003	0.0000	-6.3918	0.0000
Part B. Full DBDC				
Intercept	2.3575	0.2846	8.2846	0.0000
BID	-0.0004	0.0000	-8.9704	0.0000
Age	-0.0151	0.0044	-3.4481	0.0006
Gender	0.0988	0.1213	0.8146	0.4153
Educated	-0.4296	0.1922	-2.2349	0.0254
Income	-0.0261	0.0663	-0.3928	0.6945
Economic activity				
Civil servant	0.3823	0.3757	1.0175	0.3089
Employee	0.3344	0.4768	0.7014	0.4831
Farmer +	-0.1903	0.2356	-0.8075	0.4194
Homestay	-0.0126	0.7267	-0.0174	0.9861
Hotel	0.2627	0.8768	0.2996	0.7645
Shop	-0.3963	0.2841	-1.3951	0.1630
Other	0.8152	0.6989	1.1663	0.2435
Wetland sites				
Bumdeling -0.18040.1556-1.15920.2435				
Gaytsa -0.74220.2155-3.44320.0006				
Sakteng -0.02090.2057-0.10160.9191				

Note: DBDC-Double Bounded DichotomousChoice. The Simple DBDC models include only the intercept. The full DBDC model includes other socio-economic and site variables. Farmer + means farmer who has other economic activities. Other includes economic groups other than those listed here but relevant to remote areas.

6.5 Estimation of WTP

In contingent valuation, we assume that each individual has a true, but unobserved WTP denoted by:

$$WTP_i = \beta_0 + \beta_1 * BID + \beta_2 * Age + \beta_3 * Gender + \beta_4 * Educated + \beta_5 * Income + \beta_6 * Activity \quad \text{(II)}$$

WTP is a latent utility or the maximum amount the person is willing to pay. In the context of DBDC, we don't observe WTP directly, but we infer it from binary responses. In DBDC, since we have two responses per person, we could infer as follows:

- ✔ "Yes-Yes" ⇒ WTP ≥ High BID
- ✔ "Yes-No" ⇒ First BID ≤ WTP < High BID
- ✔ "No-No" ⇒ WTP < Low BID

So, the estimated model uses these responses to estimate the latent WTP. We usually focus on the overall WTP information. If the survey is based on a sample of the community that is representative of the whole community, then it is a good measure of the community's willingness to pay. But sometimes we are interested in the WTP of specific groups. For example, we might be interested in the difference between the WTP of people with different economic activity, or wetland sites. Here, we show how to calculate the total willingness to pay (WTP) and the WTP for different groups of people. We also compare their WTP[5] (**Table 6.3**).

We've already looked at the coefficient results, but what we're really interested in from a policy standpoint is the WTP estimate. When looking at the median WTP estimate, there is not much difference between the simple model and the more general full SBDC model. The median WTP for the simple model is Nu.8,244.23/HH/year, and the median WTP for the full

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5 We use the following equations to estimate WTP:

- Forsimple SBDC/DBDC models, (I)

  Median WTP= - 0BID

  - o The numerator is theintercept,anddenominatoris the coefficient of the BID
- For FULLSBDCandDBDCmodels,toestimateoverall (II)

  Median WTP= - 0+ i=1kkXikBID

  - The numerator isthecoefficient for all the variables included in the model multiplied by thevalue of therespectivevariable for an individual, and the denominator is the coefficient of the BID.
- For FullSBDCandDBDCmodels,toestimatesubgroup (III)

  Median WTPsubgroup=- 0+kXkBID

  - Thenumeratoristhe coefficientforonly the subgroup variable multiplied by the valueofthatvariable foranindividual, and the denominator is the coefficient of the BID.

model with additional explanatory variables is Nu.7,781.33/HH/year. When we have a sample of data from a representative group, these results are not unusual. However, we are interested in understanding the factors that determine WTP. Even if we have a sample that is a good representation of the whole group, it is important to consider a model with explanatory variables.

If we look at the full summary in (**Table 6.3**), and the median WTP value, we can see that the estimate from the DBDC model is around half the value reported for the SBDC model. Asking the second question makes things a lot more precise. Similarly, when looking at the median WTP estimate, there is not much difference between the simple model and the more general full DBDC model. The median WTP for the simple model is Nu.3,685.48/HH/year, and the median WTP for the full model with additional explanatory variables is Nu.3,386.26/HH/year.

Table 6.3: Estimated median willingness to pay (WTP) by model, economic activity, and site

Particulars	Median WTP in Ngultrum
Model	
Simple SBDC	8,244.23
Full SBDC	7,781.33
Simple DBDC	3,685.48
Full DBDC	3,386.26
*Economic activity**	
Farmer	3,423.52
Civil servant	4,351.63
Employee	4,035.85
Farmer +	2,774.22
Homestay	3,985.54
Hotel	4,686.50
Shop	2,764.30
Other	4,691.17
*Wetland sites**	
Sakteng, Trashigang	3,775.66
Gangtey-Phobji	3,354.27
Bumdeling, Trashiyangtse	1,889.49
Gaytsa-Domkhar	3,518.09
*Educated**	
No	3,433.88
Yes	3,037.69

Note: SBDC-Single Bounded Dichotomous Choice. DBDC-Double Bounded Dichotomous Choice. * Estimated WTPs are calculated from the Full DBDC model using equations in footnote 2. Simple SBDC and DBDC models include only the intercept. Full SBDC and DBDC models includeother socio-economic and site variables. Estimated WTP are median values. Farmer + meansfarmer who have other economic activities. Other includes economic groups other than thoselisted here but relevant to remote areas.

6.5.3 WTP estimation and comparison by sub-group

The overall WTP information is generally what we focus on, and if the survey is based on a representative sample of the community, then this is a good measure of community willingness to pay. However, sometimes we are interested in the WTP of specific groups. For example, we might be interested in the difference between the WTP of educated and uneducated people, people undertaking different economic activity, or the WTP differences between different wetland sites. In (**Table 6.3**), we demonstrate the process of evaluating WTP for different sub-groups and compare the WTP of educated and uneducated respondents, between people with different economic activity and wetland sites. The WTP is Nu. 3,423.52/HH/year of a respondent whose sole economic activity is farming, and this is not different from other economic backgrounds such as people running a homestay (WTP of Nu. 3,985.54/HH/year) or hotel (WTP of Nu. 4,686.50/HH/year). There is a significant difference between WTP of the respondents in Sakteng (Nu.3775.66/HH/year) from Bumdeling (Nu.1889.49/HH/year). Similarly, the WTP of educated respondents (Nu.3,037.69) is less compared to responses of the uneducated (Nu.3,433.88/HH/year).

One interesting observation is that there is no difference in WTP between Sakteng, Gangtey-Phobji and Gaytsa, but these three sites have higher WTP compared to Bumdeling. Higher WTP in thosesites might suggest greater perceived benefit from the wetland ecosystem, or strongerengagement with the ecosystem services generated by the wetland. Lower WTP may reflectlimited ability to pay or lower perceived relevance or benefits. If we further look at WTP byeconomic activity, Age and Education, in different wetland sites, we can note some interestingobservations (**Figure 6.1**):

- ✔ WTP is generallyvery similar (low variation) and lower for different economic activity, age andeducation level in Bumdeling.
- ✔ WTP has highervariation for different economic activity, age and education level in Sakteng, Gangtey-Phobji and Gaytsa.

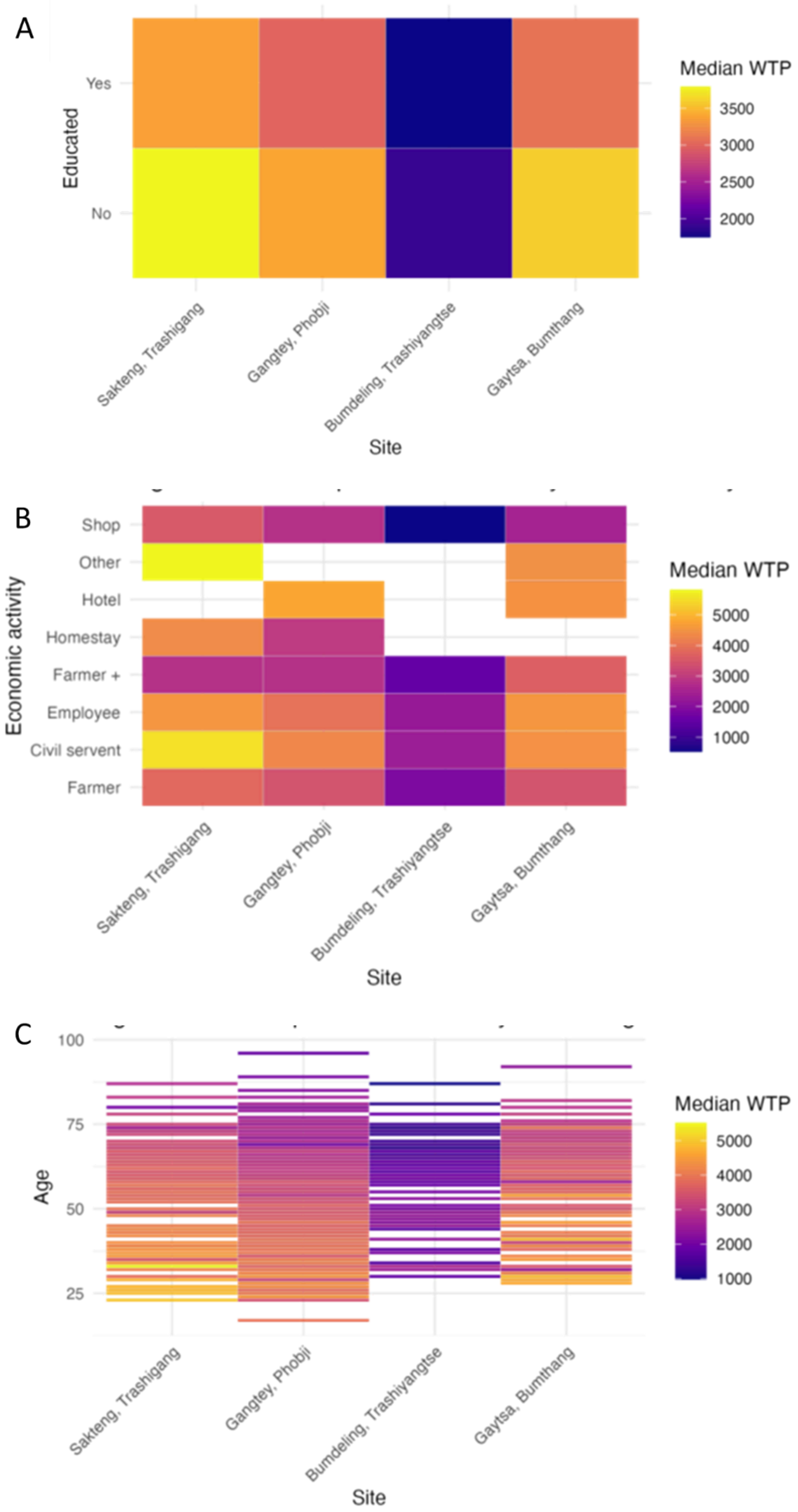

Figure 6.1. Heatmap of median WTP by (A) site and activity, (B) site and age, and (C) site and education.

6.5.4 Prediction of WTP

The predicted acceptance probability of a WTP bid in a DBDC model can help us to understand how likely a respondent will say "yes" to a given bid, based on their characteristics and the bid amount[6]. By plotting acceptance probabilities across a range of bid values, we can get the empirical demand curve which shows how households value the ecosystem services generated by the wetland. **Figure 6.2** A and B show the empirical demand for the wetland ecosystem services from the simple DBDC and full DBDC model respectively. A predicted acceptance probability of 0.80 means the model estimates an 80% chance the respondent will accept that bid amount. In figure 1a, for any bid amount lower than Nu.3,685.478/household/year, the chance that respondents will accept the bid is 50% or more. Similarly, in **Figure 6.2** A, for any bid amount lower than Nu.3,386.26/household/year, the chance that respondents will accept the bid is 50% or more. The predicted probability of acceptance decreases gradually as the bid amount is increased, demonstrating the existence of a law of demand for non-market values of ecosystem services.

We can also compare acceptance probabilities across groups (**Figure 6.2** C and D) shows acceptance probability among different wetland sites, and economic activities respectively. We can note some interesting observations:

- ✔ Acceptance probability follows a typical law of demand, meaning as bid increases the probability that households will select that bid decreases.
- ✔ Based on the characteristics and bid, Sakteng has the highest acceptance probability among the wetland sites and Bumdeling has the lowest acceptance probability.
- ✔ People who run small shops are among the economic groups with lowest acceptance probability.
- ✔ Hotels and homestays have a higher acceptance probability compared to farmers

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[6] The acceptance probability for bid 'b' is calculated using:

Pb, X= 11+exp (-0+1*BID+1X1+2X2+ …)

Where the X's represent different social, geographical and economic characteristics of the respondents.

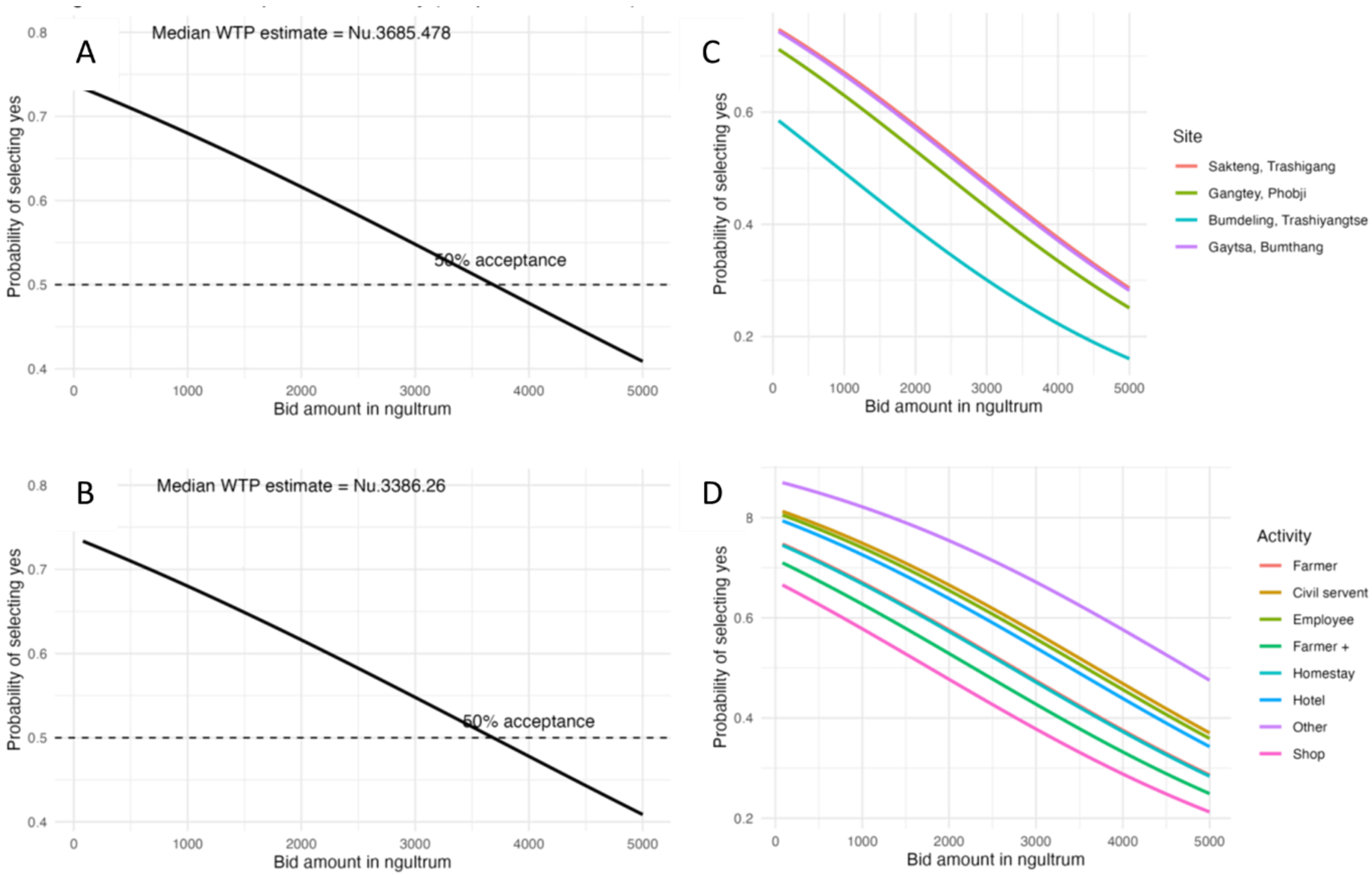

Figure 6.2: (A) Bid vs acceptance probability (Simple DBDC Model), (B) Bid vs acceptance probability (Full DBDC model), (C) Prediction of bid vs acceptance probability by site, and (D) Prediction of bid vs acceptance probability by activity.

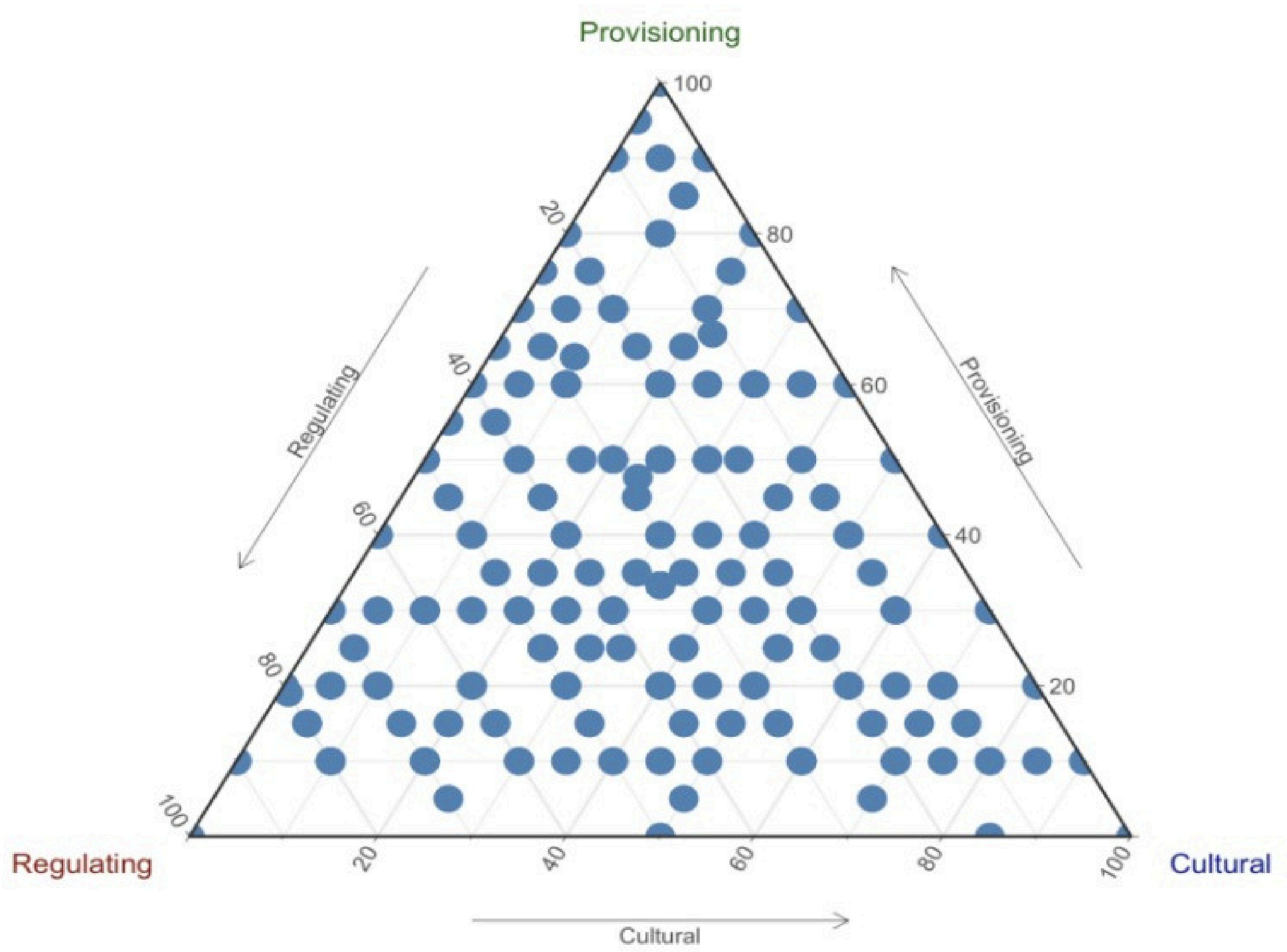

Figure 6.3. Perceived distribution of bid among the three ecosystem services.

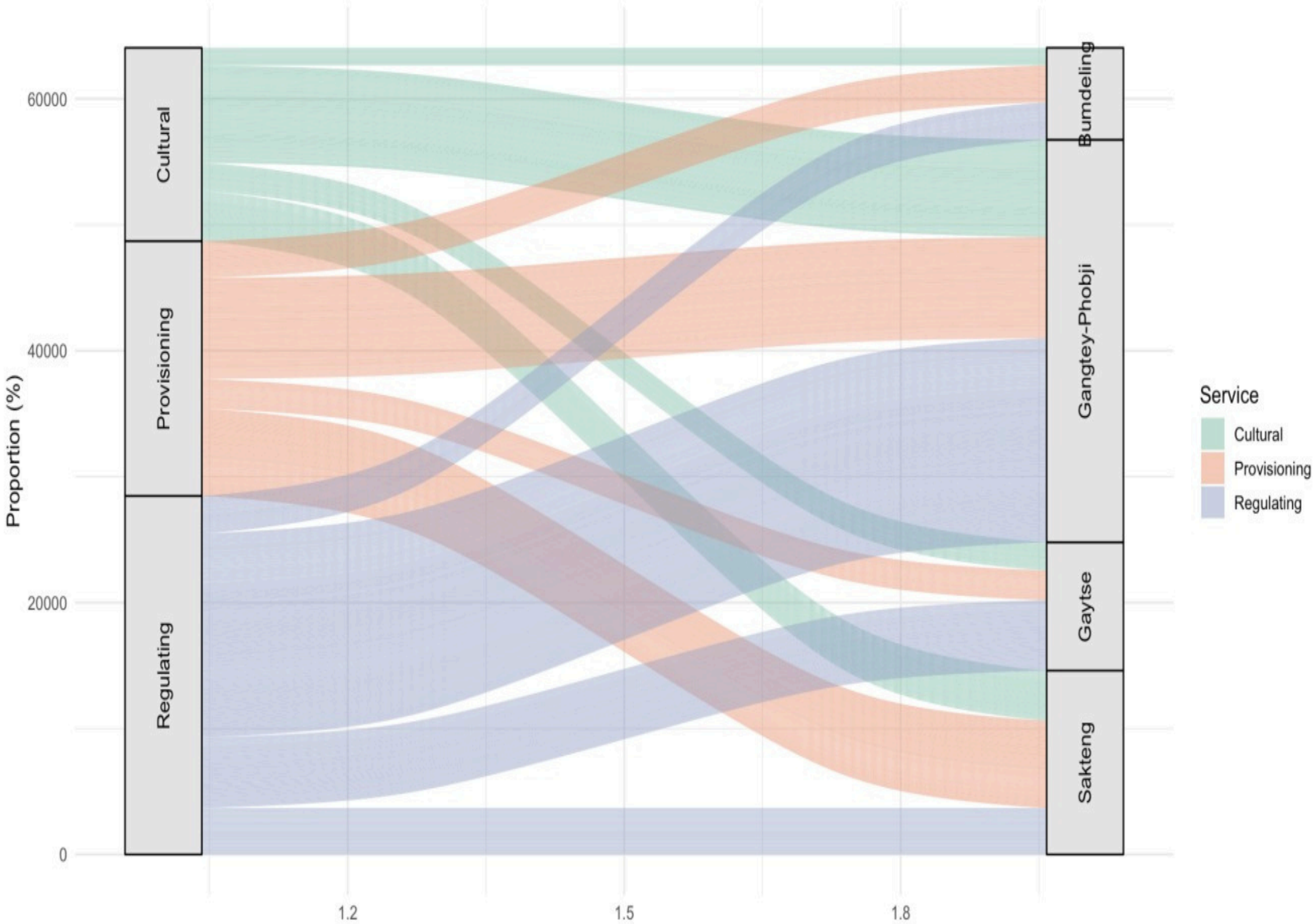

Figure 6.4. Perceived bid distribution among ecosystem services by site.

6.5.5 Perceived distribution of bid

In the context of CV employing the DBDC format, the concept of WTP signifies the maximum financial amount an individual is willing to allocate for a particular non-market good or service (e.g., conservation, clean water, access to protected areas, etc.). The median response of 3,386.26/HH/year indicates that, on average, respondents are willing to pay. The estimated cost of the proposed change or good is Nu.3,386.26/HH/year, which would be allocated to improving ecosystem services or ecosystem conservation. However, the specific ecosystem service for which respondents are providing monetary compensation is of interest. The distribution of bid amounts is illustrated in (**Figure 6.3**). As illustrated in (**Figure 6.3**), these perceived bid distributions reveal that:

- ✔ A negligible number of respondents allocated their compensation exclusively to deriving services from provisioning, regulating, or cultural services (corner points).
- ✔ A considerable number of respondents allocated their compensation for deriving services from joint ecosystem services. These services include provisioning and regulating services, as well as cultural regulating and provisioning and cultural services (edges).
- ✔ Most respondents allocated their compensation for deriving all three ecosystem services together, meaning the combination of provisioning, regulating, and cultural services (points inside the triangle).

The distribution of bids across ecosystem services is perceived to vary according to the characteristics of the respondent. As illustrated in **Figure 6.4**, the respondents' allocation of bids is indicative of the ecosystem services that they deem to be significant. It is evident that:

- ✔ Most respondents expressed the opinion that the regulating services from wetland ecosystems should be prioritized, with provisioning and cultural services being considered of lesser importance.
- ✔ In Bumdeling, respondents consider the provisioning and regulating of services from the wetland to be of greater value than cultural services.
- ✔ In Sakteng, most respondents expressed a preference for the provisioning services, with cultural and regulatory services being considered of lesser importance.
- ✔ In Gaytsa and Gangtey-Phobji, most respondents expressed a preference for the regulating services, followed by both cultural and provisioning services which are considered of equal importance.
- ✔ In essence, all the ecosystem services are regarded as being significant within all the designated wetland sites.

6.5.6 Perceived dependency on wetland ecosystem

At the onset of the survey, respondents were queried about the extent of their reliance on the wetland ecosystem. A taxonomy was developed in which various ecosystems were classified within the overarching category of provisioning, regulating, and cultural services. The respondents were asked to respond by choosing "highly dependent" on the ecosystem, "sure" they were dependent, and "not sure" whether they derived benefits from the ecosystem services (**Figure 6.5**). As illustrated in (**Figure 6.6**), the perceived dependency on wetland ecosystem services is further disaggregated, demonstrating the complexity of environmental interactions and the multifaceted benefits provided by these ecosystems. It can be observed that:

- ✓ The respondents' perceptions of dependency on provisioning and cultural services were well-defined, while their understanding of regulating services from the wetland ecosystem was minimal. This is evidenced by their selection of the options "sure" and "highly dependent."
- ✓ Cultural ecosystem services, such as those related to recreation and cultural values, are among the most frequently perceived dependent ecosystem services.
- ✓ The provision of ecosystem services, including the provision of food, water, and raw materials, is also among the ecosystem services perceived to be dependent on.
- ✓ The respondents' perception of the importance of regulating services from wetland ecosystems is notable. However, a considerable number of respondents expressed uncertainty regarding the potential benefits of regulating services. These include the formation of soil, pollination, water purification, genetic resources, biological control, the prevention of erosion, and water regulation.
- ✓ The respondents from all wetland sites expressed a high degree of reliance on the cultural services provided by the wetland.
- ✓ It is evident that respondents recognize the paramount importance of wetland-sourced provisioning services, such as food and water, across all wetland locations.
- ✓ Among the ecosystem services, those services that are the least certain to provide benefits include the regulating services of pollination and the formation of soil in all the wetland sites.

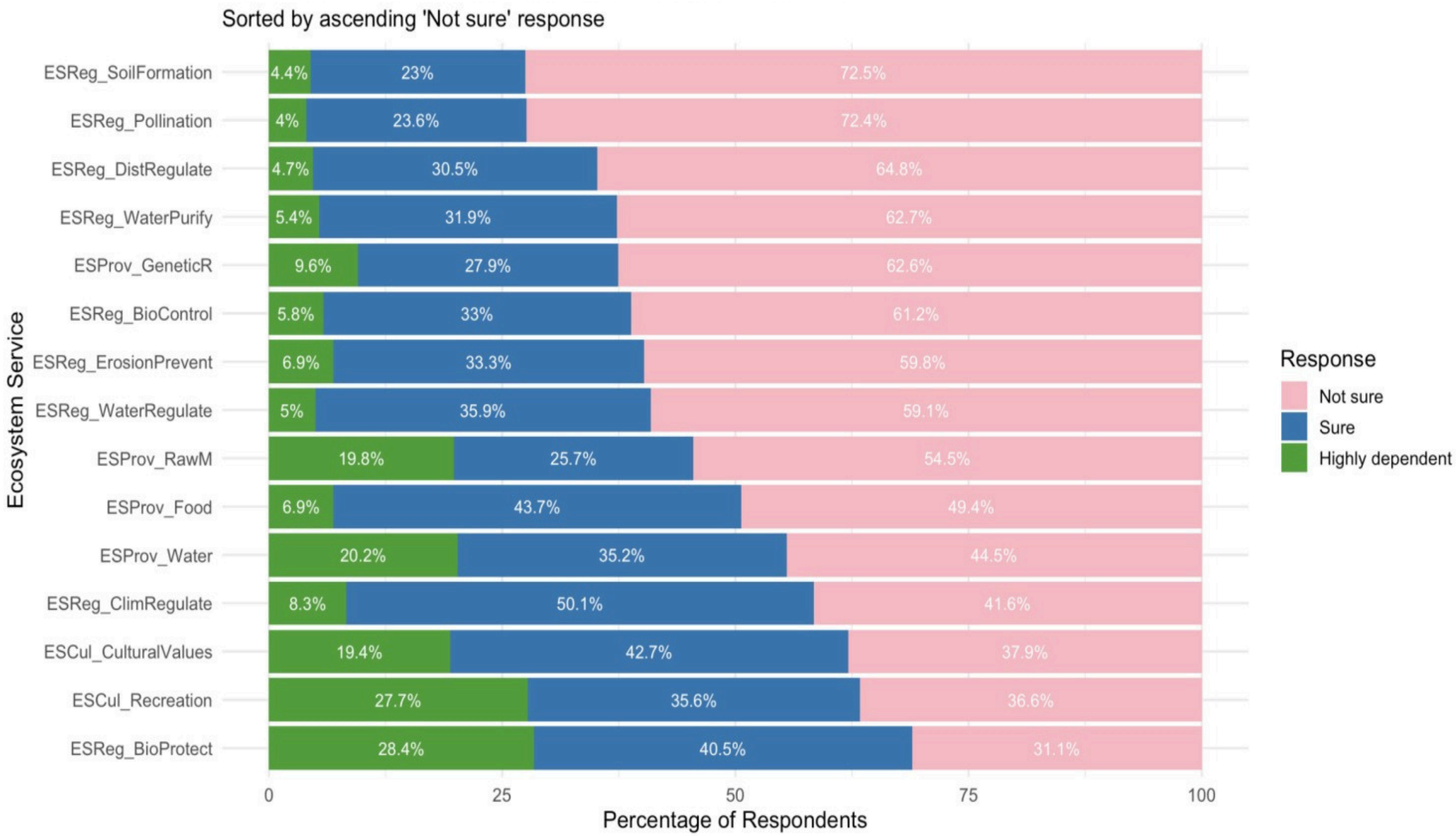

Figure 6.5. Perceived dependency on ecosystem services.

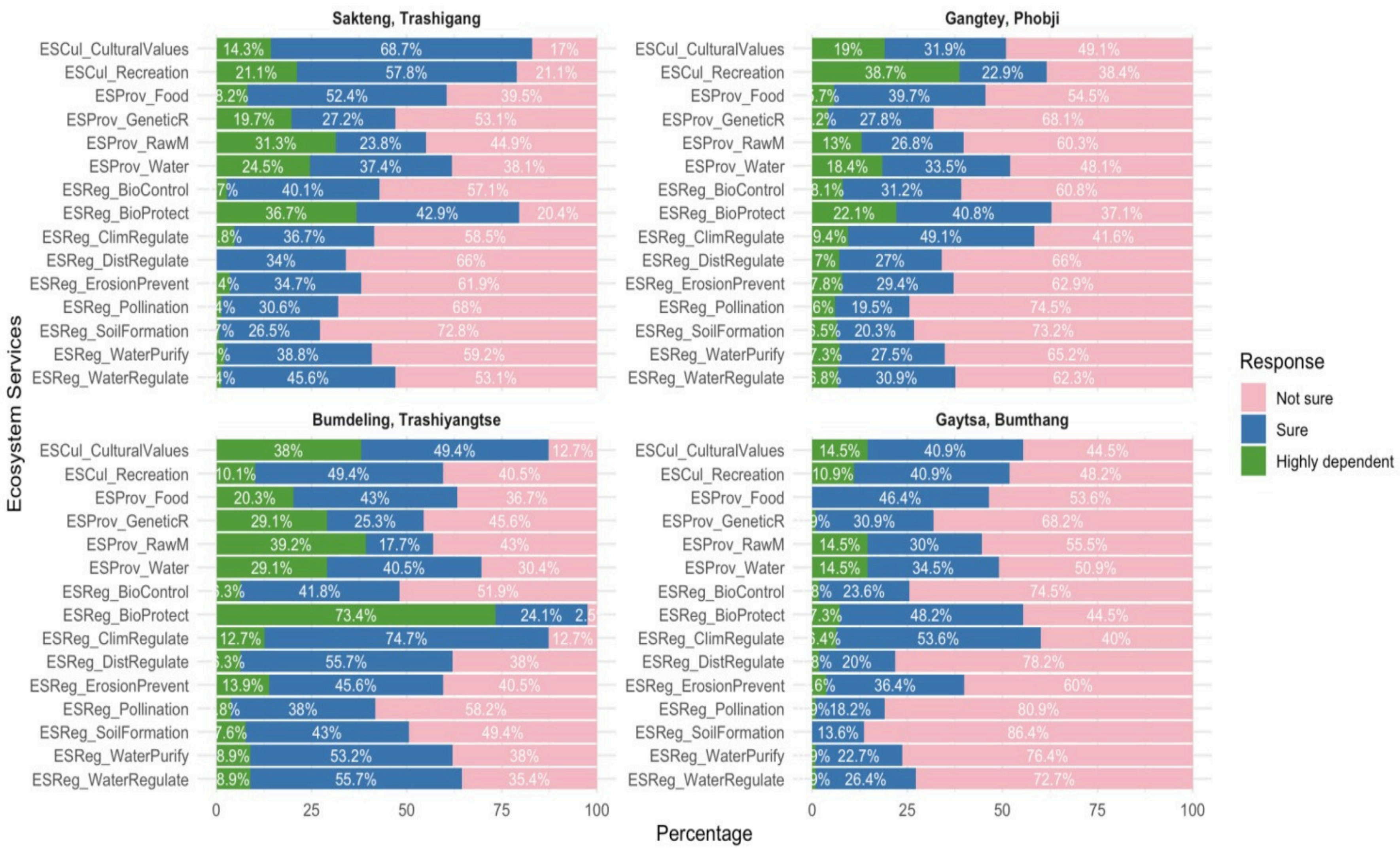

Figure 6.6. Perceived dependency on ecosystem services by site

7 Livelihood and Climate Vulnerability

7.1 Livelihood Vulnerability

Livelihood vulnerability assessments here are based on the Livelihood Vulnerability Index (LVI) and its IPCC-framed variant (IPCC-LVI), developed by Hahn et al., (2009). For this, survey responses were grouped into eight major components—socio-demographic profile, livelihood strategies, social networks, health, food, water, and natural disasters/climate variability—each built from multiple subcomponents. Subcomponent values were standardized to a 0–1 scale relative to the minimum and maximum observed across the dataset, which were then averaged within each major component and finally combined into a single weighted LVI score. The weighted score ranges from 0 (least vulnerable) to 1 (most vulnerable).

For the IPCC-LVI, the same major components were regrouped into three contributing factors —Exposure, Sensitivity, and Adaptive Capacity—and combined as weighted means. The overall IPCC-LVI was then calculated as (Exposure − Adaptive Capacity) × Sensitivity, also yielding a score between 0 and 1.

Overall, the LVI was consistent across sites, ranging from 0.39 to 0.41 (**Table 7.1**). Within the possible range of 0.0 – 1.0, the LVI of 0.4 suggests moderate vulnerability across any four sites. The major components in the LVI composition typically exhibited a difference of <0.15 between the highest and lowest scores, except for the Health MC. A high score in sites like Gaytsa-Domkhar can be attributed to longer travel distance to health clinics.

Of all the major components, livelihood was the component with the highest level of vulnerability overall, with MC scores ranging from 0.61–0.76. Bumdeling had a MC score of 0.76, much higher than the other sites (**Figure 7.1** and **Table 7.1**). Bumdeling and Gaytsa-Domkhar had higher numbers of people working outside the community, and Bumdeling was by far the most dependent on its own farming for subsistence, with 92% of households relying on self-farmed sources for at least 75% of their total food.

What is notable about the Social Networks MC is that the overall scores exhibit low vulnerability (0.15-0.28), especially in Gaytsa-Domkhar. It should be noted here that we view social networks as an indicator of lower vulnerability.

The Food MC was similar across sites that were moderately vulnerable (0.37-0.46). Nevertheless, there was substantial variation in the subcomponent scores. In Bumdeling, for instance, only 24% of households were without irrigated wetland, whereas 84-99% of households in the other three sites were without irrigated wetland. To the contrary, however, households in Gaytsa-Domkhar were more likely to have more dry land area than the other sites. Hence, In Gangtey-Phobji, 48% of households had experienced a shortage of own-produced food as opposed to the other sites where only 15-30% households experienced a shortage. More than 30% of households in Bumdeling were dependent on Cordyceps for income, whereas no households in the other sites collected. More than half of households in Gaytsa-Domkhar had experienced a shift in farming schedule, indicating challenges with potato farming for livelihood were 62% dependent on it.

Table 7.1. Subcomponent values (indexed) calculated for each study area, categorized into Major Components of the Livelihood Vulnerability Index (LVI MC). Numbers in bold after each LVI MC group are the mean of subcomponents for that village. The type of IPCC factor for each LVI MC is noted in Column 1 and used for regrouping and calculating the Climate Vulnerability Index (IPCC-LVI). Subcomponent values that are approximately 0.2 higher than the lowest value for that subcomponent (i.e., more vulnerable by 0.2) are in italics and underlined.

IPCC	LVI Major Component	Subcomponent description	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng
Adaptive Capacity	Sociodemographic	Percent of hh rating their climate change awareness as "Low"	***0.64***	0.29	0.33	***0.63***
Adaptive Capacity	Sociodemographic	Pct HH with at least 2 illiterate members	0.65	0.65	0.54	0.70
Adaptive Capacity	Sociodemographic	Pct female-headed HH	0.49	***0.69***	***0.71***	0.32
Adaptive Capacity	Sociodemographic	Indexed Age of the household head (inverse)	0.48	0.56	0.51	0.53
Adaptive Capacity	Sociodemographic	Percent of households for which the head is not educated	***0.91***	***0.81***	0.62	***0.88***
Adaptive Capacity	Sociodemographic	Percent of households with at least one disabled family member	0.21	0.11	0.14	0.14
Adaptive Capacity	Sociodemographic	Percent of hh with at least one sick family member	0.44	0.31	0.30	0.35
		Sociodemographic score	**0.55**	**0.49**	**0.45**	**0.51**
Adaptive Capacity	Livelihood	1 - (site median income.ann - min) / (90% value of total distribution - min)	***0.94***	0.60	***0.90***	***0.88***
Adaptive Capacity	Livelihood	Percent households without an off-farm income source	0.33	0.52	0.38	0.48
Adaptive Capacity	Livelihood	Indexed inverse number of economic sources	0.96	0.85	0.86	0.80
Adaptive Capacity	Livelihood	Percent of hh with at least one family member working outside community	***0.67***	0.46	***0.65***	0.50
Adaptive Capacity	Livelihood	Percent of hh for which at least 75% of food comes from self-farmed sources	***0.92***	0.59	0.51	0.62
		Livelihood score	**0.76**	**0.61**	**0.66**	**0.66**

IPCC	LVI Major Component	Subcomponent description	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng
Adaptive Capacity	Social networks	Percent of hh seeking support after disaster	0.12	0.10	0.03	0.08
Adaptive Capacity	Social networks	Percent of hh receiving support from neighbors	0.08	0.07	0.03	0.13
Adaptive Capacity	Social networks	Percent of hh seeking support from government or NGO	0.16	0.07	0.00	0.09
Adaptive Capacity	Social networks	Percent of hh not participating in community-based climate adaptation programs	0.76	0.65	0.54	0.82
		Social networks score	**0.28**	**0.22**	**0.15**	**0.28**
Sensitivity	Health	Time to health facility (minutes walking)	0.15	0.15	0.45	0.08
		Health score	**0.15**	**0.15**	**0.45**	**0.08**
Sensitivity	Food	Inverse of the number of crop varieties planted	0.14	0.29	0.18	0.25
Sensitivity	Food	Percent of hh without irrigated wetland	0.24	0.90	0.84	0.99
Sensitivity	Food	1 - (site median irrig.area - min) / (95% of total distribution - min)	0.50	1.00	1.00	1.00
Sensitivity	Food	1 - (site median dry.land - min) / (95% value of total distribution - min)	0.75	0.75	0.50	0.88
Sensitivity	Food	Percent of hh experiencing shortage of self-farmed food	0.15	0.48	0.24	0.30
Sensitivity	Food	Percent of hh primarily depending on potato for food	0.93	0.87	0.62	0.56
Sensitivity	Food	Percent of hh primarily depending on chili for food	0.66	0.17	0.05	0.71
Sensitivity	Food	Percent of hh depending on Cordyceps for income	0.32	0.03	0.03	0.00
Sensitivity	Food	Percent of hh shifting crop farming schedule	0.25	0.35	0.51	0.04
Sensitivity	Food	Percent of hh experiencing irrigation water shortage	0.33	0.01	0.03	0.04
Sensitivity	Food	Percent of hh experiencing at least 25% crop yielddecrease	0.20	0.21	0.11	0.11
		Food score	**0.41**	**0.46**	**0.37**	**0.44**

IPCC	LVI Major Component	Subcomponent description	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng
Sensitivity	Water	Percent of hh experiencing decrease in spring water availability	0.32	***0.44***	***0.49***	0.23
Sensitivity	Water	Percent of hh experiencing decrease in stream water availability	0.25	***0.41***	***0.43***	0.20
Sensitivity	Water	Percent of hh experiencing drinking water shortage	***0.46***	~~0.39~~	~~0.24~~	0.17
Sensitivity	Water	Percent of houses not on a ridge	0.15	0.23	0.35	0.28
Sensitivity	Water	Percent hh living near river	0.41	0.68	0.76	0.90
		Water score	**0.32**	**0.43**	**0.45**	**0.36**
Exposure	Natural disasters and climate variability	Percent of hh that are not storm resistant	0.24	***~~0.56~~***	***~~0.65~~***	0.16
Exposure	Natural disasters and climate variability	Percent of hh that are not flood resistant	0.34	***~~0.59~~***	***~~0.62~~***	0.26
Exposure	Natural disasters and climate variability	Indexed Average storms (removing large outlier of 200)	0.04	0.05	0.01	0.08
Exposure	Natural disasters and climate variability	Indexed average floods	0.09	0.11	0.00	0.04
Exposure	Natural disasters and climate variability	Indexed average droughts	0.17	0.07	0.04	0.15
Exposure	Natural disasters and climate variability	Indexed average landslides	0.03	0.06	0.01	0.01
		Natural disasters and climate variability score	**0.15**	**0.24**	**0.22**	**0.12**
		Livelihood Vulnerability Index	**0.41**	**0.41**	**0.39**	**0.39**

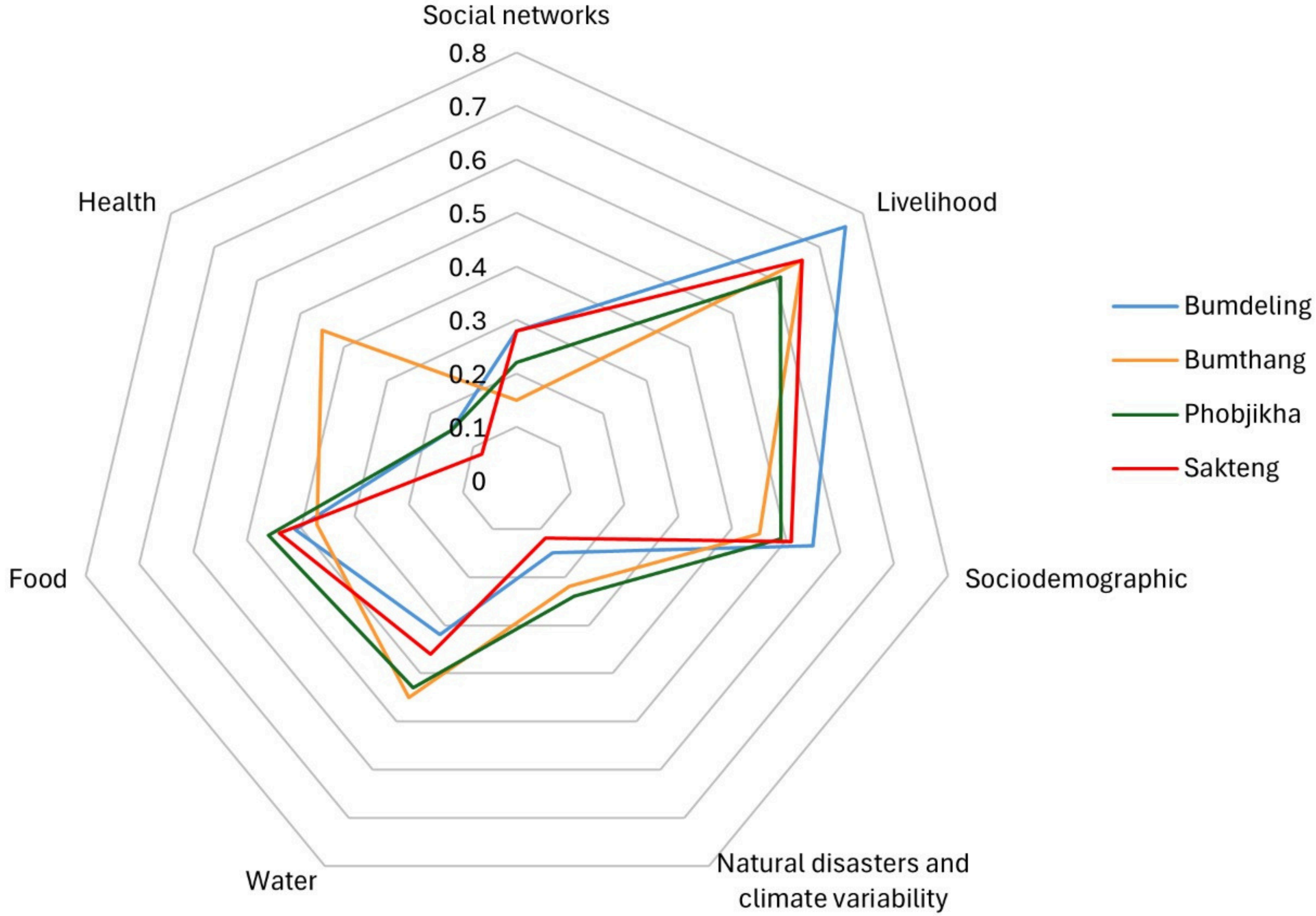

Figure 7.1. Radar diagram showing Major Components of the Livelihood Vulnerability Index across the four sites. The index has a theoretical range of 0.0 – 1.0. Where, 1.0 indicates the greatest vulnerability

All sites were moderately vulnerable to water (0.32–0.45), with more than 40% of households in Gangtey-Phobji and Gaytsa-Domkhar experiencing decreases in spring and stream water; 46% of households in Bumdeling experienced shortages in drinking water.

Finally, vulnerability to natural disasters and climate variability were generally low (0.12-0.24). The only large variation across sites was for the percent of households that were storm or flood resistant, with Gangtey-Phobji and Gaytsa-Domkhar having about 60% of their households falling into that category, far higher than Bumdeling and Sakteng (34% and 26%, respectively).

7.2 Climate vulnerability

The results of the IPCC-LVI calculations across all sites show negative scores due to low exposure values and high adaptive capacity values (**Table 7.2, Figure 7.2**). The differences in the contributing factor scores were small as well, with Gangtey-Phobji and Gaytsa-Domkhar having higher exposure values and lower adaptive capacity than Bumdeling and Sakteng. Sensitivity was identical across the four sites. Overall, Gangtey-Phobji and Gaytsa-Domkhar had relatively higher IPCC-LVI scores and therefore are considered relatively more vulnerable to climate change than Bumdeling and Sakteng.

Table 7.2: Climate Vulnerability Index (IPCC-LVI) for the four sites

IPCC contributing factor	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng
Exposure	0.15	0.24	0.22	0.12
Adaptive capacity	0.55	0.46	0.44	0.50
Sensitivity	0.36	0.43	0.40	0.40
IPCC-LVI (E-AC) *S	**-0.14**	**-0.09**	**-0.09**	**-0.15**

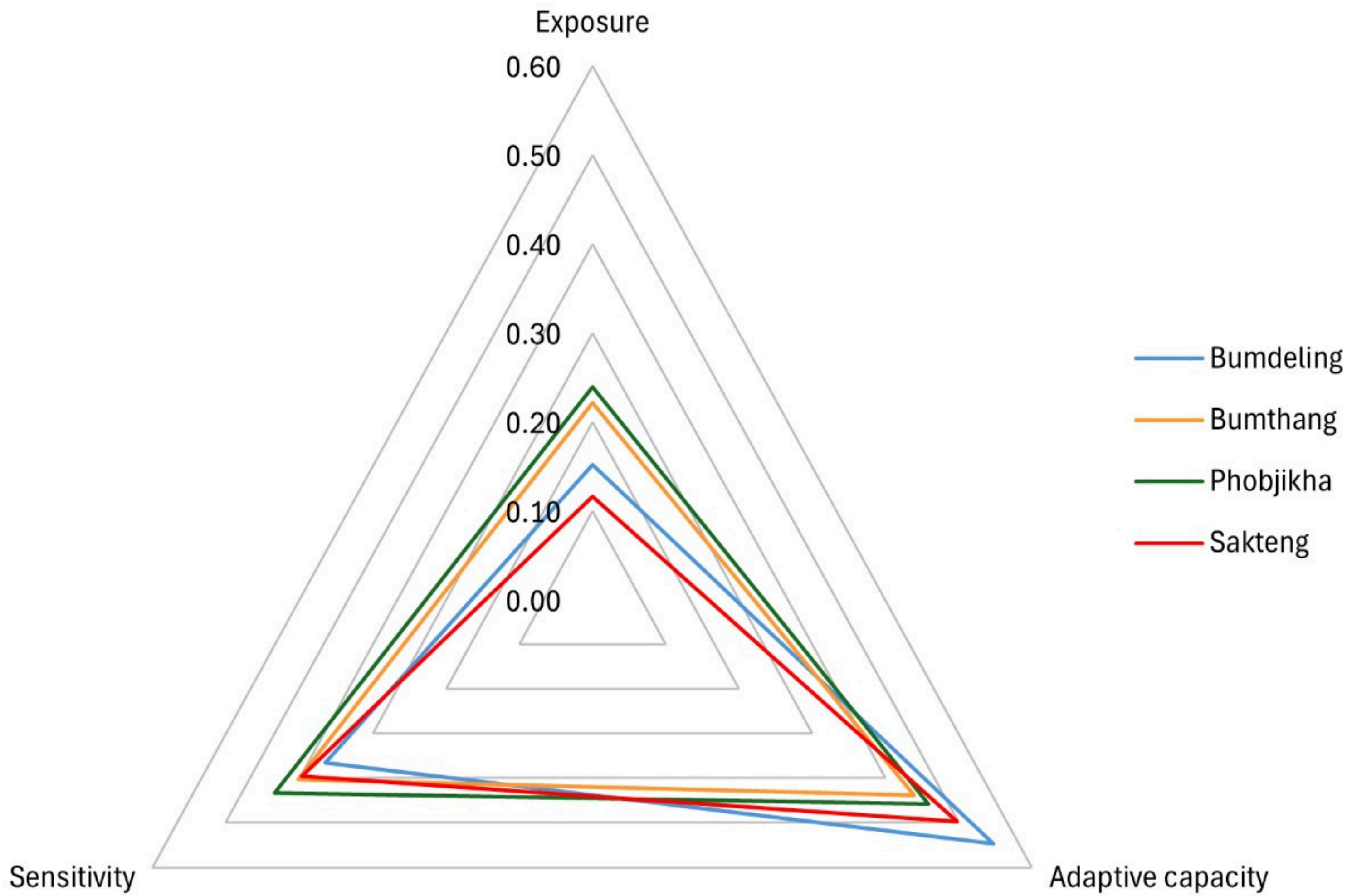

Figure 7.2. Radar diagram showing the three Contributing Factors to the Climate Vulnerability Index, across the four sites. The index has a theoretical range of 0.0 – 1.0. Where, 1.0 indicates the greatest vulnerability

8 Key Vulnerabilities and Priority Actions

Identifying keyareas of vulnerability to climate change isa critical first step in formulating effective adaptation and resilience-building plans and programs. Given the constraints on human, technical, and financial resources, it is essential that available resources are strategically directed toward the most vulnerable sectors to ensure the protection of communities and ecosystems most at risk.

This chapter focuses on identifying priority interventions to address the key climate vulnerabilities of high-altitude wetland communities in Bhutan, as represented by the four study sites. These areas of vulnerability have been derived from earlier chapters, specifically i) Socio-economic conditions, and ii) local experiences and perceptions of climate change and its impacts, iii) biodiversity assessments, and iv) climate change vulnerability analyses.

Understanding how these four elements interconnect at the local level is essential for accurately identifying vulnerabilities and designing effective, context-specific interventions. While the Climate Change Vulnerability Index (CVI) provides a useful analytical framework, it often falls short of capturing the lived realities of small communities whose vulnerabilities are shaped by diverse biophysical conditions and socio-economic contexts (Pandey & Jha, 2012).

Recognizing that the study areas consist of smallholder farming communities, the analysis was further strengthened using climate projections from secondary sources and qualitative insights from household surveys and focus group discussions in this study. This integrated approach ensures a more grounded and nuanced understanding of key vulnerabilities.

8.1 A Techni-quantitative Perspective on Climate Vulnerability

The use of the well-known Livelihood Vulnerability Index (LVI) and the climate vulnerability index (IPCC-LVI) offers a good preliminary overview of factors that may be conferring vulnerability to overall livelihood (LVI) or to a specific stressor, in this case climate change. The use of these two indices was popularized by Hahn (Hahn et al., 2009) and has become a popular method to assess current vulnerabilities of communities, and the dimensions (Major Components, Subcomponents) comprising that vulnerability.

Overall, the analysis of both the LVI and the IPCC-LVI support two general conclusions: (1) all sites exhibit low to moderate *overall* vulnerability; and (2) there are minor variations across sites for the overall indices or the constituent subcomponents. The LVI and its subcomponents are interpreted as low vulnerability (< 0.3), moderate vulnerability (0.3- < 0.5) and high vulnerability (≥ 0.5-1.0). **Table 8.1** shows IPCC-LVI subcomponents which are contextualized by color coding to indicate relative vulnerability levels. Since IPCC-LVI is calculated as (E – AC) * S, where E = exposure, AC = adaptive capacity and S = sensitivity, the only way to get a negative IPCC-LVI value is when adaptive capacity (vulnerability therein) exceeds vulnerability to exposure. Therefore, *to reduce overall vulnerability, adaptive capacity components must be improved*. These include climate awareness including increased participation in climate adaptation and mitigation programs, literacy, education, and diverse income sources.

In the IPCC-LVI formula, the Sensitivity index serves to amplify the difference between Exposure and Adaptive Capacity. Thus, key areas of concern include lack of crop irrigation and the overall amount of irrigated cropland area, a high dependence on chili and potato farming, dry cropland area, shift in cropping schedule, and issues related to other water uses.

An important constraint on the IPCC-LVI index is that it focuses on present conditions in the study area sites and therefore provides a current snapshot of vulnerability within the boundaries set by the survey questions. Since climate change is dynamic and constant, while LVI and IPCC-LVI are static assessments, it’s critical to integrate other approaches to evaluate vulnerability now and in the future. Not only should policy and intervention consider the current situation but need to proactively counteract foreseeable alterations to the biophysical environment related to the components of the LVI or IPCC-LVI.

8.2 Climate change, Biodiversity, Socio-economic and Ecosystem Valuation Inter-linkages

8.2.1 Climate Change in High-Altitude Areas: Local Experience Viewpoints

It should be highlighted that the self-reported level of knowledge about climate change was moderate to low across the four study sites. Nevertheless, there were important contingents in the communities who affirmed that climate change is a present and pressing reality, with communities and ecosystems increasingly showing signs of vulnerability. For example, 42% of respondents overall reported experiencing changing temperature and rainfall conditions compared to the past. These local observations align with climate change projections for Bhutan’s high-altitude regions, where both maximum and minimum surface air temperatures have shown a marked increase—particularly in the northern and western parts of the country (NCHM, 2024; Tshencho, D. & Tamang, T. B., 2019). Moreover, focus group discussions and household interviews across the study sites revealed that households had observed increasingly erratic and unpredictable precipitation patterns. Rainfall has become more intense and less predictable, while winter snowfall has declined in both frequency and volume. These local experiences align with broader findings that describe a pattern of excessive rainfall during periods when it is least needed, and insufficient or absent rainfall during critical times, leading to the drying of irrigation sources as experienced in other parts of the country (Chhogyel & Kumar, 2018; Chhogyel, N. & Kumar, L., 2018).

8.2.2 Unfolding Impacts of Climate Change on Biodiversity and Socio-Economic Systems

Local community testimonies indicate that the impacts of climate change are gradually becoming evident, though not yet perceived as alarming. Communities across all four study sites displayed a high dependence on provisioning, regulating, and supporting ecosystem services for their livelihoods. These include access to drinking and irrigation water, timber and non-wood forest products, and cultural and recreational values that are increasingly being tapped through emerging tourism activities.

Table 8.1. Categories of LVI subcomponent scores organized by the IPCC-LVI contributing factor and color coded to facilitate comprehension. Adaptive capacity variables here have not been transformed for calculation of the IPCC-LVI, to keep the vulnerability scores in the same direction. Color coding: green = low vulnerability <0.3; yellow = moderate vulnerability 0.3 – <0.5, red = high vulnerability ≥0.5-1.0.

LVI subcomponent	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng
Exposure				
Housesnotstorm-resistant	green	red	red	green
Housesnotflood-resistant	yellow	red	red	green
Stormfrequency	green	green	green	green
Floodfrequency	green	green	green	green
Droughtfrequency	green	green	green	green
Landsidefrequency	green	green	green	green
Adaptive capacity				
Low climate awareness	red	green	yellow	red
Illiteracy in family (≥2 members)	red	red	red	red
Female-headed household	yellow	red	red	yellow
HH age	yellow	red	red	red
Uneducated HH head	red	red	red	red
Disabled family members	green	green	green	green
Sick family members	yellow	yellow	yellow	yellow
Annual income	red	red	red	red
No off-farm income	yellow	red	yellow	yellow

LVI subcomponent	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng
Lack of economic diversity				
Absent family members (outside community)				
High reliance on own farm for food				
Seeking support after disaster				
Receiving support from neighbors				
Seeking support from government or NGO				
No participation in climate adaptation programs				
Sensitivity				
Access to health facility				
Planted crop diversity				
Lack of irrigation				
Irrigated cropland area				
Dry cropland area				
Shortage of self-farmed food				
Dependence on potato farming for food				
Dependence on chili farming for food				
Dependence on Cordyceps for income				
Shift in cropping schedule				
Irrigation water shortage				
At least 25% crop yield decrease				

LVI subcomponent	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng
Decrease in spring water availability				
Decrease in stream water availability				
Drinking water shortage				
Houses not on a ridge				
Houses near river				

Climate change is producing both positive and negative socio-economic effects. On one hand, rising temperatures have allowed the cultivation of crops previously unsuited to the area. On the other hand, communities are witnessing the disappearance of native species and the emergence of invasive species that negatively affect agriculture and livestock productivity. A key concern is the shrinking habitat for high-altitude livestock such as yaks. The reduction in suitable grazing areas threatens not only the survival of these species but also the transhumant lifestyles of herder communities. Herders in Sakteng, for instance, are already experiencing the upward shift of ecological zones, where the intrusion of vegetation into higher-elevation pastures and the shortened grazing period in lower elevations have constrained traditional grazing patterns.

8.2.3 Water Security and Climate Change

Rising temperatures are posing serious challenges to future water availability. Water security in the high Himalayas depends heavily on the seasonal snowmelt cycle, where snow and glacial cover accumulated during winter feed rivers and streams during warmer months. Similarly, downstream regions rely on this sustained hydrological flow from higher elevations.

The natural storage of water in the form of glaciers, ice, snow cover, and permafrost wetlands ensure year-round water availability across Bhutan's north–south agro-ecological zones. However, communities are already observing reduced snowfall and the gradual depletion of these frozen water reservoirs. As temperatures continue to rise, further reductions in this solid water storage are expected, leading to increased seasonal disparities in stream flow and more pronounced water scarcity—both temporally and spatially.

Given that water is vital to all forms of life, including ecosystems and economies, any disruption in its availability will result in ecosystem degradation, biodiversity loss, reduced agricultural and livestock productivity, and ultimately, adverse effects on human health and well-being.

8.2.4 Extreme Weather Events and Associated Hazards

Rapid-onset events such as storms and cloudbursts make both high-altitude and downstream communities vulnerable to flash floods, landslides, and soil erosion. These are already resulting in loss and damage:

- Loss of lives and livelihoods: In Bumdeling, repeated flash floods have devastated irrigated paddy fields, depriving farmers of their sustainable livelihood sources, particularly food and income (MoENR & UNDP, 2025). These disasters exemplify the concept of "loss and damage," where the adverse effects of climate change exceed the capacity of communities to adapt or recover. Owing to lack of resources, river training and restoration of agricultural lands have not happened.
- Soil erosion and declining productivity: In Gangtey-Phobji, increased surface runoff is degrading slope agriculture, particularly potato cultivation.

- Landslides and infrastructure damage: Deep ravines carved by runoff are increasingly visible, raising the likelihood of damage to infrastructure, farms, and settlements during intense monsoon rains.

Climate projections suggest that rainfall patterns will become increasingly erratic and intense (Salick et al., 2014; Tshencho, D. & Tamang, T. B., 2019) leading to what the National Environment Commission (2016) describes as "the problem of plenty"—too much water when and where it's not needed, and too little when and where it is needed. This imbalance highlights the twin risks of floods and droughts.

8.2.5 Socio-Economic Development and Its Impacts on Biodiversity and Climate Change

The four ESRAM study sites provide a snapshot of the non-polluting subsistence economies of the high-altitude areas of Bhutan. Livelihood of communities are centered around agriculture and livestock farming with minimal impact to climate change due to absence of polluting industries and relatively intact ecosystems. As documented in this report, communities rely heavily on ecosystem services such as water, timber, manure, pasture and non-wood forest products (NWFPs). Improved access to electricity, farm roads, and nearby markets has enhanced the economic opportunities in these areas, creating pathways for development while also increasing exposure to external influences. Some of the observed activities with indirect linkages to climate change are:

- Logging: Prevalence of coniferous forest logging in Gangtey-Phobji and Gaytsa-Domkhar.
- Wetland degradation**:** Despite their abundance of water and ecological importance, wetlands in all sites—particularly in Gangtey-Phobji, Gaytsa-Domkhar, and Sakteng—are under threat from road construction, drainage, fencing, and infrastructure development. Further, upland forest harvesting can result in siltation in the rivers, which may lead to habitat degradation for fish and invertebrates downstream.
- Solid waste issues: Improper solid waste management is an increasing concern, especially in Gangtey-Phobji and Gaytsa-Domkhar. Although communities participate in monthly clean-up drives, local administrations lack adequate facilities and resources for proper waste disposal.
- Low to moderate climate awareness**:** While communities are aware of the changing climate and its impacts, there is limited understanding of its causes and of the critical role wetlands play in water security. Nonetheless, community recognition of the value of ecosystem services is evident through their willingness to pay for them.

9 Issues, Recommendations and key interventions

With climateimpacts becomingincreasingly pronounced inhigh-altitude wetlands,proactive and context-specific interventions are critical to safeguarding livelihoods, biodiversity, and ecosystem services. The proposed interventions are derived from bio-physical and socio-economic context, biodiversity status, and community knowledge and experiences about climate change, impacts, and vulnerabilities identified from the study.

The interventions outlined below underscore the importance of locally tailored, multi-level, and cross-sectoral approaches to climate adaptation and mitigation. Community-based strategies empower those most affected by climate change; ecosystem-based interventions safeguard the natural foundations of resilience; and enabling policy frameworks create the conditions for sustained, coordinated action. The proposed interventions are designed to enhance adaptive capacity, reduce exposure to climate risks, and support sustainable development. The interventions are presented under three main sections.

9.1.1 Community based Adaptation and Mitigation Strategies

9.1.1.1 Reduced agriculturalandforestresilience

Issue	Agriculture land destroyed by flash floods
Recommendation	Restoration of flood-affected farmlands in Bumdeling
Key Interventions	- Removal of sand and debris from flood affected areas - Restoration of bunds
CVI-CF addressed	- Exposure

Issue	Reduced agriculture productivity due to shifting climate zones
Recommendation	Promote climate resilient crop varieties
Key Interventions	- Introduce climate resilient varieties for target area o Conduct crop suitability study for target area (match crop requirement with local climate and soil conditions) o Create demonstration farms - Provide and or facilitate access to improved seeds, appropriate machinery, equipment and tools - Build capacity of local farmers in adopting new variety crops o Train farmers on farming techniques for each variety of crops to be introduced o Provide hands-on technical support

CVI-CF addressed	- Exposure - Adaptive Capacity

Issue	Reduced agricultural productivity due to wildlife crop predation
Recommendation	Reduce crop damage by wildlife
Key Interventions	Support communities with physical protection of agricultural areas - Identification of wildlife prone agricultural areas in each target site - Provide chain-links fencing (reported to be effective) of wildlife prone agricultural areas o Design and cost estimation of chain-link fencing o Procurement of materials o Construction of fences
CVI-CF addressed	- Adaptive Capacity

Issue	Erosion of topsoil on sloping agriculture fields (Gangtey-Phobji)
Recommendation	Promote sustainable land management practices[g1]
Key Interventions	- Promote contour farming and terracing - Strip cropping – alternating strips of erosion prone crops with erosion resistant crop
CVI-CF addressed	- Sensitivity

Issue	Limited sources of income
Recommendation	Diversify source of income by developing ecotourism products

Key Interventions	- Identify ecotourism products based on natural and cultural uniqueness of the area o Low impact nature-based tourism activities (bird watching and wildlife tours, homestays, cultural/ heritage tours) o Develop local art and handicrafts products - Support development of tourism facilities - Build/ improve visitor centre o Identify and secure locations with Gewog Administration o Prepare design and drawings o Construct and equip visitor centre o Establish and operationalize visitor centre - Promotion of eco-tourism products o Promotion and familiarization trips for tour operators o Use website and social media
CVI-CF addressed	- Adaptive Capacity

Issue	Forest degradation due to pest infestation or fires
Recommendation	Incorporate community-based monitoring and response
Key Interventions	- Initiate and train for community monitoring protocols - Training for and investment in human resources for emergency responses
CVI-CF addressed	- Exposure - Adaptive Capacity

9.1.1.2 Lowlevelofawarenessaboutclimatechange

Issue	Low level of climate awareness
Recommendation	Enhance climate awareness
Key Interventions	- Initiate a Climate Education and Awareness program - Develop content (suggested topics: Basic climate science; Understanding climate change impacts; Climate and livelihood linkages; climate and water resources, mitigation and Adaptation measures) - Target groups: local community residents; schools, and institutions
CVI-CF addressed	- Adaptive Capacity

9.1.2 Disaster risk reduction

9.1.2.1 Soil erosion and land destabilization (Gangtey-Phobji)

Issue	Erosion and slope destabilization during intense rainfall
Recommendation	Prevent soil erosion and slope stabilization measures
Key Interventions	- Build check dams and stone bunds in appropriate places across gullies and waterways - Prevent formation of gullies by planting dense grasses along natural drainage paths - Plant bushes and grasses along waterways and drainage paths.
CVI-CF addressed	- Exposure

9.1.2.2 Productive agriculture and grazing lands affected by floods (Bumdeling)

Issue	Changing river course and floods damage cattle grazing areas and agricultural fields
Recommendation 1	Undertake flood control measures through river training and embankment
Key Interventions	- Undertake appropriate river training activities o Prepare a flood management plan for the Bumdeling o Construct River training and embankment in appropriate places - Undertake periodical clearing of debris and blockages along river channels
Recommendation 2	Disaster response and Early Warning System development and deployment
Key Interventions	- Strengthen disaster response mechanism at Gewog level - Install and operationalize Early Warning System - Periodic training of local community in disaster response measures
CVI-CF addressed	- Exposure

9.1.3 Ecosystem based Adaptation Approaches

9.1.3.1 Wetland restoration and protection

Issue	Poorlydefinedwetland extent

Recommendation	Develop high-resolution, accurate wetland maps
Key Interventions	- Undertake comprehensive mapping of high-altitude wetlands and lakes including micro wetlands - Identify wetland areas falling in private land
CVI-CF addressed	- Sensitivity

Issue	Wetland fragmentation and degradation
Recommendation	Restore wetland integrity
Key Interventions	- Identify degraded wetlands i.e., previously known wetland and lakes areas - Enhance recharge capacity in degraded wetlands o Restore natural hydrology in ways that direct flow into wetland areas o Control outflow with check dams and dykes o Construct infiltration trenches and swales - Plant native wetland species and remove invasive species - Protect/ restore upstream watershed areas
CVI-CF addressed	- Sensitivity

Issue	Conversion of wetlands and encroachment for development purposes
Recommendation	Prevent encroachment into wetlands
Key Interventions	Restrict permits and approvals for development activities that result in fragmentation and drainage of wetland areas.
Recommendation	Acquire land for conservation
Key Interventions	- Replacement: Initiate a program to replace privately owned wetland with government land. - Government buys private land to avoid development and restore habitat. - Initiate conservation easement - where private owners voluntarily give up certain development rights to conserve the wetland.
CVI-CF addressed	- Sensitivity - Adaptive Capacity

Issue	Poorly defined wetland extent
Recommendation	Develop high-resolution, accurate wetland maps
Key Interventions	- Undertake comprehensive mapping of high-altitude wetlands and lakes including micro wetlands - Identify wetland areas falling in private land
CVI-CF addressed	- Sensitivity

9.1.4 Ecosystem based Adaptation Approaches

9.1.4.1 Policy advocacy

Issue	Insufficient wetland protection
Recommendation	Secure legal protection for wetlands in the context of climate change
Key Interventions	- Prepare a policy paper focusing on importance of high-altitude wetland - Organize advocacy webinars and presentations to Parliamentary committees on Environment
CVI-CF addressed	- Adaptive Capacity

9.1.5 Biodiversity

9.1.5.1Vegetation andForestBiodiversity

Issue	Invasive and dominant species reducing forest biodiversity (e.g. blue pine monoculture at Gaytsa-Domkhar)
Recommendation	Control dominant species spread and restore native forest biodiversity
Key Interventions	- Map and monitor extent of blue pine (*Pinus wallichiana*) dominance in Gaytsa-Domkhar and Gangtey-Phobji - Initiate silvicultural interventions (selective thinning) to encourage mixed-species regeneration - Promote natural regeneration of native broadleaf and mixed conifer species in degraded plots - Establish permanent monitoring plots to track species composition changes over time
CVI-CF addressed	- Sensitivity - Adaptive Capacity

Issue	Low tree species richness and evenness at high-altitude sites (Gaytsa-Domkhar, Sakteng) indicating ecological fragility
Recommendation	Enhance native species richness and structural diversity in high-altitude forests
Key Interventions	- Identify and protect seed source trees of underrepresented native species - Establish community nurseries for native tree and shrub propagation - Conduct enrichment planting in low-diversity forest patches - Protect high-diversity sites (Bumdeling, Gangtey-Phobji) from logging and encroachment
CVI-CF addressed	- Sensitivity

9.1.5.2Aquatic Biodiversity

Issue	Dominance of non-native brown trout (Salmo trutta) displacing native fish species across sites
Recommendation	Manage invasive brown trout populations and protect native fish habitat
Key Interventions	- Assess the spatial extent of brown trout distribution across all four sites - Develop and implement a brown trout management plan in consultation with DoFPS and CNR - Identify and protect refugia for native species (*Schizothorax richardsonii, Creuteuchiloglanis bumdhelingensis)* - Restrict further introduction of non-native fish species - Engage local fishing communities in monitoring and reporting programs
CVI-CF addressed	- Sensitivity - Adaptive Capacity

Issue	Water quality degradation (elevated turbidity, nutrients) threatening aquatic macroinvertebrate communities and fish habitat
Recommendation	Reduce pollutant loads entering streams and rivers from surrounding land uses
Key Interventions	- Establish riparian buffer zones (minimum 10 m) along key streams at all sites - Conduct regular water quality monitoring at established sampling points - Implement drainage and waste management measures at upstream settlements and yak camps

	- Restrict vehicle washing and disposal of solid waste in and near streams
CVI-CF addressed	- Sensitivity - Exposure

9.1.5.3 Avifauna and Mammals

Issue	Habitat loss and disturbance threatening Black-necked Crane (Grus nigricollis) wintering habitat in Gangtey-Phobji and Bumdeling
Recommendation	Protect and restore Black-necked Crane wintering wetland habitat
Key Interventions	- Enforce existing buffer zones around Black-necked Crane foraging and roosting areas - Restore degraded wetland feeding grounds through hydrology improvement and invasive plant removal - Regulate tourist activities and enforce codes of conduct during crane wintering season (November-February) - Strengthen community-based crane monitoring and reporting networks
CVI-CF addressed	- Sensitivity - Adaptive Capacity

9.1.6 Wetland valuation

9.1.6.1 Financing and Payment for Ecosystem Services

Issue	Absence of formal payment for ecosystem services (PES) mechanisms despite demonstrated community willingness to pay (median WTP: Nu. 3,386/HH/year)
Recommendation	Establish a pilot Payment for Ecosystem Services scheme for high-altitude wetlands
Key Interventions	- Design a PES framework using WTP estimates (Nu. 3,386/HH/year) to set conservation fund contribution levels - Identify and formalize the institutional home for a wetland conservation fund (e.g., DoFPS, RSPN, or Gewog administration) - Develop contribution collection mechanisms aligned with existing payment systems (e.g., annual land tax cycle) - Define eligible conservation activities and transparent disbursement criteria for fund use - Pilot in Sakteng and Gangtey-Phobji where WTP and perceived ecosystem dependency are highest
CVI-CF addressed	- Adaptive Capacity

Issue	Low community awareness of the regulating services provided by wetlands (water purification, soil formation, pollination), limiting valuation and conservation support
Recommendation	Strengthen community understanding of regulating ecosystem services to broaden conservation support
Key Interventions	- Develop accessible communication materials (posters, videos in Dzongkha) explaining regulating services and their links to livelihoods - Integrate ecosystem services content into existing extension and community outreach programs - Conduct site-specific workshops on wetland water regulation, focusing on Gangtey-Phobji and Gaytsa-Domkhar where water-related WTP is high - Use local influencers (village elders, religious leaders) as messengers in awareness campaigns
CVI-CF addressed	- Adaptive Capacity

Issue	WTP significantly lower in Bumdeling (Nu. 1,889/HH/year) compared to other sites, reflecting limited economic capacity and perceived dependency
Recommendation	Address underlying economic vulnerability constraining conservation investment in Bumdeling
Key Interventions	- Assess barriers to ecosystem service awareness and economic participation specific to Bumdeling households - Link conservation financing with income diversification support (non-farm livelihoods, market access) - Apply lower contribution tiers in any PES scheme for Bumdeling, proportionate to household income levels - Promote co-benefits framing in conservation messaging: wetland health linked to flood protection, water availability, and crop yields
CVI-CF addressed	- Adaptive Capacity - Sensitivity

9.1.7 livelihood vulnerability

9.1.7.1Adaptive Capacity

Issue	High proportion of uneducated household heads across all sites (62-91%), limiting adaptive capacity and constraining climate resilience

Recommendation	Improve literacy and functional education levels to enhance household adaptive capacity
Key Interventions	- Expand non-formal and adult literacy programs targeting household heads, prioritizing Bumdeling and Sakteng where illiteracy rates are highest - Integrate climate change, livelihood, and natural resource management content into non-formal education curricula - Support children's school retention through scholarships, boarding facilities, and incentive programs - Train local para-educators drawn from within communities to deliver continuing education
CVI-CF addressed	- Adaptive Capacity

Issue	Very low livelihood diversification across all sites (indexed economic source score 0.80-0.96), with high dependence on subsistence agriculture making households highly exposed to climate shocks
Recommendation	Diversify household income sources to reduce climate-related livelihood vulnerability
Key Interventions	- Identify and develop market-linked non-farm income opportunities tailored to each site (e.g., ecotourism in Gangtey-Phobji and Sakteng, NWFPs value-addition in Gaytsa-Domkhar and Bumdeling) - Facilitate access to micro-credit and rural enterprise support for non-farm startup activities - Build skills for value-added processing of agricultural products (potato, dairy, medicinal plants) - Strengthen linkages between communities and domestic markets through improved rural road connectivity and digital market information
CVI-CF addressed	- Adaptive Capacity

Issue	Low participation in community-based climate adaptation programs (54-82% of households not participating), weakening collective resilience
Recommendation	Increase community engagement in climate adaptation planning and implementation
Key Interventions	- Map existing community-based organization (CBOs) and identify entry points for climate adaptation program integration

	- Co-design community climate action plans with Gewog administrations, linked to national Nationally Determined Contributions (NDCs) - Establish community climate monitors and adaptation champions at village level - Document and systematically integrate traditional ecological knowledge into adaptation strategies
CVI-CF addressed	- Adaptive Capacity

9.1.7.2Sensitivity

Issue	High food sensitivity due to lack of irrigated wetland area (84-99% of households at Gangtey-Phobji, Gaytsa-Domkhar, and Sakteng) and over-dependence on single crops (potato, chili)
Recommendation	Reduce food system sensitivity through irrigation improvement and crop diversification
Key Interventions	- Conduct irrigation needs assessments and feasibility studies for small-scale irrigation infrastructure at Gangtey-Phobji, Gaytsa-Domkhar, and Sakteng - Rehabilitate and expand traditional irrigation channels with community labor contributions - Introduce climate-resilient vegetable and grain varieties to reduce dependence on potato and chili monocultures - Support household food storage facilities to buffer seasonal food shortfalls
CVI-CF addressed	- Sensitivity - Adaptive Capacity

Issue	Widespread decrease in spring and stream water availability (40-49% of households in Gangtey-Phobji and Gaytsa-Domkhar), with 46% of Bumdeling households facing drinking water shortages
Recommendation	Secure household water supply against climate-induced reductions in water availability
Key Interventions	- Conduct catchment-level water security assessments at each site to identify critical spring recharge zones - Implement spring catchment protection measures (fencing, reforestation, grazing exclusion) - Construct rainwater harvesting systems at key community nodes and high-risk households - Develop community-managed water-use protocols during dry season shortages - Install and maintain water quality monitoring at primary drinking water sources

CVI-CF addressed	-	Sensitivity
	-	Exposure

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11. Appendices

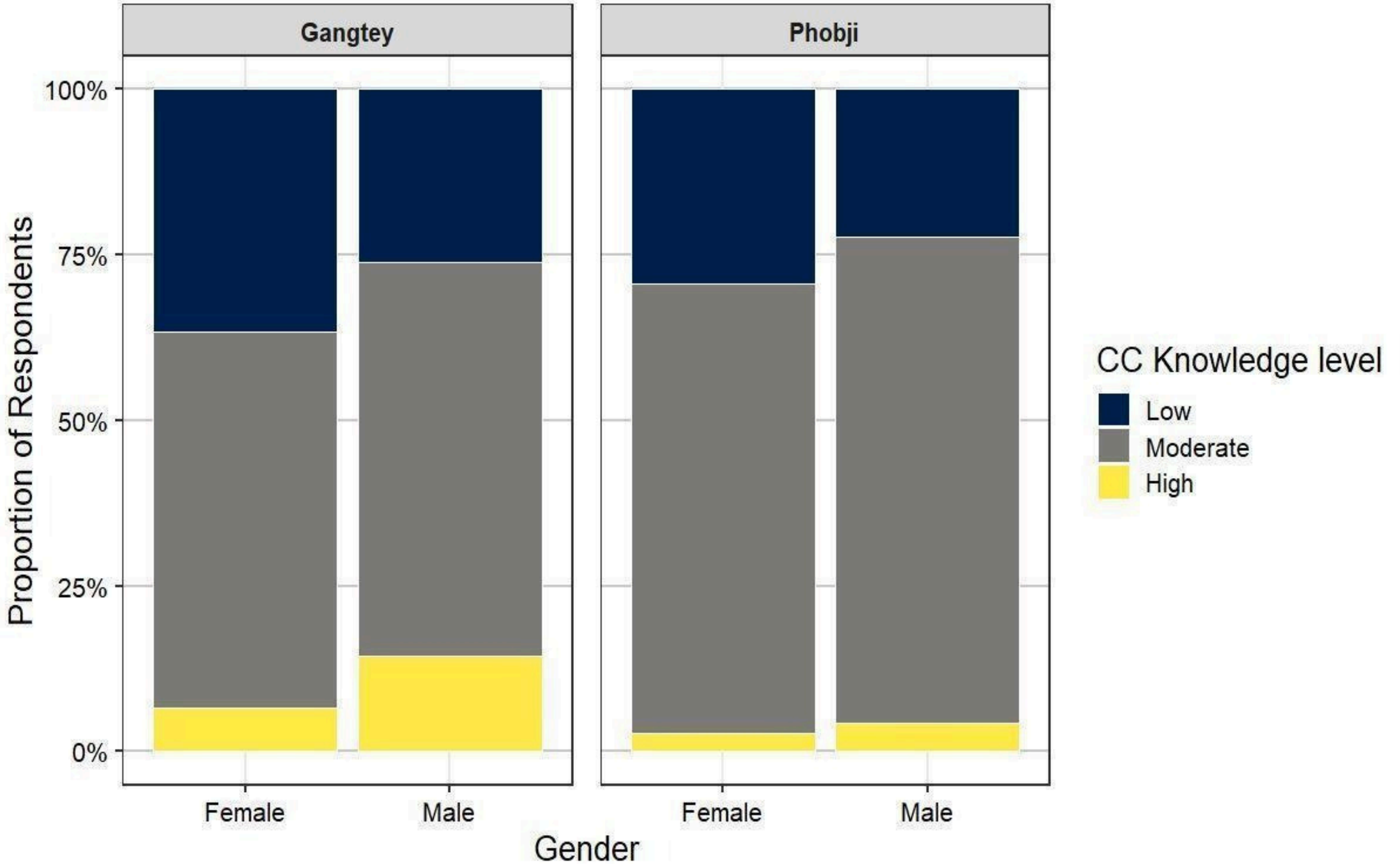


Figure A 4.1. Climate change knowledge level in each gewog of Gangtey-Phobji.

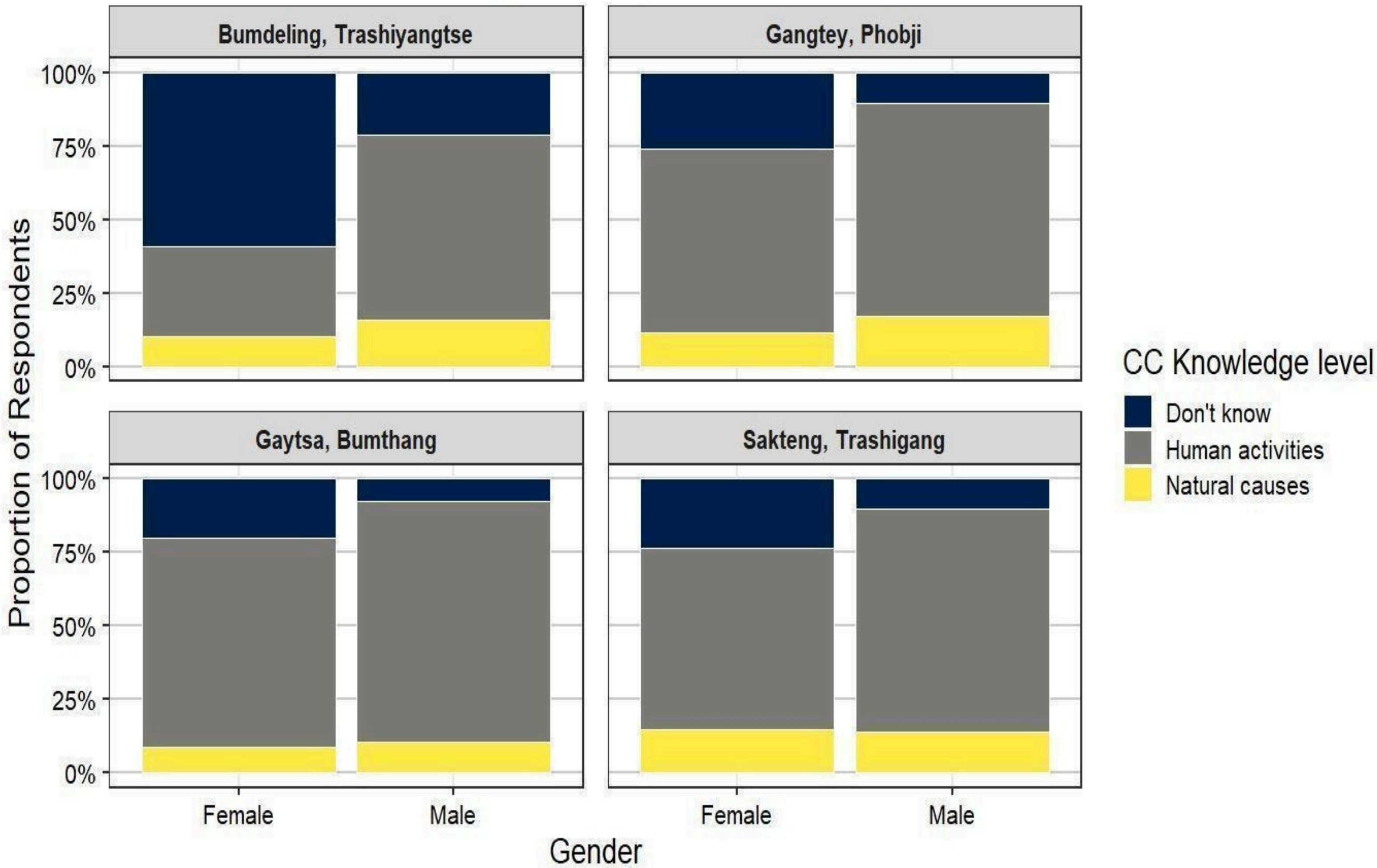


Figure A4.2: Causes of climate change: Local knowledge by gender across all sites

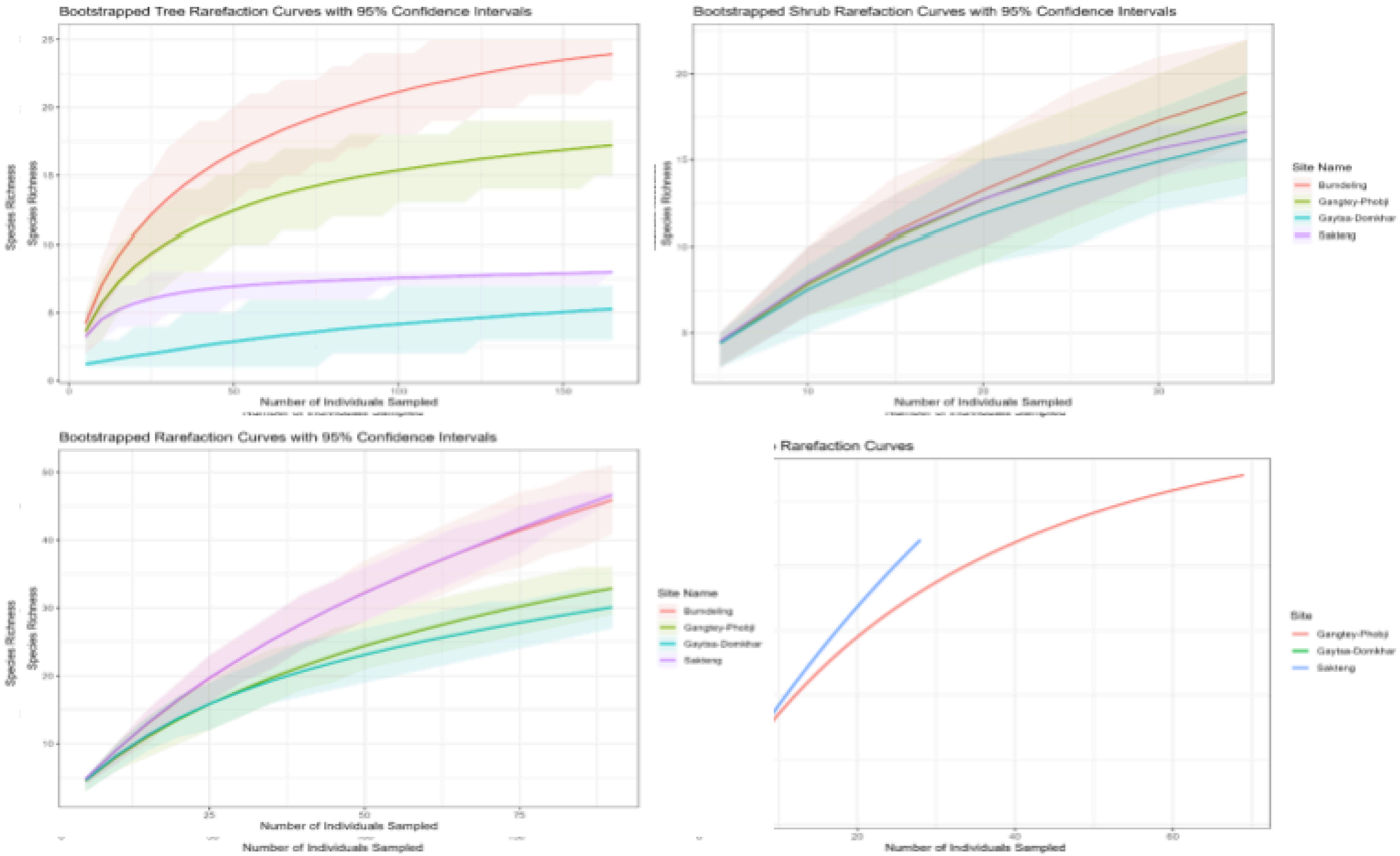


Figure A5.1. Individual-based rarefaction curves for trees, shrubs, forest herbs and wetland herbs across the surveyed sites.

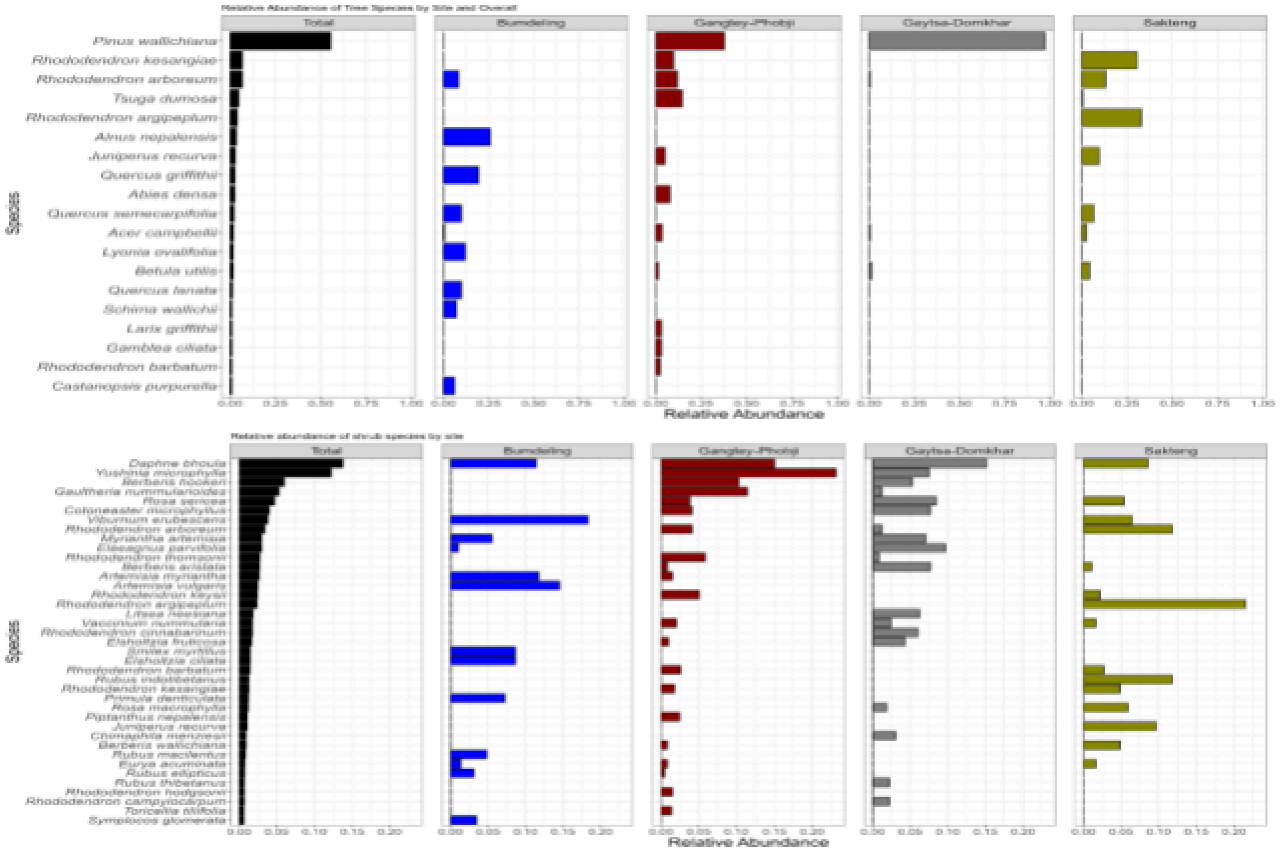


Figure A5.2. Bootstrapped individual-based rarefaction curves for trees, shrubs and herbs, with 95% confidence interval and cut off at the largest common sample size for direct comparison of species accumulation rates.

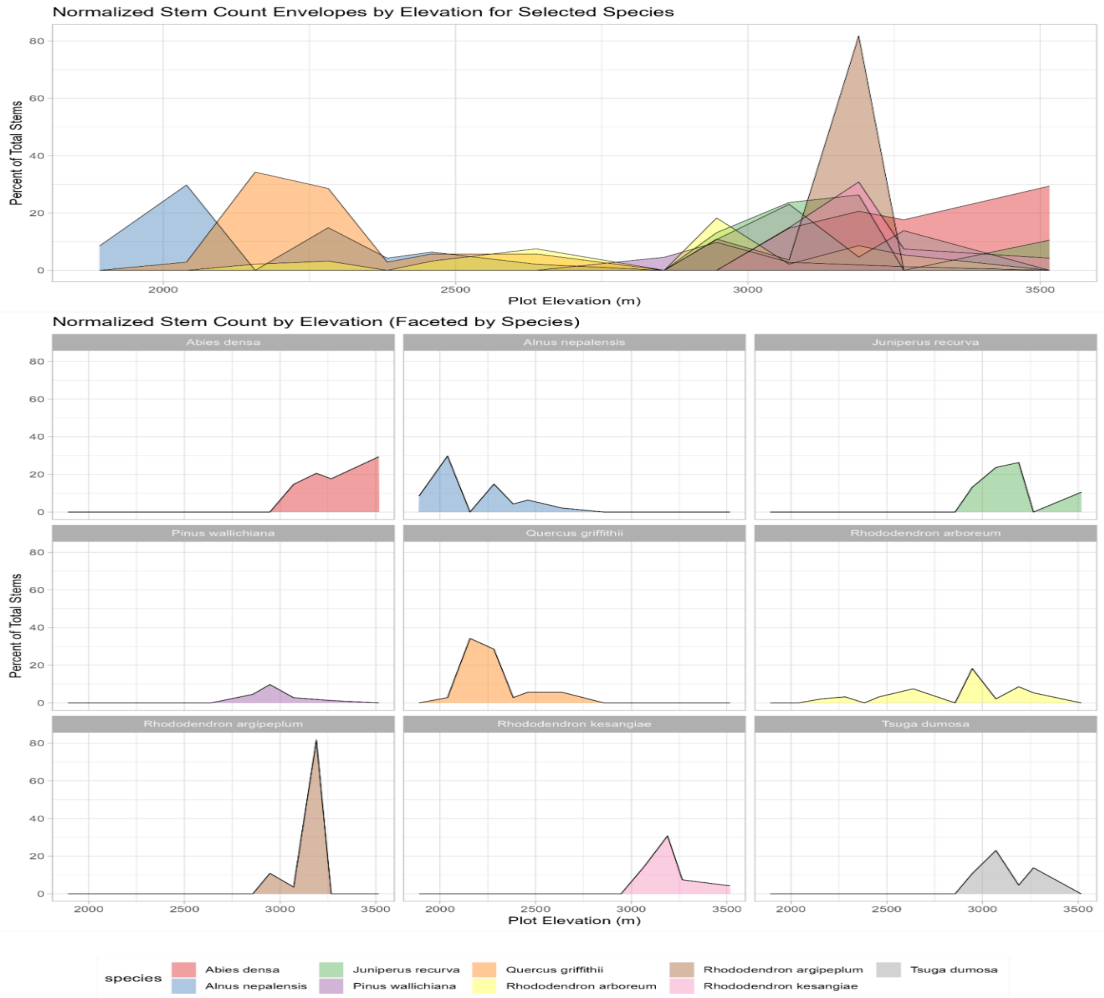


Figure A5.4. Normalized stem count envelopes, which were derived based on the number of individuals of each species across the elevation gradient. Top panel: all species combined. Lower panels: individual species distributions

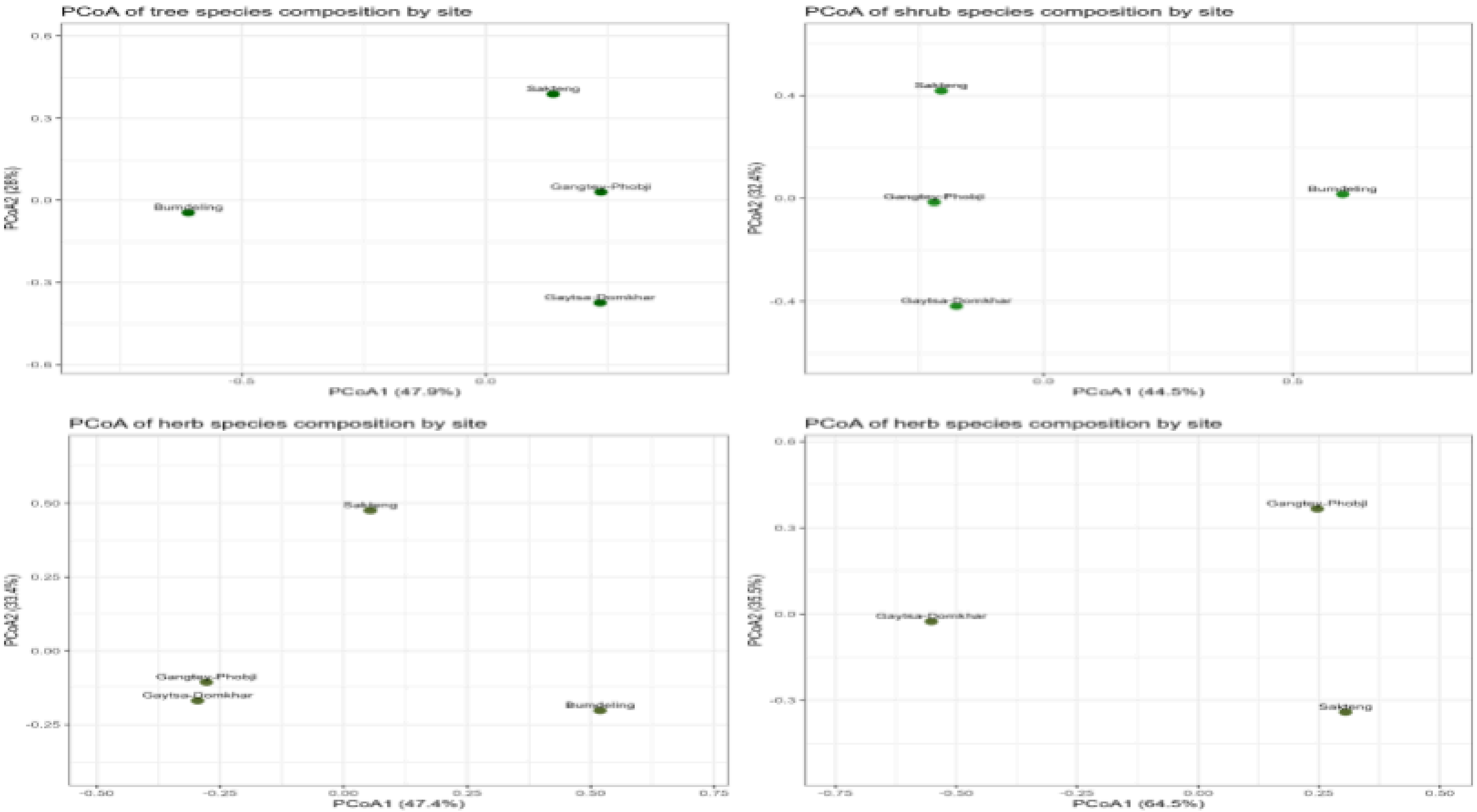


Figure A5.5. Principal Coordinate Analysis (PCoA) of tree, shrub, forest herb, and wetland herb communities across the four sites. The analysiswas based on Jaccard distance measures of the species p=by-plot matrix (presence-absence)

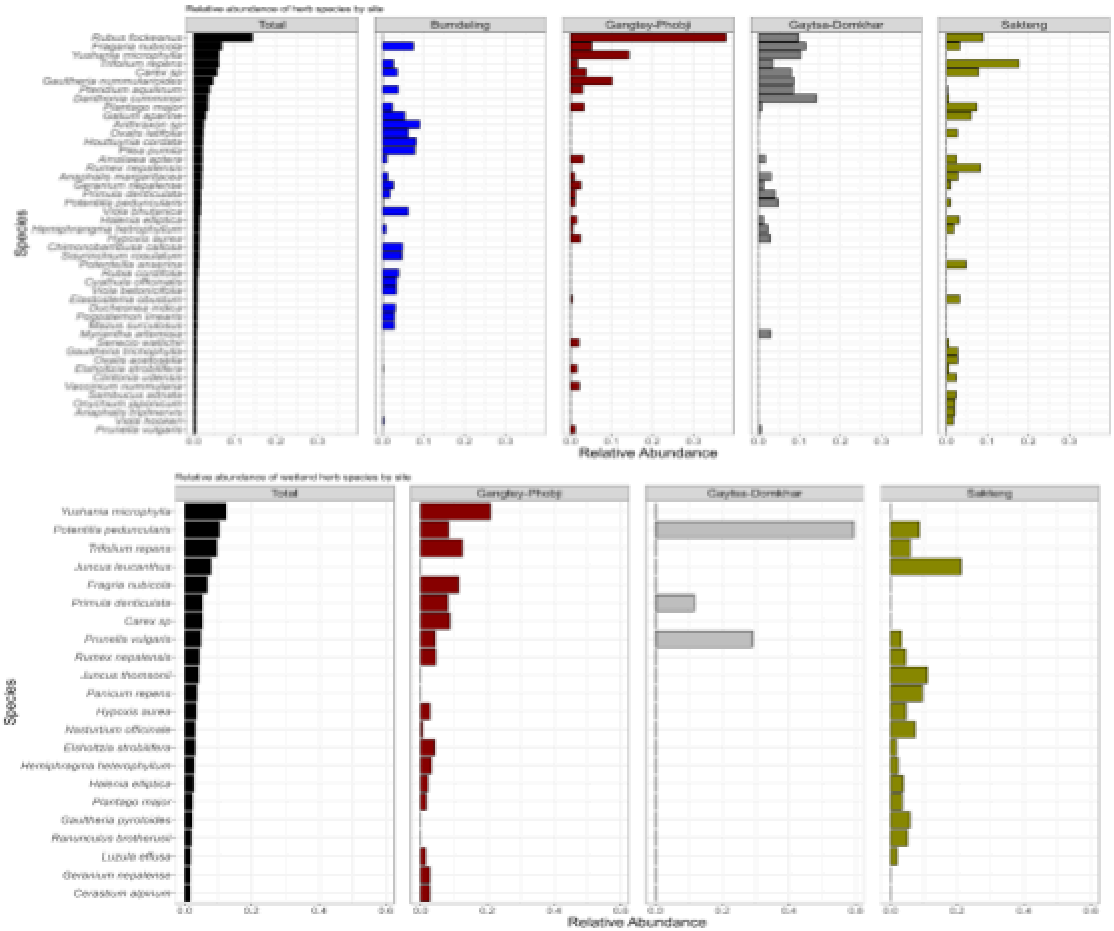


Figure A5.6. Relative abundances of forest herb and wetland herb species.

Table A5.1: Abundance of trees with dbh ≥10 cm at the four sites.

Species	Gangtey-Phobji	Bumdeling	Gaytsa-Domkhar	Sakteng	Total
Plots	22	28	26	10	86
Area (ha)	0.88	1.12	1.04	0.4	3.44
Abies densa	34	0	0	0	34
Acer campbellii	15	1	4	4	24
Acer oblongum	0	2	0	0	2
Acer spicatum	5	0	0	0	5
Alnus nepalensis	0	47	0	0	47
Betula alnoides	0	2	0	0	2
Betula utilis	6	0	9	7	22
Castanopsis purpurella	0	11	0	0	11
Cinnamomum tamala	0	5	0	0	5
Corylopsis himalayana	0	4	0	0	4
Eurya acuminata	0	8	0	0	8
Gamblea ciliata	13	0	0	0	13
Ilex dipyrena	0	2	0	0	2
Juglans regia	0	5	0	0	5
Juniperus recurva	22	0	0	16	38
Larix griffithii	13	0	0	0	13

Species	**Gangtey-Phobji**	**Bumdeling**	**Gaytsa-Domkhar**	**Sakteng**	**Total**
Lindera neesiana	0	0	3	0	3
Lyonia ovalifolia	0	22	0	0	22
Persea sp	0	3	0	0	3
Picea spinulosa	1	0	7	0	8
Pieris formosa	1	0	0	0	1
Pinus bhutanica	0	2	0	0	2
Pinus wallichiana	167	0	621	0	788
Populus sp	0	0	1	0	1
Prunus sp	0	3	0	0	3
Quercus griffithii	0	35	0	0	35
Quercus lanata	0	18	0	0	18
Quercus oxyodon	0	2	0	0	2
Quercus semecarpifolia	0	18	0	11	29
Rhododendron arboreum	52	15	4	22	93
Rhododendron argipeplum	0	0	0	55	55
Rhododendron barbatum	11	0	0	0	11
Rhododendron grande	5	0	0	0	5
Rhododendron hodgsonii	5	0	0	0	5
Rhododendron kesangiae	43	0	0	51	94
Rhododendron keysii	7	0	0	0	7

Species	Gangtey-Phobji	Bumdeling	Gaytsa-Domkhar	Sakteng	Total
Rhododendron thomsonii	3	0	0	0	3
Salix sp	1	2	0	0	3
Schima wallichii	0	13	0	0	13
Sorbus thibetica	8	0	1	0	9
Symplocos dryophila	0	8	0	0	8
Symplocos glomerata	0	4	0	0	4
Toxicodendron succedaneum	0	3	0	0	3
Tsuga dumosa	64	0	0	1	65
Viburnum erubescens	0	2	0	0	2
Total	**476**	**237**	**650**	**167**	**1530**

Note: Unidentified individuals in a genus for which individuals were identified to species, were removed from analysis to prevent over-inflation of diversity indices. Individuals identified to a genus for which no individuals were identified to species, were retained.

Table A5.2: Abundance of shrub individuals across the four sites.

Species	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng	Total
Aconogonun molle	5	3	0	0	8
Artemisia myriantha	34	11	0	0	45
Artemisia vulgaris	42	0	0	0	42
Berberis aristata	0	6	38	2	46
Berberis asiatica	0	2	4	0	6
Berberis hookeri	0	76	26	0	102
Berberis wallichiana	0	6	0	9	15
Betula utilis	0	0	0	7	7
Buddleja coveli	0	3	0	0	3
Chimaphila menziesii	0	0	15	0	15
Coraria sp	0	3	0	0	3
Corylopsis himalayana	2	0	0	0	2
Cotoneaster bumthangensis	0	0	6	0	6
Cotoneaster horizontalis	0	7	0	0	7
Cotoneaster microphyllus	0	30	38	0	68
Daphne bhoula	33	110	75	16	234
Elaeagnus parvifolia	3	0	48	0	51
Elsholtzia ciliata	25	0	0	0	25
Elsholtzia fruticosa	0	7	21	0	28
Euphorbia griffithii	0	0	2	0	2

Species	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng	Total
Eurya acuminata Gaultheria	4 6 0 0 84 6 8 0 0 0 7 0 0 0 2 3 0 0 0 9 0 1 0 0 3 0 0			3	13
nummularioides Girardinia	0 0 0 0 0 3 0 0 31 8 0 1 16 0 35 1 0 0 0 5 0 0 18 0 21			0	90
diversifolia Hedera	0 0 8 0 0 0 0 0			0	8
nepalensis Helichrysum sp				0	7
Hypericum oblongifolium				0	2
Ichonocarpus fructescens				0	3
Ilex dipyrena				0	9
Isodon lophenthoides				0	1
Juniperus recurva				0	3
Lindera sp				18	18
Litsea neesiana				0	3
Lyonia ovalifolia				0	31
Myriantha artemisia				0	9
Persia sp				0	51
Pieris formusa				0	1
Piptanthus nepalensis				0	5
Primula denticulata				0	18
Prinsepia utilis				0	21
Quercus semicarpifolia				0	8
				2	2

Species	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng	Total
Rabdosia rugosa Rhododendron	1 0 0			0	1
Arboreum Rhododendron	0 2 0			0	2
arboreum Rhododendron	0 30 6			22	58
argipeplum Rhododendron	0 0 0			40	40
barbatum Rhododendron	0 19 0			5	24
campylocarpum Rhododendron	0 0 11			0	11
cinnabarinum Rhododendron	0 0 30			0	30
hodgsonii Rhododendron	0 11 0			0	11
kesangiae Rhododendron keysii	0 13 0			9	22
Rhododendron lepidotum	0 37 0			4	41
Rhododendron thomsonii	0 7 0			0	7
Rosa macrophylla	0 43 4			0	47
Rosa sericea	0 0 9			11	20
Rubus ellipticus	0 28 42			10	80
Rubus indotibetanus	9 3 0			0	12
Rubus macilentus	0 0 0			22	22
Rubus thibetanus	14 0 0			0	14
Salix longiflora	0 0 11 0 0 3 25 0 0			0	11
Smilex myrtillus				0	3
				0	25

Species	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Sakteng	Total
Solanum viarum	3	0	0	0	3
Strobilanthes sp	3	0	0	0	3
Symplocos glomerata	10	0	0	0	10
Toricellia tiliifolia	0	10	0	0	10
Tripterospermum volubile	0	4	0	0	4
Uritica sp	5	0	0	0	5
Vaccinium nummularia	0	15	12	3	30
Viburnum erubescens	53	0	0	12	65
Yushinia microphylla	0	170	37	0	207
Zanthoxylum acanthopodium	6	0	0	0	6
Total	**346**	**785**	**516**	**195**	**1842**

Note: Unidentified individuals in a genus for which individuals were identified to species, were removed from analysis to prevent over-inflation of diversity indices. Individuals identified to a genus for which no individuals were identified to species, were retained.

Table A5.3: Abundance of herbs across the four sites.

Species	Sakteng	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Total
Acer campbellii	13	0	0	0	13
Aconogonun molle	8	0	0	0	8
Ainsliaea aptera	40	18	55	28	141
Anaphalis margaritacea	46	22	17	50	135
Anaphalis triplinervis	33	0	0	0	33
Anthraxon sp	0	163	0	0	163
Artemisia myriantha	0	0	8	16	24
Arumdenela bengalaris	0	0	26	0	26
Begonia sp	0	2	0	0	2
Berberis sp	0	0	0	3	3
Bidens pilosa	0	17	0	0	17
Blumea sp	0	0	3	0	3
Bulbophyllum gurungianum	0	11	0	0	11
Bupleurum candollei	0	0	0	3	3
Calamagostris sp	0	0	0	3	3
Cardamine flexousa	12	0	0	0	12
Cardamine impatiens	0	3	0	0	3
Carex sp	127	65	68	130	390
Cerastium sp	13	0	0	0	13
Chimaphila menziesii	0	0	0	23	23

Species	Sakteng	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Total
Chimonobambusa callosa	0	88	0	0	88
Chlorogalum gandriflorum	0	3	0	0	3
Chrysosplenium nepalense	29	0	0	0	29
Cirsium verutum	0	5	9	0	14
Clinopodium umbrosum	0	12	0	0	12
Clintonia udensis	39	0	0	0	39
Colocasia sp	0	14	0	0	14
Commelina bengalensis	0	25	0	0	25
Cotanaester microphylla	0	0	13	0	13
Cyathula officinalis	0	61	0	0	61
Cynoglossum furcatum	5	6	0	0	11
Danthonia cumminsii	8	0	0	231	239
Daphne bhoula	0	0	4	3	7
Desmodium laxum	0	0	2	0	2
Diplazium esculentum	0	1	0	0	1
Duchesnea indica	0	56	0	0	56
Elastostema obustum	53	0	7	0	60
Elsholtzia ciliata	0	13	0	0	13
Elsholtzia strobilifera	9	2	28	0	39
Fimbristylis sp	0	13	0	0	13

Species	Sakteng	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Total
Fragaria nubicola	53	135	92	187	467
Galium aparine	98	97	0	2	197
Gaultheria nummularioides	0	0	181	141	322
Gaultheria trichophylla	45	0	0	0	45
Gentiana bryoides	8	0	0	0	8
Gentiana elwesii	0	0	0	13	13
Geranium nepalense	16	47	45	21	129
Gnaphalium affine	0	4	0	0	4
Goodyera schlechtendaliana	0	6	0	0	6
Halenia elliptica	50	0	27	19	96
Hedera nepalensis	0	9	0	0	9
Hedychium aurantiacum	0	5	0	0	5
Hedychium spicatum	0	13	0	0	13
Helichrysum sp	0	0	0	2	2
Hemiphrangma hetrophyllum	30	15	10	37	92
Houttuynia cordata	0	147	0	0	147
Hydrocotyle himalaica	0	20	0	0	20
Hypericum gramineum	0	7	0	0	7
Hypoxis aurea	0	0	43	47	90
Ichnocarpus frutescens	0	0	6	0	6

Species	Sakteng	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Total
Impatiens exilis			0 10 0	0	10
Impatiens radiata			0 7 0	0	7
Impatiens scitula			25 0 0	0	25
Isodon lophenthoides			0 19 0	0	19
Lamium sp			0 7 0	0	7
Lepidium virginicum			7 0 0	0	7
Leucas ciliata			0 16 0	0	16
Ligularia mortonii			1 0 0	0	1
Luzula sp			0 0 0	3	3
Lycopodium japonicum			0 0 0	3	3
Mazus surculosus			0 52 0	0	52
Mianthemum fuscum			0 1 0	0	1
Myriantha artemisia			0 0 0	48	48
Onychium japonicum			33 0 0	0	33
Oxalis acetosella			44 0 0	0	44
Oxalis corniculata			0 9 0	0	9
Oxalis latifolia			43 112 0	0	155
Panicum repens			0 23 0	0	23
Paris polyphylla			0 2 0	0	2
Parthenocissus semicordata			0 1 0	0	1

Species	Sakteng	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Total
Persicaria nepalensis Persicaria	7	16	0	0	23
runcinata	7	22	0	0	29
Pilea pumila	0	142	0	0	142
Plantago major	120	43	59	12	234
Pogostemon linearis	0	52	0	0	52
Polygonatum cathcartii	5	0	0	0	5
Potenteilla anserina	78	0	0	0	78
Potenteilla arbuscula	14	0	0	0	14
Potentilla peduncularis	16	2	20	79	117
Primula bhutanica	8	0	0	0	8
Primula denticulata	0	32	21	65	118
Primula gracilipes	0	0	1	0	1
Prunella vulgaris	0	0	20	11	31
Pseudohnaphalium hypoleucum	0	0	5	0	5
Pteridium aquilinum	4	69	53	139	265
Puzolzia hirta	0	25	0	0	25
Ranunculus chinensis	11	0	0	0	11
Risleya atropurpurea	0	0	3	0	3
Rubia cordifolia	0	71	0	0	71
Rubus calycinus	0	20	0	0	20

Species	Sakteng	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Total
Rubus fockeanus	145	0	676	159	980
Rumex acetosella	5	0	8	0	13
Rumex nepalensis	135	0	2	1	138
Rumex patienti	2	0	0	0	2
Salvia campanulata	0	13	0	0	13
Sambucus adnata	38	0	0	0	38
Selliguea griffithiana	0	2	0	0	2
Senecio laetus	6	0	0	0	6
Senecio raphanifolius	0	0	3	0	3
Senecio wallichii	9	0	36	0	45
Sisyrinchium rosulatum	0	85	0	0	85
Smilex sp	0	0	0	1	1
Stellaria vestita	16	0	0	0	16
Swertia macrosperma	0	0	0	7	7
Tradescantia occidentalis	0	5	0	0	5
Trifolium repens	288	47	30	57	422
Tripterospermum volubile	0	0	23	4	27
Tupistra wattii	0	2	0	0	2
Uritica dioca	0	7	0	0	7
Vaccinium nummularia	0	0	38	0	38

Species	Sakteng	Bumdeling	Gangtey-Phobji	Gaytsa-Domkhar	Total
Verbascum thapsus	0	0	20	0	20
Veronica himalensis	0	0	0	4	4
Viola betonicifolia	0	60	0	0	60
Viola bhutanica	0	113	0	0	113
Viola hookeri	27	5	0	0	32
Yushania microphylla	0	0	254	168	422
Total	**1829**	**2197**	**1916**	**1720**	**7662**

Note: Unidentified individuals in a genus for which individuals were identified to species, were removed from analysis to prevent over-inflation of diversity indices. Individuals identified to a genus for which no individuals were identified to species, were retained.

Table A5.4: Abundance of wetland herb species across three of the four sites. In Gaytsa-Domkhar, there was no wetland outside of agricultural land.

Species	Gangtey-Phobji	Sakteng	Gaytsa-Domkhar	Total
Anaphalis margaritacea	7	0	0	7
Apium prostratum	2	0	0	2
Carex sp	98	0	0	98
Cerastium alpinum	30	0	0	30
Chlorogalum angustifolium	0	1	0	1
Cirsium verutum	5	0	0	5
Clinopodium umbrosum	26	0	0	26
Elsholtzia strobilifera	47	12	0	59
Fragria nubicola	128	0	0	128
Gaultheria nummularioides	3	0	0	3
Gaultheria pyroloides	0	41	0	41
Gentiana bryoides	0	6	0	6
Geranium nepalense	30	0	0	30
Gnaphalium affine	11	0	0	11
Halenia elliptica	24	27	0	51
Hemiphragma heterophyllum	36	16	0	52
Hydrocotyle himalaica	0	28	0	28
Hypoxis aurea	31	33	0	64

Species	Gangtey-Phobji	Sakteng	Gaytsa-Domkhar	Total
Juncus leucanthus	0	150	0	150
Juncus thomsonii	0	78	0	78
Luzula effusa	17	14	0	31
Nasturtium officinale	7	52	0	59
Panicum repens	0	68	0	68
Plantago depressa	0	19	0	19
Plantago major	18	25	0	43
Potenteilla anserina	0	16	0	16
Potentilla peduncularis	94	61	41	196
Primula denticulata	91	0	8	99
Prunella vulgaris	49	23	20	92
Ranunculus brotherusii	0	36	0	36
Rubus fockeanus	0	17	0	17
Rumex acetosella	29	0	0	29
Rumex nepalensis	50	32	0	82
Saginia procumbens	19	0	0	19
Saussurea gossypiphora	3	0	0	3
Trifolium repens	141	42	0	183

Species	**Gangtey-Phobji**	**Sakteng**	**Gaytsa-Domkhar**	**Total**
Veronica sp	4	0	0	4
Yushania microphylla	235	0	0	235
Total	**1235**	**797**	**69**	**2101**

Note: Unidentified individuals in a genus for which individuals were identified to species, were removed from analysis to prevent over-inflation of diversity indices. Individuals identified to a genus for which no individuals were identified to species, were retained.

Figure A5.7. Description of Species

Salmo trutta (Linnaeus, 1758)

Common names: Brown trout, river trout.

Synonyms: *Salmo fario* Linnaeus, 1758; *Trutta fario* (Linnaeus, 1758).

Description: Dorsal fin rays 7-3-4/7-11, pectoral 1/12, ventral 9, anal 3-4/7-10, and caudal 18-20. Body brown with shades of greenor bluish tinge, has red spots and and adipose fin. Maximum length 40-100 cm. Maximum recorded weight 20 kg.

Distribution: Widely established in the cold water bodies of the temperate region of Ha, Paro, Thimphu, Punakha, Gasa, Wangdue, Trongsa, and Bumthang.

Conservation status: Introduced sport species.

Figure A5.8. Description of Species

Schizothorax richardsonii (Gray 1832)

Common names: Snowtrout, spotted snowtrout, asaila, butte asala, dhumke asala, yulnya.

Synonyms: *Barbus guttatus* McClelland, 1838; *B. maculatus* McClelland, 1838; *Cyprinus richardsonii* Gray, 1832; *Diptychus annandalei* Regan, 1907; *Gonorhynchus petrophilus* McClelland, 1839; *Oreinus guttatus* (McClelland, 1838); *O. maculatus* (McClelland, 1838); *O. punctatus* McClelland, 1839; *O. richardsonii* (Gray, 1839).

Description: Dorsal fin rays 3/8-9, pectoral 17, ventral 10, anal 2-3/5, and caudal 19. Lateral scales 100. Body golden-silver with small scales, black spotted or not; head length 4 to 6 in total length with ventral mouth; snout with tubercles prominent in males; barbels 2 pairs. Maximum length about 60 cm.

Distribution: Wangchhu in Thimphu, Hachhu in Ha, Pachhu in Paro, Punatsangchhu in Punakha, Budichhu in Tsirang, Dangchhu in Wangdue, Mangdechhu in Trongsa, Chamkharchhu in Bumthang, and Lauri in Samdrup Jongkhar.

Conservation status: Vulnerable, but widely distributed in Bhutan

Figure A5.9. Description of Species

Creuteuchiloglanis bumdhelingensis (Thoni and Gurung 2018)

Common Name: N/A

Synonyms: N/A

Description: The species exhibits a dorsoventrally flattened head and body with smooth dorsal and ventral profiles, a keeled inter-dorsal region, and a truncate caudal fin. The head is broad, with reduced subcutaneous eyes, an inferior mouth, smooth maxillary barbels, and exposed arched premaxillary teeth. Dorsal (i,6), anal (i,4), pectoral (15–16 rays), and pelvic fins (i,5) are well-developed. Live coloration is pale tan with a darker dorsum, pink lateral stripe, and distinct dark markings near the adipose, anal, and caudal regions, including a red spot below the eye. Preserved specimens are dark Gray dorsally, pale ventrally, with a dark lateral line and dusky adipose fin.

Conservation status: Not Evaluate

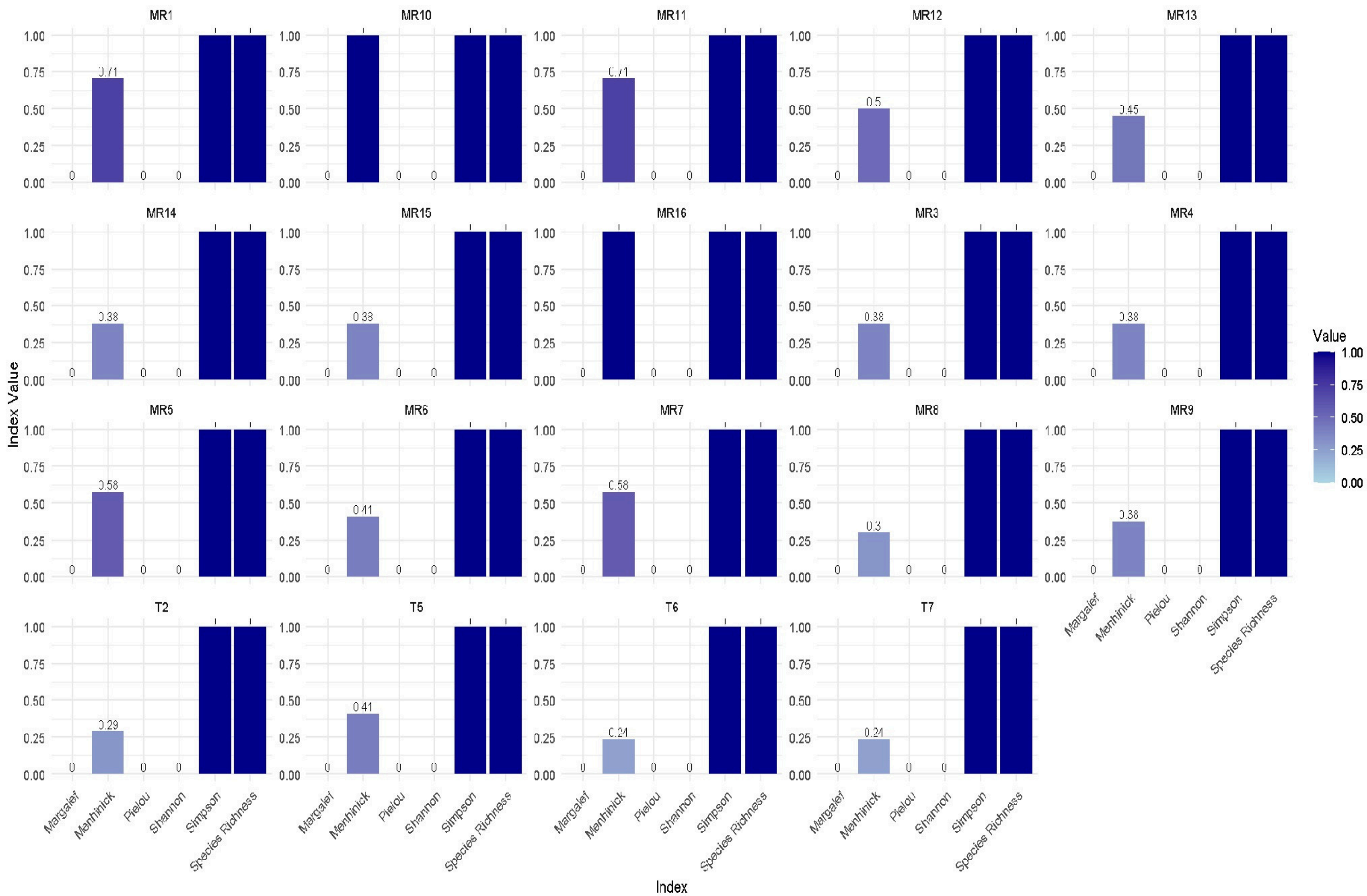


Figure A5.10. Plot-Wise Distribution of Fish Biodiversity Index Values for Gangtey-Phobji

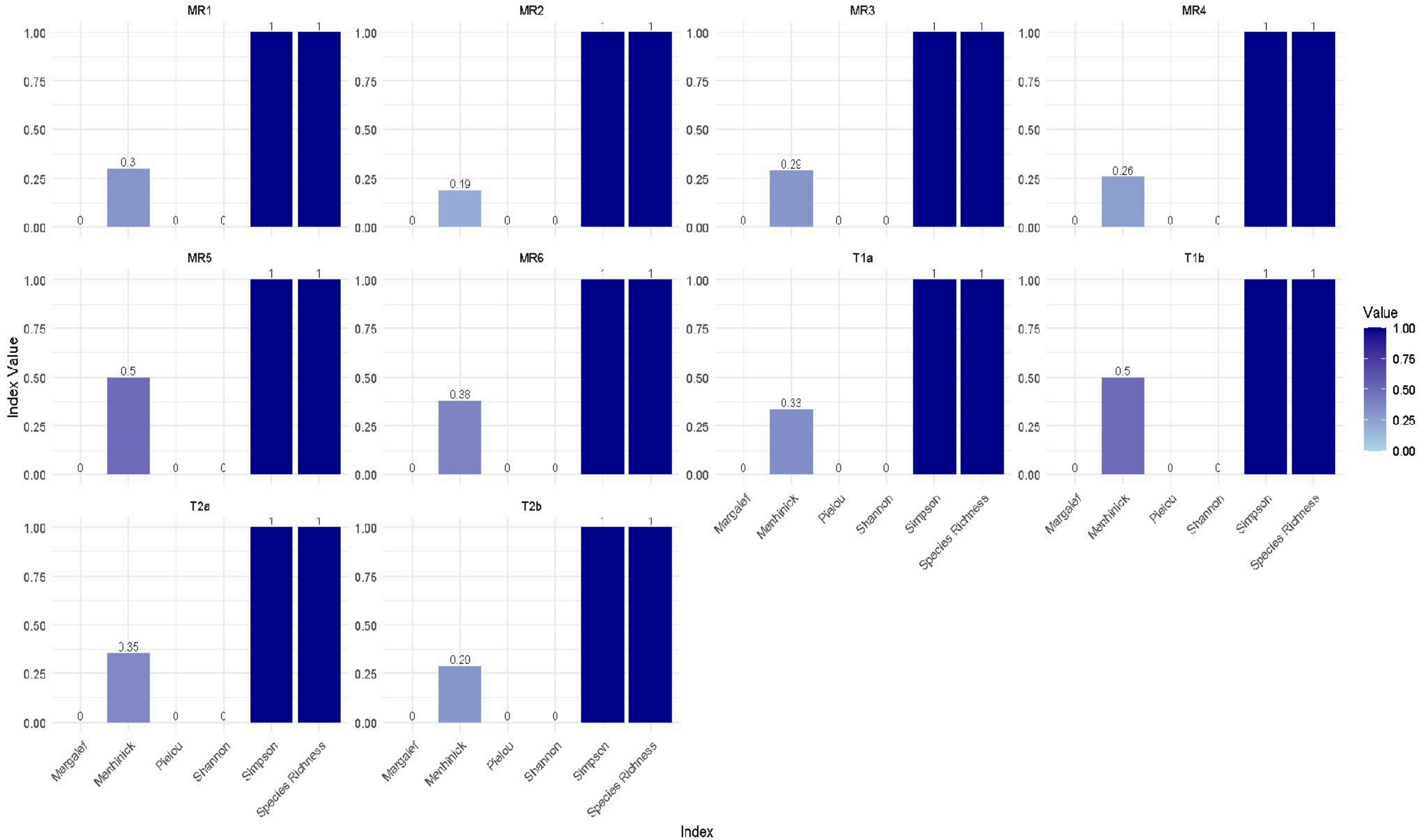


Figure A5.11. Plot-Wise Distribution of Fish Biodiversity Index Values for Gaytsa-Domkhar

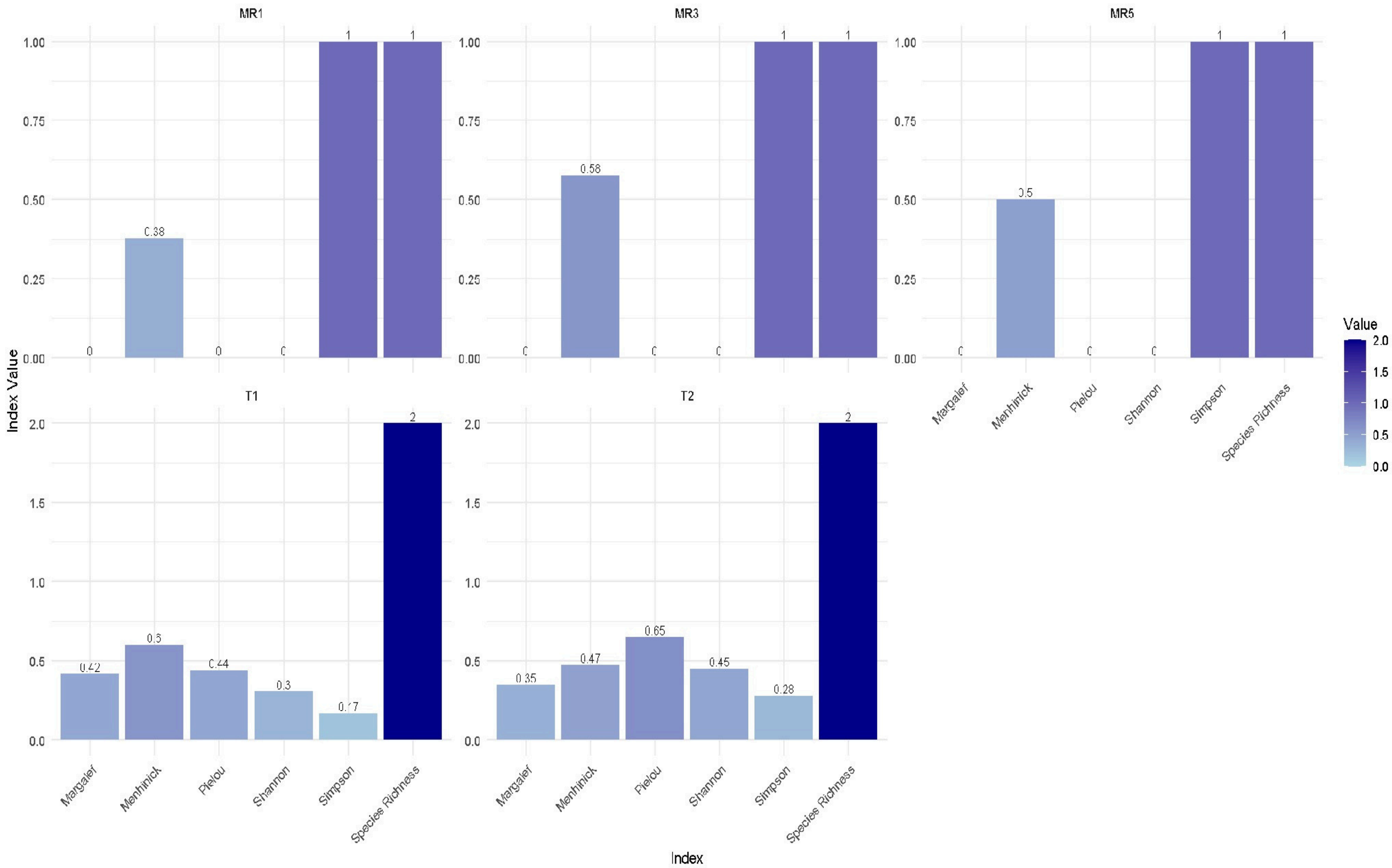
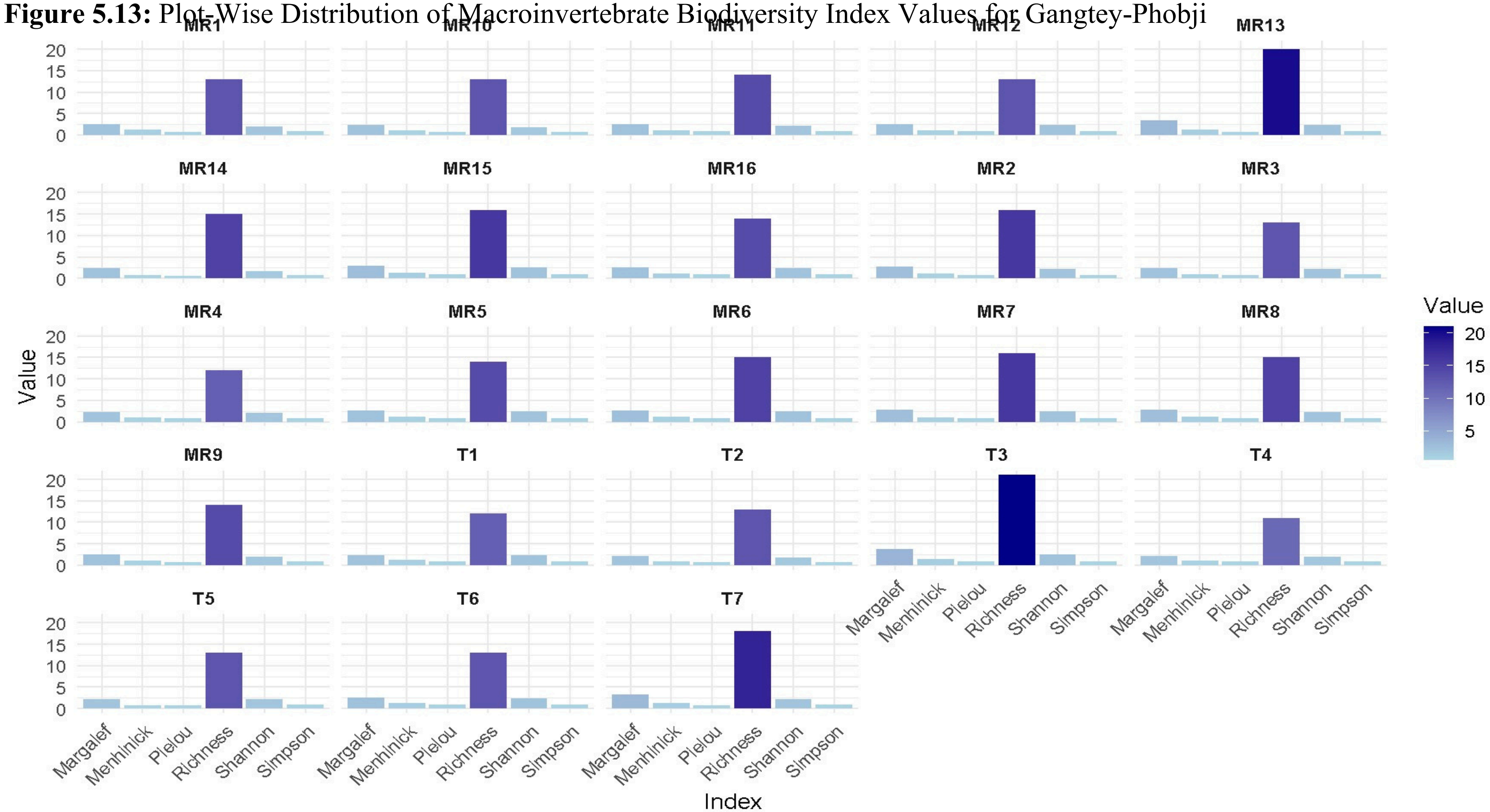


Figure A5.12: Plot-Wise Distribution of Fish Biodiversity Index Values for Bumdeling.

Figure 5.13: Plot-Wise Distribution of Macroinvertebrate Biodiversity Index Values for Gangtey-Phobji



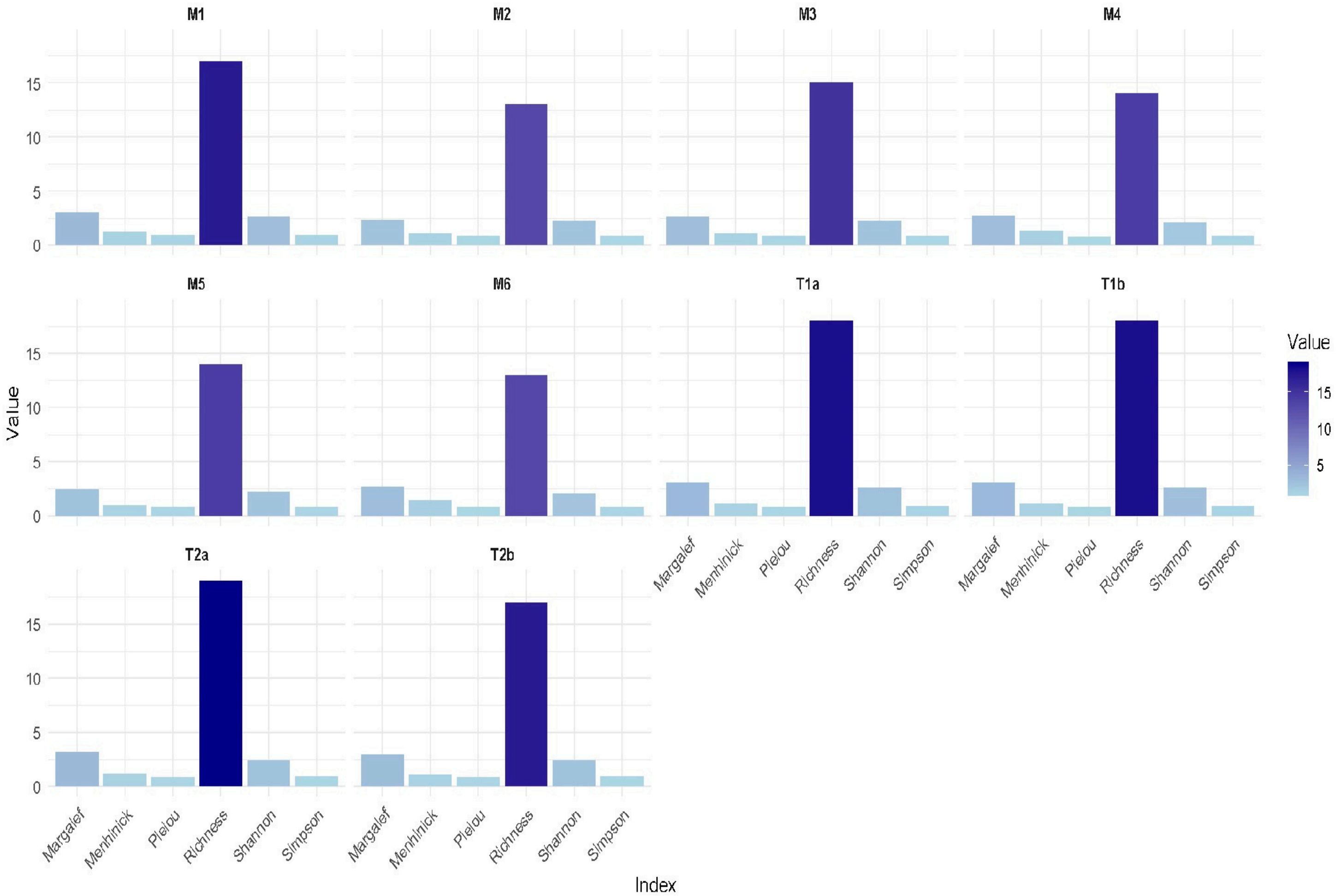


Figure 5.14: Plot-Wise Distribution of Macroinvertebrate Biodiversity Index Values for Gaytsa-Domkhar. Plots are Categorized by Stream Type: T = Tributary and MR = Main River.

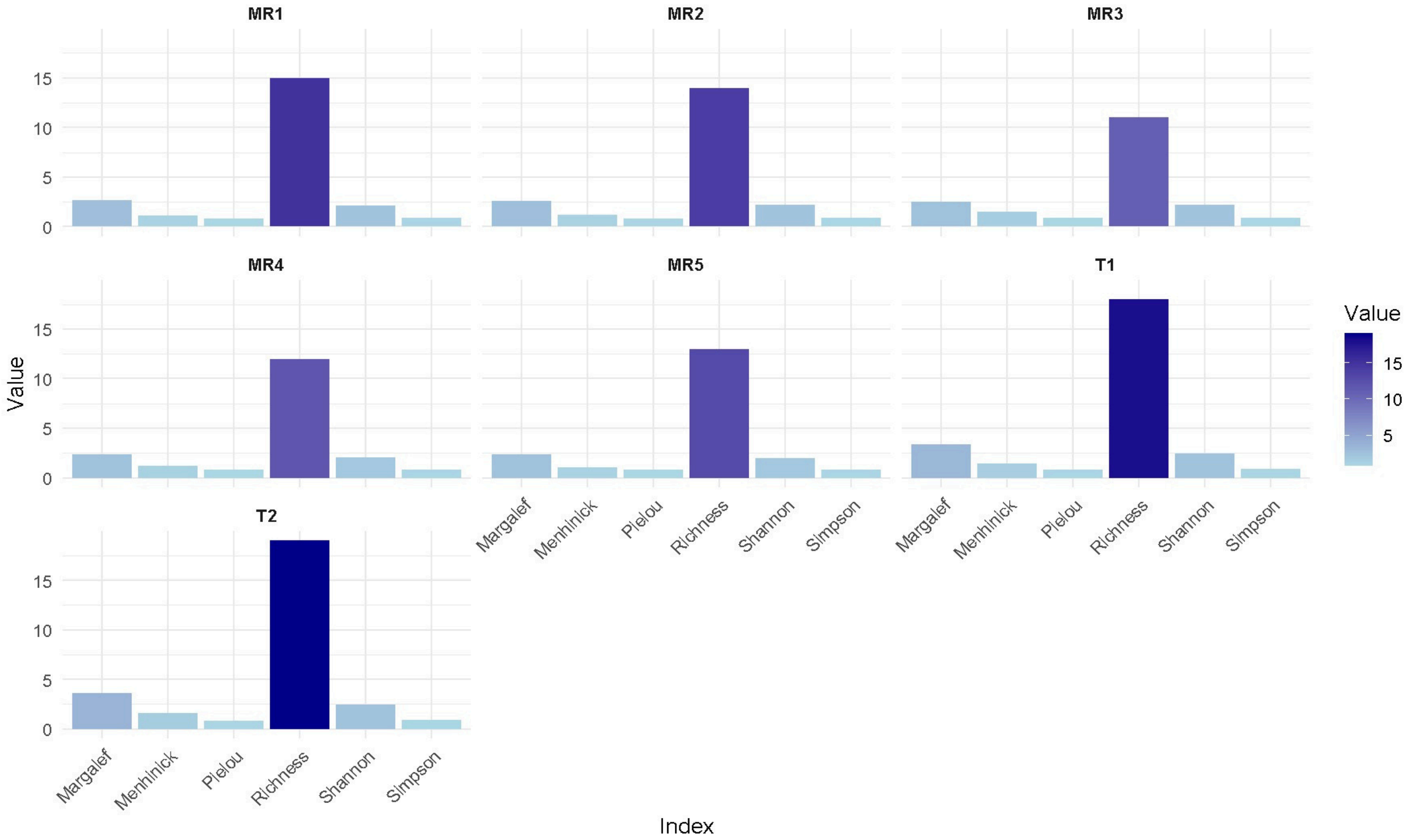


Figure A5.15: Plot-Wise Distribution of Macroinvertebrate Biodiversity Index Values for Bumdeling.

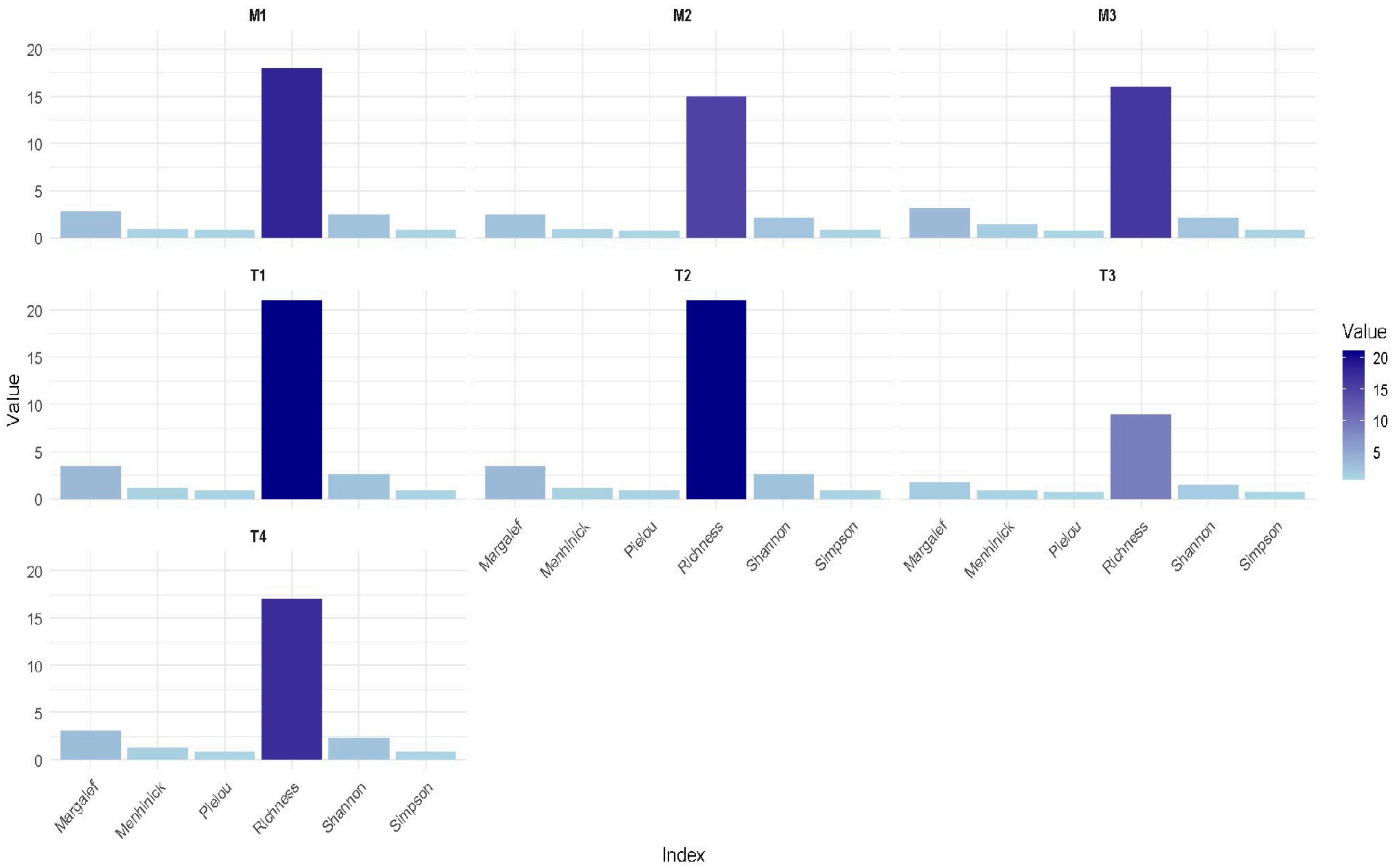


Figure A5.16: Plot-Wise Distribution of Macroinvertebrate Biodiversity Index Values for Sakteng. Plots are Categorized by Stream Type: T = Tributary and MR = Main River.

Table A7.1: The level of education of the household head in the surveyed households, at four sites

Site	Higher secondary	Not educated	Primary school	University
Bumdeling	1.1	90.8	8.0	0.0
Gangtey-Phobji	6.1	80.9	9.9	3.1
Gaytsa-Domkhar	7.3	69.1	18.7	4.9
Sakteng	3.1	88.1	6.9	1.9

Table A7.2: Number of households earning more than 500,000 Ngultrums per year

	Earning >500k Nu. per year		
Site	**Total**	**N**	**Percent**
Bumdeling	87	2	2.3
Gangtey-Phobji	392	41	10.5
Gaytsa-Domkhar	123	1	0.8
Sakteng	160	1	0.6
Total	**762**	**45**	**5.9**

Table A7.3: Median annual income values per village relative to the minimum and 90th percentile of annual income earnings across all villages

Site	Income (Ngultrums)			Index
	Minimum	Median	90^{th} pct	
Bumdeling	0	30,000	500,000	0.94
Gangtey-Phobji	0	200,000	500,000	0.60
Gaytsa-Domkhar	0	57,000	500,000	0.89
Sakteng	0	60,000	500,000	0.88

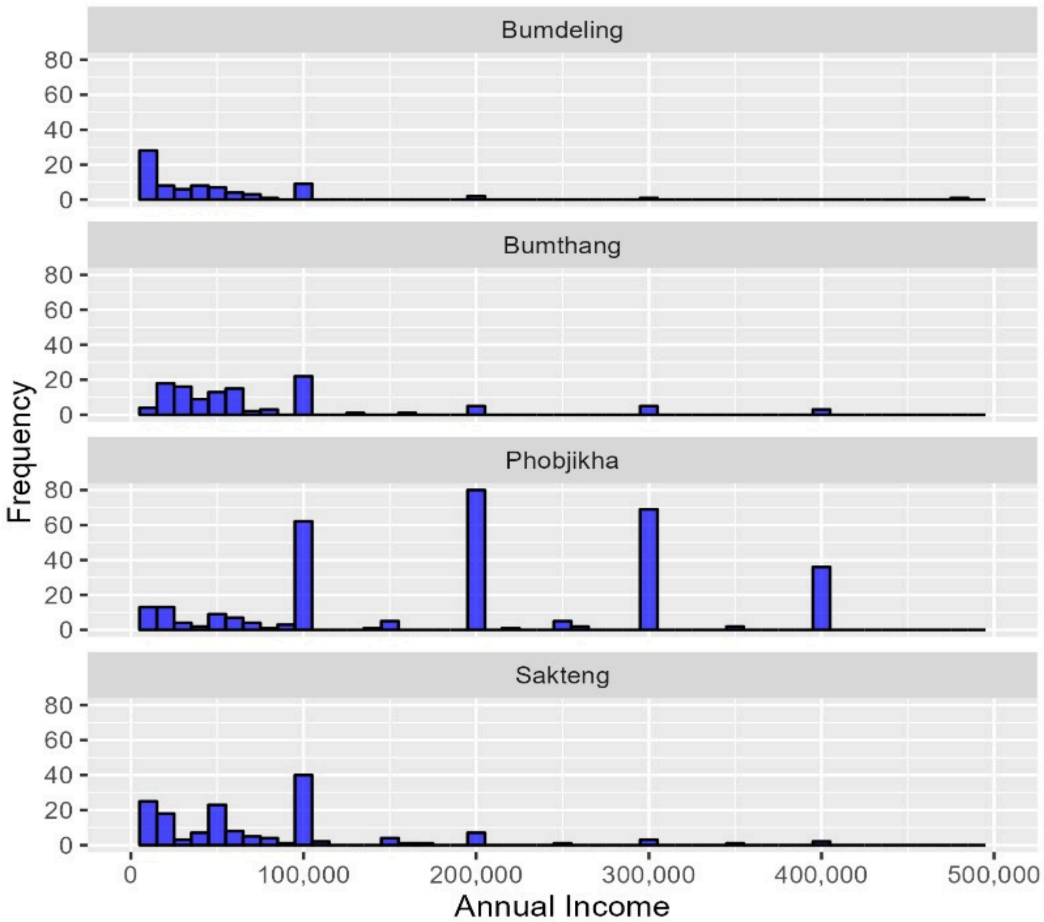


Figure A7.1. Histograms of annual income across all sites. Note the high frequency of very wealthy households in Gangtey-Phobji relative to the other sites