Original Research Article

Assessing theLivelihood Vulnerability to Impact of Climate Change in Western Bhutan.

ABSTRACT:

Climate changepossesses vagaries threats to the subsequent livelihood of the people in Bhutan and it is crucial to enhance adaptive capacity. Therefore, building resiliency requires information on vulnerability of the system of interest. Therefore, this study assessed smallholder farmer's vulnerability to impacts of climate change and variability in western parts (Punakha, Wangdue, Gasa) of Bhutan. A survey was conducted from 392 randomly selected households based on seven major livelihood components of sociodemographic profiles, livelihood strategies, social network, health, food, water and natural disaster and climate variability. Data was analyzed using Livelihood Vulnerability Index approach (LVI) and IPCC framework approach (LVI-IPCC). The result showed that the LVI (range 0.39 to 0.43) and LVI-IPCC (range −0.018 to 0.030) differed across the districts. Punakha district (0.43) was most vulnerableby the LVI approach, whereas Gasa district (0.03) revealed as most vulnerable using LVI-IPCC approach.The degree of vulnerability in a district differed according to their level of exposure and adaptive capacity to climate change impacts of smallholder farmers. Higher exposure to climatic extremes, dependency on natural resources and weak social networking were identified as components that determine overall vulnerability. The results are likely to serve as empirical evidence to design appropriate intervention to cope with climate change impacts and increase resiliency for sustainable livelihood.

Keywords:*Climate change impacts; farmer; exposure; adaptivecapacity; livelihood; vulnerability*

1. INTRODUCTION

By virtue of it being located in a mountainous Himalaya, Bhutan is dominated by rugged terrains and steep topography. Despite its location in a fragile mountainous geography, Bhutan has committed to remain carbon negative country where it has adopted a unique philosophy of Gross National Happiness (GNH) that harmonies the highest priority for the conservation of environment. Ecologically, farming in high elevation is beset at greater challenges and issues due to large fluctuations and weather swings over altitudinal gradient. Large topographical differences are accompanied by huge altitudinal variation, erratic climatic natural hazards such as flashfloods, landslides and glacial outburst which are likely to intensify in the future. Agriculture is a livelihood strategy for thousands of people who have access to limited amount of land. The country is predominantly dependent on agriculture whereby about 62.2% of the population is engaged in subsistence agriculture for their livelihood and are particularly vulnerable to

climate change. The average land holding size is three acres of which farmers grow variety of crops under different climatic conditions and farming practices [1]. This indicates that country has limited arable land due to mountainous topographic features.

Global climate change is a creeping disaster that is biggest threat to both the human health and environment on earth. Current climatic shocks have already had a significant influence on livelihood vulnerability, particularly in rural areas[2]. Even moderate increase in temperature can have adverse impacts on staple crops through pests and disease outbreaks, crop failure and higher livestock mortality. The areas of glaciers, snow and ice in the mountains are mostly sensitive as they grow and shrink in response to changing temperature. Consequently, such threat could destroy communities' key infrastructure, livelihoods, ecosystem services, health and other aspects of human wellbeing [3]. Due to vast exposure to natural disasters, residentiaries have a higher risk of casualties. Despite the challenges, people have become adapted to living in these places due to cultural interaction, job creation and livelihood diversifications. Henceforth, growth is inevitable. This shows that addressing particular adaptations also reducing challenges and opportunities can change them into long-term development programs. Nonetheless the urgency, scientific research that provides a groundwork for livelihood trajectories, as well as different adaptive options and capacities is scarce[4,5].

Potential impacts of climate change on vegetation were also observed through shift in the tree-line in spatial distribution of plant communities. A study from the eastern Himalayas suggests that by 2050-2070, 16-18% of endemic angiosperm species are likely to lose their habitat. These potential changes could impact on functions and ecosystem provided by forest ecosystems and on the socio-economic conditions of the rural communities where livelihood is so dependent upon forest resources. For instance, the distribution of fungus is believed to be affected by summer and winter temperatures and precipitation seasonality where a study by Kunzang showed that precipitation in the driest quarter of 60-100 mm was consistent with temperature between -5°C and 5°C[6].

Climatic trends over Bhutan indicated increasing temperature and decreasing rainfall[7].Farmers reported change in rainfall patterns which is affecting water sources and crop productivity. Bhutan is expected to experience an increasing temperature (0.8°C -3.2°C) with larger increase predicted in higher altitudes and 10% to 30% annual increasing precipitation according to recent forecasts. Farmers also reported a change in rainfall pattern which is affecting water sources and crop productivity. Since the cultivation in Bhutan are mostly rainfed, agriculture is highly prone to climate factors and livelihood security of smallholder farmers is highly sensitive to climatic shocks.Therefore, reducing smallholder farmers vulnerability to impacts of climate change is crucial for Bhutan.

The concept of vulnerability has evolved from varieties of research discipline such as human ecology and physical science. The impacts from climate change are a primary factor affecting the livelihood of marginalized rural farming households around the world. Livelihood comprises of assets, capabilities and activities required as a mean of living. Therefore, livelihood is challenged by vagaries of vulnerabilities

where people need to make it sustainable when effectively coped with the stress and maintained without depleting the resource base.

Situations of Climate change impacts in Asia is similar to Africa as both the continents equally depends on rain-fed agriculture and natural based resources for livelihood. As densely populated region with high population living along the rivers and at low elevation zones, Asia has among the highest number of people prone to impacts of climate related hazards. Similarly, it has been reported intense retreat of glaciers, increase temperature and irregular weather variabilities in Nepal. Likewise in Bangladesh, the two major source of Income, rice and fish farming have been drastically impeded, resulting to a loss of 0.5 million tons of rice annually and immense decline in fish production due to prolonged flood and other climate anomalies [8].

A previous study employed the tool to assess smallholder farmers vulnerability to impacts of climate change in Two central districts (Trongsa and Bumthang) of Bhutan and it recommended similar assessments in other regions of the country [7]. However, a closer look to the literature suggests increasing need for findings from such studies because to enhance resilience, assessment of vulnerability should be carried out of the system of the interest. Therefore, the present study is focused on assessing the smallholder's vulnerability to impacts of climate change in western Bhutan and northern region of the Himalaya.

2. MATERIAL AND METHODS

2.1 study area

The study was conducted in Punakha, Wangdueand Gasa districts of western Bhutan. The research sites are located at elevations ranging from 1500 m to 3500 m above sea level, which are characterized by warm to cool temperate agroecological climatic zones with mean temperature ranging from 1°C to 25°C and an annual rainfall ranging from 650 mm to 750 mm [9]. As majority of the population are predominantly agriculturist based in all the three districts. The rural population encompasses 67% in Punakha, 62.2% in Wangdue Phodrang and 42% in Gasa respectively. The major source of livelihoods ranges from wetland cropping like paddy cultivation, potation cultivation to forest products utilization [10].

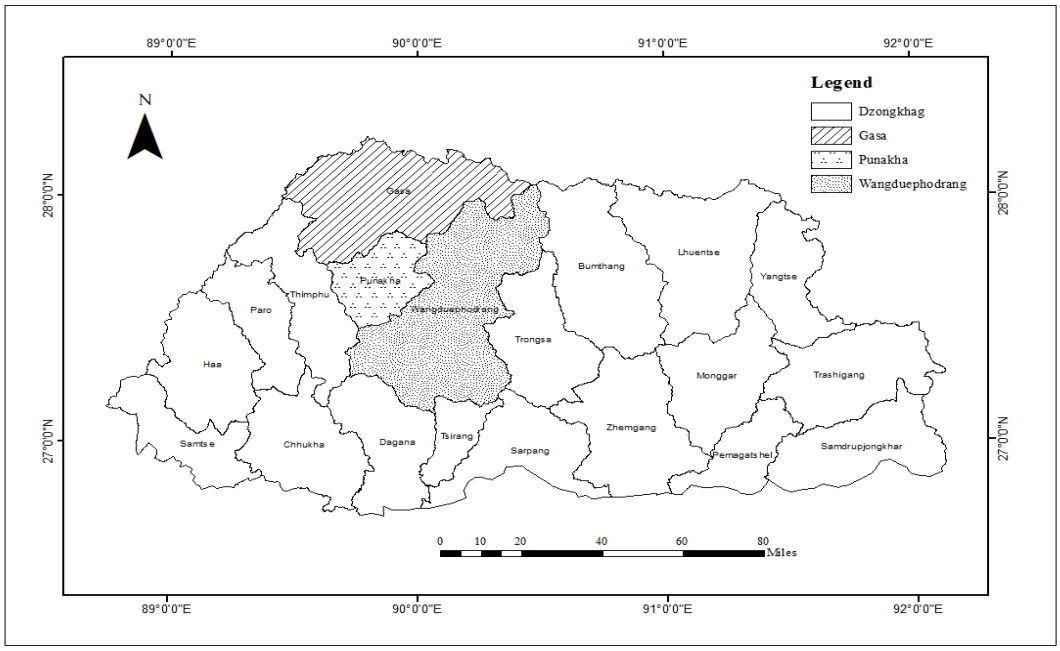

Figure 1. Study area map showing Punakha, Wangdue Phodrang and Gasa Dzongkhag in Bhutan

2.2 Sampling and data collection

Based on a sample calculation [11] at the 95% confidence level, ±5% precision, 392 households were surveyed in the study districts. Multistage Random sampling design was employed for selecting the households without any bias [12]. In the first stage, twelve villages were selected from three districts. secondly, 38 households were randomly selected from each of the sampled sub-district maintained at their respective administration. A total of 392 households were interviewed from the study districts (152 from Punakha district, 120 from Wangdue and Gasa districts).

The study was based on primary data collected from the three study districts (Figure 1) by employing semi-structured, pre-tested and in-depth survey questionnaire using CAPI (Computerized-Assisted Personal Interviews) data collection method[13]. Prior to the implementation of the questionnaire survey, the purpose of the study and verbal consent to conduct the survey were obtained from the dzongkhag administration and head of the household.

A ten-year period from 2012 – 2021 was usedregarding climate data on temperature and precipitation published by National Centre for Hydrology and Meteorology [14].

Table 1. Major components and sub-components comprising the Livelihood Vulnerability index and their assumed functional relationship to vulnerability developed for three study districts

Major component	Sub-component	Explanation of Subcomponents	Assumed functional relationship	Sources
Socio-demographic Profile (SDP)	SDP Variable 1: Dependency Ratio	Ratio of the population under 15 and over 65 years of age to the population between 15 and 65 years of age.	Higher dependency ratio reflects more vulnerability and lesser ability to adapt	Hahn, 2019
	SDP Variable 2: %Female headed households	Percentage of female-headed households during the time of the interview	Female headed households are assumed to have less adaptive capacity	Hahn, 2019
	SDP Variable 3: Average age of female headed households	Average age of the heads of households	Younger female head of households are assumed to have lesser experience and therefore more vulnerable	Hahn, 2019
	SDP Variable 4: %Households where head of household has not attended school.	Percentage of households where the head of the household (female/male) reports that they have attended 0 years of school.	Education increases awareness of the issue and enhances adaptive capacity	Hahn, 2019
Livelihood Strategies (LS)	LS Variable 1: % Households with family members working in different community	Percentage of households that report at least 1 family member working outside of the community for their primary work activity and earning a wage	Income diversification reduces vulnerability and increases adaptive capacity	Hahn, 2019
	LS Variable 2: % Households solely dependent on agriculture for income	Percentage of households that report only agriculture as a source of income	Households with limited source of income are more vulnerable	Hahn, 2019
	LS Variable 3: Average Agricultural	The additional livelihood activities undertaken by households, calculated as the inverse of the number of agriculture livelihood	Diverse livelihood activities reduces vulnerability	Hahn, 2019

	Livelihood diversification index (range 0.20 – 1)	activities (+1) reported by a household (e.g., a household that cultivates potato as the main crop and also cultivates vegetables for sale, and collects mushrooms from forests will have a Livelihood Diversification Index = 1/ (3 + 1) = 0.25)		
Social Networks (SN)	SN Variable 1: Average help received/ given ratio, in-kind	The ratio of the number of types of help received by a household in the past month (+1) to the number of types of help given by a household to someone else in the past month (+1) (e.g., help received during the sale of crops divided by the help given during times of need/emergency)	A household frequently relying on others for help is more vulnerable	Hahn, 2019
	SN Variable 2: Average borrow - lend money ratio (range 0.5 – 2).	The ratio of a household borrowing money (in the past month) to a household lending money (in the past month) (e.g., if a household borrowed money but did not lend money, the ratio is 2:1 or 2; if a household lent money but did not borrow any, the ratio is 1:2 or 0.5)	A household frequently borrowing money from others is financially stressed and therefore more vulnerable	Hahn, 2019
	SN Variable 3: %Households that have not gone to their local government for assistance in the past 12 months.	Percentage of households that reported they had not asked their local government for any assistance in the past 12 months	Household with access to public services are less vulnerable	Hahn, 2019
	SN Variable 4: % Households not associated with any organization		Association with self-help groups increases adaptive capacity	Hahn, 2019
Health (H)	H Variable 1: Average time to health facility	The average time taken by the households to get to the nearest health facility on foot	Longer distance indicates higher sensitivity	Hahn, 2019

	(minutes)			
	H Variable 2: %Households with family member with chronic illness	Percentage of households that report at least 1 family member with chronic illness, where 'chronic illnesses' was defined subjectively by respondents	Households with chronically ill family members are more sensitive	Hahn, 2019
	H Variable 3: %Households where family member has missed school or work in past two weeks	Percentage of households that has missed school/work due to dreadful disease	Higher percentage indicates higher sensitivity	Hahn, 2019
Food (F)	F Variable1: %Households solely dependent on family farm for food	Percentage of households reporting that they depend solely on the family farm for their food.	Households with limited source of food are more sensitive	Hahn, 2019
	F Variable2: Average crop diversity index (0-1)	Calculated as the inverse of the number of crops grown by a household (+1) (e.g., a household that grows pumpkin, maize, chili, and beans will have a Crop Diversity Index = 1/ (4 + 1) = 0.2)	Diverse varieties reflect lesser sensitivity	Hahn, 2019
	F Variable 3: %Households that do not save crops	Percentage of households that report that they do not save crops	Households that do no save crops are more sensitive to disasters	Hahn, 2019
	F Variable 4: %Households that do not save seeds	Percentage of households that report that they do not save seeds for next seasons	Households that do not save seeds are more sensitive to disaster	Hahn, 2019
	F Variable 5: %Households reporting crop losses to wild animals in the last 1 year	Percentage of households reported crop losses to wild animals	Higher percentage indicates more sensitivity.	Hahn, 2019

	F Variable 6: Avg. number months of household food shortage	Average number of months that households has reported food shortage	More months imply higher sensitivity	Hahn, 2019
Water (W)	W Variable 1: %Households reporting water problems	Percentage of households reporting having conflicts over water in their community	Higher percentage reflects higher sensitivity	Hahn, 2019
	W Variable 2: %Households that utilize natural water source	Percentage of households reporting utilization of water through a natural source (spring, river/stream)	Household depending on natural water source such as spring, pond, streams etc. are more sensitive	Hahn, 2019
	W Variable 3: %Households that do not have consistent water supply	Percentage of households reporting that they do not have consistent water supply	Households with consistent water supply are less sensitive	Hahn, 2019
Natural Disasters and Climate Variability (NDCV)	NDCV Variable 1: Avg. No. of flood, windstorms and drought events in past 5 years	Percentage of households reporting increasing occurrences of natural hazards affecting crop production in the past 5 years	Higher number indicates higher exposure	Hahn, 2019 & modified
	NDCV Variable 2: %Households with losses to physical assets due to natural disasters	Percentage of households reporting an injury due to natural disasters in the past 12 months	Higher percentage indicates higher exposure	Hahn, 2019 & modified
	NDCV Variable3: %Households that do not receive a warning about the pending natural disasters	Percentage of households reporting not receiving any warnings prior to natural disasters	Households that receive prior information on impending natural disasters are more prepared and therefore less exposed	Hahn, 2019 & modified

	NDCV Variable 4: Mean standard deviation of the daily average maximum temperature by month (2012 – 2017)	The standard deviation of the average daily maximum temperature by month from 2012 to 2017, averaged for each study district	Higher variability indicates higher exposure	Hahn, 2019 & modified
	NDCV Variable 5: Mean standard deviation of the daily average minimum temperature by month (2012 – 2017)	The standard deviation of the average daily mminimum temperature by month from 2012 to 2017, averaged for each study district	Higher variability indicates higher exposure	Hahn, 2019 & modified
	NDCV Variable 6: Mean standard deviation of the daily average precipitation by month (2012 – 2017)	The standard deviation of the average daily precipitation by month from 2012 to 2017, averaged for each study district	Higher variability indicates higher exposure	Hahn, 2019 & modified

2.3 Data Analysis

The mathematical method for calculating the indices was applied from Hahn et al. where two approaches were used to analyze data: Livelihood Vulnerability Approach (LVI) and IPCC framework approach (LVI-IPCC) as explained below.

2.3.1 Calculation of Livelihood vulnerability Index (LVI) Approach

The Livelihood vulnerability of smallholder farmers to climate variability was analyzed using the vulnerability assessment model [15], commonly applied in various LVI studies [16,17,4]. The LVI can provide a comprehensive assessment of vulnerability to analyze key components that make up household's livelihood[15]. Also facilitate the development of targeted interventions to address specific vulnerabilities. Accordingly, the LVI was derived for each household and district level based on an assessment of the literature on each major components and feasibility of collecting the data needed through household surveys. We used seven major components that were relevant to the Bhutanese context (Table 1);Sociodemographic Profile (SDP), Livelihood Strategies (LS), Social Networks (SN),

Health (H), Food (F), Water (W), and Natural Disaster and Climate Variability (NDCV). The LVI uses a balanced weighted average technique[18], in which each sub-components contributes equally to the overall index, although each major components includes different number of sub-components.

Step 1: Each sub-component is standardized using the following Equation1. The equation 1 was adapted from the Human Development Index to calculate the life expectancy index[19]which is calculated as follows:

$$index_{s_d} = \frac{s_d - s_{min}}{s_{\max} - s_{min}} \text{ (Equation 1)}$$

Where sd is the original value of the sub-component for district *d,* and s_{min} and $s_{\max}$ are the minimum and maximum values, respectively for each of the sub-components determined using data from all the households of the three study from districts. each minimum and maximum values of these sub-components was used to standardize the index.

Step 2: After each of the sub-components was standardized, all the sub-components were then averaged, using Equation 2 to calculate the value for each major components such as SDP.

$$M_d = \frac{\sum_{i=1}^{n} index_{sd_i}}{n} \text{(Equation 2)}$$

Where M_d is one of the seven major components for district d, $index_{sd_i}$represents the sub-components indexed by *i,* n = number of sub-components in each of the major components.

Step 3: Once all the value for each of the seven major components for three districts were calculated, they were averaged using Equation 3 to obtain the specific district wise LVI:

$$LVI_d = \frac{\sum_{i=1}^{7} w_{M_i} M_{di}}{\sum_{i=1}^{7} w_{M_i}} \text{(Equation 3)}$$

Equation 3 can also be written as follows:

$$LVI_d = \frac{W_{SDP} SDP_D + W_{LS} LS_d + W_{SN} SN_d + W_H H_d + W_F F_d + W_w W_d + W_{NDCV} NDCV_d}{W_{SDP} + W_{LS} + W_{SN} + W_H + W_F + W_w + W_{NDCV}}$$

Where LVI_d is the Livelihood vulnerability Index of district d, w_{M_i} are the amount of sub components that reflects all the main component with the same contributor for overallLivelihood Vulnerability Index.In this study, LVI is scaled from 0 (least vulnerable) to 0.7 (most vulnerable) [15].

2.3.2 Intergovernmental Panel for Climate Change Framework for calculating LVI (LVI-IPCC)

LVI-IPCC incorporates the IPCC's definition of vulnerability. Seven major components were first grouped under three contributing factors: Adaptive capacity, Exposure and Sensitivity.

Step 1: Each contributing factor was calculated using Equation 4. But for calculating adaptive capacity, the inverse of the sub-component socio-demographic, livelihood strategies and social Networks were used. In LVI these sub components contributed to vulnerability, whereas LVI-IPCC the inverse value of these sub-components contributes to adaptive capacity.

$$CF_d = \frac{\sum_{i=1}^{n} W_{M_i} M_{d_i}}{\sum_{i=1}^{n} W_{M_i}} \text{(Equation 4)}$$

Where CF_d is contributing factor (Exposure, Sensitivity and Adaptive Capacity) for district *d,* M_{d_i} aremajor components for district *d* indexed *i,* W_{M_i} is the weight for each of the major components, *n* is number of major components in each contributing factors

Step 2: once the adaptive capacity, exposure and sensitivity are calculated, the three contributing factors were combined using Equation 5 to calculate LVI-IPCC.

$$LVI - IPCC_d = (e_d - a_d) * s_d \text{(Equation 5)}$$

Where $LVI - IPCC_d$ is the LVI for district d expressed using IPCC vulnerability framework, *e* is the calculated exposure score for district d, *a* is the calculated adaptive capacity score for district *d*, *s* is the calculated sensitivity score for district *d*. Accordingly, the LVI-IPCC was scaled from -1 (least vulnerable) to 1 (most vulnerable).

3. RESULTS

3.1 Livelihood Vulnerability Index (LVI) for three study districts

The results of the study showing anindexed sub-component with its respective major components and the overall LVI values for the study districts are given in Table 2. The overall LVI score was higher for Punakha (0.43) compared to Wangdue (0.41) and Gasa (0.39). In terms of SDP major components, Punakha district was the most vulnerable (an index value of 0.52), followed by Wangdue (0.46) and the least vulnerable Gasa (0.43). On the "dependency ratio" sub-component of SDP, the highest was Punakha (0.38) and the least was Gasa (0.31) which shows that children and people over 65 are numerous in Punakha and had much higher percentage of inactive household members whereas it also implies that Gasa district have a larger active working population than minors and people above the age of 65. Punakhadistrict revealed the highest percentage of the respondents reporting female head of household (83%) while the lowest was Gasa (59%). The average age of head of households ranged from 24 to 47 across all the three districts. Punakha district reported the largest percentage of heads of households who has not attended school (65%), with other two districts falling between 50 % and 60%.

Regarding the Livelihood strategies (LS) component which comprises of three sub-components, Punakha district demonstrated the highest vulnerability score (0.74) and Gasa (0.68) the lowest.

Punakha reported 80% of households being solely dependent on agriculture for income with the remittances results shows compounded vulnerability. In terms of agriculture livelihood diversification index, Gasa showed the highest index value of 0.54, indicating the lowest levels of diversification index activities among the study districts. Most households are involved in collection of cordyceps and incense whereas some of the household raise livestock (yak and horse service) at the same time. But the region has less opportunity of crop diversification due to harsh cold temperatures and extreme weather conditions leading to crop failure.

Examining results from Social Network (SN) major component, it revealed a greater vulnerability for Punakha (0.36) and lowest for Wangdue (0.33) in social networking. Average help received-to-given

ratios were similar across the streets while rates differ for borrowing -to-lending ratios, where Wangdue reported highest proportion (0.46) and Punakha (0.28) the lowest. Overall, the households reported good relationships with their neighbors. Fair percentage of households in the study area reported they were not going to their local government for any assistance in cash or kind. This can be observed in the responses reported, as 26%, 22% and 15% relative to Punakha, Wangdue and Gasa districts. Most of the households seeks assistance from their local government offices owing to highest level of awareness in the community. However, the proportion of households that were not associated with any farm cooperatives was higher in Punakha (76%) and lower in Gasa (69).

The vulnerability scores for the health major component at the aggregate level were highest for Punakha (0.18) and lowest for Wangdue (0.1). These results were driven by the responses from three sub-components, where Punakha remained at the top and Gasa at the bottom (with exception being a chronic illness where only Gasa district showed households with their family member chronically ill). Households in Punakha spend an average longer time to access to health facility compared to other households in Wangdue and Gasa (Punakha 50 minutes, Wangdue 40 minutes and Gasa 26 minutes). Similarly, the proportion of households that reported a family member missing work in past two weeks due to illness was also higher in Punakha (Punakha =21%, Wangdue = 7.5 and Gasa = 10%).

The major component, Food comprises of five sub-components. Punakha reported 90% of households who depend solely on family farm for food with 46% in Gasa and 72% in Wangdue. On average, households in Punakha (0.07) grew more varieties of crops compared to Wangdue (0.06) and Gasa (0.03). Besides, the average number of months in a year, household struggle without enough food was similar for all the three districts, Punakha (0.01), Wangdue (0.02) and Gasa (0.03). Thus, Gasa was more vulnerable on the average crop diversity index compared to Punakha and Wangdue (0.07, 0.06 and 0.03) respectively. Similarly, a greater proportion of households in Punakha (95%) andWangdue (90%) reported crop losses to wild animals in the past one year compared to Gasa (60%). Whereas the proportion of households that did not save crop was similar in all the three districts, Punakha (18%), Wangdue (16%) and Gasa (10%) and the one sub-component demonstrating a marked disparity among districts was the proportion of household that do not save seeds. Gasa reported at the highest rate (70%) and Punakha at the lowest (20%). The alarming rate for Gasa and similar rate of 20% for Punakha warrants further examination. Overall, the vulnerability score on food component was highest for Punakhadistrict than Wangdue andGasa (FPunakha: 0.37, F Wangdue: 0.33, F Gasa: 0.35).

The major component, Water (W) comprises of three sub-components. The vulnerability score for water major component was highest for Punakha (0.61) and lowest for Gasa (0.3). The proportion of households that reported water conflict was higher in Punakha (90%) followed by Wangdue (60%) and Gasa (50%). Similarly, the proportion that did not have a consistent water supply was higher in punakha (95%) and lowest in Gasa (40%). Whereas 50% of households in Wangdue did not receive consistent water supply. None of the households from the study area reported utilizing a natural water source such a

pond, spring and stream. All the households that were interviewed for this study has access to piped water supply.

Last the Natural Disasters and Climate variability (NDCV) major component, it consists of six sub-components. Based on the average reported number of floods, windstorms and drought in the past 10 years, Gasa (0.75) and Wangdue (0.75) scored highest and Punakha (0.58) the lowest. At the same time the proportion of households who did not receive a warning about the pending natural disasters was higher in Gasa (80%) compared to Wangdue (60%) and Punakha (66%). Losses to natural disasters was reported to be similar in all three districts. The score for the mean standard deviation of daily average maximum temperature by month (2012-2021) was higher for Wangdue (0.9) compared to Gasa (0.59) and Punakha (0.17). Similarly, the score for the mean standard deviation of daily average minimum temperature by month (2012-2021) was higher Gasa (0.97) compared to Punakha (0.23) and Wangdue (0.01). And the score for the mean standard deviation of daily average precipitation by month (2012-2021) was higher in Wangdue (0.09) compared to Gasa (0.05) and Punakha (0.01). overall, the vulnerability score on the NDCV was higher for Gasa compared to Wangdue and Punakha (F Gasa: 0.62, F Wangdue: 0.48, F Punakha: 0.36).

Table 2 Indexed sub-components, major components and overall LVI for three study districts in Bhutan

Components	Punakha	Wangdue	Gasa
Sociodemographic Profile (Major component)	0.52	0.46	0.43
	sub-component		
Dependency ratio	0.38	0.36	0.31
% Female-headed household	0.83	0.7	0.59
Avg. age of female head of household	0.22	0.29	0.25
% Households where head of households has not attended school	0.65	0.5	0.6
Livlihood strategies (Major component)	0.75	0.67	0.52
	sub-component		
% Households with family members working in a different community	0.95	0.89	0.62
%Households dependent solely on agriculture as a source of income	0.8	0.6	0.4
Avg. Agricultural Livelihood Diversification Index (range: 0.30–1)	0.51	0.52	0.54
Social network (Major component)	0.36	0.33	0.34
	sub-component		
Avg. help Received:Help Given ratio (range: 0–15)	0.15	0.16	0.15
Avg. Borrow-lend money ratio (range 0.5-2)	0.28	0.46	0.37
%Households that have not gone to their local government for assistance in the past 12 months	0.26	0.22	0.15
% Households not associated with any organization (cooperative/group)	0.76	0.73	0.69
Health (Major component)	0.18	0.1	0.13

	sub-component		
Avg. time to health facility (minutes)	0.33	0.23	0.11
% Households with family member with chronic illness	0	0	0.091
% Households where a family member had to miss work or school in the last 2 weeks due to illness	0.21	0.07	0.1
Food (Major component)	0.36	0.33	0.38
	sub-component		
% Households dependent on family farm for food	0.9	0.72	0.46
AvG. crop diversity index (range 0-1)	0.07	0.06	0.03
% Households that do not save crops	0.18	0.16	0.1
% Households that do not save seeds	0.12	0.35	0.3
% households reporting crop losses to wild animals in the last 1 year	0.95	0.9	0.7
Avg. number of months in a year a household struggles without enough food	0.01	0.02	0.03
Water (Major component)	0.61	0.36	0.3
	sub-component		
% Households reporting water conflicts	0.9	0.6	0.5
% Household that utilize a natural water source	0	0	0
% Households that do not have a consistent water supply	0.95	0.5	0.4
Natural Disaster and Climate Variability (Major component)	0.36	0.48	0.62
	sub-component		
Avg. number of flood, windstorms, and dought events in the past 6 years (range: 0–7)	0.58	0.75	0.75
% Households with losses to physical assets (house/machinery) due to natural disasters	0.56	0.58	0.6
% households that did not receive a warning about the pending natural disasters	0.66	0.6	0.8
Mean standard deviation of the daily avg. maximum temperature by month (2012-2021)	0.17	0.9	0.59
Mean standard deviation of the daily avg. minimum temperature by month (2012-2021)	0.23	0.01	0.97
Mean standard deviation of avg. precipitation by month (2012-2021)	0.01	0.09	0.05
overall LVI	0.43	0.41	0.39

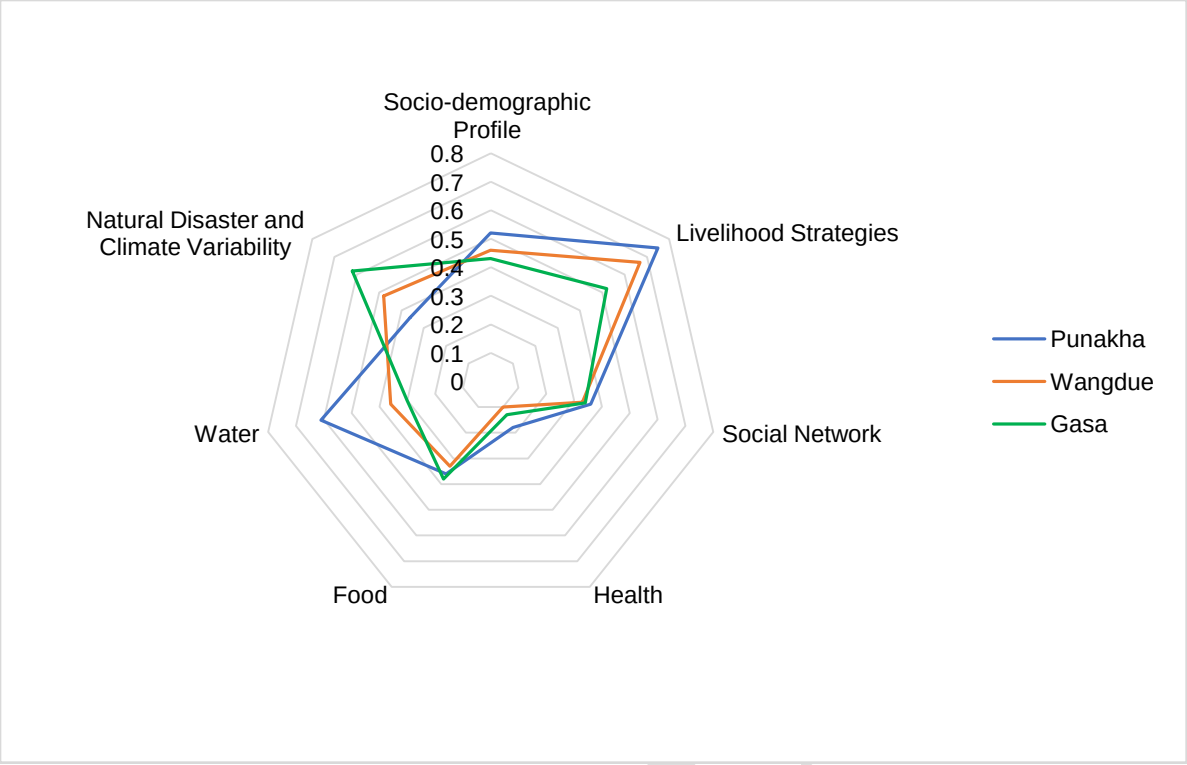

Figure 2. Vulnerability spider diagram for major components of the Livelihood Vulnerability index (LVI) for study area

3.2 Livelihood Vulnerability Index- Intergovernmental Panel for Climate change for three study districts

The vulnerability triangle illustrates the scores for three contributing factors respectively — for each of the study districts as shown in Table 3 and Figure 3**.** The triangle diagram indicates that Punakha district (0.37) is most sensitive to impacts of climate change with the least sensitive district being Gasa district (0.25). Similarly, Gasa district is more exposed (0.62) to climate change impacts but with highest score (0.5) of adaptive capacity among other districts. on the other hand, Punakha (0.36) was the least exposed with adaptive capacity of 0.41.

Table 3. LVI-IPCC contributing factors for calculating for three study districts

IPCC Definition of Vulnerability	Punakha	Wangdue	Gasa
Adaptive capacity	0.41	0.38	0.5
Sensitivity	0.37	0.28	0.25
Exposure	0.36	0.48	0.62
LVI-IPCC	-0.0185	0.028	0.03

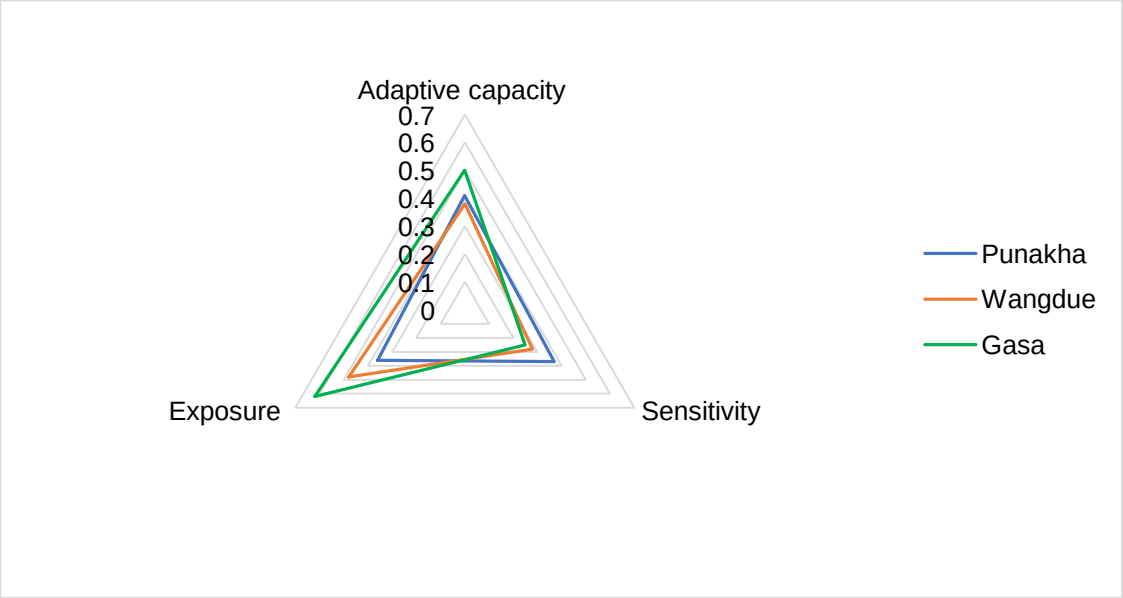

Figure 3. Vulnerability triangle diagram of the contributing factors of the livelihood vulnerability index-IPCC (LVI-IPCC) for three study districts. The LVI-IPCC is on a scale from -1 (Least vulnerable) to 1(most vulnerable).

4. DISCUSSIONS

4.1 Livelihood Vulnerability Index for the three study districts

The results of the overall LVI for the seven major components gathered for the three study districts reported that Punakha as the most vulnerable and Gasa as the least vulnerable (Table 2). One key finding from the data analysis is that the Gasa district was less vulnerable than the other two districts. when considered and compared at individual major component level, the results were slightly different. Further, the LVI results of the major component of the three study districts shows (Figure 3) the greater variation between the districts, with the livelihood strategies as the most vulnerable and health as the least across the districts.

4.1.1Socio-demographic Profile

The dependency ratio of Punakha district is significantly higher (0.38) compared to Wangdue (0.36) and Gasa (0.31), which shows that children and people over 65 are numerous in Punakha district. In the survey, Punakha district 65% of the household headed were illiterate and only one -third of the household's head in Wangdue and Gasa districts had some schooling. On the other hand, districts of Punakha and Wangdue, located in the western part of Bhutan, received first development initiatives such as modern road, market connections and better livelihood options over time under First Five-Year Plan during 1960s [20].

4.1.2 Livelihood strategies

Punakha and Wangdue district were more vulnerable than Wangdue districts.it is noteworthy that 95% of the households in Punakha reported that at least one of their family members reside outside of the community. In other words, family members residing outside a district cause a slumping of livelihood

assets in terms of both financial and human capital for the household's nourishment and sustenance due to reduced farm output. But not every household with large number of family members who have migrated out of the district will have better livelihood outcomes depending on the place's feasibility at individual level. Notwithstanding some people send remittances to relatives which help build resilience to climate change impacts. A higher percentage of households in Punakha are dependent on agriculture for their primary source of income indicating the higher vulnerability to risks from uneven weather events and climatic aberrations. Similar studies have highlighted that farmer living in low elevation are relatively more vulnerable due to their limited coping mechanisms to resist to climate change impacts at the household level [21]. A similar response was observed in the average agricultural livelihood diversification of the respondents as Gasa district and Wangdue district was higher. Most of the households in the highland are involved other household activities such as collection of medicinal herb and incense materials, yak products, horse and transportation and conducting trekking for tourists[22].

4.1.3 Social Network

Borrow-Lend ratio and the help received-help given ratio were included under social network sub-component on the basis that those households frequently relying on others for financial and in-kind assistance were more insecure compared to those with excess money and time to offer help [15]. On the contrary, smallholder farmers in Bhutan practice a system of reciprocal labour exchange which highlights their subsistence agricultural practice[23]. This practice could help secure subsistence livelihoods in rural communities relative to climate change.Accordingly, the proportion were similar for all the three districts in this sub-component which shows that households were receiving financial and in-kind assistance more frequently. Nevertheless, Overall Social Network status was higher in Gasa and Punakha districts probably due to the most mountain specificities and Gasa district is the only district located in the highland at the northern region of the country. This shows that these households were interdependent and seek co-operations among themselves, as noticed during the survey. By way of having a good relationship with neighbors, it will beneficial for decreasing climate change impacts. moreover, it will serve as strong basis to initiate a resiliency program for community against climate change impacts in the future [24,25].However not seeking assistance from local government leads to low level of awareness on new agriculture innovations such as high yielding seeds, manual labour during planting and harvesting and other helpful accessibilities [26]. Sujakhu et al.[27] highlighted that communities with less access to or unable to reap benefits from community-based institutions such as agriculture centers were found to be more vulnerable with than those with awareness and access to innovations.

4.1.4 Health

Despite its rugged terrain and limited resources, achievements in good health indicators make Bhutan pioneer for promotion of primary health care thereby attaining most of the Millennium Development Goals [28]. In Bhutan, the state prioritizes the well-being people by providing free access to basic public health services including treatment inside and outside country for high-end therapies. Households in Punakha districts takes an average of 33 minutes by foot to a nearby health facility while households in Gasa

reported an average of 11 minutes. One main key findingfrom data analysis under this sub-component is that even though Gasa is located in a mountainous community they were reported to be receiving good health care services in their community. Because of the rugged and less population in mountainous community, great efforts and priorities are set at a national level[29]. The health infrastructure covers more than 90% of the population within 2h of travel distance by motor vehicle and 95.2% have access to improved sanitation facilities [30]. Punakha district is located in urban center and the interviewed households reported only getting access to health facilities from the main urban center rather the hospital located just few minutes by foot in rural areas, while health facilities in rural areas have remained underutilized[31].

However, 9% of households in Gasa reported to be chronically ill while none of the households from Punakha and Wangdue districts reported a prevalence of any chronically illness. While road networks have improved in many places, factors other than availability of transportation cause difficulties in accessing healthcare. The preset study revealed higher proportion of households in punakha missing work or school in the past two works due to illness. A family with an ill member is assumed to be sensitive to climate change impacts due to relinquished labor contribution associated with time and resource obligations resulting in implications on household income [32].

4.1.5 Food

There was a narrow range of vulnerability index (0.33 to 0.38) for food major component showing rough similarities among the districts. The primary source of food for Bhutanese farmers, in general is the food produced from their own farms, as evidenced by more than 80% of households solely dependent on family farm across three districts[33]. Meanwhile, households in Gasa district plant vegetables in greenhouse due to unsuitable harsh weather for crop growth. Nonetheless, New Insects have which commonly been seen in hot region has become a threat for farming in Gasa and communities are concerned about agriculture production. These indicate a very high vulnerability due to farming is sensitive and susceptible to any climatic aberration [15]. The highest number of months facing food shortages were reported by the respondents from Gasa (0.03) district. Even though the households in Gasa raised their own limited seasonal food on greenhouse and cooked mostly with their forest firewood, due to regions limited land base, poor soil fertility, cold climate and short growing seasons, they had to acquire staple meals from the nearest market. Also, it might be the limited accessibility of road networks which required households to trek for several hours to reach to the nearest vehicle stop. The study revealed that crop depredation by wild animals was higher in across all the districts.

4.1.6 Water

The Vulnerability of the households on the water major component was relatively higher in Punakha district.Conflict over water is another parameter to gauge a community's vulnerability and the number of households reporting conflicts over water is assumed proportionally to community's sensitivity to climate change impacts. All the households interviewed for this study had access to piped water supply for drinking purpose. As illustrated (Table 2 and figure 2),90% of the household reported water conflicts in

Punakha highlighting water shortage. Drinking water source is located around 2km away from their households. Moreover 95% of the households in Punakha district do not have access to supply of drinking water and irrigation which are the signs of climate change impacts and indirectly threats to Department of agriculture's vision of achieving food and nutrition security.Punakha district is one of the Bhutan's largest contiguous rice cultivation areas and referred to as Bhutan's rice bowl where rice is the most important crops in terms of area, production and employment.Drying up of water sources, inconsistent supplies and shortages affects farming productivity and delaying paddy transplantation.

4.1.7 Natural Disaster and Climate Variability

Climatic modelling studies on Bhutan have projected drastic change in the mean temperature and precipitation. Due to increased variability in timing of monsoon, the weather pattern has become gradually unpredictable [34]. Based on the climatic data from National Centre for Hydrology and Meteorology, the variability in monthly average maximum and minimum daily temperatures are higher in Gasa district and the variability in monthly average precipitation is higher in Wangdue district. Furthermore, such slight climatic variations have also been demonstrated to exacerbate the emergence of new and unidentified pests and directly affect the crop yield [34]. Such emerging climatic threats would mean that livelihoods of 86.3% of the households who depend on potato as the main source of income may face a substantial risk. Similar to the findings, most organic farmers (83.7%) identified pest and disease problem as a main constraint for their low organic crop productivity [35].

With increased precipitation and better reporting, Bhutan is recording more disasters. Correspondingly, Wangdue and Gasa district (indexof 0.75) reported higher average count of natural disasters with flashflood and landslide being the most frequent. Similar to the findings hazards such as flashfloods and landslides are projected to increase in the future as result of climatic changes in high altitude and upland areas of the Himalayan region [36]. According to the Bhutan status report 2020 by the UN Office for Disaster Risk Reduction, more than 70% of the country's settlements and most agricultural land and infrastructure are located along the country's main river basins. Bhutan lies in a high rainfall zone and the monsoon brings in 70% of the country's annual precipitation between June and September, when landslides and flooding usually occur[37]. The proportion of households receiving prior information on impending natural disasters was significantly lower for all the three districts. While Publishing weather forecasts on social media is not enough. Like many other countries in the region and beyond, Bhutan has yet to get grip with the increased risk of disasters brought by climate change. Studies suggest that Lack of technical capacity and low education levels possess tough challenge and leaves household exposed to natural disasters. Therefore, it is evident that there is need to improve the efficiency and effectiveness of early warning system in the future to help farmers plan accordingly for extreme weather events in three districts.

4.2 LVI-IPCC for the three Study Districts

The visual summary for the LVI-IPCC analysis based on the three contributing factors are depicted in Figure 3. The analysis showed that Gasa district is most vulnerable compared to rest of the districts. The

exposure of Gasa district is higher than those of Wangdue and Punakha but the adaptive capacity of Gasa district is higher. This suggests the need to strengthen the quality and quantity of climatic observations to approach disaster risk reduction programs and deal with meteorological extremes. The LVI-IPCC finding is dissimilar to that of LVI (Table 2 Figure 2). Such observation serves as precondition to climate adaptation and measures in the country.

5. CONCLUSION

The study assessed smallholder farmers vulnerability to impacts of climate change and variability using LVI and LVI-IPCC approach in three districts of Bhutan. The results from LVI approach revealed that Punakha district is more vulnerable to impacts of climate change (Table 2 Figure 2) whereas the result from LVI-IPCC approach showed that Gasa district is vulnerable (Table 3). The holistic findings from this study on climate change impacts and IPCC's framework approach have several benefits in designing and prioritizing future agriculture interventions and climate change coping strategies. Such practical tool can be used to identify most vulnerable community contributing vulnerability at district or community level and prioritize the area for intervention. Livelihood diversification are essential to enhance adaptive capacity for reducing vulnerability of local community[38].The findings demonstrate close connections among several aspects of livelihood vulnerability. The high-altitude regions should be introduced to more ideas on climate-smart agriculture technologies and techniques to help increase their resilience to climate change. it is vital that relevant stakeholders and NGOs introduce more food processing and preservation technologies in study area. This will help the smallholder farmer to preserve food crops over longer period so farmers can remain self-sufficient throughout the year. Long-term actions with issues of livelihood could be solved by implementing policy measures designed to minimize the sensitivity of the community, increase resilience, sustainable livelihood alternatives and improve individual stability. Two approaches of LVI and LVI-IPCC did not necessarily generate convergent conclusions in some instances, therefore it gives compelling insights into more specialized researcher. However, the paper provides valuable insights to readerships of policymakers, planners, and smallholder farmers to design appropriate interventions to cope with climate change impacts based on underlying vulnerability of a community. Accuracy of this study is based on the relevancy of indicators and reliability of smallholder farmers.

CONSENT

As per international standard or University standard, respondents written consent has been collected and preserved by the authors. Authors UD and ND — Review, editing and supervision. All the authors have read and approved the final manuscript.

REFERENCES

1. Ministry of Agriculture and Forestry (2018). *Twelfth Five Year Plan 2018-2023—Volume II: Central Plans: Vol. II*.
2. Sujakhu, N. M., Ranjitkar, S., Niraula, R. R., Salim, M. A., Nizami, A., Schmidt-Vogt, D., & Xu, J. (2018). Determinants of livelihood vulnerability in farming communities in two sites in the Asian Highlands. *Water International*, *43*(2), 165–182. https://doi.org/10.1080/02508060.2017.1416445
3. Gerlitz, J.-Y., Macchi, M., Brooks, N., Pandey, R., Banerjee, S., & Jha, S. K. (2017). The Multidimensional Livelihood Vulnerability Index – an instrument to measure livelihood vulnerability to change in the Hindu Kush Himalayas. *Climate and Development*, *9*(2), 124–140. https://doi.org/10.1080/17565529.2016.1145099
4. Kayastha, R. B., Lee, W.-K., Shrestha, N., & Wang, S. W. (2023). Assessing the Livelihood Vulnerability of Nomads to Changing Climate in the Third Pole Region of Nepal. *Land*, *12*(5), 1105. https://doi.org/10.3390/land12051105
5. Hardoy, J., & Romero Lankao, P. (2011). Latin American cities and climate change: Challenges and options to mitigation and adaptation responses. *Current Opinion in Environmental Sustainability*, *3*(3), 158–163. https://doi.org/10.1016/j.cosust.2011.01.004
6. Choden, K., Nitschke, C. R., Stewart, S. B., & Keenan, R. J. (2021). The potential impacts of climate change on the distribution of key tree species and Cordyceps in Bhutan: Implications for ecological functions and rural livelihoods. *Ecological Modelling*, *455*, 109650. https://doi.org/10.1016/j.ecolmodel.2021.109650
7. Rinzin, P., Sonam, T., Tshering, S., & Chapagai, P. P. (2020). Smallholder Farmers' Vulnerability to Impact of Climate Change in Central Bhutan. *International Journal of Environment and Climate Change*, 286–299. https://doi.org/10.9734/ijecc/2020/v10i1230305
8. Mitra, S., & Vivekananda, J. (2013). *Strengthening responses to climate variability In South Asia*. *April*.
9. National Center for Hydrology and Meteorology. (2022). *Records of Extreme weather events in Bhutan*. weather and climate services division: National Center for Hydrology and Meteorology. https://www.nchm.gov.bt/attachment/ckfinder/userfiles/files/Extreme%20Weather%20Events%20Records%202022_docx-compressed.pdf
10. Forest Resources Development Division. (2017). *Land Use and Land Cover of Bhutan 2016, Maps and Statistics*. Forest Resources Management Division Department of Forests & Park Services Ministry of Agriculture and Forests.
11. NSB. (2012). *The Economic Value of Voluntary Work in Bhutan*. National Statistics Bureau of Bhutan.
12. Daniel, E. (2016). The Usefulness of Qualitative and Quantitative Approaches and Methods in Researching Problem-Solving Ability in Science Education Curriculum. *Journal of Education and Practice*.

13. Forster, E. (1999). Computer Assisted Personal Interviewing: A Method of Capturing Sensitive Information. *IASSIST Quarterly*, *23*(2), 19. https://doi.org/10.29173/iq727

14. National Center for Hydrology and Meteorology. Climate data book of Bhutan, Thimphu; 2018
15. Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global Environmental Change*, *19*(1), 74–88. https://doi.org/10.1016/j.gloenvcha.2008.11.002
16. Vincent, K. (2007). Uncertainty in adaptive capacity and the importance of scale. *Global Environmental Change*, *17*(1), 12–24. https://doi.org/10.1016/j.gloenvcha.2006.11.009
17. Shen, J., Duan, W., Wang, Y., & Zhang, Y. (2022). Household Livelihood Vulnerability to Climate Change in West China. *International Journal of Environmental Research and Public Health*, *19*(1), 551. https://doi.org/10.3390/ijerph19010551
18. Haeberli, W., & Burn, C. R. (2017). *Natural Hazards in Forests: Glacier and Permafrost Effects as Related to Climate Change*.
19. UNDP. (2007). *Human development reports*. http://hdr.undp.org/en/ (accessed 17 July 2023)
20. Ministry of Works and Human Settlement. (2015). *Infrastructure Development in Bhutan: A Journey Through Time*.MOWHS.
21. Katel, O., Khandu, Y., & Gurung B, D. (2016). Farmer's Vulnerability to climate Variability in Bhutan (Himalaya). *Poster*, 2. https://doi.org/10.13140/RG.2.1.2975.7043
22. Dorji, T., Yangzom, D., Norbu, N., Rinchen, S., Dorjee, J., & Tenzin, T. (2023). Understanding the impact of climate change and resilience among highlanders in northern parts of Bhutan: A case study in Gasa district. *PLOS Climate*, *2*(4), e0000079. https://doi.org/10.1371/journal.pclm.0000079
23. National Statistics Bureau of Bhutan. (2012). *The Economic Value of Voluntary Work in Bhutan*.NSB.
24. Thomas, D. S. G., Twyman, C., Osbahr, H., & Hewitson, B. (2007). Adaptation to climate change and variability: Farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change*, *83*(3), 301–322. https://doi.org/10.1007/s10584-006-9205-4
25. Wiesinger, G. (2007). The importance of social capital in rural development, networking and decision-making in rural areas. *Revue de Géographie Alpine*, *95–4*, 43–56. https://doi.org/10.4000/rga.354
26. Amuzu, J., Kabo-Bah, A. T., Jallow, B. P., & Yaffa, S. (2018). *Households' Livelihood Vulnerability to Climate Change and Climate Variability: A Case Study of the Coastal Zone, The Gambia*.
27. Sujakhu, N. M., Ranjitkar, S., He, J., Schmidt-Vogt, D., Su, Y., & Xu, J. (2019). Assessing the Livelihood Vulnerability of Rural Indigenous Households to Climate Changes in Central Nepal, Himalaya. *Sustainability*, *11*(10), 2977. https://doi.org/10.3390/su11102977

28. Ministry of Health. (2012). *National Health Policy* (pp. 3–24). MoH.
29. Tobgay, T., Dorji, T., & Pelzom, D. (2011). Progress and delivery of health care in Bhutan, the Land of the Thunder Dragon and Gross National Happiness. *Tropical Medicine and International Health*, *16*, 731–736. https://doi.org/10.1111/j.1365-3156.2011.02760.x
30. Ministry of Health. (2021). *Annual Health Bulletin 2021*. Royal Government of Bhutan.
31. Tenzin, K., Dorji, T., & Dorji, G. (2022). Health inequities in Bhutan's free healthcare system: A health policy dialogue summary. *Public Health Challenge*, 2–8. https://doi.org/10.1002/puh2.34
32. Panthi, S. (2014). Livelihood Vulnerability Approach to Assess Climate Change Impacts to Mixed Agro-Livestock Smallholders Around the Gandaki River Basin of Nepal. *American Geophysical Union, Fall Meeting 2014, Abstract Id. GC41B-0543*. https://ui.adsabs.harvard.edu/abs/2014AGUFMGC41B0543P/abstract
33. Renewal Natural Resources. (2019). *Ministry of Agriculture and Forests: Bhutan RNR statistics*. https://www.nsb.gov.bt/rnr-census-reports/
34. Chhogyel, N., Kumar, L., Bajgai, Y., & Hasan, M. K. (2020). Perception of farmers on climate change and its impacts on agriculture across various altitudinal zones of Bhutan Himalayas. *International Journal of Environmental Science and Technology*, *17*(8), 3607–3620. https://doi.org/10.1007/s13762-020-02662-8
35. Lepcha, N., Panya Mankeb, & Suwanmaneepong, S. (2021). Productivity and profitability of organic and conventional potato (*Solanum tuberosum* L.) production in West-Central Bhutan. *Open Agriculture*, *6*(1), 640–654. https://doi.org/10.1515/opag-2021-0044
36. Xu, J., Grumbine, R. E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y., & Wilkes, A. (2009). The Melting Himalayas: Cascading Effects of Climate Change on Water, Biodiversity, and Livelihoods. *Conservation Biology*, *23*(3), 520–530. https://doi.org/10.1111/j.1523-1739.2009.01237.x
37. UN Office for Disaster Risk Reduction. (2021). *Disaster Risk Reduction in Bhutan: Status Report 2020*. https://reliefweb.int/report/bhutan/disaster-risk-reduction-bhutan-status-report-2020
38. National Institute of Food and agriculture. Crop Protection and Pest Management. United States Department of Agriculture. 2023; 51(2): 234-342