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Smallholder Farmers' Vulnerability to Impact of Climate Change in Central Bhutan

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Authors' contributions

This work was carried out in collaboration among all authors. Author PR designed the study, performed the analysis and wrote the first draft manuscript. Authors TS, ST and PPC managed the literature reviews. All authors read and approved the final manuscript.

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ABSTRACT

Climate change carries immense threat to the livelihood and food security of smallholder farmers in Bhutan and it is therefore crucial to enhance their adaptive capacity. However, building resiliency to climate impact require information on vulnerability of the system of interest. Therefore, this study assessed smallholder farmers' vulnerability to impacts of climate change and variability in central regions (Bumthang and Trongsa) of Bhutan. Data was collected from 247 randomly selected households by administering a pre-tested survey questionnaire. Data was analyzed using composite index approach (LVI) and IPCC framework approach (LVI-IPCC). The LVI analysis revealed that Bumthang was more vulnerable in terms of Socio-demographic profile (0.55), social networks (0.45), health (0.31) and natural disasters and climate variability (0.47) compared to Trongsa. Whereas, Trongsa was more vulnerable in terms of livelihood strategies (0.31) and water (0.13). Vulnerability score on the food component was same for both the districts (0.27). Overall, Bumthang was more vulnerable compared to Trongsa on both LVI (Bumthang: 0.36, Trongsa: 0.34) and LVI-IPCC (Bumthang: 0.24, Trongsa: 0.13) analysis. The findings could be used for

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designing micro-level context specific interventions to enhance smallholder farmers' adaptive capacity to impacts of climate change in central Bhutan.

Keywords: Climate Change; farmer; impact; livelihood; vulnerability.

1. INTRODUCTION

Climate change is anticipated to disproportionately impact mountainous regions [1] and agrarian communities in developing countries [2,3]. In particular, poor households in rural areas are identified as especially vulnerable in terms of food and water security, and agricultural incomes [4]. For a least developed and agrarian country like Bhutan which is located in the fragile Himalayan Mountains, the disproportionate impacts of climate change are a serious threat to people's livelihoods [5,6].

Climatic trends over Bhutan indicated increasing air temperature [7] and decreasing rainfall [8,9]. Farmers also reported a change in rainfall pattern, which is affecting water sources and crop productivity [9]. Since the staple food (eg. rice) and major cash crop (eg. potato) cultivation in Bhutan are mostly rainfed which is highly prone to climate factors [6], the food and livelihood security of smallholder farmers are highly sensitive to climatic shocks. Such risk threatens the national economy which is highly dependent on climate sensitive sectors like agriculture, forestry and hydropower [10]. In particular, for about 62% of the populace residing in rural areas [11], climate change poses huge risks as their livelihoods directly depend on subsistence oriented mixed agro-livestock and forest related activities. Therefore, reducing smallholder farmers' vulnerability to the impacts of climate change is crucial for Bhutan.

Vulnerability to climate change depends on both biophysical and social processes [4]. Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as a function of three contributing factors namely exposure, sensitivity and adaptive capacity [12]. Exposure is the severity and extent to which a system is exposed to climatic variations, sensitivity is the degree to which the system is affected by exposure and adaptive capacity is the ability to endure or recover from the exposure [12]. Within this framework, Hahn et al. developed an indicator-based vulnerability assessment tool [13], which was also a modification of the Sustainable Livelihoods Approach which looks at five types of household asset such as natural, social, financial, physical and human capitals [14]. The tool provides a flexible approach to suit the needs of different geographical location [15]. It involves grouping and aggregating indicators based on themes for different districts, which can be very useful for context specific adaptation planning [13].

A previous study employed the tool to assess farmers' vulnerability in two western districts (Punakha and Wangduephodrang) of Bhutan and it recommended similar assessments in other parts of the country [16]. However, a closer look to the literatures reveal a limited attention being paid to the issue despite the increasing need and scope for findings from such studies, because improving adaptive capacity start with assessment of vulnerability of the system of interest [17]. Therefore, the present study focused on assessing smalholder farmers' vulnerability to impacts of climate change and variability in central regions of Bhutan. The findings from this study are expected to be useful for designing micro-level context specific interventions to enhance climate change resiliency in the central regions of Bhutan.

2. METHODS

2.1 Study Area

Fig. 1. shows the study area. Bumthang district covers three agro-ecological zones with elevations ranging from 1800-7500 masl, whereas Trongsa district covers five agro-ecological zones with elevations ranging from 600-7500 masl [18]. About 9712 acres of agricultural land is owned by the smallholder farmers in Bumthang with 68% of that land under operation [19]. Whereas in Trongsa, about 6830 acres of agricultural land is owned by the smallholder farmers of which about 61% is under operation [19]. A major portion of the land in both the district is mostly utilized for subsistence crop and livestock production as majority of the populace are predominantly agrarian based in both districts. The rural population comprises 62.8% and 82.2% in Bumthang and Trongsa respectively [11], with major source of livelihoods ranging from dryland cropping such as wheat, barley, potato cultivation and wetland cropping

like paddy cultivation which is supplemented by livestock rearing and forest products utilization [10].

2.2 Sampling Design

A multistage random sampling design was employed for selecting respondents. In the first stage, six Chiwogs were randomly selected from each district. In the second stage, 20 households were randomly selected from each of the sampled Chiwogs from the list of households maintained at the respective Geog administration. A total of 247 households were interviewed from the entire study area (118 from Bumthang and 129 from Trongsa). Two sampled households from Bumthang were absent at the time of the survey. Whereas from Trongsa, an additional 9 households were surveyed.

2.3 Data Collection

Primary household data was obtained by administering a face-to-face interview using a pre-tested survey questionnaire. The head of the households were interviewed on the seven major components required for calculating the LVI (Table 1). Each major component is composed of several sub-components (For example, under Socio-demographic profile, sub-indicators are Dependency Ratio, % of female headed households, % of households where head of the households has not attended school). Climate data regarding temperature and precipitation was used from the Climate Data book of Bhutan 2018 published by National Centre for Hydrology and Meteorology [20].

2.4 Data Analysis

The mathematical method for calculating the indices was drawn from Hahn et al. wherein two approaches were used to analyze data: Composite index approach (LVI) and IPCC framework approach (LVI-IPCC) approach [13] as explained below.

2.4.1 Composite index approach (LVI)

Although the number of sub-components varies under different major components, each sub-component contributed equally to the overall index as the LVI uses a balanced weighted average approach.

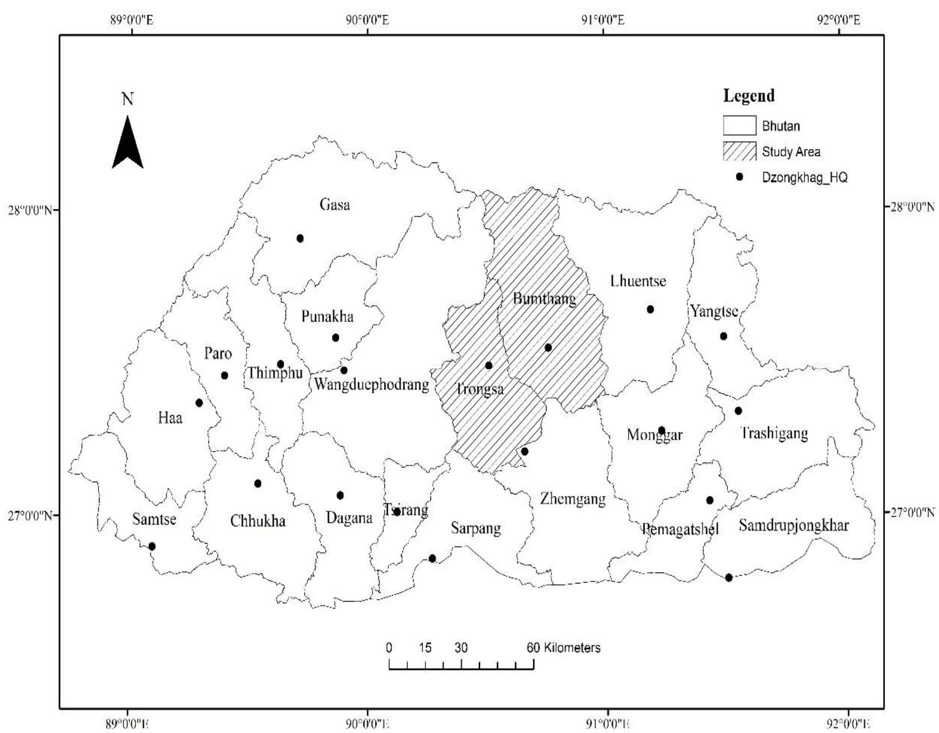

Fig. 1. Study area map showing Bumthang and Trongsa districts

Step 1**:** The unit for measuring different sub-components varied, therefore each sub-component was first standardized using the Equation 1.

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

Here s_d is the actual value of the sub-component for district *d*, s_{min} and s_{max} are the minimum and maximum values respectively for each sub-component from both the districts.

Step 2: Once the sub-components were standardized, all the sub-components were then averaged using Equation 2 to calculate the value for each major component.

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

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

Step 3: Once the values for each of the seven major components are measured for a district, they were averaged using Equation 3 to calculate the overall district level LVI.

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

Which can also be expressed as:

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

Table 1. Indexed sub-components, major components and overall LVI for Bumthang and Trongsa

Sub-component	Bumthang	Trongsa	Major component	Bumthang	Trongsa
SDP variable 1	0.20	0.21	socio-Demographic Profile (SDP)	0.55	0.53
SDP variable 2	0.75	0.65			
SDP variable 3	0.37	0.44			
SDP variable 4	0.86	0.81			
LS variable 1	0.20	0.16	livelihood strategies (LS)	0.29	0.31
LS variable 2	0.60	0.75			
LS variable 3	0.06	0.02			
SN variable 1	0.12	0.15	Social Networks (SN)	0.45	0.35
SN Variable 2	0.32	0.34			
SN Variable 3	0.73	0.63			
SN Variable 4	0.62	0.30			
H Variable 1	0.22	0.22	Health (H)	0.31	0.20
H Variable 2	0.43	0.22			
H Variable 3	0.28	0.15			
F Variable 1	0.63	0.77	Food (F)	0.27	0.27
F Variable 2	0.07	0.01			
F Variable 3	0.03	0.03			
F Variable 4	0.05	0.06			
F Variable 5	0.82	0.72			
F Variable 6	0.01	0.01			
W Variable 1	0.13	0.17	Water (W)	0.11	0.13
W Variable 2	0.00	0.00			
W Variable 3	0.19	0.22			
ND&CV Variable 1	0.15	0.49	Natural disasters and climate variability (ND&CV)	0.47	0.45
ND&CV Variable 2	0.19	0.19			
ND&CV Variable 3	0.86	0.75			
ND&CV Variable 4	0.73	0.35			
ND&CV Variable 5	0.81	0.26			
ND&CV Variable 6	0.09	0.68			
Overall LVI	0.36	0.34			

Here LVI_d is the livelihood vulnerability index for district *d*, and W_{m_i} are determined by the number of sub-components that make up each major component. For this study, the LVI score was scaled from 0 (least vulnerable) to 0.6 (most vulnerable).

2.4.2 IPCC framework approach (LVI-IPCC)

LVI-IPCC method incorporates the IPCC's definition of vulnerability. Unlike the LVI approach where all the major components are grouped together in one step, the seven major components were first grouped under three contributing factors (Adaptive Capacity, Exposure and Sensitivity) in LVI-IPCC approach as shown in Table 2. Then the LVI-IPCC is calculated using the steps below.

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

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

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

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

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

Where $LVI\text{-}IPCC_d$ is the LVI for district *d* expressed using the IPCC vulnerability framework, *e* is the calculated exposure score for district *d* (equivalent to Natural Disaster and Climate Variability major component), *a* is the calculated adaptive score for district *d* (weighted average of Socio-demographic Profile, Livelihood Strategies and Social Networks major components), *s* is the calculated sensitivity score for district *d* (weighted average of Health, Food and Water major components). The LVI-IPCC score was scaled from -1 (least vulnerable) to 1 (most vulnerable).

3. RESULTS

3.1 LVI Comparison between Bumthang and Trongsa

The results are presented comparatively between Bumthang and Trongsa districts to get a relative understanding of their vulnerability. The overall LVI score was higher for Bumthang (0.36) compared to Trongsa (0.34). The result for LVI comparison is summarized in Table 1 and further explanations of the individual variables are provided in Appendix 1. The result indicated that Bumthang is slightly more vulnerable to the impacts of climate change and variability compared to Trongsa taking into consideration the current socio-demographic profile, livelihood strategies, social networks, health, food, water, and natural disasters and climate variability.

3.1.1 Socio-demographic profile

A higher proportion of households in Bumthang were headed by females compared to Trongsa (75%, n=89 and 65%, n=84 respectively). Similarly, the proportion of the head of households who have not attended school was also higher in Bumthang than Trongsa (86%, n=101 and 81%, n=105 respectively). But on average, female head of household were younger in Trongsa compared to Bumthang (43.44±11.34 and 48.23±12.35 respectively). The dependency ratio was similar in the two districts. Overall, Bumthang showed a slightly greater vulnerability on the Socio-demographic profile component as compared to Trongsa ($SDP_{Bumthang}$: 0.55, $SDP_{Trongsa}$: 0.53).

3.1.2 Livelihood strategies

The proportion of households without any family member working in other community was higher in Bumthang compared to Trongsa (20%, n=17 and 16%, n=12). But, the proportion of households solely dependent on agriculture as a source of livelihood was higher in Trongsa (75%, n=97) compared to Bumthang (60%, n=71). Similarly, the average livelihood strategies was also higher in Trongsa compared to Bumthang (2.9±0.4 and 2.6±0.7), which was reflected in the average agricultural livelihood diversification index (Bumthang: 0.06, Trongsa: 0.02).Overall, Trongsa showed a higher vulnerability on the livelihood strategies component as compared to Bumthang ($LS_{Trongsa}$: 0.31, $LS_{Bumthang}$: 0.29).

3.1.3 Social networks

The proportion of households that have not gone to local leaders for help in the past 12 months was higher in Bumthang compared to Trongsa (73%, n=86 and 63%, n=81 respectively). But the households in Trongsa borrowed money and received assistance in kind more frequently compared to Bumthang (borrow:lend ratio: Trongsa 0.34 and Bumthang 0.32; receive:give ratio: Trongsa 0.15 and Bumthang 0.12). However, the proportion of households that were not associated with any farm cooperatives was higher in Bumthang compared to Trongsa (62%, n=73 and 30%, n=39 respectively). Overall, Bumthang was more vulnerable on the social networks component as compared to Trongsa ($SN_{Bumthang}$: 0.45, $SN_{Trongsa}$: 0.35).

3.1.4 Health

The average distance to the nearest health facility was similar in both the districts (Trongsa 57±18 minutes, Bumthang 57±58 minutes). The proportion of households that reported chronic illness was higher in Bumthang compared to Trongsa (43%, n=51 and 22%, n=28 respectively). Similarly, the proportion of households that reported a family member missing work in the past two weeks due to illness was also higher in Bumthang compared to Trongsa (28%, n=33 and 15%, n=19 respectively). Therefore the overall vulnerability score on the health component was higher for Bumthang compared to Trongsa ($H_{Bumthang}$: 0.31, $H_{Trongsa}$: 0.20).

3.1.5 Food

The average number of months in a year a household struggled without enough food was equal for both Bumthang (0.01) and Trongsa (0.01). The proportion of households primarily dependent on family farm for food was higher in Trongsa compared to Bumthang (77%, n=99 and 63%, n=63 respectively). On average, households in Trongsa grew more varieties of crops compared to Bumthang (15.4±2 and 11.7±4.4 respectively). Thus Bumthang was more vulnerable on the average crop diversity index compared to Trongsa (0.07 and 0.01 respectively). Similarly, a greater proportion of households in Bumthang reported crop losses to wild animals in the past one year compared to Trongsa (82%, n=97 and 72%, n=93 respectively). Whereas the proportion of households that did not save seeds or crops was similar in the two districts. Overall, the vulnerability score on food component was similar for both districts ($F_{Bumthang}$: 0.27, $F_{Trongsa}$: 0.27).

3.1.6 Water

The proportion of household that reported water conflict was higher in Trongsa compared to Bumthang (17%, n=23 and 13%, n=15 respectively). Similarly, the proportion of household that did not have a consistent water supply was higher in Trongsa compared to Bumthang (22%, n=28 and 19%, n=23 respectively).None of the households from the study area reported utilizing a natural water source such as a spring, pond or stream. All households that were interviewed for this study had access to piped water supply. Overall, Trongsa was more vulnerable on the water component compared to Bumthang ($W_{Trongsa}$: 0.13, $W_{Bumthang}$: 0.11).

3.1.7 Natural Disasters and Climate Variability

Based on the average reported number of floods, wind and hail storms, and droughts in the past 3 years, Trongsa scored higher on the sub-component compared to Bumthang (0.49 and 0.15 respectively). But the proportion of households who did not receive a warning about the impending natural disaster was higher in Bumthang compared to Trongsa (86%, n=102 and 75%, n=97 respectively). Losses to physical assets due to natural disasters was reported to be similar in both the districts.The score for mean standard deviation of daily average maximum temperature by month (2007-2017) was higher for Bumthang compared to Trongsa (0.73 and 0.35 respectively). Similarly, the score for mean standard deviation of the daily minimum temperature by month (2007-2017) was also higher for Bumthang compared to Trongsa (0.81 and 0.26 respectively). However, the mean standard deviation of average precipitation by month (2007-2017) was much higher for Trongsa compared to Bumthang (0.68 and 0.09 respectively). Overall, the vulnerability score on the natural disasters and climate variability component was higher for Bumthang compared to Trongsa ($ND\&CV_{Bumthang}$: 0.47, $ND\&CV_{Trongsa}$: 0.45).

3.2 LVI-IPCC Comparison between Bumthang and Trongsa

The LVI-IPCC score was calculated based on three contributing factors namely exposure, sensitivity and adaptive capacity, as shown in Table 2. Bumthang might be more exposed to impacts of climate change compared to Trongsa (0.47 versus 0.45 respectively). Similarly, taking into account the current health status, food and water security, Bumthang may be more sensitive to climate change impacts compared to Trongsa (0.24 versus 0.22 respectively). Based on socio-demographic profile, livelihood strategies and social networks, Trongsa Dzongkhag (0.39) indicated a higher adaptive capacity compared to Bumthang (0.37). Overall, LVI-IPCC analysis indicated that Bumthang (0.24) is more vulnerable to climate change impacts compared to Trongsa (0.13).

4. DISCUSSIONS

4.1 LVI Comparison between Bumthang and Trongsa

The visual summary of the LVI analysis for both the districts are depicted in Fig. 2. The vulnerability score for both the districts was highest for the social-demographic component and was lowest on the water component.

Table 2.Categorizing seven major components into three contributing factors and their values for Bumthang and Trongsa

Major Components	IPCC contributing factors to vulnerability	Bumthang	Trongsa
Natural disasters and climate variability	Exposure	0.47	0.45
Health Food Water	Sensitivity	0.24	0.22
Socio-demographic profile Livelihood strategies Social networks	Adaptive Capacity	0.37	0.39
	LVI-IPCC	0.24	0.13

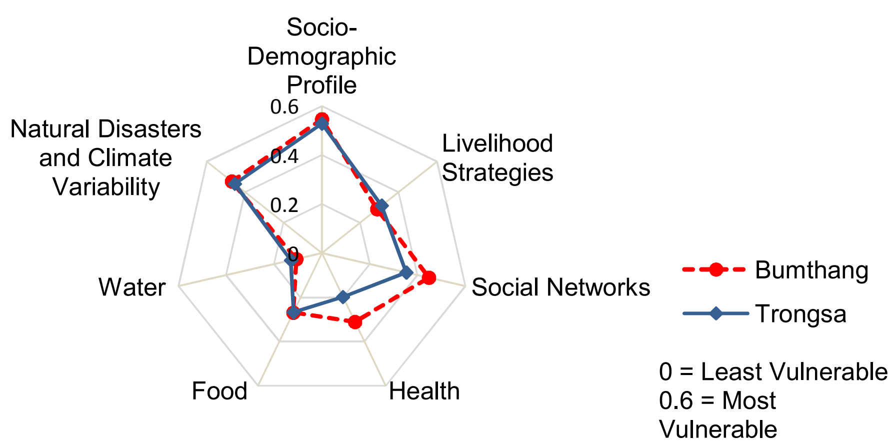

Fig. 2. Vulnerability spider diagram for the major components of the livelihood vulnerability index (LVI) for Bumthang and Trongsa

Female headed households constituted a major portion of the agricultural holdings in both Bumthang and Trongsa. The finding was congruent with earlier studies where these two districts were found to have the highest proportion of female headed households in the agricultural sector in Bhutan [19]. A major proportion of the farmers in Bhutan are in the age range of 20-64 years with women constituting the majority[19]. Women typically are viewed as being more vulnerable to climate induced disasters and having lesser adaptive capacity [21]. However, future studies could investigate the gender disaggregated impacts of climate change to get a better understanding for more focused interventions. The present study also revealed that the dependency ratio was quite similar in the two districts, but the population and housing census survey in 2017 revealed that the dependency ratio was much higher in Bumthang compared to Trongsa [11]. This mismatch could have emerged from difference in sampling procedure, where PHCB 2017 undertook a census survey whereas the present study took only a representative sample of rural farmers. Higher dependency ratio reflects lesser capacity to adapt to the climate change impacts.

The borrow-lend ratio and the receive-give assistance ratios were included in the LVI framework, under social network component, on the premise 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 [13,15]. On the contrary, smallholder farmers in Bhutan practice a system of reciprocal labor exchange which underscores their subsistence agricultural practice [22,23]. This practice could actually help secure subsistence livelihoods in rural communities in the context of climate change. Although, the households in Trongsa reported receiving financial and in-kind assistance more frequently, Bumthang was found to be more vulnerable on the overall social networks component. This is because a lesser proportion of households in Bumthang reported having affiliations with farmers' cooperatives compared to Trongsa. This suggests the need to form new groups and strengthen existing ones in both the districts, and motivate house hold participation to enhance collective self-help capacity and solidarity through collective action [24]. Studies have proven that participation in self-help groups enhances household resiliency to climate change impacts [25].

A high proportion of households in both the districts reported having family members work in a different community. Income diversification by engaging in different livelihood strategies and working beyond agriculture is assumed to increase a household's adaptive capacity [15,25]. A higher proportion of households in Trongsa reported having family members work in other districts compared to Bumthang. But Bumthang households reported diversifying their source of income beyond agriculture by engaging in tourism, *Yathra* weaving and also Cordyceps (*Cordyceps Sinensis*) collections in some parts of the district. These activities are also carried out in Trongsa although not as widespread as in Bumthang. Due to its scenic landscape and various traditional festivals, Bumthang attracts a significant number of international tourists which forms an important economic activity in the district. Another significant income earning livelihood activity for some households in Bumthang is the Cordyceps collection which accrues enormous financial benefits to the participating households. However, relevant authorities could intervene with new livelihood diversification programs to enhance smallholder farmers' source of income.

All households interviewed for this study had access to piped water supply for drinking purpose. But, the PHCB 2017 revealed that about 1.7% (n=62) households in Trongsa and about 0.8% (n=32) in Bumthang depended on unimproved drinking water sources [11]. This mismatch could have emerged as the present study might not have covered those affected households in the representative sampling. Conflict over water is another parameter to gauge a community's vulnerability and the number of house holds reporting conflict over water is assumed to proportionately reflect a community's sensitivity to climate change impacts [15].In both the districts, conflict over water was reported mainly regarding irrigation water for wetland cultivation. Earlier studies revealed that about 83% of agricultural holdings in Trongsa were engaged in paddy cultivation and about 70% of them irrigated their land, while about 14% of the holdings in Bumthang cultivated paddy and about 35% irrigated their land [19]. In future, climate change induced water scarcity could have implications on the rice growing areas of Bhutan [5,26].Therefore, improving irrigation would enhance farmers' resilience to climate change impacts in both the districts.

The number of month a household struggles without adequate food is assumed to be associated with their sensitivity to climate change impacts [15]. A small proportion of households reported food insufficiency in the past one year in both the districts. The finding was similar to earlier findings where 5.7% of the households in Trongsa and 4.2% in Bumthang were found to have experienced food insufficiency in the past 12 months [11]. Climate change is expected to exacerbate food security issues especially for children and elderly people [25]. Crop depredation by wild animals is a particular threat to the food security in rural areas [27]. This study revealed that crop depredation by wild animals was higher in Bumthang compared to Trongsa, and it was also in congruence with earlier findings of RNR Census Survey 2019 [19]. Securing farmers' crops from losses to wild animals by installing electric fences, which were found to be effective against most wild animals [28], would help reduce vulnerability on the food component. In addition, relevant authorities could also develop a fair compensation scheme for crop losses to protect food security of the subsistence agricultural holdings.

Climate change carries immense threat for public health and society [29]. Studies have revealed that climate warming for prolonged duration favors geographical expansion of some infectious diseases [30,31]. Vector borne infectious diseases that were previously limited to lower altitude are now being increasingly reported at higher elevations [29]. In 2019, Bhutan reported incidences of mosquito borne dengue fever outbreak in places previously unknown to such disease [32,33]. Recently, mosquitoes have also been spotted in cold places of Bhutan like Lunana that lie at around 4000 masl [34]. With upward movement of vectors like mosquitoes due to increasing temperature [35], Bumthang and Trongsa districts could experience new disease outbreaks with implications for community health and livelihoods in future. The present study revealed a higher proportion of households in Bumthang missing work or school in the past two weeks due to illness. A family with an ill member is assumed to be more sensitive to climate change impacts [15] due to forgone labor contribution, associated time and resource obligations, and resulting implications on the household income.

Bhutan is characterized by huge variations in climatic conditions due to drastic changes in topography and altitude over short distances [36]. With increasing variability in intensity, frequency and timing of monsoon, the weather pattern in Bhutan is becoming increasingly unpredictable [6]. Based on the climate data for the period 2007-2017, the variability in monthly average maximum and minimum daily temperatures are higher in Bumthang, but the variability in monthly average precipitation was higher in Trongsa. Correspondingly, Trongsa reported a higher average count of natural disasters with flash floods and landslides being the most frequent. Higher variability and more frequent natural disasters are assumed to

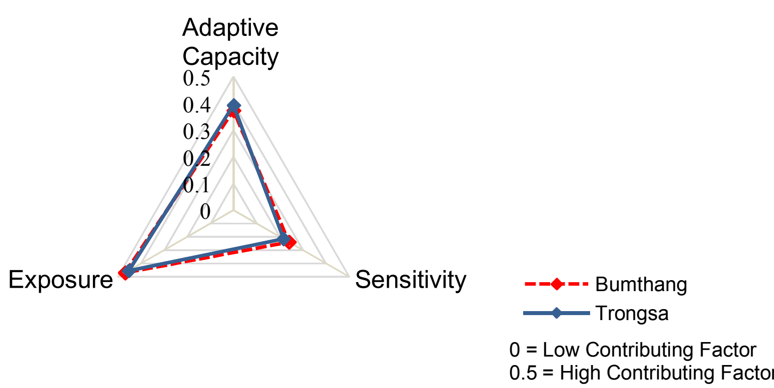

Fig. 3. Vulnerability triangle diagram of the contributing factors of the livelihood vulnerability index-IPCC (LVI-IPCC) for Bumthang and Trongsa

increase exposure to climate related risks. The proportion of households receiving prior information on the impending disasters was significantly lower in both the districts. Thus, improving the efficiency and effectiveness of early warning system would help farmers plan accordingly for extreme weather events in both the districts.

4.2 LVI-IPCC for Bumthang and Trongsa

The visual summary for the LVI-IPCC analysis based on the three contributing factors are depicted in Fig. 3. Both the districts were highly exposed to natural shocks and disasters due to climate variability. Although there is a lack of adequate data for Bhutan, extreme climate induced events are being reported with increasing frequency and intensity in the recent years [36]. This suggests the need to intensify climate adaptation and disaster risk reduction programs. Overall, Bumthang could be more vulnerable to climate change impacts due to the higher exposure and sensitivity, and a lower adaptive capacity compared to Trongsa.

5. CONCLUSION

Recent studies have indicated the changing trend in climatic conditions over Bhutan and its impact on the agricultural sector. Building climate resilience in the agricultural sector is of utmost importance for Bhutan as the sector employs a major portion of the population. This study assessed smallholder farmers' vulnerability to the impacts of climate change and variability using LVI and LVI-IPCC approach in the two central districts of Bhutan. The results from both the approach revealed that Bumthang may be more vulnerable to climate change and variability impacts compared to Trongsa ($LVI_{Bumthang}$: 0.36, $LVI_{Trongsa}$: 0.34, $LVI\text{-}IPCC_{Bumthang}$: 0.24, $LVI\text{-}IPCC_{Trongsa}$: 0.13). The analysis revealed a detailed understanding of the aspects in which certain interventions could be introduced to enhance a household's resilience. The results suggests, in central regions of Bhutan, farm households' vulnerability in the context of climate change could be reduced by improving irrigation, enhancing households' participation in self-help groups, minimizing crop depredation and improving the efficiency and effectiveness of early warning systems.

CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Appendix 1. Explanation on sub-components and their assumed functional relationship to vulnerability

Major Component	Sub-component	Assumed functional relationship
Socio-demographic profile (SDP)	SDP variable 1: Dependency Ratio	Higher dependency ratio reflects more vulnerability and lesser ability to adapt
	SDP Variable 2: Percentage of female headed households SDP Variable 3: Average age of female head of households	Female headed households are assumed to have less adaptive capacity Younger female head of households are assumed to have lesser experience and therefore more vulnerable
	SDP Variable 4: Percentage of households where head of household has not attended school	Education increases awareness of the issue and enhances adaptive capacity
Livelihood Strategies (LS)	LS Variable 1: Percent of households without family members working in a different community	Income diversification reduces vulnerability and increases adaptive capacity
	LS Variable 2: Percent of households dependent solely on agriculture as a source of income LS Variable 3: Average Agricultural Livelihood Diversification Index (range: 0.20–1)	Households with limited source of income are more vulnerable Diverse livelihood activities reduces vulnerability
Social Networks (SN)	SN Variable 1: Average Receive:Give ratio (range: 0–15) SN Variable 2: Average Borrow-lend money ratio (range 0.5-2)	A household frequently relying on others for help is more vulnerable A household frequently borrowing money from others is financially stressed and therefore more vulnerable
	SN Variable 3: Percent of households that have not gone to their local government for assistance in the past 12 months	Household with access to public services are less vulnerable
	SN Variable 4: Percentage of households not associated with any organization (cooperative/group)	Association with self-help groups increases adaptive capacity
Health (H)	H Variable 1: Average time to health facility (minutes)	Longer distance indicates higher sensitivity
	H Variable 2: Percent of households with family member with chronic illness	Households with chronically ill family members are more sensitive
	H Variable 3: Percent of households where a family member had to miss work or school in the last 2 weeks due to illness	Higher percentage indicates higher sensitivity
Food (F)	F Variable 1: Percent of households solely dependent on family farm for food F Variable 2: Average crop diversity index (range 0-1)	Households with limited source of food are more sensitive Diverse varieties reflect lesser sensitivity
	F Variable 3: Percent of households that do not save crops	Households that do no save crops are more sensitive to disasters
	F Variable 4: Percent of households that do not save seeds	Households that do not save seeds are more sensitive to disaster
	F Variable 5: Percent of households	Higher percentage indicates more

	reporting crop losses to wild animals in the last 1 year	sensitivity
	F Variable 6: Average number of months in year a household struggles without enough food	More months imply higher sensitivity
Water (W)	W Variable 1: Percent of households reporting water conflicts	Higher percentage reflects higher sensitivity
	W Variable 2: Percent of household that utilize a natural water source	Household depending on natural water source such as spring, pond, streams etc. are more sensitive
	W Variable 3: Percent of households that do not have a consistent water supply	Households with consistent water supply are less sensitive
Natural Disasters and Climate Variability (ND&CV)	ND&CV Variable 1: Average number of flood, windstorms, and dought events in the past 3 years	Higher number indicates higher exposure
	ND&CV Variable 2: Percent of households with losses to physical assets (house/machinery) due to natural disasters	Higher percentage indicates higher exposure
	ND&CV Variable 3: Percent of households that did not receive a warning about the pending natural disasters	Households that receive prior information on impending natural disasters are more prepared and therefore less exposed
	ND&CV Variable 4: Mean standard deviation of the daily average maximum temperature by month (2007-2017)	Higher variability indicates higher exposure
	ND&CV Variable 5: Mean standard deviation of the daily average minimum temperature by month (2007-2017)	Higher variability indicates higher exposure
	ND&CV Variable 6: Mean standard deviation of average precipitation by month (2007-2017)	Higher variability indicates higher exposure

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