A Quantitative Approach Towards Human-Thermal Vulnerability

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A Quantitative Approach towards Human-Thermal Vulnerability

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Abstract

Human vulnerability towards extreme heat exposure has generally been expressed as the cumulative expression of social, demographic, agricultural, environmental factors. Besides this, behavioural and physiological characteristics of individual may be responsible for significant differences in thermal perception and health effects towards extreme heat. The present endeavour is towards the identification and derivation of the quantitative scale of human-thermal vulnerability considering the social, human and thermal indicators. The study illustrates district-wise and village-wise human vulnerability considering different conventional indicators from social and environmental domain along with the factors accountable towards human warmth. The vulnerability was assessed, as representative for the state of Punjab, Haryana and West Bengal of India. Principle Component Analysis (PCA) was used as means of aggregating diverse indicators and to develop clusters of different variables as the respective principal components. The analysis indicated the utility of the expression of different types of vulnerability and the reasons to consider various indicators and their relative weightages. Accordingly, a quantitative scale of human-thermal vulnerability is arrived at, considering the social, human and thermal indicators.

Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Conflict of interest

The authors declare that they have no conflict of interest.

Authors' contributions

Both the author has made a significant contribution towards the concept of the article, the methodological development, analysis, and interpretation of the data.

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1. Introduction

Worldwide concerns have been raised about the potential impacts of the changing climate, climate variability and the associated weather extremes (Aubrecht and Özceylan, 2013). Evidences reaffirm that extreme climatic condition makes the human being more and more vulnerable (Patz et al., 2005; Kjellstrom et al., 2016). Research has been carried out in different communities to assess the level of vulnerability towards climatic hazards (Rabindranath et al., 2011; Walker et al., 2014; Zein and Tonmoy, 2015). The relationship is apparent about the facts of the increasing climatic stress on human health and wellbeing, particularly among people in the tropical and sub-tropical zones (Nag et al., 2009; Sen and Nag 2019). However, people have innate ability to adapt physiologically and technologically towards the changing climatic condition up to a certain limit (O'Brien et al., 2004). Beyond which high temperature exacerbates human vulnerability in terms of mortality, morbidity and health related hazards (Reid et al., 2009). Prolonged exposure in extreme heat intensifies the health risk due to elevated physiological responses and inadequacy in the thermoregulatory controls that manifest into a varied forms of heat disorders and injury (Parsons, 2009). Excessive storage of heat in the body due to inappropriate evaporative heat loss (Zhao et al., 2009) in the moist thermal environment significantly decrease labour productivity (Dunne et al., 2013). Several studies (Sahu et al., 2013; Zander et al., 2015; Krishnamurthy et al., 2017) emphasized on the profound effect of heat exposure over worker's productivity. Different human thermal indices, such as WBGT (Wet Bulb Globe Temperature) (Kjellstorm et al., 2009; Nag et al., 2009), Heat Index (a combined measure of temperature and relative humidity) were proven as useful (Aubrecht and Özceylan, 2013; Rosenthal et al., 2014) in the identification of heat related stress and disorders. Exposure limit of such indices signifies the degree of vulnerability in the extreme climatic conditions (Lundgren et al., 2014).

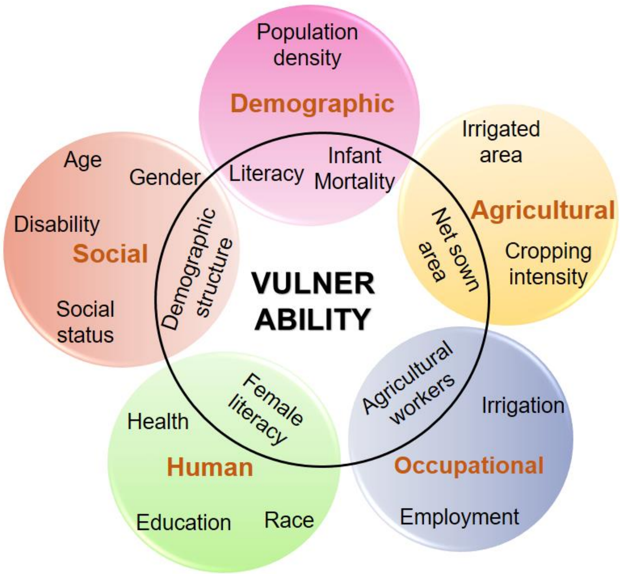

Figure 1. Indicators used to assess vulnerability

Concerning heat exposure, researchers from different domain explored the level of vulnerability linking heat related health issues with social and environmental factors (Harlan et al., 2006; Reid et al., 2009; Jhonson et al., 2012). Over the decade, several parameters and approaches have been utilized in an alternative way to assess different kind of vulnerability such as social, demographic and agricultural vulnerability (Figure 1). Such parameters have been chosen to describe sensitivity and adaptive capacity of the exposed population, with least consideration of individual physiological, psychological (Ford et al., 2006) and behavioural characteristics (Vincent, 2004). Human being exposed towards similar climatic condition may experience different perception and health effects, leading to variations in the vulnerability (Nikolopoulou and Steemers, 2003; Sen and Nag, 2019b). Undoubtedly, the assessment of vulnerability considering the tolerance, sensitivity, and adaptive capacity of the individual in tropical climatic area is scanty (Nag et al., 2013). Needless to mention that establishing the degree of vulnerability of a population towards heat exposure is a complex phenomenon. The challenge remains in defining the potentials of risk due to heat exposure in individual level involving a combination of location-dependent physiological variables, social and environmental factors. This study is a modest endeavour to arrive at the degree of vulnerability integrating different facets of vulnerability. Such an approach may be applied to varied regional and local perspectives.

2. Methods and materials

In the present contribution, vulnerability assessment was done incorporating multidimensional data. Moreover, individual physiological and behavioural parameters were integrated along with the conventional parameters (as mentioned in Figure 1) over diverse spatial scale. To represent a more comprehensive characterization of vulnerability 28 districts of two northwestern states of India (i.e., Punjab and Haryana) and the rural sector of West Bengal in eastern India (Figure 2) was taken into consideration.

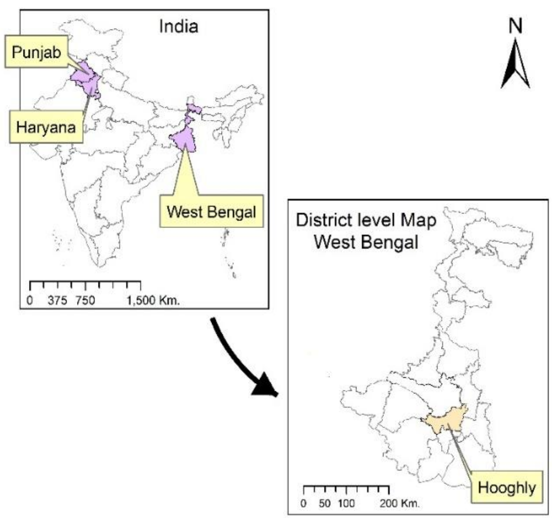

Figure 2. Location Map of the study area

District wise vulnerability analysis:

District wise social, human, as well as climatic vulnerability, were assessed for 28 districts of Punjab and Haryana. These two Indian states were moderately developed according to 2017 HDI ranking (2017 HDI value >0.7). Most of the region of these two states experience semi-arid steppe climate, according to Köppen (1919) climate classification, which indicates extreme weather throughout the year.

A set of 18 widely used social variables (Table 1) were taken into account to assess the district wise social vulnerability of these states. Such indicators have distinct functional effect in the overall vulnerability. Data were gathered from the Indian statistical abstract (Census 2011). Over the decades, the cumulative influence of such indicators was found to be useful in the assessment of the degree of vulnerability in a particular time and place (Leichenko et al., 2004; Gbetibouo and Ringler, 2009, Rabindranath et al., 2011). Researchers adopted similar technology like PCA (Principal Component Analysis) to derive clusters of non correlated variables (Ravindranath et al. 2011; Abson et al., 2012). Normalization technique was applied to make the indicator unit free and maintain the competency of combining multiple indicators prior to the analysis. According to the component loadings and component score coefficients, the normalized weights of the principal components were transformed into a summated loading of components to express district wise social vulnerability.

Table 1: Parameters used to analyze district wise vulnerability

Indicators	Description	Increase (+) or decrease (-) vulnerability
Population density	Due to higher population density, resources cannot be used at its' optimum level (Islam Nazrul et al., 2013).	+
Female literacy	Higher female literacy rate in society helps to reduce fertility rate, infant mortality, as well as gender bias (Leichenko et al., 2004).	-
Rural population	Overpopulation in rural areas creates pressure over natural resources (Rao et al., 2013). In such areas, more people are directly exposed to extreme climatic events (Gbetibouo et al., 2009).	+
Disabled population	Disable persons are not able to respond individually at the time of disaster (Rygel et al., 2006). Also, difficulty persists in the specific identification of the physically or mentally disabled person (Dwyer et al., 2004).	+
Unemployed person	Unemployment signifies towards the higher proportion of people below the poverty line. Lack of support systems elevates the level of vulnerability in situations of crisis and disaster (Gbetibouo and Ringler, 2009; Flanagan et al., 2011).	+
Total main worker	Such people have an engagement in work over the year and are capable of coping up in adverse situations (Patnaik & Narayanan, 2009).	-
Child labour	Child labour is an indication of poor economic condition and household vulnerability (Guarcello et al., 2010).	-
Net area sown	More sown area indicates more agricultural dependency and therefore enhance the vulnerability towards natural calamity (Rao et al., 2013; ICAR report, 2013)	+

Total cropped area	The larger area under total crop production indicates the improved adaptive capacity (Islam Nazrul et al., 2013).	-
Average size of landholding (<2 hec.)	Small agricultural landholding indicates the marginal and small farmers (Rabindranath et al., 2011).	+
Net irrigated area	Irrigation is a vital adaptation-enabler as it enables farmers to save crops during dry spells or droughts. It is also strongly related to technology adaption (Rao et al., 2013).	-
Fallow land	Fallow land indicates towards the deforestation, soil erosion and increment of pollution level (Vezina et al. 2006).	+
Area under forest	Forest area is an essential primary activity of people and produces various jobs (Fatemi et al., 2017).	-
Fertilizer consumption	Consumption of fertilizers in agricultural land is an indicator of sufficient food production and hence indicates the adaptive capacity (Rabindranath et al., 2011; Rao et al., 2013).	-
Household having electricity	The facility of domestic electricity helps to determine the overall development (Rao et al., 2013).	-
Total metal road length	It is an indicator of good accessibility in the market place and helps to integrate the industries (Rao et al., 2013).	-
Total Govt. employee	In terms of money and other competencies, people engaged in government sectors have more security benefit than others (Cutter et al., 2003, Fatemi et al., 2013)	-
Cultivator	People engaged in cultivation have the least scope to opt for other occupation due to the lack of knowledge and expertise in other organized sectors (Gbetibouo and Ringler, 2009)	+

The climatic vulnerability was ascertained in the form of thermal stress as depicted by different human-thermal indices. District wise climatic vulnerability was visualized according to the stress level of the internationally approved standard human-thermal indices, WBGT (Wet Bulb Globe Temperature) (ISO 7243:2003). This index is the combination of the wet bulb, dry bulb and globe temperature. Meteorological data were obtained from the automatic weather stations (AWS), of the India Meteorological Department (IMD). Primarily, the analysis was done from the data of 28 AWS for 28 individual districts of Punjab and Haryana. In the present analysis, meteorological data was compiled for a particular time (6 UTC) at every alternative day, over a period of 1 year, i.e., from July'15 to June'16. The data included ambient temperature (T_a) (ºC), dew point temperature (T_d) (ºC), mean sea level pressure (mslp) (hPa), and wind speed (v) (knot). Other climatic parameters like relative humidity (RH), wet bulb temperature (T_w), saturated (svp) and unsaturated vapor pressure (vp), globe temperature (T_g), mean radiant temperature (MRT), etc., were computed based on the conventional formula (Sen and Nag, 2019). Some districts were excluded from the analysis due to non-availability or non-uniformity of the meteorological data.

Further other conventional human thermal indices PMV (Predicted Mean Vote) and SET* (Standard Effective Temperature) were also taken into account with the social indicators to assess the district wise overall human vulnerability. Fanger (1970) proposed the predicted mean vote (PMV) using individual perception and sensation to study the comfort level. SET* is an improved version of thermal indices (Gagge et al., 1986) and use the mechanism of the CFD model (Lin et al., 2008). To compute these two indices using RayMan model Ver. 1.2 (Matzarakis et al., 2010) the required human parameters were set at body surface area (1.47 m^2), clothing value (0.4 clo) and metabolic rate (50 W/m^2) (Nag et al., 2009). Again, the normalized value of these social and meteorological variables was treated for PCA (Principal Component Analysis) to achieve the degree of human vulnerability.

Village level vulnerability analysis:

Village wise vulnerability was analyzed using a survey-based technique and generation of data from 22 villages of the rural areas of Hooghly districts of the state of West Bengal in eastern India. Large population of this area is habitually engaged in farming activities. To ensure the outdoor exposure he study period was chosen during the months of November to April 2015 to 2017.

Social data were obtained from Census 2011 for the selected villages to achieve the degree of social vulnerability. 28 variables (Table 2) were treated to assess the social vulnerability of these villages adopting the similar methodology of the PCA technique. The relevance of these social variables in vulnerability study has already been briefly described. For the micro-region vulnerability assessment, some basic amenities and assets parameters were also considered from the census data in correspondence to each village. Percentage of these parameters in the individual villages denotes the living standards.

Table 2: Indicators to assess village wise social vulnerability

Social indicators	Household amenities & assets
• Total population • Female literacy • Total main worker • Total household • Cultivator • Forest area • Net area sown • Irrigated area • Unirrigated area • Canal area • Culturable waste land • Non-agricultural land • Fallow land	• Concrete roof • Burnt brick wall • Cement floor • Sufficient rooms • Permanent house • Ownership status of house • Electric facility • Drinking water facility • Within premises drinking water • Kitchen facility • Latrine facility within the premises • Improved pit latrine • LPG/PNG fuel • Television • Scooter/ Motorcycle

Observations of over 1000 people were considered in the assessment of the human thermal vulnerability for the selected villages. Subjective and objective measurements, such as, height, weight, body temperature, heart rate of the surveyed population were obtained at the time of field investigation of the mentioned villages. The objective measurements and the perceived responses recorded after taking ethical consent of the workers for their participation in the study. The environmental parameters included dry-bulb (T_a) and wet bulb temperature (T_{wb}) measured by the dry and wet bulb thermometer, and wind-speed (v) by an anemometer. Other parameters like relative humidity and globe temperature were calculated using the conventional formulae.

Based on the environmental and biophysical parameters (Table 3), the human thermal vulnerability was yielded for the individual person applying a similar methodology of PCA analysis. Since engaging the same sample of population covered during the field survey in an individual village was not within the control of the investigator, the average degree of human thermal vulnerability of the village dwellers was depicted as the village wise thermal vulnerability.

Table 3: Biophysical & environmental parameters obtained from the village survey

Biophysical parameters	Maximum value	Minimum value	Description
Body height (cm)	188.0	121.9	Body height and weight are used to calculate body surface area (BSA) which is used to determine the heat exchange between the body and the environment (Parson, 2003)
Body weight (kg)	87.0	27.5	
Normal Body core temperature (ºC)	37.2	36.0	In heat exposure, an immense relationship exists between the physiological mechanisms and body core temperature. Changes in core temperature determine the tolerance level of human being and hence the vulnerability (Nag et al., 2013).
Change in body core temp (ºC/ min)	0.063	0.005	
Oxygen consumption (l/min) (predicted)	1.8	0.5	The total oxygen demand significantly varies with the enhancement of environmental warmth. Increase or decrease of oxygen demand of one litre was equivalent to a corresponding one minute change in tolerance time (Nag et al., 1997).
Clothing insulation value (clo)	1.2	0.2	Clothing insulation value is essential to understand the heat exchange mechanism between the skin and clothing surface (Parson, 2003).
Work load (watt)	125.0	50.0	Metabolic heat production in the body is significantly related with the working load. Increasing workload exacerbate heat load in the body and therefore decrease productivity (Nag and Nag, 1992).

Evaporative exchange through skin surface (watt/ sq.m.)	845.5	49.7	It signifies the relative change in the evaporative exchange from the body surface with the increasing environmental warmth (Sen and Nag, 2019).
Ambient temperature (ºC)	37.0	17.0	These parameters are used in the assessment of different human thermal indices
Wet bulb temperature (ºC)	30.0	15.0	
Relative humidity (%)	82.9	44.6	
Dew point temperature (ºC)	28.9	13.2	
Wind velocity (m/ sec)	2.3	0.4	
Globe temperature (ºC)	41.4	19.8	
Mean radiant temperature (ºC)	42.8	20.4	

3. Results

The social indicators (Table 1) for the individual districts of Punjab and Haryana were treated for statistical analysis to quantify the degree of vulnerability. PCA was done using the SPSS V.20.0 software. 18 parameters were applied to PCA technique using varimax rotation (Kaiser normalization) and therefore, arrived at a quantitative indicator of the social vulnerability of the concerned districts of Punjab and Haryana (Figure 3a), with convergence to a maximum of 10 iterations. The analysis allowed elucidation and determination of the component structure of the dimensions, grouping them into subscales of three components (PC1 to PC3). Each component had an eigenvalue greater than 1. These components were defined as (a) social facilities, (b) agricultural facilities, and (c) demographic structure that had noted influence on social vulnerability.

1. Social facilities (PC1, 3 items) covered the responses that describe the general facilities like domestic electricity, metalled road length and the total main worker, which explained 36.3% variabilities.
2. Agricultural facilities (PC2, 2 items) included fertilizer consumption and net area under irrigation, explaining 24.4% of the total variance.
3. Demographic structure (PC3, 2 items) referred to the population density and female literacy rate that explained 23.5% of the total variance. That is, the three components combined accounted for 84.2% of the total variance.

The principal components, PC1 to PC3, were analyzed for internal consistencies, by estimating the reliability coefficients (Cronbach's alpha). The reliability coefficients of PC1 and PC2 were high (i.e., Cronbach’s alpha values varied in the range of 0.78 to 0.92), whereas Cronbach’s alpha value was moderate for the demographic structure (0.64), PC3. The component loadings of PC1 to PC3, component score coefficients, and the summated weights of the clustered subjective responses in PC1, PC2 and PC3 are given in Table 4. The product of the component loading of each item with the component score coefficient yielded the individual weights of subjective responses, which were further summated to obtain the weights of PC1, PC2 and PC3 as 1.03, 0.98, and 0.89 respectively. Accordingly, the respective parameters of PC1, PC2 and PC3 were normalized for each sample using the formulae below to derive coefficients of individual components.

$$N_i = \sum_{i=1}^{n} \frac{x_{ji} - \bar{x}_j}{\sigma_j} \times W_j$$

where, N_i= Normalized value for i^{th} sample; x_{ji}= Actual value of the indicator j for i^{th} sample; $\bar{x}_j$= Mean value of indicator j; σ_j= Standard Deviation of indicator j; and W_j= summated weight of the indicator j. The scores of the individual components of the entire sample were 2.30 ± 1.79 for PC1, 1.32 ± 1.26 for PC2, and 1.30 ± 0.87 for PC3, respectively. The average scores of the three components were transformed to unity to attain a generalized social vulnerability indicator, as below:

$$V_S = 0.47 * A + 0.27 * B + 0.26 * C$$

where, V_S = social vulnerability; A = social facilities; B = agricultural facilities; and C = demographic structure. The summated value of each district was represented further using equal interval scale and pointed as low, moderate, high. Apart from this, the Likert attitude scale values of the social, agricultural and demographic dimensions grouped under A, B and C may be applied to obtain the S value in a scale of five, from 1, low to 5, high level of social vulnerability of individual districts for any of such randomized location.

Table 4. Principal component loadings, component score coefficients and summated weights of different factors describe social vulnerability (Punjab and Haryana)

	PC1		PC2		PC3		Component score coefficient	Summated weights
	Social facilities (36.3% variance explained)		Agricultural facilities (24.4% variance explained)		Demographic structure (23.5% variance explained)			
Social Vulnerability	Domestic electricity	0.917					0.367	1.03 (PC1)
	Total main worker	0.896					0.365	
	Total metalled road (Km.)	0.895					0.405	
			Fertilizer consumption (kg/ hec.)	0.904			0.550	0.98 (PC2)
			Net irrigated area (%)	0.881			0.543	
					Population density/ sq km.	0.922	0.615	0.89 (PC3)
					Female literacy rate	0.727	0.446	

Further, based on WBGT the climatic vulnerability was ascertained for individual districts and depicted as low (<24ºC), moderate (24 - 28ºC), high (>28ºC) vulnerability (Figure 3b) (Blazejczyk et al., 2012).

Similarly, the cumulative human vulnerability to climate was ascertained, based on the socio-demographic parameters along with the thermal indices, i.e., WBGT, PMV, and SET*. The extracted 3 components were labelled as (a) socio-demographic factors, (b) climatic stressors, (c) farm resources. The factor loadings and weightages of the components are presented in Table 5. These three components explained 87.4% of the total variance. The Internal consistencies (reliability coefficients as Cronbach's alpha) for PC1 to PC3 were high (i.e., 0.94, 0.99 and 0.72 respectively). The scores of the individual components of the entire sample were 2.98 ± 2.00 for PC1, 2.29 ± 1.87 for PC2, and 2.16 ± 1.11 for PC3, respectively. The average scores of the three components were transformed to attain a generalized human vulnerability indicator, as below:

$$V_H = 0.40 * J + 0.31 * K + 0.29 * L$$

where, V_H = human vulnerability; J = socio-demographic factors; K = climatic stressors; and L = farm resources. Based on this method, human vulnerability was obtained for individual districts (Figure 3c) and categorized under low, moderate, high level of vulnerability using equal interval.

Table 5. Principal component loadings, component score coefficients and summated weights of different factors to describe human vulnerability (Punjab and Haryana)

	PC1		PC2		PC3		Component score coefficient	Summated weights
	Socio-demographic (36% variance explained)		Climatic stressors (29.7% variance explained)		Farm resources (21.7% variance explained)			
Human vulnerability	Total disabled person	0.973					0.289	0.96 (PC1)
	Total child labour	0.949					0.297	
	Total unemployed person	0.944					0.276	
	Total rural population	0.753					0.182	
			SET*	0.984			0.348	1.01(PC2)
			WBGT	0.978			0.350	
			PMV	0.969			0.338	
					Average size of land holding (<2 hec.)	0.806	0.394	0.89(PC3)
					Fallow land ('000 hec)	0.782	0.381	
					Cultivator	0.781	0.347	

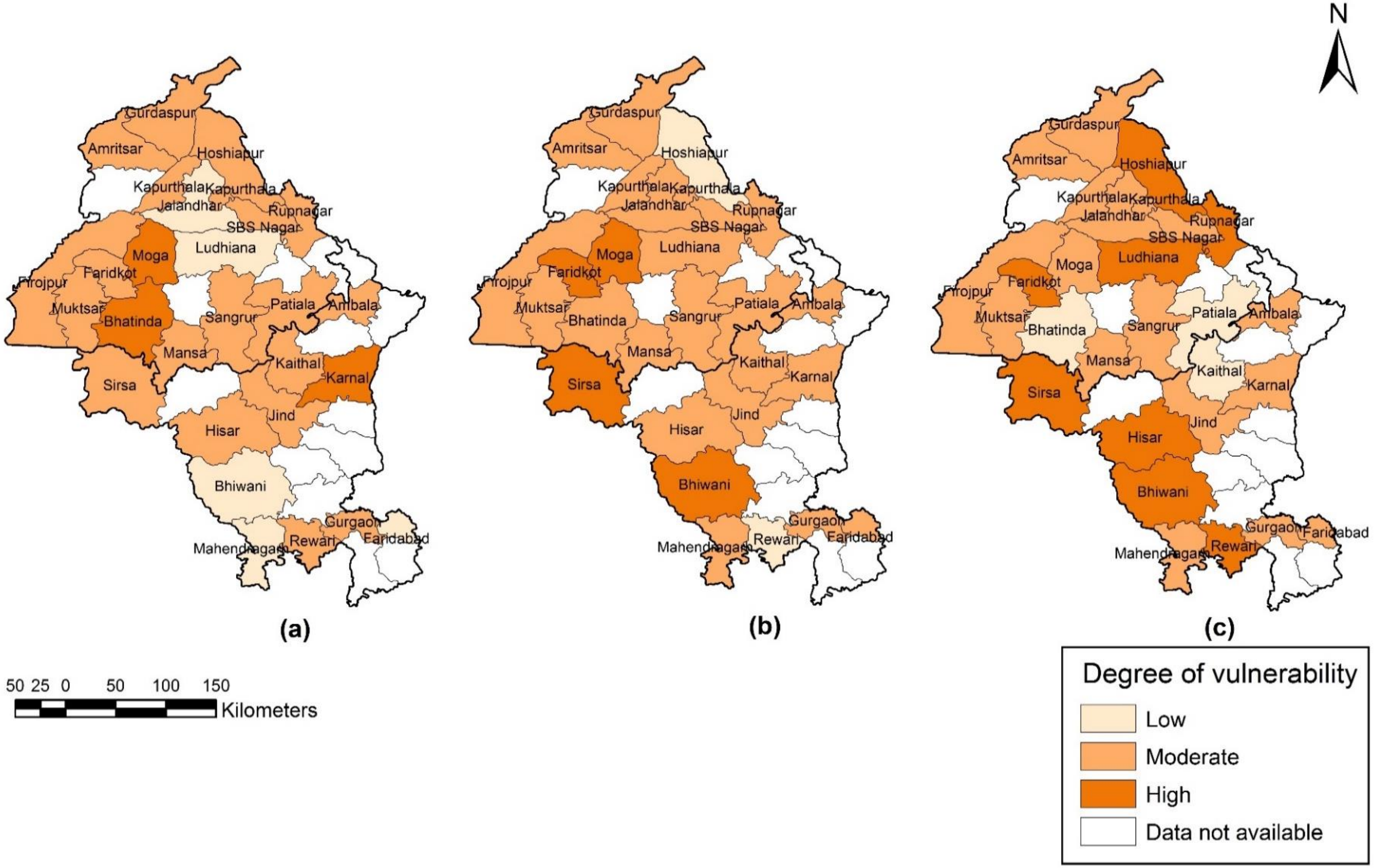

Figure 3. District wise (a) social, (b) climatic & (c) human vulnerability in Punjab & Haryana

Accordingly, the data of 22 villages of West Bengal were analyzed based on 28 parameters related to the socio-demographic, agricultural and economic status of the villages, mentioned in Table 2. The PCA analysis yielded 3 components, labelled as (a) household amenities, (b) development indicators, (c) basic amenities (Table 6), explaining 72.5% of the total variance. The reliability coefficients (Cronbach's alpha) were high for the PC1 and PC2 (alpha >0.9) and low for PC3 (alpha 0.15). The scores of the individual components of the entire sample were 7.00 ± 5.07 for PC1, 2.37 ± 4.34 for PC2, and 0.62 ± 0.46 for PC3, respectively. Thereby, a generalized social vulnerability indicator was attained as:

$$V_{sv} = 0.70 * P + 0.24 * Q + 0.06 * R$$

where, V_{sv} = social vulnerability (village level); P = household amenities; Q = development indicators; and R = basic amenities. Based on this method, social vulnerability was obtained for the individual village (Figure 4a) and categorized under low, moderate and high level of vulnerability with equal interval.

Similarly, from 15 indicators describing environmental and biophysical parameters (Table 3), the human thermal vulnerability was ascertained. Village level thermal vulnerability was computed based on the degree of vulnerability of the respondents for individual villages. The extracted 3 components, labelled as (a) environmental parameters, (b) biophysical parameters, (c) body dimensions explained 91% of the total variance (Table 7), with high (PC1 and PC2 - Cronbach's alpha 0.87 to 0.99) internal consistencies of the clustered dimensions and with moderate consistency for PC3 (alpha - 0.67). The scores of individual components of the entire sample were 2.06 ± 1.57 for PC1, 2.24 ± 1.54 for PC2, and 1.52 ± 0.91 for PC3, respectively, from which a generalized human thermal vulnerability indicator was obtained, as below:

$$V_{HT} = 0.35 * X + 0.39 * Y + 0.26 * Z$$

where, V_{HT} = human thermal vulnerability; X = environmental parameters; Y = biophysical parameters; and Z = body dimensions. Based on this method, human thermal vulnerability was obtained for the individual village (Figure 4b) and represented as same. The analysis shows differences in the village wise social and thermal vulnerability and supports that socially vulnerable regions might not indicate climatic vulnerable and vice versa.

Table 6. Principal component loadings, component score coefficients and summated weights of different factors for social vulnerability (Village, W.B)

	PC1		PC2		PC3		Component score coefficient	Summated weights
	Household amenities (36.9% variance explained)		Development indicators (25.8% variance explained)		Basic amenities (9.8% variance explained)			
Social vulnerability	Concrete roof	0.900					0.151	0.99 (PC1)
	Scooter/ Motorcycle	0.864					0.160	
	Latrine facility within premises	0.861					0.154	
	Cement floor	0.807					0.145	
	Improved pit latrine	0.790					0.125	
	Television	0.705					0.170	
	LPG/ PNG fuel	0.689					0.154	
	Brunt brick wall	0.658					0.102	
	Electric facility	0.652					0.110	
			Net Area Sown	0.976			0.257	0.93 (PC2)
			Female literacy	0.953			0.245	
			Total main worker	0.947			0.244	
			Canal Area	0.906			0.241	
					Drinking Water facility within premises	0.759	0.521	0.40 (PC3)
					Drinking water facility	0.097	0.066	

Table 7. Principal component loadings, component score coefficients and summated weights of different factors for human thermal vulnerability (Village, W.B)

	PC1		PC2		PC3		Component score coefficient	Summated weights
	Environmental parameters (42% variance explained)		Biophysical parameters (29% variance explained)		Body dimension (20% variance explained)			
Human thermal vulnerability	Globe temperature	0.981					0.301	0.88 (PC1)
	Ambient temperature	0.980					0.300	
	Wet bulb temperature	0.972					0.302	
			Oxygen uptake	0.977			0.455	1.01 (PC2)
			Change in body core temperature	0.935			0.400	
			Evaporative exchange through skin surface	0.684			0.273	
					Body height	0.885	0.582	0.96 (PC3)
					Body weight	0.828	0.540	

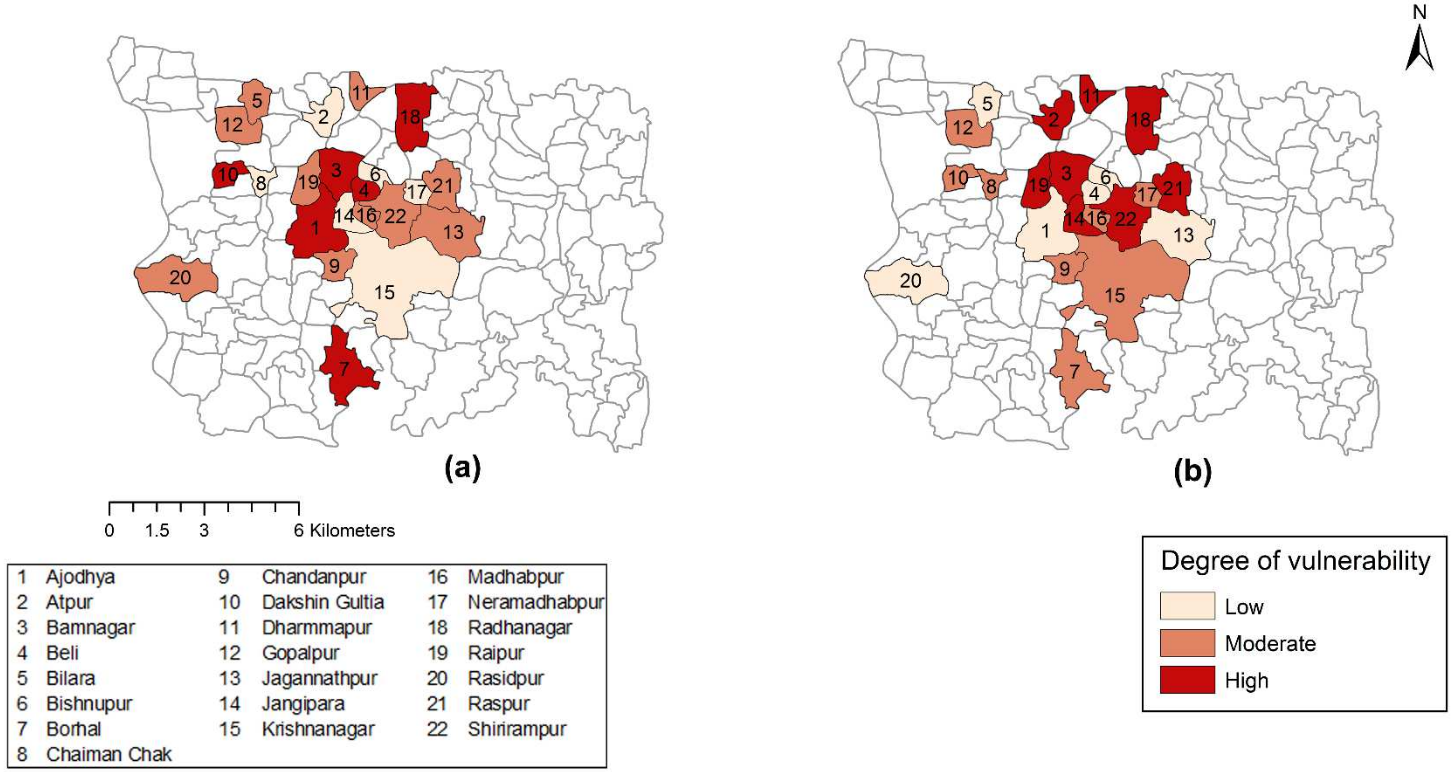

Figure 4. Village wise (a) social and (b) human thermal vulnerability in rural West Bengal

4. Discussion

In general, vulnerability refers to the degree of risk towards human lives and properties with adverse climatic condition concerning individual or group of person (McCarthy et al., 2001; Blaikie et al., 2004). In the context of climate change, an intense relationship has been established between the increasing temperature and the degree of vulnerability towards human health and wellbeing, particularly in the tropical and sub-tropical regions (Kjellstorm et al., 2013). A strong association between heat exposure and mortality has been recorded (Morabito et al., 2006). According to the National Crime Records Bureau, thousands of people each year loss their lives due to heatstroke in India (Dubbudu, 2018). Xiang et al. (2014) established that increase of 1°C daily maximum temperature exacerbates heat injury every day by about 0.2% among outdoor workers in Adelaide, Australia. During the last 15 years (1992-2006) in the United States, about 423 workers in agricultural and nonagricultural industries died due to high heat stress (CDC, 2018). Evidence supports that the higher degree of thermal stress, determined by thermal indices, significantly reduce the productivity of the workers, engaged in diverse farming and allied activities and have a negative implication on health and wellbeing (Watts et al., 2018; Dally et al., 2018). Different health implications, tropical diseases, and job attrition were the commonly identified issues towards the significant loss of workers' productivity in tropical climate (Lundgren et al., 2013). Some recent studies have also estimated the economic cost of productivity loss (Hübler et al., 2008, Zander et al., 2015) which is expected to increase to billions of US$ in Indonesia, Thailand, Malaysia, Philippines and Vietnam by 2030 (Kjellstorm et al., 2013). In Central Italy, the daytime apparent temperature about 25–28°C in summer signified towards increasing heat stress and hence the work-related mortality and morbidity (Morabito et al., 2006). Although, in similar climatic exposure human being may experience varied perception and health effects which leads to variation in the vulnerability level (Nikolopoulou and Steemers, 2003; Sen and Nag, 2019b). Over the years various social, agricultural, biophysical parameters have been identified and alternatively used to describe sensitivity and adaptive capacity of the exposed population (Cutter et al., 2000; Wu et al., 2002). However, research is scanty towards the determination of heat related vulnerability considering individual physiological, psychological and behavioural characteristics (Ford et al., 2006; Vincent, 2004). The present study is a modest attempt towards the quantification of human thermal vulnerability concerning human thermal indicators along with social and climatic characteristics of the different region of topical India to explore the degree of vulnerability. The derivation of the relationship of social, human and thermal indicators, is a maiden attempt to reach a quantitative scale of human-thermal vulnerability.

The socio-demographic factors, agricultural parameters were generally used towards the quantitative assessment of social vulnerability in most of the researches. In the present study, social vulnerability was assessed for Punjab and Haryana evolving similar type of parameters. Climatic vulnerability was identified based on the thermal stress, defined by standard heat indices. Further, the degree of human vulnerability was ascertained with the help of social and climatic factors. As described in the results, the social indicators of some districts of Punjab and Haryana states of India were statistically treated using PCA to arrive at a quantitative indicator of the social vulnerability. Three-component structure of the dimensions was defined as (a) social, and (b) agricultural facilities, and (c) demographic structure. The social facilities explaining ~36% of the total variance described the general facilities like domestic electricity supply, availability of metalled road and the total main worker. Fertilizer consumption and net area under irrigation were included under agricultural facilities and explained about 24% of the total variance. Demographic structure (PC3, 2 items) referred to the population density and female literacy rate that explained 23.5% of the total variance. Summated weights of the individual principal component were further normalized to derive coefficients of individual components. The average scores of the three components were transformed to unity to attain a generalized social vulnerability indicator. Climatic vulnerability of individual districts was illustrated with the internationally accepted standard of WBGT (ISO 7243: 2003). Further, a group of parameters including socio-demographic and internationally accepted thermal indices were taken into consideration to ascertain the overall level of human vulnerability adopting similar methodology of PCA technique. The extracted 3 components explained 87.4% of the total variance and were labelled as (a) socio-demographic factors, (b) climatic stressors, (c) farm resources. These three components individually explained 36%, 29.7% and 21.7% of the total variance respectively. A generalized degree of human vulnerability for each district was derived from the normalized degree of derived coefficients of individual components. Dissimilarity persists among the ascertained social, climatic and human vulnerability level. Analysis reveals that socially vulnerable areas may not be vulnerable towards climatic exposure and hence the degree of human thermal vulnerability, the combination of social and climatic factors, may also differ accordingly.

With the same principle, social vulnerability for 22 villages of West Bengal was ascertained using 28 parameters related to the socio-demographic, agricultural and economic status of the villages. Three components marked as (a) household amenities, (b) development indicators, (c) basic amenities, explaining 72.5% of the total variance resulted from PCA analysis. Apart from PC3, the reliability coefficients were also very high for the PC1 and PC2. A generalized form of social vulnerability was obtained from this analysis. Furthermore, human thermal vulnerability was computed for these villages using 15 environmental and biophysical indicators, collected from the field survey. Village level thermal vulnerability was assessed according to the degree of thermal vulnerability of the respondents for individual villages. In this analysis, three components labelled as (a) environmental parameters, (b) biophysical parameters, (c) body dimensions and explained 91% of the total variance. A generalized form of human thermal vulnerability was also obtained. The analysis shows differences in the village wise social and thermal vulnerability and supports that socially vulnerable regions might not indicate climatic vulnerable and vice versa. The overall analysis reveals the existing difference in the level of vulnerability over varied time and space. Vulnerability is a relative term and therefore, the degree of vulnerability largely depends on the measured indicators.

WHO emphasized the detrimental effect of heat related specific health hazards and proposed interventions in regional level to prevent the susceptible population (Patz et al., 2005). Implementing appropriate heat prevention plan requires a better understanding of the location-specific spatial pattern with health-related risk (Aubrecht and Özceylan, 2013). An immense relationship has been established among the social, agricultural, biophysical characteristics and overall vulnerability (Cutter et al., 2000; Wu et al., 2002). However, literature supports that quantifying the level of risk associated with the heat-related mortality and morbidity and involving behavioural, social and environmental variables is a complex domain to decipher (Harlan et al., 2006). Heat vulnerability research demands thorough investigation and engagement of individual physical and health characteristics irrespective of time and space (Reid et al., 2009). Most of the heat related vulnerability study was documented in Europe and North America, where the plan and strategies were developed at the local level (Azhar et al., 2017). Whereas, heat related health hazards and the resultant vulnerability is yet to be established in developing countries like India (Nag and Nag, 2009) where heavy physical work is common, and the hot season is long (Kjellstorm et al., 2016).

Vulnerability is not a directly observable phenomenon and hence difficult to quantify the level of vulnerability by assigning specific criteria (Luers et al., 2003). A variety of vulnerability approaches and assessment techniques were suggested over the decades based on the relative efficacy and applicability (O'Brien et al., 2004a, Cutter et al., 2003). However, most of the study engaged either in the identification of the most indicative variables or in the assessment of the level of vulnerability in the form of composite index aggregating diverse variables (Hahn et al., 2009; Reid et al., 2009; Johnson et al., 2012) in a parochial manner. Assessment of vulnerability is a complex interaction of environmental, social as well as the biophysical phenomenon and discrepancies might arise from the selection of variables and assigning the relative weights (Gbetibouo and Ringler, 2009). Needless to reiterate that the vulnerability study is in the developing phase undertaking different approaches (Rygel et al., 2006). However, in the context of climatic exposure, physical characteristics cannot alone manifest vulnerability (Wolf and McGregor, 2013). Gaps remain in the micro-level vulnerability assessment (Vincent, 2004) and creating a model for future projection of vulnerability over varied climatic regions. Also, there is an obvious need to identify such indicators which can be used globally and may apply to propose a modelling approach (Kelly and Adger, 2000) towards the assessment of human vulnerability. The present analysis is affirmative that the interaction between biophysical and social processes may be suitable for micro to macro-regional (e.g., village and district level) vulnerability assessment. In this analysis, indicators were used to assess different types of vulnerability (such as social, human, climatic and thermal vulnerability). Further stated that any single parameter might not be adequate to determine the degree of vulnerability (Adger et al., 2004; Vincent, 2004).

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