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Livelihood vulnerability and climate change: a comparative analysis of smallholders in the Indo-Gangetic plains

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Abstract

In the Indo-Gangetic Plains, one of India's most productive agricultural regions, smallholder livelihood vulnerability can inhibit sustainable development. As there are significant differences in economic development, natural resources and agricultural productivity within the region, we estimate the Livelihood Vulnerability Index in two districts (Vaishali, Bihar and Karnal, Haryana) to determine suitable adaptation strategies under diverse conditions. To reflect different aspects of climate exposure, we include both self-reported climate shocks and spatially interpolated weather data. The assessment of 1127 households shows that while both districts have similar exposure and adaptive capacity levels, the sensitivity dimension makes Vaishali more vulnerable to climate change. To reduce sensitivity, decision-makers should focus on improving infrastructure (e.g., permanent housing, latrines, health centers, alternative energy sources). To improve adaptive capacity and reduce climate risk in both regions, policymakers should promote the expansion of extension training for livelihood diversification, information and communication technologies as well as conservation agriculture.

Keywords Climate change · Livelihood vulnerability · India · Smallholders

1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), a temperature increase of 1.5 °C above the preindustrial level poses risks for natural and human systems such as agriculture (Masson-Delmotte et al., 2018). As developing countries such as India are highly dependent on agriculture, climate change leads to additional challenges including increasing pressure on food systems, exacerbating land degradation and hindering poverty eradication (Mall et al., 2006; Vermeulen et al., 2012). If temperatures rise between 2–3.5 °C, India's net revenue will decrease between 9 and 25%, which will result in severe

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and cumulative effects for smallholders (Kasperson & Kasperson, 2001; Spijkers, 2010). To reduce local climate-related risks, it is necessary to understand the drivers of livelihood vulnerability (Ellis, 1998; Olsson et al., 2018).

Local-level vulnerability assessments are important for understanding the implications of climate change, particularly as the adaptive capacity of a system depends on political, cultural, technological, financial and institutional capacities (Adger, 2006; Downing et al., 1996; Kelly & Adger, 2000; Smit & Wandel, 2006). Vulnerability assessment focuses on three components: exposure, sensitivity and capacity related to a social or natural system (Field, 2014). Exposure captures variation in climate as well as extreme natural events (magnitude and frequency) within a certain timeframe (long- or short-term) and location. Sensitivity shows how a system responds to shocks, either positively or negatively (Leichenko & O'Brien, 2002). Finally, adaptive capacity refers to a system's capability to react to disruption (Füssel & Klein, 2006; Kelly & Adger, 2000; Smit & Wandel, 2006).

There are several methods of assessing vulnerability: qualitative participatory models and bottom-up approaches, quantitative model-based approaches and indicator-based approaches. These approaches can also be combined. Qualitative approaches rely on interviews, focus group discussions or cognitive mapping to depict perceptions of vulnerability from a local community (Schröter et al., 2005; Smit & Wandel, 2006; Turner et al., 2003). Quantitative model-based approaches include the Ricardian method to estimate farm climate sensitivity, biophysical models in climate research and GIS-based methods including meteorological data to assess vulnerability from a natural sciences point of view (Mendelsohn, 2014; O'Brien et al., 2004; Panda, 2017). Finally, indicator-based approaches seek to combine aspects of both approaches and are based on quantitative data derived from surveys, censuses and climate data (Cutter et al., 2003; O'Brien et al., 2004; Hahn et al., 2009; Ahsan and Warner 2014). An example of a combined approach is the Resilience Index Measurement and Analysis (RIMA-II), which uses both an index and a matrix to study vulnerability and recovery (FAO, 2016).

Indices have become one of the key instruments in climate vulnerability analysis as they offer flexibility for its assessment on various administrative levels (Kelly & Adger, 2000). In multivariate indicator-based approaches, sets of observable proxy variables (sub-components) are combined, which then form major components and subsequently an index (Ahsan and Warner 2014). The most popular vulnerability indices include the Human Development Index established by the United Nations Development Programme (McGillivray & White, 1993), the Socioeconomic Vulnerability Index (Ahsan and Warner 2014), the Agricultural Vulnerability Index (Varadan & Kumar, 2015), the Climate Change Vulnerability Index (Edmonds et al., 2020), the Multidimensional Livelihood Vulnerability Index (Gerlitz et al., 2017) and the Livelihood Vulnerability Index (LVI) (Hahn et al., 2009).

Rural, agrarian communities in South Asia are particularly vulnerable to climate change as weather extremes and natural hazards threaten agricultural output and, in turn, their livelihoods (O'Brien et al., 2004; Pandey & Jha, 2012; G. Alam et al., 2018). India ranks among the top countries already affected by climate change with significant pressure on food systems, poverty, land degradation and agricultural productivity (Kasperson et al., 1993; Mall et al., 2006; O'Brien et al., 2004; Turner et al., 2003; Vermeulen et al., 2012).

Several recent studies have conducted climate vulnerability assessments in South Asia using the Socioeconomic Vulnerability Index (Sam et al., 2017), the Climate Vulnerability Index (M. Alam et al., 2017), the Livelihood Vulnerability Index (Hahn et al., 2009; Devi et al., 2016; M. Alam et al., 2017; Bhattacharjee & Behera, 2018), the modified Livelihood Vulnerability Index (Madhuri et al., 2014) as well as the socio-ecological vulnerability

index (Pandey & Bardsley, 2015). Many of the studies focused on vulnerability related to extreme water events, namely droughts and floods (Devi et al., 2016; M. Alam et al., 2017; Sam et al., 2017; Bhattacharjee & Behera, 2018). The main strategies identified for reducing vulnerability included strong social networks, a supportive institutional background (Sam et al., 2017) and income diversification including through migration (Bhattacharjee & Behera, 2018; Madhuri et al., 2014) in South Asia.

The majority of these studies uses cross-sectional data retrieved from household surveys and weather data from meteorological stations. However, this is not ideal for studies of climate change as cross sectional data capture only one point in time and often lack sufficient spatial variation for weather variables (Di Falco et al., 2011). Particularly in developing countries, there is limited meteorological data with scattered station coverage. Previous cross sectional indicator-based assessments have relied on regional temperature data, self-reported historical environmental shocks or observed gradual weather changes (M. Alam et al., 2017; Gerlitz et al., 2017; Panda, 2017). However, regional temperature data may fail to capture variation at the micro level. Further, using only self-reported, retrospective data may be unreliable when events are forgotten or not salient to respondents (Beckett et al., 2001). In addition to self-reported environmental shocks and average precipitation, the minimum and maximum temperature data were spatially interpolated using the ordinary kriging method, a geostatistical approach that uses historical data to estimate unknown data (Hadi & Tombul, 2018; Piya et al., 2016). Together, this provides a more accurate picture of climate fluctuations over the five years prior to the survey and accounts for different dimensions of climate exposure. This method can be easily reproduced when surveys collect information about the longitude, latitude and elevation of households.

Thanks to its multidimensionality, flexibility and wide usage in the literature compared to other indices, the Livelihood Vulnerability Index (LVI) together with the IPCC-LVI were chosen to compare the two case study regions in the Indo-Gangetic Plains. Using the LVI approach, this study identified drivers of vulnerability and strategies for reducing climate-risk under diverse socio-economic and ecological conditions. Further, this study demonstrated how spatial interpolation can supplement retrospective data about climate events in the exposure dimension of vulnerability assessments. The following sections describe the concept of the Livelihood Vulnerability Index, its development in the context of the Indo-Gangetic Plains, the results of its application in two districts and implications for policymaking.

2 Concept of the livelihood vulnerability index

The framework is based on the Livelihood Vulnerability Index (LVI) introduced by Hahn et al., (2009), which includes the LVI and the LVI-IPCC. The LVI is a composite, multi-dimensional index that consists of major components and sub-components, which can be calculated separately (Madhuri et al., 2014; Reed et al., 2013). The LVI-IPCC aggregates the major components (natural disasters and climate variability, socio-demographic profile, livelihood strategies, social networks, health, food, water) to the three vulnerability levels: exposure, sensitivity and adaptive capacity.

In addition to the major components used by Hahn et al. (2009), components were adapted to suit the Indo-Gangetic Plains based on an extensive literature review of climate vulnerability studies in South Asia. The categories of financial stability; knowledge and education; land and infrastructure were added based on studies by Bhattacharjee and

Behera (2018), Gerlitz et al., (2017) and Madhuri et al., (2014). As shown in Table 1, the final major components include: (1) natural disasters and climate variability, (2) health, (3) food, (4) water, (5) land and infrastructure, (6) socio-demographic profile, (7) knowledge and education, (8) financial stability, (9) livelihood strategies and (10) social network.

The component natural disasters and climate variability includes the number of drought and flood events in the past 10 years, the mean standard deviation of the daily average maximum and minimum temperature by month and the mean standard deviation of the average precipitation by month. The number of self-reported shocks (floods and droughts) were included to account for the household's perception of climate change. To attain a full picture of climatic exposure, the two sub-components for maximum and minimum temperatures were adopted from Hahn et al. (2009) to determine the overall deviation of mean maximum and minimum temperatures over a time period of five years. Rather than include state level temperature data, the district level data was interpolated. Further, precipitation was included.

The component health includes average distance to the nearest healthcare center, the percentage of households without sanitary latrines and those that do not practice preventive health practices. Together, they account for the affordability, availability and acceptability of healthcare (O'Donnell, 2007). Long distances to healthcare centers can prevent individuals from accessing services and medicine as well as result in expensive transportation of the sick (Peters et al., 2008). As both Vaishali and Karnal are rural areas with an insufficient healthcare network, this indicator was included. Further, access to sanitation is important as inadequate sanitation can lead to child mortality, diarrheal diseases and death (Sam et al., 2017; Toufique & Islam, 2014). Finally, the adoption of vaccinations for yellow fever, water-borne disease prevention and care for cardiovascular and respiratory illnesses can also reduce vulnerability in the long run (Bush et al., 2011).

Food includes the percentage of consumed crops, the average livestock and crop diversity index, the number of months of food insecurity and the percent of households that lost wheat/rice due to a shock. For households that mainly rely on subsistence agriculture, land degradation and climate variability can pose a direct threat to food security and increase vulnerability (Beringer & Kaewsuk, 2018; Sivakumar & Stefanski, 2010; Vermeulen et al., 2012). Further, perceived losses of wheat/rice is an important indicator as they are the two most important crops grown in Vaishali and Karnal. Food insecurity is further measured by the number of months with insufficient food. On the other hand, crop and livestock diversification improves resilience and generates additional income (Lin, 2011; Rojas-Downing et al., 2017).

Water consists of the percentage of households reporting water scarcity and plots that are not irrigated. Water scarcity may include overall increasing water shortages, lowered water tables as well as prolonged and frequent droughts. Reports of these events indicate increased vulnerability. On the other hand, the adoption of irrigation demonstrates decreased vulnerability.

Land and infrastructure includes the percentage of households using only forest-based energy, percentage of fertile/level plots, distance to the nearest main market and percent of households that report damage to property after natural shocks. Reliance on natural resources for cooking often demonstrates vulnerability as it can have negative health impacts and reduce time available for other activities (Madhuri et al., 2014; Ravindra, 2019). Further, the percentage of fertile and level plots are important indicators of farm prosperity as intensive agriculture has led to a rapid decline in soil fertility and increased erosion (Mall et al., 2006). Additionally, the distance to the nearest market reflects the ability of a household to buy and sell food. In rural areas, long distances can present challenges

Table 1 The major components and sub-components of the LVI for Vaishali and Kamal

Major Component	Sub-component	Description	Unit	Adapted from reference(s)
Exposure	Natural Disasters and Climate Variability	Droughts	Total number of droughts that were reported by the households in the past 10 years (range 0–7)	Count Hahn et al. (2009)
		Floods	Total number of floods that were reported by the households in the past 10 years (range 0–7)	Count Hahn et al. (2009)
		Mean standard deviation of the daily average maximum temperature by month	Mean standard deviation of the average daily maximum temperature by month between 2008 and 2013 was averaged for each specific household by the spatial interpolation of weather data	Celsius Hahn et al. (2009)
		Mean standard deviation of the daily average minimum temperature by month	Mean standard deviation of the average daily minimum temperature by month between 2008 and 2013 was averaged for each specific household by the spatial interpolation of weather data	Celsius Hahn et al. (2009)
Sensitivity	Health	Mean standard deviation of average precipitation by month	Mean standard deviation of the average monthly precipitation between 2008 and 2013	Millimeters Hahn et al. (2009)
		Distance to the next health center	Average distance to reach the nearest health center	km (count) Hahn et al. (2009)
	Food	Access to a sanitary latrine	Households that do not have access or own a latrine on their premise	Percent Toufique et al. (2014)
		Preventive health practices	Households that take preventive health care practices to reduce the impact of a natural disaster	Percent Bush et al. (2011)
	Self-consumption of harvest	The amount of harvest of a household that is utilized for self-consumption	Ratio Beringer et al. (2018) and Hahn et al. (2009)	

Table 1 (continued)

Major Component	Sub-component	Description	Unit	Adapted from reference(s)
	Average livestock diversity index	The inverse of (the number of different livestock species + 1) reported by a household. Livestock diversity index: $1 / (x + 1)$; x = No. of different livestock species, e.g. sheep or buffaloes	1/# livestock species + 1	Sam et al. (2017)
	Average crop diversity index (range: 0 – 1)	The inverse of (the number of different crops grown by a household + 1) reported by a household. Average crop diversity index: $1 / (x + 1)$; x = No. of different crops grown, e.g. maize, rice, wheat	1/# crops + 1	Hahn et al. (2009)
	Insufficient food access	Average number of months, a household does not obtain sufficient food to meet the family's needs (range 0–12)	Months (count)	Hahn et al. (2009)
	Decrease in wheat yield	Households whose wheat yield decreased in the last 5–10 years due to climate induced changes	Percent	Pandey et al. (2012)
	Decrease in rice yield	Households whose rice yield decreased in the last 5–10 years due to climate induced changes	Percent	Pandey et al. (2012)
Water	Water scarcity	Households who have experienced water shortages due to droughts, increasing water shortages, prolonged and frequent droughts and an increase in soil salinity	Percent	Pandey et al. (2015)
	Irrigation	Percent of plots per household that are rainfed	Percent	Madhuri et al. (2014)

Table 1 (continued)

Major Component	Sub-component	Description	Unit	Adapted from reference(s)
Land and infrastructure	Steepness of plots	Percentage of plots per household that have a medium or steep slope	Ratio	Gerlitz et al. (2017)
	Fertility of plots	Percent of plots per household that are infertile	Ratio	Gerlitz et al. (2017)
	Use of forest-based energy and dung	Households that use wood or dung source for cooking	Percent	Madhuri et al. (2014)
	Distance to nearest main market	Distance a household must cover to reach the nearest main market from residence	Km (count)	Gerlitz et al. (2017)
	Property damage	Households whose property, in the form of cultivated or uncultivated land and housing structures were damaged due to a natural disaster (i.e. flood or drought)	Percent	Pandey et al. (2012); Bhat-tacharjee and Behera (2018)
Adaptive capacity	Socio-Demographic profile	Ratio of the population under 15 and over 65 years of age to the population between 16 and 64 years of age	Ratio	Hahn et al. (2009)
	Age of household head	Inverse age of the household head in years	Years	Notenbaert et al. (2013)
	Female headed households	Households where the adult taking major decisions is female	Percent	Hahn et al. (2009)
	Backward caste households	Households who are belonging to backward castes such as OBC, SC and ST	Percent	Sam et al. (2017)
Knowledge and Education	School attendance – head of household	Households of which the head of the household did not receive school education (illiterate/ semi-literate)	Percent	Hahn et al. (2009)

Table 1 (continued)

Major Component	Sub-component	Description	Unit	Adapted from reference(s)
	School attendance—children	Children between the age of 5–15 that do not attend school	Percent	Alam et al. (2017)
	Climate change awareness	Households which have not heard about climate change before	Percent	Amos et al. (2015)
	Use of weather forecasting	Households that use a weather forecast for making farming decisions	Percent	Singh et al. (C. Singh et al. 2018)
	Anticipation of natural disasters	The number of natural disasters that were not anticipated by a household	Ratio	Alam et al. (2017)
Financial Stability	Loans	Households that are borrowing money from relatives, friends, employer, local money lender, community members, self-help groups, cooperatives or banks	Percent	Hahn et al. (2009)
	Health expenditures	Average monthly spending on health care services (doctor's fees, medicine)	Dollars (count)	Sam et al. (2017)
	Below the poverty line	Households that have a monthly total per head consumption which is lower than 972 Rs., are classified as vulnerable	Percent	Gerlitz et al. (2017)
Livelihood Strategies	Migrants	Inverse number of migrants per household that are working outside of the community	Count	Hahn et al. (2009)
	Average livelihood diversity index	The inverse of livelihood sources (the number of major livelihood sources + 1) reported by a household	1/# non-agricultural activities + 1	Hahn et al. (2009)

Table 1 (continued)

Major Component	Sub-component	Description	Unit	Adapted from reference(s)
Social Network	Average agricultural diversity index	The inverse of agricultural activities (the number of agricultural activities + 1) reported by a household	1/# agricultural activities + 1	Hahn et al. (2009)
	Group memberships	Households that are a member of, e.g. a farmer cooperative/ union, a marketing group, a farmer association, water user association	Count	Panthi et al. (2016)
	Training attendance	Households that have received or attended trainings or information by several sources (e.g. government, NGOs, farmer cooperation)	Count	Piyya et al. (2016)
	Ownership of communication devices	Households that do not own communication media devices such as radio, television or telephone	Percent	Panthi et al. (2016)

as the time needed to travel to the next market can reduce time available for farm work. Finally, the percentage of households reporting damage after climate shocks is important as Bihar is the most flood-prone state in India (Ghosh & Mukhopadhyay, 2014).

The socio-demographic profile consists of the dependency ratio, age of the household head, percent of female-headed households and the percent of households belonging to a backward caste. The dependency ratio divides the number of young household members (from 0–15 years old) and the number of elderly people by the number of people of working age (from 16–64 years old). The lower the dependency ratio, the lower the level of vulnerability. Characteristics of the household head are important vulnerability indicators as the household head's age proxies for knowledge of farming and ability to cope with natural disasters (Notenbaert et al., 2013). On the other hand, several studies from India show that female-led households are more vulnerable as various customs suppress women and their participation in the labor force (Das Gupta et al., 2003; Drèze & Srinivasan, 1997; Last-ropes & Rajaram, 2016; Meenakshi & Ray, 2002).

The component knowledge and education consists of the percent of households of which the head did not attend school, the children that do not attend school, knowledge of climate change, usage of weather forecasts and the number of natural disasters that were not anticipated. Higher education of the household head and children is directly linked to increased livelihood stability and adaptive capacity (Mileti & Sorensen, 1990; Lutz and KC 2011). Using weather forecasts can mitigate risk by improving farming decisions (C. Singh et al., 2018). Similarly, knowledge of climate change and anticipation of natural disasters are important indicators as households can only respond to climate change when they know about it (Amos et al., 2015; Tschakert & Dietrich, 2010).

Financial stability includes the percentage of households that have loans, the consumption level of the household and the average expenditure for health care. Loans are controversial as some researchers claim that loans foster economic growth and can be understood as a proxy for adequate support from social and financial institutions, while others argue that they enhance vulnerability when borrowers are unable to repay their debts (Merriott, 2016). Access to loans is viewed here as a proxy for adequate social support. Especially in developing countries, well-being is often measured using household consumption rather than income. Following the methodology of Gerlitz et al. (2017), a consumption threshold was included based on the poverty line for rural areas in India, which is Rs. 972 per month at 2012 prices (Planning Commission 2014). Additionally, several studies have shown that high out-of-pocket payments for health care pose major financial and health risks for households (Beringer & Kaewsuk, 2018; Sam et al., 2017). This is an important indicator because no treatment can be acquired if fees cannot be paid (Shahrawat & Rao, 2012).

The component livelihood strategies measures income diversity and consists of the number of migrants per household, the agricultural diversity index and the livelihood diversity index. Migration in developing countries can be the result of climatic variability as well as economic and educational opportunities (C. K. Jha et al., 2018). In disaster-prone areas, migration can be a coping strategy to secure livelihood and income sources (Hahn et al., 2009; Perch-Nielsen et al., 2008). As Bihar has one of the highest migration rates, this sub-component was included. The agricultural diversity index measures the variety of different agricultural activities including livestock, crops, agroforestry, off-farm labor and selling water. According to Hahn et al. (2009), diversification with a greater number of activities can improve adaptive capacity. Similarly, the livelihood diversity index accounts for a household's various sources of livelihood, including income generation through labor, remittances, leasing of owned land and the sale of agricultural products. A greater diversity of livelihood sources decreases vulnerability (Ellis, 1998).

The social network component consists of the number of group memberships, the number of trainings and the percentage of households that own at least one communication device. Particularly in agrarian societies, members of farmers' union have increased access to information about new crop varieties and weather, markets and financial support (Antwi-Agyei et al., 2017; Eakin & Bojórquez-Tapia, 2008). The number of memberships from each household was included, as a greater number of memberships signals a better social network (Panthi et al., 2016; Vincent, 2004). Further, access to training is important as it can enhance productivity and rural development (M. Alam et al., 2017). Ownership of communication devices such as telephones, radios or televisions can increase awareness of natural hazards and access to markets (Panthi et al., 2016; M. Alam et al., 2017). Additionally, improved communication between stakeholders can strengthen capacity building for disasters by increasing access to information and expertise (McBean & Rodgers, 2010).

3 Material and methods

3.1 Study region

The Indo-Gangetic Plains represent one of the most productive wheat and rice regions in India, supplying approximately 40% of the Indian population with cereals (Pal et al., 2009). Estimations predict that with each degree of rising temperature, crop yields will decline (Chauhan et al., 2012). Additionally, more frequent droughts, floods and a decline in soil carbon will have long-term effects on local livelihoods, health and agricultural productivity (Aggarwal et al., 2004; Vermeulen et al., 2012). Thus, the underlying vulnerabilities must be understood to ensure the sustainable livelihood of farmers (Ellis, 1998).

There are significant differences in economic development, natural resources and agricultural productivity within the Indo-Gangetic Plains (Taneja et al., 2019). Thus, vulnerability levels in the west (Karnal, Haryana) and east (Vaishali, Bihar) were compared (Fig. 1). This allowed for the identification of structures of vulnerability under different conditions. Areas located in the semi-arid zones of the region, including Haryana, are expected to be highly climate sensitive while districts in Bihar are predicted to be medium climate sensitive with a low adaptive capacity (O'Brien et al., 2004).

The district of Vaishali, Bihar is located in the east of the Indo-Gangetic Plains with a sub-tropical to sub-humid climate. Bihar is known as one of the poorer states of India and densely populated (Directorate of Census Operations Bihar 2011). Almost 90% of the primarily rural population depends on subsistence farming of rice, wheat and sugar cane (Finance Department 2013). The state has among the highest illiteracy and poverty rates in India (World Bank, 2016; Finance Department 2018). However, this is likely to improve with the launch of economic development programs including the *Eleventh Plan*, the Bihar Agricultural Road Map III (2017–22) and the Bihar Skill Development Mission (Finance Department 2013; Finance Department 2018). Floods, droughts, and earthquakes pose major challenges. In particular, floods from the rivers Ganga and Gandak as well as run-off from the Nepalese Himalayas exacerbate agricultural losses (Ghosh & Mukhopadhyay, 2014). Prior to this study, major floods occurred in 2007 and 2008 (Kumar et al., 2013). Further, Bihar has been found to be highly vulnerable to floods, particularly in the northern regions (R. K. Jha & Gundimeda, 2019).

The district of Karnal, Haryana is located in the northeast of the Indo-Gangetic Plains with semi-arid tropical to sub-tropical climate (Directorate of Census Operations Haryana

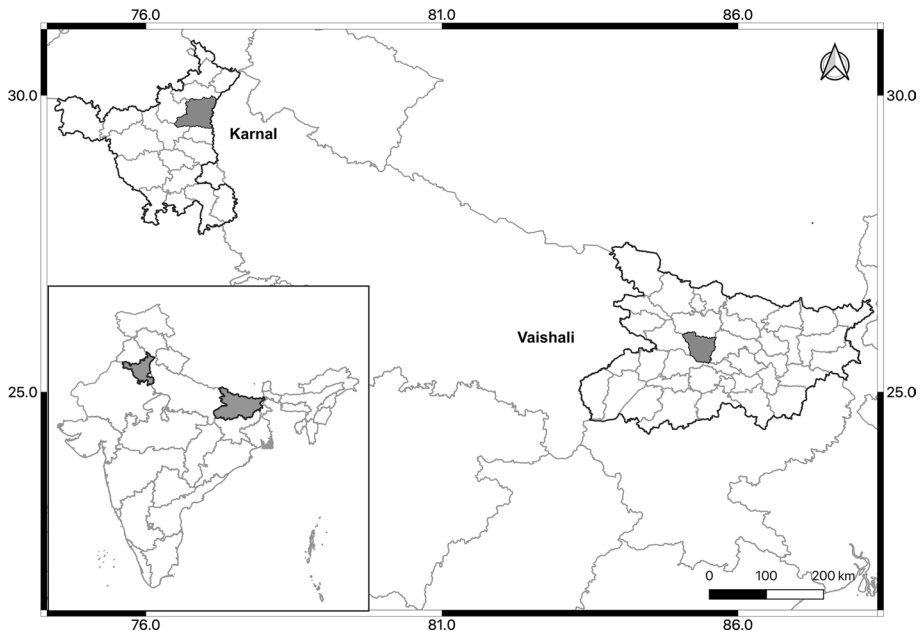


Fig. 1 Study Areas of Vaishali, Bihar and Karnal, Haryana

2011). Haryana is one of the wealthiest states in India with thriving service, industry and agricultural sectors as well as a lower poverty ratio and higher literacy rate compared to other Indian states (Directorate of Census Operations Haryana 2011). Karnal, however, is one of Haryana's districts with the highest poverty ratios (World Bank, 2017). Additionally, the dominance of high input crops (rice–wheat) has led to soil fertility loss, erosion and the decline of ground water level (Aggarwal et al., 2004; Tirol-Padre et al., 2016). In Karnal, maximum temperatures are expected to increase by 2–4 °C by 2050 and the number of rainy days are expected to decrease by more than 15 days, which will lead to heat stress for livestock and decreased crop productivity (Taneja et al., 2019).

Within the sample, some differences between the districts, particularly related to religion and caste (Table 2), are observed. In Vaishali, the majority of the households are Hindu while there is a mix of Sikh and Hindu households in Karnal. Further, Vaishali has a greater number of scheduled castes, scheduled tribes and other cases while Karnal has primarily general caste households.

4 Data

This study combined quantitative survey data with secondary meteorological data to calculate both indices. The primary data is from a household survey conducted by CGIAR as part of a larger assessment for *CCAFS sites: monitoring and planning for climate-smart interventions* in 2012–2013. Prior to implementation, the survey was pre-tested and enumerators were given extensive survey training (Bhatta et al., 2016). In

Table 2 Demographic data of Vaishali and Karnal

Variable	Category	Vaishali (%)	Karnal (%)
Gender	Male-headed household	91.3	97.0
	Female-headed household	8.7	3.0
Age	0–15 years	32.9	22.5
	16–64 years	62.6	71.8
	Older than 64	4.5	5.7
Education of the household head	No education (illiterate)	23	21.3
	No education (semi-literate)	14.7	9.6
	Primary school and higher	62.2	69.1
Religion	Hindu	99.3	72.3
	Muslim	0.7	-
	Sikh	-	27.7
Caste	General	33.2	77.1
	Scheduled Caste	24.6	8.2
	Scheduled Tribe	1.1	-
	Other	41.1	14.7

total, 1,267 households were surveyed in India. The final analysis includes 1,127 households with 564 in Vaishali and 563 in Karnal.

For the calculation of the LVI, temperature data are essential for evaluating the exposure of households to climate-related hazards. To obtain district-specific temperature data, the minimum and maximum temperature using the ordinary kriging method were interpolated in ArcGIS10. Weather data from Iowa State University's ASOS Network (2019) from 55 weather stations, which are positioned in irregular patterns across India (ASOS Network 2019), was used and they were matched to the districts using their longitude, latitude and elevation.

The ordinary kriging spatial interpolation is a common geostatistical approach, which uses historical data from weather stations to estimate unknown temperature data (Hadi & Tombul, 2018; Piya et al., 2016). It measures similarities between close observations and creates a semi-variogram, showing the average variation of each pair of points (i.e. weather stations) for the evaluation of non-similarity among points. It then predicts the values for each location by using the weighted average with the nearest neighbors (Hadi & Tombul, 2018). The quality of the interpolation depends on the density of weather stations as well as the temporal resolution.

To interpolate the temperature data, the stationary hourly temperature data was used to determine the average monthly temperature variation in the five years prior to the survey (January 2008-December 2012). First, as no weather station data for rainfall was available, the aggregated monthly precipitation data by state was used, obtained from the Open Government Data Platform India (2014). The two meteorological subdivisions for Bihar and Haryana (Delhi and Chandigarh) were selected, and the standard deviation was calculated. Second, the temperature data were interpolated for each sample area, which is a 10 × 10 km grid for each district based on the sampling blocks for this survey. Third, the monthly temperature data were extracted and the standard deviation was calculated for a five-year period.

5 Calculation of the index

In the following sub-section, the steps for calculating the LVI and the LVI-IPCC are described. Before creating the index, the data was normalized as the sub-components were measured on different scales (e.g. percent, indices, ratios or count). The following equation was used for normalization:

$$Index_{Nor} = \frac{S_{AV} - S_{Min}}{S_{Max} - S_{Min}} \quad (1)$$

where S_{AV} is the mean of the sub-component, S_{Min} is the minimum value of each sub-component and S_{Max} is the maximum value of each sub-component for the entire sample.

The average balanced weight approach was used, which gives each sub-component equal importance. This approach is the most widely used in composite indicator assessments, which improves comparability (OECD 2008; Hahn et al., 2009).

After normalizing the data, the sub-components by district were averaged to calculate the respective major components (M_d):

$$M_d = \frac{\sum_{i=1}^n Index_{Norm}^i}{n} \quad (2)$$

where M_d represents the respective major component for each district, n is the number of sub-components, $Index_{Norm}^i$ is the normalized values of the sub-components of the respective major component. The LVI is scaled from 1 (most vulnerable) to 0 (least vulnerable):

$$LVI_{IPCC_{F_d}} = \frac{\sum_{i=1}^n w_{m_i} M_{di}}{\sum_{i=1}^n w_{m_i}} \quad (3)$$

where $IPCC_{F_d}$ is the contributing factor to the overall LVI-IPCC per district (d), w is weight for each major component M , d is the district and n is the number of major components. The balanced weight approach was also used for the LVI-IPCC calculation.

After the three contributing factors were calculated, the overall LVI_{IPCC} per district was computed:

$$LVI_{IPCC_d} = (e - ac) * s \quad (4)$$

where e is the exposure component, a is the adaptive capacity component and s is the sensitivity component of households. The LVI_{IPCC} ranges from -1 (least vulnerable) to 1 (most vulnerable). If the LVI is positive (e.g. 0.9), it shows that the households were very exposed to climate change compared to their adaptive capacity to overcome these e.g. natural disasters. This means that they are very sensitive to climate changes and natural disaster. If the exposure is low and the adaptive capacity is high, sensitivity is smaller, thus indicating a lower LVI-IPCC.

6 Results and discussion

The LVI and LVI-IPCC were computed for 564 households in Vaishali and 563 households in Karnal. The LVI scores indicate that households in Vaishali (LVI=0.44) are more vulnerable than in Karnal (LVI=0.35). Table 3 shows the scores of the LVI-IPCC,

Table 3 Summary of the indices and components

LVI-IPCC	Vaishali	Karnal	Major Components	Vaishali	Karnal	Sub-component	Vaishali (norm.)	Karnal (norm)	
Exposure	0.306	0.298	Natural Disasters and Climate Variability	0.306	0.298	Number of drought events in the past 10 years	0.342	0.009	
				Number of flood events in the past 10 years			0.238	0.189	
				Mean standard deviation of the daily average maximum temperature by month			0.304	0.631	
				Mean standard deviation of the daily average minimum temperature by month			0.228	0.398	
Sensitivity	0.493	0.309	Health	0.591	0.376	Mean standard deviation of average precipitation by month	0.419	0.264	
						Average distance to the next health center	0.187	0.128	
							Percent of households without access to a sanitary latrine	0.603	0
							Percent of households that do not practice preventive health practices to reduce the impact of risk events	0.982	1
			Food	0.507	0.181	Percent of consumed from overall produced harvest per household	0.761	0.429	
						Average livestock diversity index	0.622	0.278	
						Average crop diversity index (range: 0–1)	0.464	0.348	
						Average number of months households struggle to find food (range: 0–12)	0.104	0.001	
						Percent of households that observed a wheat yield decrease in the last 5–10 years	0.543	0.021	
						Percent of households that observed a rice yield decrease in the last 5–10 years	0.548	0.011	

Table 3 (continued)

LVI-IPCC	Vaishali	Karnal	Major Components	Vaishali	Karnal	Sub-component	Vaishali (norm.)	Karnal (norm)
			Water	0.366	0.468	Percent of households reporting water scarcity	0.723	0.931
						Percent of plots which are not irrigated	0.008	0.005
			Land and infrastructure	0.47	0.358	Percent of steep slopes plots per household	0.548	0.073
						Percent of infertile plots per household	0.475	0.954
						Percent of households using only forest-based energy and dung for cooking purpose	0.929	0.575
						Distance to nearest main market	0.129	0.177
						Percent of household reporting damage to property/housing or land due to flood or drought event	0.271	0.009
Adaptive capacity	0.431	0.389	Socio-Demographic Profile	0.236	0.173	Dependency ratio	0.094	0.058
						Age of household head	0.506	0.523
						Percent of female headed households	0.087	0.03
						Percent of backward caste households	0.257	0.082
			Knowledge and Education	0.309	0.335	Percent of households where the head of household did not attend school	0.378	0.309
						Percent of children per household that do not go to school	0.033	0.004
						Percent of households that have not heard about climate change	0.085	0.222
						Percent of households not using weather forecast	0.285	0.142
						Percent of natural disasters that were not anticipated by the household	0.763	1

Table 3 (continued)

LVI-IPCC	Vaishali	Karnal	Major Components	Vaishali	Karnal	Sub-component	Vaishali (norm.)	Karnal (norm)
			Financial Stability	0.388	0.249	Percent of households that have a loan	0.674	0.607
						Average monthly health expenditure of the households (in \$)	0.001	0.005
						Percent of household with a consumption rate below the poverty line	0.489	0.135
			Livelihood Strategies	0.658	0.674	Inverse number of migrants who work or attend higher education outside of the community	0.913	0.977
						Average livelihood diversity index	0.427	0.56
						Average agricultural diversity index	0.634	0.485
			Social Network	0.708	0.623	Inverse number of groups or organizations the household is affiliated with	0.973	0.911
						The inverse number of trainings a household received for information and farming improvement	0.9	0.958
						Percent of households that do not own a communication device	0.25	0
LVI-IPCC	-0.061	-0.028	LVI	0.44	0.345			

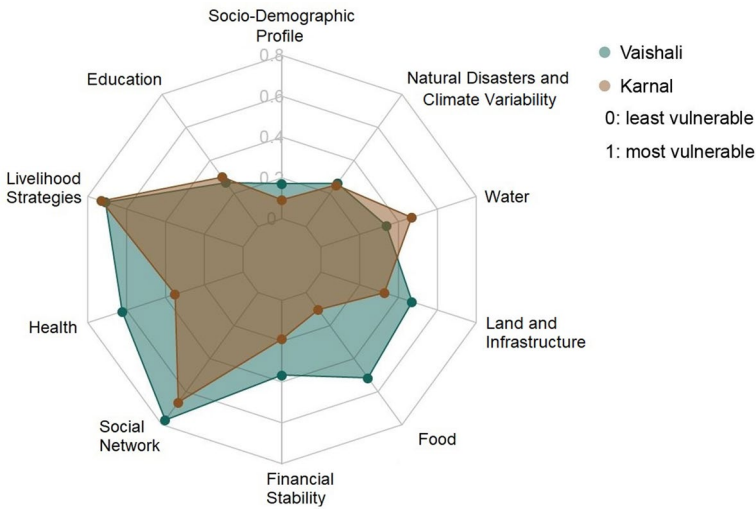


Fig. 2 The major LVI components for Vaishali and Karnal

LVI as well as the major components and sub-components. Figure 2 presents the level of vulnerability for each major component for the two districts.

7 Exposure

Both the number of droughts and floods were higher in Vaishali than in Karnal. Households in Vaishali reported an average number of 2.4 droughts for the past 10 years (before 2013) and 0.95 floods whereas households in Karnal reported an average number of 0.06 droughts and 0.76 floods over the past 10 years. For precipitation, Vaishali is more vulnerable than Karnal.

The results are consistent with previous studies. Chakraborty and Joshi (2016) found that floods and droughts more frequently and heavily affect the eastern Indo-Gangetic Plains (Vaishali) than the west (Karnal). Similarly Murthy et al. (2015) found that Karnal is among the least climate vulnerable amongst districts in Haryana. The differences in their exposure to natural hazards can be explained by biophysical factors, namely the extended dry periods and stronger rainfall during monsoon in Vaishali (Bhatta et al., 2016). Despite these differences, the exposure to natural hazards and climate variability is likely to increase in the Indo-Gangetic Plains (Mall et al., 2006; Parth Sarthi, 2019). For Bihar, Tesfaye et al. (2017) predicted that temperatures will increase by 0.8 °C by 2030 and 2.2 °C by 2050 and that precipitation will increase by 6–7% in 2030 and by up to 12% in 2050. Similarly, Haryana will face an increase in temperature with intensified precipitation (Government of Haryana, 2011). Thus, additional climate variability in the study areas may intensify vulnerability and increase pressure on the agricultural sector if adaptation measures are not implemented (Teskaye et al., 2017). With higher temperatures and increased precipitation, air humidity may increase, which will exacerbate the spread of insects, pests and diseases as well as lost yields, as already observed in Vaishali (Teskaye et al., 2017).

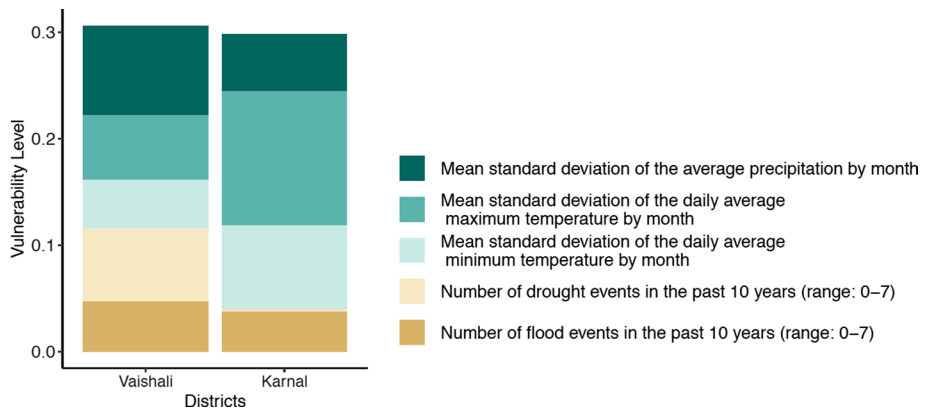


Fig. 3 Vulnerability levels of the major component Natural Disasters and Climate Variability for Vaishali and Karnal

As climate change can be identified based on (i) gradual changes in temperature and rainfall or (ii) shock events (i.e. the number of droughts and floods) (Huang et al., 2015), the results reflect different aspects of exposure. While the mean precipitation and temperature indicators show the variation experienced by all, the reported shocks reflect the household's perception. For example, some households may not have reported a flood/drought if it were not severe enough to recall. Figure 3 shows that there were not large discrepancies as the precipitation indicator shows a low level of variation, which corresponds to the few reported droughts and floods. Although precipitation does not directly account for droughts, it can be used as an indicator for the magnitude of droughts (Jenkins & Warren, 2015). In terms of minimum and maximum temperature, the spatially interpolated data accounts for a large share of vulnerability in both regions. While no definitive conclusion can be made about the impact of spatially interpolated data compared to regional level data on vulnerability levels, the method of spatial interpolation is recommended as it offers more precision and can be easily reproduced when surveys collect information about the longitude, latitude and elevation of households.

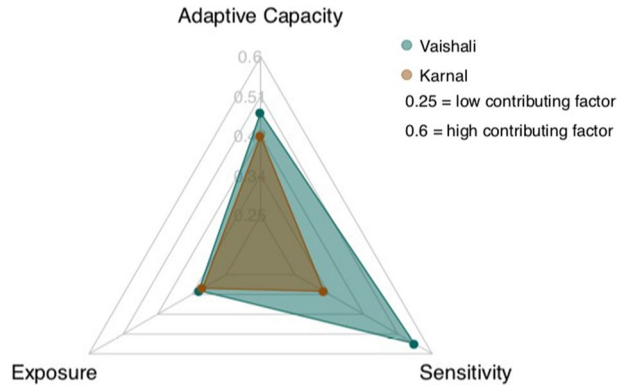
8 Sensitivity

Figure 4 shows that both districts have a similar exposure to climate change and adaptive capacity. The sensitivity level, however, makes Vaishali much more vulnerable which results in a higher vulnerability level (LVI IPCC). Sensitivity is captured by the major components of health; food; water and land and infrastructure.

Both the usage of dung and fuelwood and a lack of latrines pose a threat for the health on households in Vaishali. In the sample, 60% lack the access to a latrine, which corresponds to recent assessments which found that 75% of households in Vaishali had no toilet at home (Directorate of Census Operations Bihar 2011). Inadequate access to latrines can lead to an increased greater incidence of illness resulting from the lack of hygiene (Bush et al., 2011).

The absence of latrines combined with increased climate shocks may have severe consequences for public health. During floods, poor (or missing) sanitary facilities may

Fig. 4 Comparing exposure, sensitivity and adaptive capacity between districts



intensify infectious and water-borne disease outbreaks such as diarrhea (Howard et al., 2016). Further, fecal matter can spill and distribute via water flows (Bush et al., 2011; Dogra et al., 2019; Howard et al., 2016). As Vaishali is already more susceptible to flooding, the absence of latrines may worsen health conditions.

In case a household member falls ill, the distance to the nearest health center is important. According to May et al., (2014), Bihar lacks 91% of required community health centers and 48% of sub-centers. Households in Vaishali must travel longer distances to a health facility (4.75 km) than Karnal. This distance increases the risk of untimely treatment and reduces the time available for other livelihood activities. Comparatively, Haryana lacks 20% of community health centers and 22% of sub-centers, which is confirmed by the shorter travel distances (3.24 km) in this study (National Health Mission 2010).

Climate shocks may directly affect household food security by reducing agricultural production. Between the two districts, discrepancies in the wheat-rice yield result from weeds, crops diseases and natural disasters. Specifically, this study observes the reduced agricultural losses of Bihar's severe 2009 drought (Chattopadhyay, 2010). Further, Haryana's lower temperatures offer more favorable conditions for wheat-rice production, which diminishes the risk of pests and crop diseases (Erenstein & Thorpe, 2011; Sekar & Pal, 2012).

Climatic conditions directly influence water as well as land and infrastructure. In this study, perceived water scarcity is more significant for Karnal than Vaishali. This aligns with previous research as in Haryana, there is excessive groundwater irrigation (Hobbs et al., 2019; Sekar & Pal, 2012). In the last decade, the extraction rate of groundwater has depleted the water table, increased soil salinity and decreased soil fertility (Aggarwal et al., 2004; Sekar & Pal, 2012; B. Singh & Singh, 2012; Kasana & Singh, 2017). Excessive ground water usage can mostly be attributed to low water tariffs and incentives for irrigation, e.g. subsidies on electric pumps (Aggarwal et al., 2004; Kasana & Singh, 2017; Lal, 2010). Closely related, plots in Vaishali are more fertile than in Karnal. Intensive farming (e.g. imbalanced use of fertilizers, excessive irrigation) has likely led to the decline in soil organic carbon (Erenstein & Thorpe, 2011; B. Singh & Singh, 2012).

Damage of land and property from natural events has also increased vulnerability, especially in Vaishali. This variation is most likely related to housing facilities. In Karnal, 69% of households live in permanent housings, built from bricks, stones, metal and concrete, 27% live in semi-permanent houses, and 3% reside in temporary houses, build from *Kutch*

materials including grass, leaves, bamboo and mud (Directorate of Census Operations Haryana 2011). In Vaishali, 47% of the population live in permanent housing, 20% in semi-permanent and more than 32% in temporary housing (Directorate of Census Operations Bihar 2011). Temporary houses are prone to additional damage as the materials used for building are less durable, which may be a reason for the higher rate of damaged property reported by farmers of Vaishali (Sam et al., 2017).

Another major reason for Vaishali's higher sensitivity is the greater dependence on wood and dung for cooking purposes. This can be explained by the limited access to electricity in rural areas and the inability to purchase other energy sources in Vaishali (Madhuri et al., 2014; Ravindra, 2019). In turn, using wood and dung for cooking can worsen human health as the respiration of polluted indoor air, such as carbon monoxide and black carbon emissions, can lead to respiratory and cardiovascular health issues and burden households with higher health care costs (Pandey & Tyagi, 2012; Ravindra, 2019).

9 Adaptive capacity

In the socio-demographic profile, caste plays the most significant role. In Karnal, 8% of households belong to a backward caste compared to 26% in Vaishali. Affiliation with a marginalized social caste can lead to increased poverty as they often face restricted access to water for irrigation, social groups/networks, off-farm work and loans (Lastrapes & Rajaram, 2016; Mosse, 2018). Nonetheless, recent efforts to enhance equality (e.g. scholarships or reservation of jobs in the public sector for certain castes) can support economic development (Mosse, 2018).

In anticipation of excessive precipitation, prolonged heat waves, droughts and floods, farmers should use weather forecast information, communication devices and social networks (Mittal & Mehar, 2012; Vermeulen et al., 2012; C. Singh et al., 2018). In Karnal, 85.5% of households are using weather related information for farming compared to 72.4% in Vaishali. While farmers in both districts have similar access to groups, households in Karnal have better access to communication devices, which can democratize information and facilitate technology adoption (Mittal, 2016). In Karnal, mobile phones may simplify communication between institutions and farmers, which encourages the mutual exchange of information on agricultural production (e.g. weather, market prices), employment opportunities, education, economic development and access to remote health consultancy (Mittal & Mehar, 2012; M. Alam et al., 2017).

Differences related to financial stability stems from household consumption below the national poverty line. Haryana is among the states with the lowest poverty rate in India, but within Haryana, Karnal accounts for one of the poorest districts with 18–27% of the population living below the poverty line (World Bank, 2017). Comparatively, Vaishali has an average poverty rate of 0–19% (World Bank, 2016). In this sample, 13.5% and 48.9% of respondents have a consumption rate below in the poverty line in Karnal and Vaishali, respectively.

Diversification of livelihood sources is also important to vulnerability, including income from migration and off-farm work. Given that Vaishali has 3.6 times the number of migrants from Karnal and its more extreme weather events, migration represents an important coping strategy to overcome financial shortages (Perch-Nielsen et al., 2008; Keshri & Bhagat, 2013; Bhatta & Aggarwal, 2016; C. K. Jha et al., 2018). Alternative livelihood strategies, summarized in the non-agricultural diversity index (Ellis, 1998; Sam

et al., 2017), account for the degree of livelihood diversification. Approximately 35–50% of rural households in developing countries rely on non-farm income out of necessity and choice (Reardon et al., 2007). As farmers in Vaishali face natural disasters more frequently, livelihood diversification is a necessity for household survival (Bhatta et al., 2016). Other studies from South Asia find that farmers, who face more severe natural hazards, tend to diversify their income sources more (Madhuri et al., 2014; Bhatta & Aggarwal, 2016; Devi et al., 2016; M. Alam et al., 2017; Sam et al., 2017; Radhakrishnan et al., 2018).

10 Implications of the findings

Based on these findings, it is important to consider how the respective districts may decrease their vulnerability in the face of climate variability. Specifically, the following adaptation strategies are recommended to reduce sensitivity and improve adaptive capacities: (i) improve access to permanent housing, latrines and health centers, especially in Vaishali; (ii) increase access to affordable, alternative energy sources for cooking; (iii) encourage modifications toward conservation agriculture; and (iv) expand training and extension services for information & communication technologies in both districts.

As climate change can threaten public health in the Indo-Gangetic Plains, improved access to permanent housing, latrines and the expansion of the health center network is crucial. In the face of more frequent climate shocks, funding should be provided to help rural residents build permanent homes with sanitary latrines. As many homes are built from temporary *Kutch* materials (i.e. grass, leaves, bamboo, mud), they cannot withstand floods and usually do not have a sanitary latrine. For this reason, flooding is associated with increased rates of diarrhea, cholera and other intestine diseases and access to safe sanitation is crucial for reducing future healthcare costs (Brouwer et al., 2007; Eisenberg et al., 2014). In particular, flood-proof latrines (e.g. dry urine-diverting toilet) should be promoted as no water is needed and tanks can be installed on ground, minimizing the risk of spillage (Howard et al., 2016). Finally, improving the network of health centers would reduce rural households' travel time and the indirect costs of healthcare.

Additionally, collecting wood or dung for cooking is a time-consuming activity and burning these resources can increase the risk of respiratory diseases and future healthcare costs (Patel et al., 2019). Therefore, access to affordable, alternative energy sources such as solar panels, gas or biogas can improve household sensitivity and health as well as reduce emissions from natural resources (Ravindra, 2019). Alternatives to traditional biomass sources include clean stoves powered by liquefied petroleum gas, biogas and electric. Household biogas offers a particularly promising solution given its effect on social, environmental and health outcomes (Lewis et al., 2017).

For Karnal, the diffusion of sustainable agricultural practices would lower vulnerability levels concerning water and natural resources, land and infrastructure. Vaishali, on the other hand, should focus primarily on poverty reduction while at the same time establishing sustainable land-use practices. To reduce the threat of soil degradation, waterlogging, low water table levels, Vaishali and Karnal should adapt irrigation facilities and adjust the application of fertilizers. Irrigation subsidies could incentivize farmers to adopt water-conservation irrigation techniques including irrigation scheduling, drip-irrigation systems and zero tillage systems. The adoption of such techniques, together with trainings and extension services, could reduce sensitivity (Aggarwal et al., 2004; Hobbs et al., 2019). Further, a shift from high water-consuming crops (e.g. rice) towards climate-resilient cash

crops, which are less water intensive, may ensure long-term income (Aggarwal et al., 2004; Taneja et al., 2019). Within the two study areas, many farmers have already adopted the usage of green manure, zero tillage and laser-land-levelling. These practices could be further promoted to ensure long-term fertility of soil and reduce erosion (Taneja et al., 2019).

To reduce sensitivity, policymakers could increase the offer of training and extension services, especially for information and communication technologies (Johny et al., 2017; Sam et al., 2017). Previous research showed that asymmetric and costly information represents one of the key barriers to technology adoption (Aker et al., 2016). Thus, governments and international organizations have redirected resources to repair information failures through agricultural extension programs. These trainings could demonstrate how farmers can access up-to-date weather and market price information with mobile phones (i.e. information communication technologies), supplemented with advisory services on how this information can improve crop planting and water management decisions. By demonstrating the application of communication devices in agricultural decision-making, extension officers can help households build trust in these technologies and promote remote capacity building.

11 Conclusion

As one of the most productive agricultural regions in India, the Indo-Gangetic Plains and its smallholders face significant challenges related to climate change. To propose adaptation strategies for the region's diverse socio-economic and ecological conditions, this study estimated the Livelihood Vulnerability Index for two districts. Further, we improved the measurement of climate exposure in vulnerability assessment by including spatially interpolated weather data. This information provided a more accurate overview of climate fluctuations and supplemented indicators from previous assessments such as regional temperature data, self-reported historical environmental shocks and observed gradual weather changes.

The results reveal that while both case study districts have similar exposure and adaptive capacity levels, the sensitivity dimension makes Vaishali more vulnerable to climate change. In addition to expanding adaptive capacity through extension training for information and communication technologies and conservation agriculture, policymakers should not underestimate the importance of improving infrastructure (e.g. improved access to permanent housing, latrines and health centers) to reduce climate risk.

While the results shed light on sources of vulnerability in the Indo-Gangetic Plains, it is important to consider possible improvements to the index approach. As indices aggregate and remove interlinkages between variables (Barnett et al., 2008; Fischer & Chhatre, 2016; Polsky et al., 2007), we recommend that future studies use local knowledge for indicator selection. To this end, participatory methods are useful for collecting local knowledge in an iterative process, integrating them into vulnerability assessments and generating policy recommendations (Kettle et al., 2014). Further, most indices reflect the current state of vulnerability rather than future challenges. To improve predictions and policy suggestions, researchers can use indices as a dynamic scenario modelling tool by simulating how the system reacts under different spatial and temporal scales.

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