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Vulnerabilities to flood hazards among rural households in India

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Abstract Flooding constitutes the most predominant natural disaster in India. The degree and causes of vulnerability to flood risk vary by society, geographical region and over time. The rural people of India are highly vulnerable to flood hazards due to high dependence on natural resources for livelihood and poor socio-economic situations. The information regarding the degree of vulnerability of these people is limited. In order to formulate improved adaption policies and effective programmes to reduce vulnerability, it is crucial to quantify the vulnerability of rural households affected by floods at a regional level. Our study provides insight into the vulnerability of rural households affected by floods in India. We use primary data of 220 flood-prone rural households of Odisha state in India for analysis. The vulnerability is analysed using the Livelihood Vulnerability Index and the Socio-economic Vulnerability Index. Our results show that these households are vulnerable to flood in more than one dimension. Sociodemographic characteristics such as a low literacy rate, a high dependency ratio and a weak housing structure increase these residents' vulnerability. Access to social networks and social institutions plays a significant role in uplifting poor rural households. Our study concludes that the vulnerability of a

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household is governed by both non-climatic factors and the incidence of floods. The findings of our study may be considered in developing policies and programmes that will reduce the flood risk. The recommendations we suggested in this study can be applied in other south Asian counties with similar socio-economic profiles.

1 Introduction

Floods have been recurrent phenomena in India from time immemorial. Different regions of India have different climates and rainfall patterns; therefore, almost every year, certain parts of India face devastating floods that have strong negative economic impacts (Mishra and Mishra 2010). A total area of 49.82 million hectares in India (15% of the total area of the country) is prone to floods (Central Water Commission 2012). According to the database of the Centre for Research on Epidemiology of Disasters (CRED 2015), 308 floods affected nearly 847 million people and killed 72,039 people in India from 1900–2015. Sporadic floods in rainfed and flood-affected rural areas of India are usually caused by heavy rainfall, leading to the overflow of nearby rivers and canals, or by the tidal movements in coastal areas (Ismail et al. 2013). The five most flood-prone states in India are Uttar Pradesh, Bihar, Odisha, Assam and West Bengal (Gupta et al. 2003). The flood-prone areas in India have been increasing dramatically; consequently, millions of people have become prone to floods, and millions will become vulnerable to them in future.

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the degree to which a system is susceptible to and unable to cope with the adverse effects of climate change and extremes such as droughts, floods and cyclones (IPCC 2007). Flood vulnerability varies across time and space. It also differs across groups and individuals. There is sufficient discrepancy between the extent of flood vulnerability in developed and developing nations. Developing nations are more vulnerable to natural hazards, mainly due to their weak coping strategies and imprecise institutional frameworks (Yohe and Tol 2002). Other potential explanations for their increased vulnerability are (1) greater physical impacts, given the low levels of preparedness and the ad hoc nature of mitigation measures; (2) majority of the population depends on natural resources for livelihood; and (3) limited economic and technological capacity, which obstructs adaptation processes in swiftly occurring climatic extremes (Gray and Mueller 2012. Although floods affect every type of population, the impact is greater in the case of poor and marginalised rural populations.

The differences in the demographic, social, economic and political characteristics of a society can influence the impact of flood and the ability of communities to reconstruct following a disaster (Burton and Cutter 2008). Flood vulnerability is spatially variable among nations, regions, communities and individuals. When people are faced with vulnerable situations due to flood, they are compelled to make choices regarding the necessary adjustments in socio-economic, cultural and environmental contexts. These adjustments are formulated within the vulnerability of different systems that are constituted by both the human and natural environments. Thus, it is vital to identify the most vulnerable sections of a population as well as the degree and extent of vulnerability on a regional basis to

formulate the most suitable coping strategies and policies to overcome the flood risk for a specific region (Aryal et al. 2014).

In recent decades, many vulnerability studies have been conducted worldwide, especially in South Asian countries such as Bangladesh, Pakistan and Nepal (Mustafa 2003; Zoleta-Nantes 2002; Brouwer et al. 2007; Abbas et al. 2015). In India, most studies on floods have focused on impact assessments, while few have relied upon remote sensing or on climate change situations (Pandey and Jha 2011; Sanyal and Lu 2005). The local communities are adversely affected by floods, and they are highly vulnerable to floods in India. This is due to high dependence of rural population on agriculture and natural resources for their livelihood. In addition, less favourable social, economic and institutional conditions make them more vulnerable to flood risk (Patnaik and Narayanan 2010). Due to the lack of information regarding the degree of flood vulnerability of rural households, improved adaptation policies and programmes to mitigate the flood risk cannot be formulated in an effective way (Sam et al. 2016). A micro-level vulnerability analysis helps to identify the most vulnerable sections of the population and the most impacted livelihood resources of a particular region (Aryal et al. 2014). Therefore, this study aims to fill the above-mentioned gap by quantifying the degree of vulnerability of rural farming households that are affected by floods in India more specifically; it aims to investigate their (1) degree of livelihood vulnerability and (2) degree of socio-economic vulnerability.

2 Conceptual framework

Researchers in various knowledge fields adopt different approaches to comprehend and investigate the vulnerability to various natural hazards. Some of the approaches are risk-hazard approach, political economy approach, pressure-and-release model, resilience approach and integrated approaches. To address the issues of scale and unit of assessment, vulnerability was classified into individual and collective vulnerability. One's access to resources, income, livelihood and social status constitute individual vulnerability to natural hazard, whereas institutional structures such as infrastructure, social networks and insurance constitute collective vulnerability (Adger 1999). Both types of vulnerability affect households in different ways. Our study adopts the IPCC's holistic approach to understanding vulnerability (McCarthy et al. 2001), according to which the vulnerability of an entity is a function of exposure, sensitivity and adaptive capacity. Exposure represents the magnitude and frequency of the stress experienced by an entity; sensitivity describes the impact of stress that may result in the reduction in well-being due to a crossing of a threshold; and adaptive capacity represents the extent to which an entity can modify the impact of stress to reduce its vulnerability (Ford et al. 2006). When these functions are described at household level, drought comes under the exposure dimension. Food, water and health factors are included under the IPCC dimension of sensitivity. The household's sociodemographic characters, livelihood strategies and social networks have a significant impact on the adaptive capacity of each household.

Vulnerability studies help in monitoring vulnerability over time and space, identifying the processes that contribute to vulnerability, listing plans for reducing vulnerability and evaluating the effectiveness of these plans in different social and ecological settings (Shah et al. 2013). Quantifying vulnerability is a complex task for several reasons, such as the influence of multiple factors on vulnerability, the nonlinear interactions among them, and a lack of knowledge about their weights. To measure the vulnerability of flood-affected rural

households, the Livelihood Vulnerability Index (LVI) (Hahn et al. 2009) and the Socio-economic Vulnerability Index (SeVI) (Ahsan and Warner 2014) were used. Although the LVI and the SeVI have been used individually by researchers in other parts of the world for vulnerability assessments of natural disasters; this is the first time the LVI and the SeVI have been used together to analyse the vulnerability of rural households that are affected by floods. Studies have used a single approach to identify household vulnerability, which may lead to bias. Households may be vulnerable in terms of livelihood but may not necessarily be vulnerable in terms of socio-economic aspects and vice versa. In this context, analysing both vulnerabilities of the same household helps identify various vulnerable aspects of each household. These approaches provide sufficient information to policy makers and developmental organisations about the demographic, social, livelihood, health, water, food and flood aspects contributing to household vulnerability, thereby helping them in the effective formulation of adaptive strategies and policies under given financial limits. The LVI and the SeVI differ in aggregating the major domains. In the LVI, we obtain a clear idea of each major domain, whereas in the SeVI, major domains are grouped under three dimensions of vulnerability. The limitation of these approaches is that they provide equal weightage to all subdomains in each major domain.

3 Methods

3.1 Study area

The state of Odisha in India is located at the head of the Bay of Bengal (Fig. 1), and it has a coastal stretch of approximately 480 km to the east (Bahinipati 2014). The state shares boundaries with the states of West Bengal and Jharkhand to the north, Jharkhand and Chhattisgarh to the west and Andhra Pradesh and Telangana to the south. It is situated between the geographical coordinates of 81.27′E and 87.29′ east longitude and 17.49′N and 22.34′ north latitude.

3.1.1 Climate and flood scenario

The climate of Odisha is tropical, characterised by a high temperature, high humidity, medium to high rainfall and mild winters. The average rainfall is 1451.2 mm, to which the south-west monsoon contributes approximately 80%, during the months of June to September. Cyclones and floods are the most recurrent disasters in Odisha. The government of Odisha (2015) documented that the state experienced flood for 37 years between 1951 and 2015 and for nine consecutive years during 2001 to 2010. Of the state's total area, 21% (i.e. 3.34 million hectare) is considered flood prone (World Bank 2008). Rivers such as Mahanadi, Subarnarekha, Brahmani, Baitarani, Rushikulya and Vansadhara and their many tributaries expose vast areas of Odisha to floods due to heavy rainfall during monsoons. In addition, flood waters from the nearby states of Jharkhand and Chhattisgarh, cyclonic wind, heavy rainfall and tidal flows contribute to floods on coastal lines and in deltaic areas of the state (Chittibabu et al. 2004). The coastal districts of Odisha are highly prone to floods. Flood remains for approximately 5–15 days in many parts of the coastal belts of this state, damaging lives, properties and crop fields. Vulnerability to floods increases due to encroachment on flood plains, mud houses, poor socio-economic conditions, weak infrastructure and high population density.
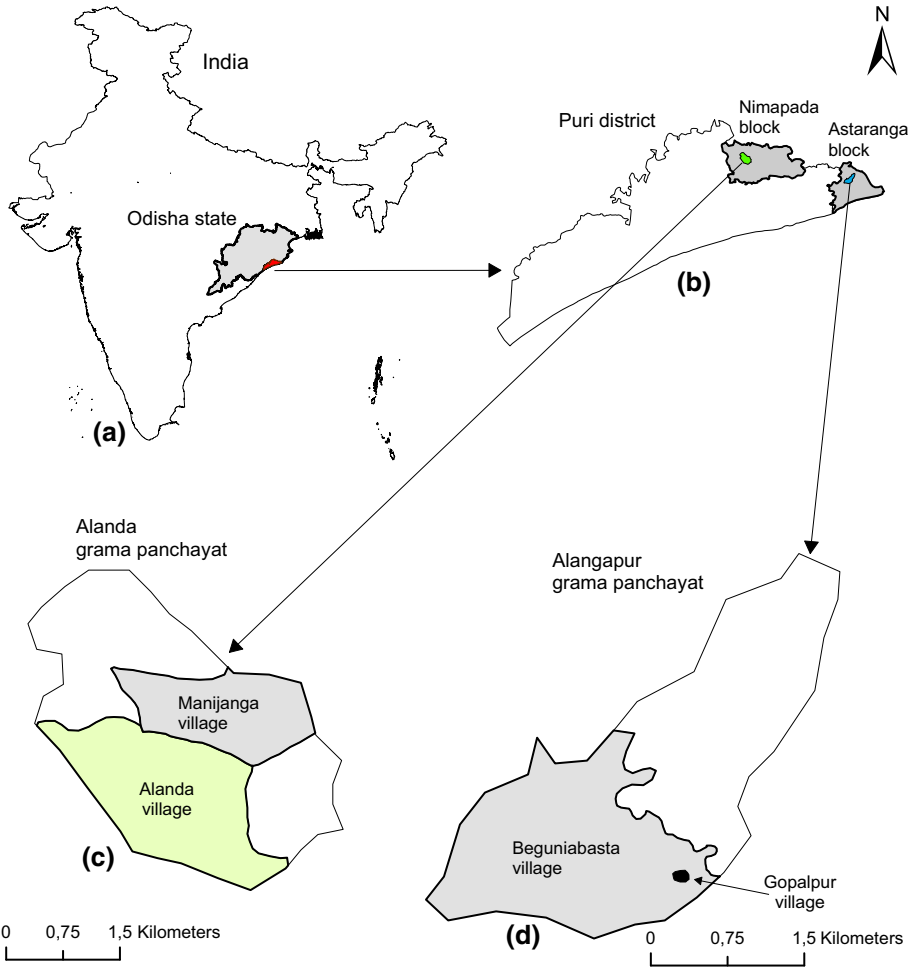
Fig. 1 **a** Map of India with Odisha state and Puri district. **b** Map of Puri district with Nimapada and Astaranga blocks and selected grama panchayats. **c** Map of Alanda grama panchayat with Alanda and Manijanga villages. **d** Map of Alangapur grama panchayat with Beguniabasta and Gopalpur village

Recurrent floods cause tangible and intangible losses in Odisha and have led to calls for mitigation and preparedness actions by various agencies and communities. Governmental organisations, non-governmental organisations (NGOs) and funding agencies have undertaken a number of disaster management programmes in attempts to mitigate disasters. Additionally, agencies such as Odisha Disaster Management Program (ODMP), Odisha State Disaster Mitigation Authority (OSDMA), United Nations Development Program (UNDP) and International Red Cross educate people and conduct mock drills at local levels (Mishra et al. 2010). Short-term management activities such as prediction systems, preparedness programmes, warning systems and evacuation processes have also been undertaken (Beura 2015).

3.1.2 Socio-economic and agricultural scenario

Odisha has a population of 42 million, which includes a large proportion of Scheduled Tribe (ST) and Scheduled Caste (SC) people (Government of India 2011).[1] Out of the total population, 83% lives in rural areas, and approximately 32.6% lives in poverty (Planning Commission of India (2013). Odisha is considered the least developed state in India based on monthly per capita income, education, health, household amenities, the poverty rate, female literacy, the proportion of the SC/ST population, the urbanisation rate, financial inclusion and physical connectivity (Savath et al. 2014). The Human Development Index (HDI) of Odisha is 0.442, which is less than that of India (0.504). The 68th round of the National Sample Survey Organization (NSSO) stated that the monthly per capita consumer expenditure (MPCE)[2] for rural and urban Odisha is also far below the respective national averages (Government of Odisha 2013).

Although the agriculture and allied sectors contribute only 15.39% to the gross state domestic product (GSDP), it provides direct and indirect livelihood opportunities to approximately 60% of the total workforce (Mishra et al. 2016). Rice is grown in 68% of the 6.6 million hectare gross cropped area (Government of Odisha 2013). A major share of cultivated rice is rainfed and depends on favourable monsoons for good harvest. However, production suffers from low yield and high instability due to various climatic changes and natural hazards, especially floods, at various phonological stages of crop growth (Paltasingh and Goyari 2013).

3.2 Sampling and data collection

For the study, six stages of sampling frames were developed to select the final sampling units (households). To select a sample for each stage of sampling frames, either purposive sampling or simple random sampling was adopted. Out of 29 states in India, Odisha state was purposively selected on account of the frequent occurrence of floods, the high dependence on agriculture for livelihood and the high poverty rates there. The selected state has 30 total districts. The coastal district Puri was also selected purposively for the following reasons: (1) flood is a perennial and repetitive phenomenon in this district, (2) flood and poverty cause economic, social, psychological and political misery to the people of the district, and (3) it is a predominantly agrarian district, where more than 70% of the population depends on agriculture for their livelihood (Government of Odisha 2015).

Astaranga and Nimapada blocks were selected randomly from 11 blocks from Puri district. Astaranga block consist of 14 grama panchayats and out of them, Alangapur grama panchayats was randomly selected. Alangapur grama panchayat consists of six villages and by using simple random sampling technique Beguniabasta and Gopalpur villages were selected. Nimapada block consists of 28 blocks, and Alanda grama panchayat was selected randomly from Nimapada block. Out of the six villages in Alanda grama panchayat, Manijanga and Alanda villages were selected randomly. Finally, sample households were selected from these four villages by simple random sampling technique. The lists of total

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[1] ST and SC are terms used in the Indian Constitution to refer to specific tribal and caste groups that face social exclusion and are granted administrative and welfare privileges to help offset their disadvantage (Thomas et al. 2015). ST and SC continue to be among the most socio-economically disadvantaged groups in India and have some of the lowest health outcomes in the country (Balarajan et al. 2011)

[2] The MPCE for rural Odisha and urban Odisha is 904.79 rupees and 1830.35 rupees, respectively; the national MPCE average is 1287.17 rupees for rural areas and 2477.03 rupees for urban areas

households in each village were collected from the grama panchayat offices, and the households were selected randomly as the socio-economic characteristics of households were almost similar in the villages.

In this study, a simplified formula (Eq. 1) provided by Yamane (1967) and Israel (1992) was used to determine the required sample size at 95% confidence level, 0.5 degree of variability and 7% level of precision.

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

where n is the sample size, N is the population size (total number of households in the district), and e is the level of precision. The total number of rural households in the selected Puri district is 313,188 (DCO 2011). Thus, the minimum total sample size of households required was 204. To maintain the minimum sample size and uniformity, we selected 55 households from each village. Therefore, the size of total sample households was 220 for this study. The data were collected from the households by four trained interviewers from March to June 2015. All 220 households agreed to participate in the survey, and the non-response error for the questions linked to this study was nil in regard to all households.

3.3 Analytical framework

3.3.1 Livelihood vulnerability index

The LVI approach assimilates climate exposure and household adaptation practices that are needed in order to evaluate livelihood risks (Hahn et al. 2009). The LVI comprises seven major domains, and each major domain consists of few subdomains. The major domains are sociodemographic, livelihood strategies, social networks, health, water, food and flood. These subdomains are potentially useful means of observing vulnerability over time and space, identifying the processes that contribute to vulnerability, prioritising strategies for reducing vulnerability and evaluating the effectiveness of these strategies in different social and ecological settings (Adger 2003). Table 1 shows the major domains, subdomains and explanations of the subdomains.

This research included the subdomains that are relevant to rural communities of India. These subdomains were developed based on a literature review and expert consultation (Pandey and Jha 2011; Aryal et al. 2014; Gentle et al. 2014; Hahn et al. 2009; Ahsan and Warner 2014; Singh et al. 2014). The sociodemographic domain largely pertains to the social and demographic aspects of society, and it focuses on the sociodemographic status of individuals or households. Most of the sociodemographic characteristics used in our study were similar to the ones used in previous research, except the social caste subdomain. The caste system still plays a significant role in Indian society, especially in rural India, which influences the accessibility and entitlement of the group to any programme or scheme.

In livelihood strategies, we selected five subdomains that are very particular to the rural Indian context. For instance, the livestock assets include cows, goats, chicken and buffalo, which are common in the study area. The durable assets subdomain includes assets such as bicycles, mobile phones, television, radio and bikes. Similarly, access to informal money lenders as a social network, access to potable water and access to PDS are important domains for the livelihood security of the rural population.

Table 1 Major domains and subdomains designed for rural India

Major domains	Subdomains	Explanation of subdomains
Sociodemographic	Dependency ratio	Ratio of the population under 15 and over 65 years of age to the population between 19 and 64 years of age
	Percent of female-headed households	Percentage of households where the primary adult is female. If a male head is away from the home for more than 6 months per year, the female is counted as the head of household
	Percent of illiterate household heads	Percentage of households reporting that the head of household has attended 0 years of school
	Percent of backward caste households	Percent of households belonging to backward castes such as OBC[a], SC and ST
	Type of housing structure[b]	The inverse of (the type of housing structure +1) reported by a household
Livelihood strategies	Average livelihood diversification index[b]	The inverse of (the number of livelihood activities +1) reported by a household
	Percent of households with no migrant member	Percentage of households reporting no migration as a source of income
	Percent of households depending solely on agriculture for livelihood	Percentage of households with agriculture as only source of income
	Average livestock asset diversification index[b]	The inverse of (the number of livestock raised by a household +1)
	Average durable asset diversification index[b]	The inverse of (the number of durable assets of a household +1)
Social networks	Percent of households with no assistance from NGO/SHG[c]	Percentage of households reporting that they have not received any assistance from NGO/SHG in the past 6 months
	Percent of households with access to informal money lenders	Percentage of households reporting access to informal money lenders
	Percent of households with no bank access	Percentage of households reporting no access to banks
	Percent of households with no school access	Percentage of households reporting no access to schools
Health	Average distance to the Public Health Centre (PHC)	Average distance from each household to the nearest health facility
	Percent of households with disease not due to flood	Percentage of households reporting at least one family member with any type of illness during any time of the year apart from the flood period
	Average per month health expenditure of household index (US$)	The average per month health expenditure of households in US$

Table 1 continued

Major domains	Subdomains	Explanation of subdomains
Water	Percent of households depending on own sources of water for household activities	Percentage of households depending on own source of water for household activities such as cooking, drinking, washing, cleaning and bathing
	Percent of households depending on public/natural sources of water for household activities	Percentage of households depending on public/natural source of water for household activities
	Percent of households having problems accessing water for household activities	Percentage of households with problems accessing water for household activities
	Percent of households having problems accessing water for irrigation	Percentage of households with problems accessing water for irrigation
Food	Percent of households with insufficient food for consumption in a year	Percentage of households with food insecurity problems
	Average number of months households struggle to find food	Average number of months households struggled to obtain food for their family during the prior twelve months
	Percent of households depending on own farm for food	Percentage of households that obtain food primarily from their own farms
	Percent of households not depending on Public Distribution System (PDS)	Percentage of households not depending on PDS for subsidised food items
	Average per month food expenditure of household index[b]	The inverse of the average per month household food expenditure in US$
Flood	Percent of household having yield reduction/loss due to flood in prior six years	Percent of household reporting any yield reduction/loss due to flood in prior six years (2009–2014)
	Percent of households with disease due to flood in prior six years	Percentage of households reporting any disease for one of their family members due to flood in the prior six years (2009–2014)
	Percent of household reporting damage to property/house due to flood in prior six years	Percent of household reporting any damage to property/house due to flood in prior six years (2009–2014)
	Percent of households that had undergone any stress during flood over prior six years	Percentage of household reporting any stress to any family member due to flood in prior six years (2009–2014)

[a] *OBC* Other backward caste

[b] The assumption of this study was that a greater number/value of these subdomains would make the household less vulnerable. Taking the inverse of the crude value of such subdomains would provide a lower index score value to households with a greater number/value

[c] *NGO* non-governmental organisation, *SHG* self-help group

The subdomains were measured on different scales, such as ratios, percentages and indices. Therefore, it was necessary to standardise each subdomain. The index (Eq. 2) was a ratio of the difference between the actual score (S_v) and the minimum value (S_{min}) of each subdomain obtained from the total sample (i.e. four villages) to the difference between the maximum (S_{max}) and minimum values (S_{min}) for each subdomain in the total sample (UNDP 2007).

$$Index_{sv} = \frac{S_v - S_{\min}}{S_{\max} - S_{\min}} \tag{2}$$

For the subdomains measured in percentage, the maximum and minimum values were 100 and 0, respectively. For other domains, such as the type of housing structure, livelihood diversification, livestock diversification, asset diversification and average per month household expenditure, indices were created because it was assumed that an increase in the crude value of these subdomains would decrease the household vulnerability. The maximum and minimum values of such subdomain were also modified according to this logic.

A balanced weighted approach was used to measure the index score, assuming that each of the subdomains had an equal contribution to the overall index (Sullivan et al. 2002). The weights of each major domain were determined by the number of subdomains of which it was comprised. The weighted scores of major domains were averaged to obtain the final LVI for each village (Eq. 3). The LVI was scaled from 0 (least vulnerable) to 1 (most vulnerable).

$$LVI_v = \frac{\sum_{i=1}^{7} W_{MDi}MD_{vi}}{\sum_{i=1}^{7} MD_{vi}} \tag{3}$$

MD_{vi} is the index values of one of the major domains for a village, indexed by i.
W_{MDi} is the weight of each major domain for a village, indexed by i.

3.3.2 Socio-economic vulnerability index

The SeVI was used to identify the flood vulnerability of communities by assessing the interacting elements of various social and economic relationships and by considering the IPCC dimensions of climate change (Ahsan and Warner 2014). By using the same data (given in Table 1), the seven major domains were grouped under IPCC dimensions (Table 2) to estimate the SeVI.

The index for adaptive capacity (Eq. 4), sensitivity (Eq. 5) and exposure (Eq. 6) is calculated as follows:

$$\text{Adptive capacity}_v = \frac{W_{SD}SD_V + W_{SN}SN_V + W_{LS}LS_V}{W_{SD} + W_{SN} + W_{LS}} \tag{4}$$

$$\text{Sensitivity}_v = \frac{W_H H_V + W_F F_V + W_W W_V}{W_H + W_F + W_W} \tag{5}$$

Table 2 Classification of major domains under the IPCC vulnerability dimensions

IPCC dimensions of vulnerability	Major domains
Adaptive capacity	Sociodemographic (SD)
	Livelihood strategies (LS)
	Social networks (SNs)
Sensitivity	Health (H)
	Water (W)
	Food (F)
Exposure	Flood (FL)

$$\text{Exposure}_v = W_{\text{FL}}\text{FL}_V \tag{6}$$

SD_V, SN_V, LS_V, H_V, F_V, W_V, FL_V are the index values of each major domain for each village.

W_{SD}; W_{SN}; W_{LS}; W_H: W_F: W_W; W_{FL} are the weights of each major domain for each village.

The indexed values for adaptive capacity, sensitivity and exposure were combined to calculate the SeVI (Eq. 7). The SeVI possessed a direct relationship with the system's exposure and sensitivity and an inverse relationship with its adaptive capacity (Ford and Smit 2004). Hence, for the SeVI index calculation, one minus the adaptive capacity domain index score was used. The SeVI was also scaled from 0 (least vulnerable) to 1 (most vulnerable).

$$\text{SeVI}_v = \frac{(1 - \text{Adpaptive capacity}_v) + \text{Sensitivity}_v + \text{Exposure}_v}{3} \tag{7}$$

4 Results

The subcomponent values with their minimum and maximum values for four villages in the Puri district are given in Appendix of Electronic Supplementary Material (Table A1), which provides an idea about the sociodemographic situations in the four villages. The results of the vulnerability analysis are presented in two different parts. First, the results obtained from the assessment of individual major domains and subdomains are presented together with the overall LVI. Second, the index values for the three dimensions (sensitivity, exposure and adaptive capacity) of vulnerability are presented along with the overall SeVI of the four villages.

4.1 LVI, major domains and subdomains

The results for the subdomains along with the LVI of four villages are presented in Table 3, and Fig. 2 provides information about the index values of the seven major domains. The LVI of households provides a clear indication of the capabilities, assets and activities required for a sustainable means of living for households. All villages had similar LVIs, with slight variations. Alanda had the highest LVI, indicating higher vulnerability. This may be due to the high index values of subcomponents such as sociodemographic profile, livelihood strategies and water. The LVI was the lowest for Beguniabasta village, showing less vulnerability in terms of sociodemographic profile, livelihood strategy, health and flood, which made this village the least vulnerable to livelihood. Manijanga had a LVI of 0.439. This village had the highest scores for subcomponents such as dependency ratio, livelihood diversification, average distance to PHC, problems in irrigation water access, property damage and stress. The LVI of Gopalpur was 0.419; this village had the highest vulnerability level in terms of flood and social networks.

4.2 SeVI and vulnerability dimensions

The indexed values for each dimension, i.e. adaptive capacity, sensitivity and exposure, along with the SeVI, are presented in Table 4. The SeVI was highest for Alanda village

Table 3 Index values for subdomains and LVI

Subdomains	Alanda	Manijanga	Beguniabasta	Gopalpur
Sociodemographic profile				
Dependency ratio	0.092	0.160	0.109	0.152
Percent of female-headed households	0.273	0.236	0.164	0.327
Percent of illiterate household heads	0.018	0.036	0.018	0.109
Percent of backward caste households	0.473	0.218	0.000	0.182
Type of housing structure	0.503	0.272	0.593	0.389
Livelihood strategies				
Average livelihood diversification index	0.744	0.848	0.556	0.684
Percent of households with no migrant member	0.436	0.564	0.618	0.382
Percent of households depending solely on agriculture for livelihood	0.182	0.200	0.127	0.200
Average livestock asset diversification index	0.651	0.373	0.289	0.389
Average durable asset diversification index	0.223	0.216	0.376	0.237
Social networks				
Percent of households with no assistance from NGO/SHG	0.309	0.400	0.000	0.491
Percent of households with access to informal money lenders	0.455	0.509	1.000	0.891
Percent of households with no bank access	0.436	0.436	0.509	0.255
Percent of households with no school access	0.600	0.491	0.527	0.418
Health				
Percent of households with disease not due to flood	0.382	0.509	0.364	0.691
Average distance to PHC	0.921	0.929	0.035	0.150
Average per month health expenditure of household index	0.255	0.245	0.582	0.362
Water				
Percent of households depending on own sources of water for household activities	1.000	0.545	0.545	0.418
Percent of households depending on public/natural sources of water for household activities	1.000	0.673	0.618	0.509
Percent of households having problems accessing water for household activities	1.000	0.818	0.818	0.418
Percent of households having problems accessing water for irrigation	0.920	1.000	0.976	1.000
Food				
Percent of households with insufficient food for consumption in a year	0.582	0.418	0.400	0.455
Average number of months households struggle to find food	0.120	0.105	0.138	0.112
Percent of households depending on own farm for food	0.455	0.436	0.745	0.582
Percent of households not depending on PDS	0.509	0.436	0.564	0.636
Average per month food expenditure of household index	0.141	0.097	0.162	0.135
Flood				
Percent of household having yield reduction/loss due to flood in prior six years	0.455	0.436	0.745	0.582

Table 3 continued

| Subdomains	Alanda	Manijanga	Beguniabasta	Gopalpur
Percent of households with disease due to flood in prior six years	0.509	0.418	0.400	0.636
Percent of household reporting damage to property/house due to flood in prior six years	0.382	0.545	0.236	0.309
Percent of households that had undergone any stress during flood over prior six years	0.582	0.582	0.273	0.473
LVI	0.487	0.439	0.416	0.419
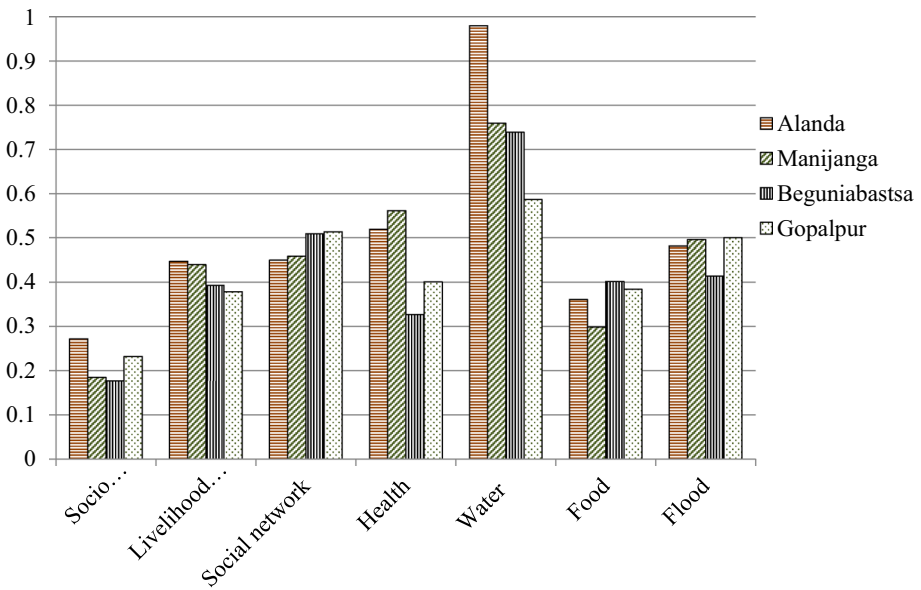
Fig. 2 Index values for major domains of study villages

and lowest for Beguniabasta village. Alanda had the highest vulnerability level in terms of adaptive capacity. The high index value of the sociodemographic profile and livelihood strategies led to the high vulnerability of the adaptive capacity of Alanda. The index value for sensitivity was highest for Alanda. A high index value of water issues, average distance to PHC and insufficient food for consumption made Alanda village highly sensitive to drought risk. The index value for exposure was highest for Gopalpur village. All villages were affected by floods on a yearly basis. Because most of the households in these villages listed agriculture as the primary occupation, floods affect agriculture, leading either to crop loss or yield reduction. The people reported that flood is a common scenario and had become part of their life.

Table 4 SeVI and index values for vulnerability components

Vulnerability components	Alanda	Manijanga	Beguniabasta	Gopalpur
Adaptive capacity	0.385	0.354	0.349	0.365
Sensitivity	0.607	0.518	0.496	0.456
Exposure	0.482	0.495	0.414	0.500
SeVI	0.568	0.553	0.520	0.530

5 Discussion

Sociodemographic characteristics can influence an individual's or group's ability to anticipate, cope with, resist, recover from and adapt to external stress (Kelly and Adger 2000). A higher dependency ratio would indicate that economically active individuals had many others to support, and thus, resources for coping with natural disasters would be more limited (Brenkert and Malone 2005). The vulnerability of households may increase with a high dependency ratio. The study villages, like any rural part of India, have an average family size of five. Female-headed households are more vulnerable than male-headed households (Waite 2000). In Odisha, approximately 10% of households are headed by females (Ray-Bennett 2009). Due to the patriarchy system and the associated culture prevailing in the rural areas of Odisha, approximately 75% of heads of household were males in all study villages. It was also observed that females were heads of household not by choice but due to the absence of a male member in the family. In these villages, most families are nuclear families, and men migrate to other states, leaving behind women as the household heads.

A higher education of the household head has a negative association with natural disasters and climate change risks (Brody et al. 2008). According to the 2011 census, the male literacy rate in Puri district is 90.8%, while the female literacy rate is 78.3% (DCO 2011). The wide gap between male and female literacy rates indicates an enduring gender bias in the district. In Gopalpur village, the percentages of female-headed households and illiterate household heads are high. In most of the female-headed households, women are the primary income earner, and they face gender discrimination with respect to education, earnings, rights and economic opportunities. When female household heads are school aged, several societal restrictions prevail in preventing them from going school. The poverty, backward caste and gender of the heads of household make households vulnerable. Floods will further increase the vulnerability of such households unless adequate measures are put in place to uplift the sociodemographic profile of households efficiently.

The backward caste and housing structure subdomains were the most influential in determining the highest index value of the sociodemographic profile of Alanda village. The Indian caste system is an important rural dimension, where people are socially differentiated through class, religion, region, tribe and language (Deshpande 2010). People of India belong to either the forward caste or the backward caste, which includes SC and ST (Pruthi 2004). People belonging to backward classes comprise the most backward section of society socially, economically and educationally (Cutter et al. 2003). Race and ethnicity contribute to vulnerability through a lack of access to resources, cultural differences, and the social, economic, and political marginalisation that is often associated with disparities. A poor housing structure may lead to an increase in vulnerability (López-Marrero and Yarnal 2010). Most houses in the four villages are constructed with mud or brick walls, and

the roofs are thatched with paddy straw. Such houses are highly susceptible to natural disasters. Rarely, houses are constructed with brick and cement walls, and the roofs are either concrete or thatched with clay tiles.

In Alanda village, the livelihood diversification and livestock diversification subcomponents largely contributed to the livelihood strategies domain. Adaptive capacity depends on characteristics of people's livelihood, such as the assets they possess and the services provided by external infrastructure and institutions (IISD 2003). The livelihood strategies of a household are important variables that influence mechanisms for coping with flood (Paavola 2008). Very few people collect all their income from any one source, and many households diversify their assets, incomes, and activities to reduce risk in case of the failure of any one of them (Barrett et al. 2001). Agriculture is the major source of livelihood for a large majority of the population in Odisha state, and this is also true for the sample villages. In addition, people work as agricultural labours, and some people migrate to other districts or states. Migration is considered one possible type of adaption strategy when households are exposed to natural disasters (Perch-Nielson et al. 2008). Young adults migrate from these villages to other parts of the country due to frequent floods and lower profits from farming. In their destination states, they are mostly engaged in construction, brick kiln, factory, and similar work. Another push factor we found for migration was the low wage rate. The average daily casual labour wage rate per day is US$2–2.5 for males and US$1–1.5 for females. Thus, a wide wage disparity exists between men and women.

The percent of households depending solely on agriculture was low in all the sample villages. The agricultural sector is highly dependent on the climate, and it is adversely affected by slight variations in climate (Cutter 2008). The profit margin in agricultural produce is comparatively low, and there are no adequate marketing facilities in these villages. In such a situation, depending solely on agriculture as a livelihood option is too risky. As the number of assets increases, a household will be less vulnerable to shocks (Heltberg et al. 2009). A cattle is the most common livestock found in the four villages. Other livestock found in the villages include buffalo, goats, sheep and chickens. The most common durable assets in the Puri villages are bicycles and mobile phones. A few households have a television or a motor bike. When poor people have assets, they can sell them to cope with the adverse effects of natural disasters and poverty.

There was little variation in the index values of the social network domains of the study villages. Social networks such as NGOs, savings and credit institutions, employment networks, and other social institutions such as schools and hospitals are considered important indicators of adaptive capacity in response to natural disasters (Rakodi and Jones 2015). As access to social networks increases, households become less vulnerable to shocks because their ability to cope with risk also increases (Lokshin and Yemtsov 2001). All households in Manijanga village seek assistance from NGO/SHG; the index for households seeking no assistance from NGO/SHG was found to be zero for this village. NGOs play an important role in natural disaster mitigation and preparedness as they work with poorer and marginalised groups in society (Benson et al. 2001). Many informal money lenders charge very high and varying interest rates, thereby hindering the welfare of rural people by limiting their access to credit (Mariwah 2012). Informal money lenders with exploitative and high rates of interest constitute a major obstacle for the economic development of the people in these villages. Most small and marginal farmers are compelled to take loans from private money lenders to perform their agricultural activities and meet other needs. In the process of loan repayment, people become dispossessed from their productive assets such as land, and they have to sell major share of their agricultural produce during the harvest season. This in turn makes the household more vulnerable.

Most of the migrant households in the study villages had access to banks, and migrant family members sent remittances to their families through banks. Though more than 83 percent of the population resides in rural areas, the percentage of rural branches constitutes only 57.5 percent of the total commercial banks functioning in Odisha (Subudhi and Ram 2012). The villagers reported that because the average monthly income of the rural households is very low, they invest less in the education of their children, leading to a serious underinvestment in education. The preference of households to invest in the education of male children rather that of female children is widely prevalent in the households of these villages. Poor families are more likely to keep girls at home to care for younger siblings or to work in family farms. The villages have primary schools, but the high schools, secondary schools and colleges are located in nearby towns. A lack of commuting facilities to nearby towns also made it difficult to continue education.

The contribution of average distance to PHC and diseases influenced the high index value of the heath domain of Manijanga village. Many researchers have mentioned in previous studies that the high vulnerability of rural households may be due to health issues (Béné 2009; Mills et al. 2011). The majority of the households in all villages lack toilets. Villagers defecate in open areas, which increase the risk of water contamination and thus contagious diseases, such as diarrhoea, hepatitis and skin disease. The general trend found in the villages was that when people are affected by disease, they prefer to use home-made remedies. They go to hospitals only when the home-made remedies fail to provide a cure. Manijanga had the lowest index score for the average per month health expenditure of the households, with an average monthly health expenditure of US$ 4.1. Large healthcare expenditure likely requires a sacrifice of the consumption of other goods, possibly including basic needs, which will make the household more vulnerable (Wagstaff and van Doorslaer 2003).

The water domain had the highest index values among all major domains. Access to water is an important factor that influences vulnerability (Gentle et al. 2014). Approximately 80 percent of rainfall is received from south-west monsoons from June to September, and rest of the rainfall occurs in the other eight months (Mohapatra and Mohanty 2004). Out of the total rainfall, approximately 80 percent is lost by flow to the sea as surface run-off due to the lack of proper rainwater harvest facilities. This may lead to severe water scarcity problems during the summer months. In the villages, it was found that people depend on groundwater for drinking. They also depend on surface water, such as rivers and ponds, for domestic uses. The depletion and deterioration of the surface water have inevitably led to overdependence on groundwater for domestic uses. The main problem in the villages was the scarcity of safe and good-quality water. Additionally, the villages face a range of issues associated with drinking water, such as the operation and maintenance of sources, the depletion of groundwater tables and inadequate water harvesting facilities. Women walk an average distance of a half kilometre to retrieve water from a nearby source for cooking. They collect water twice a day, in the early morning and in the afternoon. Due to the drying of most of the rivers for approximately two-thirds of the year, people have changed their source of irrigation from natural sources to groundwater. While the dependency on groundwater has increased significantly, these aquifers are unable to provide sufficient water for drinking and domestic use or to meet the requirements of irrigation, leading to a severe water scarcity problem, especially in summer months (Rejani et al. 2009).

Most households in the four villages face food security issues. Natural disasters such as floods likely increase their vulnerability and problems related to rural household food security (Dilley and Boudreau 2001). Most farming households in the villages belong to

either a marginal farming household (a household with an operational land holding of up to one hectare) or a small-scale farming household (an operational holding of between one and two hectares) and perform subsistence farming. Agriculture in these villages is affected by erratic rainfall, floods and cyclones, leading to low productivity. The villages struggle for food for an average of two months per year. Rice is harvested between November and January. A large portion of the agricultural produce is sold by the farmers to repay their loans. The farmers also retain some portion of the agriculture produce for consumption year round. The Public Distribution System (PDS) is a nationwide network that provides subsidised food grains and other essentials at subsidised prices to poor people. Almost half of rural households' calorie intake from staple food grains in India comes from the PDS (Ray 2007). Households with access to PDS are considered less vulnerable.

Natural disasters such as floods likely increase the vulnerability of households that are already vulnerable to many other factors. Between 2009 and 2014, the Puri district faced six floods. Every year, the flood continues approximately 5–10 days and causes damage to life and property. The flood causes the submergence of crop plants, leading to a yield loss or a crop loss. Infectious disease may occur during the flood period, lasting days, weeks or even months after the onset of the flood. The most common disease during the flood is diarrhoeal disease, which spreads rapidly due to the contamination of drinking water. Other illnesses include hepatitis, skin diseases and fever. As most of the houses in the villages are easily destroyable in floods, the houses are reconstructed and roofs are thatched after the flood every year. Many livestock die during the flood period. During the flood, village families go to the relief shelters, and the livestock are set free, which may lead to their death.

6 Conclusions

In this article, we investigated the livelihood and socio-economic vulnerability of rural households in one of the poorest and most flood-prone parts of India. The adaptation process usually starts with a vulnerability assessment associated with climate-induced extreme weather events and the impact it has on poor households with limited access to capital assets. Depending on household access to endowments and entitlements, the adaptation-enhancing measures of each household may vary significantly. Based on our study, we recommend specific intervention strategies to reduce the vulnerability of rural households. The most influential interventions to reinforce the sociodemographic profile of households would be to raise the level of formal education of all people, especially those of household heads. Livelihood diversification may be the most beneficial intervention for reducing livelihood vulnerability. Initiating livelihood opportunities for at least one member of the household to earn an income outside of a natural resource-dependent activity will help reduce the livelihood vulnerability of households that depend on natural resources.

Regarding sensitivity, food, water and health factors must be addressed with the greatest importance by households, local communities and the government. Ensuring adequate food for consumption, especially during the flood period, reduces household vulnerability. Improved health facilities and a safe and adequate water supply will help reduce households' vulnerability. The lack of improved infrastructure and access to health and water infrastructure indirectly increase the vulnerability of households.

Flood causes failure of crops, loss of property and diseases, and it increases the vulnerability of rural households. Flood disaster management and relief plans must be formulated in conjunction with local communities. Ex post impact assistance must also be developed to ensure speedy recovery from the negative effects of floods. Along with the increasing severity of impacts both temporally and spatially, systemic changes may be required by different stakeholders in rural communities, especially financial sectors and government institutions that handle social protection and welfare administration. The outcomes of this study may be taken into account to develop location-specific strategies, policies and programmes that reduce the vulnerability of rural households, particularly in India. It is likely that the findings and recommendations of this study will be applicable in other rural, natural resource-dependent countries with similar socio-economic profiles, such as other South Asian countries. A comparison of the LVI and the SeVI between countries with different socio-economic characteristics is inconsistent because the subdomains used vary by region. Therefore, this study paves the way for future research on standardising these subcomponents so that the results can be applied to different countries affected by natural disasters in order to calculate and compare the LVI and the SeVI on a common scale.

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