Assessment of vulnerability to cyclones and floods in Odisha, India: a district-level analysis

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Most of the districts in Odisha, India are prone to both cyclones and floods. However, the existing studies have assessed vulnerability mainly for the coastal districts, and are largely focused on the biophysical components. Therefore, a comprehensive vulnerability assessment will help unravel the scale of vulnerability across the districts of Odisha, and provide a better understanding of the adaptive capacity of households towards these extreme events. An 'integrated approach' was adopted to assess vulnerability which is viewed as a function of exposure, sensitivity and adaptive capacity. A number of proxy indicators were considered to represent these components, and a normalization procedure was adopted in order to aggregate them into a single value. Three key observations emerged. First, components like sensitivity and adaptive capacity were found to act as the major determinants of vulnerability. Secondly, eight districts were found to have a higher vulnerability score, and surprisingly, some of the districts are non-coastal. Thirdly, factors like demography, agriculture and economic capacity emerged as the major cause for increasing vulnerability. These results have policy implications in the context of prioritizing limited resources among the vulnerable districts and determinants through the disaster risk management programme at state and district levels.

Keywords: Cyclone and flood, district-wise, integrated approach, Ohisha, vulnerability,

THE state of Odisha, India, consisting of 30 districts and geographically situated at the head of the Bay of Bengal (Figure 1), has a coastal stretch of around 480 km. In addition, a number of perennial rivers such as Mahanadi, Brahmani, Baitarani, Rushikulya, Birupa, Budhabalanga and Subarnarekha, and their tributaries pass through Odisha, making the state prone to flooding. During 1804–2010, both cyclones and floods, for instance, have occurred for 126 years in the state[1–4], and in particular, outbreak of floods has been reported for nine consecutive years during 2001–2010 (ref. 4). The intensity of these events was relatively higher during the late 20th century and the last decade, and caused unprecedented loss of life and property in the state[5–7]. The frequency and intensity of these events are likely to increase in the foreseeable future due to climate change[8]. In the spatial context, at least 15 districts were affected 10 times by the cyclones and floods during 1995–2010 (ref. 4). Further, Mohapatra *et al.*[9] found that 14 districts of the state were prone to cyclonic storms. This indicates that the state not only experiences frequent cyclones and floods, but also that majority of its districts are regularly affected by both events.

A wide range of studies have assessed vulnerability of Odisha to cyclones and/or floods. These studies either focus on the coastal districts of India, including Odisha[9–13] or exclusively on the coastal districts of Odisha[14–16]; and most of the studies are mainly focused on the biophysical components. Since a majority of the districts in Odisha are frequently affected by cyclones and floods with different intensity levels[4,9] and both the events are complementary in nature, a comprehensive assessment will help unravel the scale of vulnerability across the districts of Odisha and provide a better understanding of the adaptive capacity of households to these extreme events. To assess vulnerability empirically, many recent studies have adopted an 'integrated approach' where vulnerability is the function of exposure, sensitivity and adaptive capacity[17–26]. This approach has an advantage over the previous approaches as it combines both socio-economic and biophysical vulnerability[25,27].

By adopting an 'integrated approach', the present study, therefore, aims to assess vulnerability of all the districts in Odisha with respect to cyclones and floods. In doing so, not only the vulnerable districts were identified, but also the determinants of vulnerability (i.e. exposure, sensitivity and adaptive capacity) that make a district more vulnerable were outlined. From the policy perspective, this provides recommendations for meeting the urgent need of prioritizing the limited resources among the vulnerable districts and determinants in the disaster risk management (DRM) programme in the state as well as districts. After the super cyclone[28,29] that badly hit Odisha in 1999, the Odisha State Disaster Management Authority (OSDMA) implemented the disaster risk management (DRM) programme in 16 disaster-prone districts

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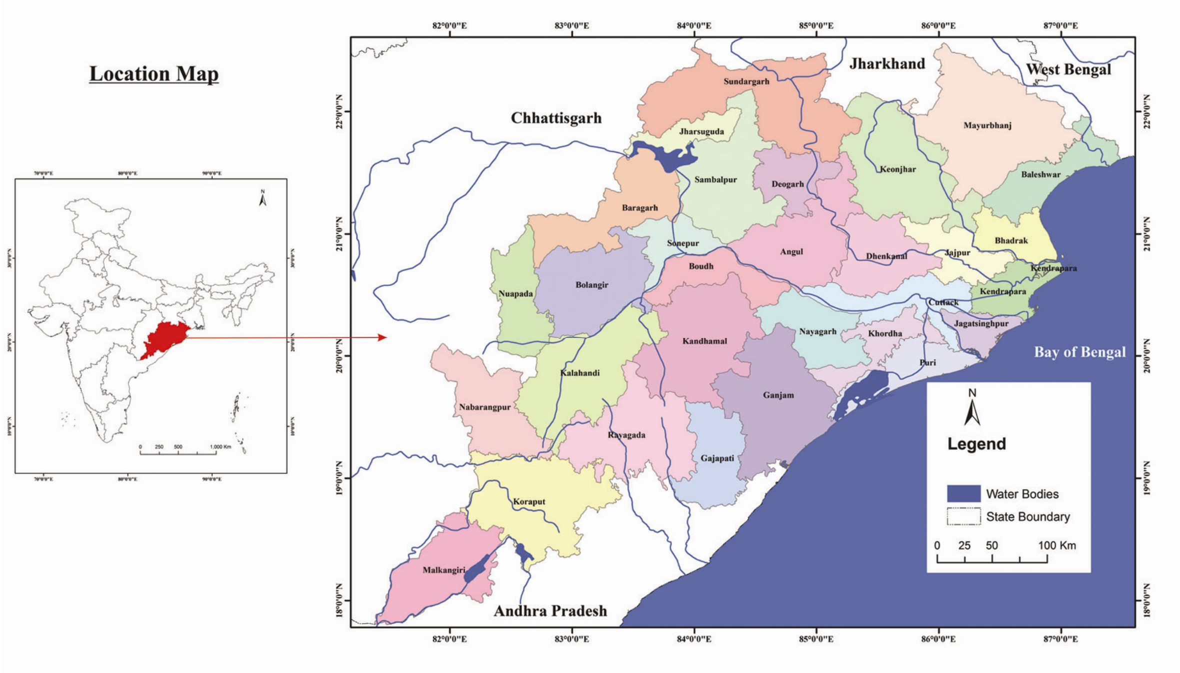

Figure 1. Geographical map of Odisha.

Table 1. Frequency of cyclones in the east-coast states of India

State	Mandal[33,a]	GTECCA[34,b]	Mohanty and Gupta[35,c]	IMD[31,d,e]
West Bengal	69 (22.40)	67 (20.93)	49 (19.14)	149 (18.55)
Odisha	98 (31.81)	106 (33.12)	94 (36.71)	387 (48.19)
Andhra Pradesh	79 (25.64)	90 (28.12)	65 (25.39)	177 (22.04)
Tamil Nadu	62 (20.12)	57 (17.81)	48 (18.75)	90 (11.21)
Total	308 (100.00)	320 (100.00)	256 (100.00)	803 (100.00)

[a]Study period 1881–1989; [b]Study period 1877–1995; [c]Study period 1891–1994; [d]Study period 1891–2007; [e]This includes low pressure, depression, deep depression, cyclonic storm, severe cyclonic storm, very severe cyclonic storm and super cyclonic storm. Figures in parentheses indicate percentage.

of the state during 2002–08 to reduce potential impacts of cyclones and floods[30].

Trends and patterns of cyclones and floods

Cyclonic storms

Among the four states situated at the head of the Bay of Bengal (West Bengal, Odisha, Andhra Pradesh and Tamil Nadu), Odisha has experienced a large number of cyclonic storms (Table 1). The India Meteorological Department (IMD)[31], for instance, outlines that 48.19% of the total number of cyclones (i.e. 387 out of the 803 cyclones that hit the eastern coastal states) occurred in Odisha during 1891–2007. According to the vulnerability atlas of Building Materials and Technology Promotion Council (BMTPC), 35.8%, 2.4% and 61.7% of the total area of the state are at risk under a wind velocity of 55 and 50 m/s, 47 m/s and, 44 and 39 m/s respectively[32]. Further, Mohapatra *et al.*[9] found that there are 14 cyclone-prone districts in the state, which includes six coastal districts (Balasore, Bhadrak, Kendrapada, Jagatsinghpur, Puri and Ganjam) and eight non-coastal districts (Khurda, Mayurbhanj, Jajpur, Keonjhar, Dhenkanal, Cuttack, Nayagarh and Gajapati).

With regard to the temporal scale, there was no evidence of any increasing trend of cyclonic storms in the state during 1891–2007 (Table 2)[33–35]. During this period, it was found that a higher number of cyclonic storms (i.e., 46 times) occurred during two decades, viz. 1891–1900 and 1931–40. Srivastava *et al.*[36] and Niyas *et al.*[37] also observed decreasing trend for the tropical cyclones in India. But, other studies[5,6,37] highlight that the intensity of the cyclonic storms has been increasing, particularly during the second half of the last century. With reference to the monsoon and month-wise occurrence of cyclonic storms, it has been noticed that a higher number of storms occurred during the monsoon period, for example, 351 cyclones out of total 387 (i.e. 90.7%) occurred during June–September (Table 3). Apart from this, a relatively higher number of cyclones occurred in the month of October (25 cyclones – 6.46%). Moreover, Unnikrishnan *et al.*[38] predict an increasing trend for the occurrence of cyclones during the late monsoon season (i.e. August and September) in 2071–2100 compared to the baseline scenario (i.e. 1961–1900) in the Bay of Bengal. Since a major portion of the agricultural land is cultivated during the *kharif* season (i.e. May to November) in Odisha[39], the frequent occurrence of cyclonic storms during August–October in the Bay of Bengal has affected the agricultural crops[4], and is likely to follow a similar trend in the foreseeable future. This, in turn, affects livelihoods of a large percentage of households in the state, as 61.8% of the total working population depends on agriculture, according to the 2011 census. For example, the occurrence of unseasonal cyclonic rainfall in 2010 caused major crop loss across 24 districts in Odisha, with the value of crop loss estimated[4] to be around Rs 60,000 million.

Table 2. Decade-wise frequency of cyclones in Odisha during 1891–2007 (ref. 31)

Period	Frequency
1891–1900	46 (11.89)
1901–1910	26 (6.72)
1911–1920	36 (9.30)
1921–1930	35 (9.04)
1931–1940	46 (11.89)
1941–1950	43 (11.11)
1951–1960	39 (10.08)
1961–1970	34 (8.79)
1971–1980	30 (7.75)
1981–1990	27 (6.98)
1991–2000	14 (3.62)
2001–2007	11 (2.84)
Total (1891–2007)	387 (100.00)

Figures in parentheses indicate percentage.

Table 3. Monsoon and month-wise frequency of cyclones in Odisha during 1891–2007 (ref. 31)

		Frequency	
Monsoon	Month	Month-wise	Monsoon-wise
Winter monsoon	January	0 (0.00)	0 (0.00)
	February	0 (0.00)	
Pre-monsoon	March	0 (0.00)	5 (1.29)
	April	0 (0.00)	
	May	5 (1.29)	
Monsoon	June	52 (13.44)	351 (90.70)
	July	97 (25.06)	
	August	119 (30.75)	
	September	83 (21.45)	
Post-monsoon	October	25 (6.46)	31 (8.01)
	November	6 (1.55)	
	December	0 (0.00)	
Total		387 (100.00)	

Figures in parentheses indicate percentage.

Floods

Like cyclonic storms, floods are also a major concern for Odisha as a large number of perennial rivers pass through the state. The intensity of floods is more severe if it merges with the high tides, especially during the cyclone period; this causes more damage to the coastal districts in comparison to other districts of the state. Of the state's total area, 21% (i.e. 3.34 million ha) is considered as flood-prone[14]; 75% of this is spread across eight districts, including six coastal districts, namely Balasore, Bhadrak, Kendrapada, Jagatsinghpur, Puri and Ganjam, and two non-coastal districts Cuttack and Jajpur[14]. It is also noted that the trends of frequency and intensity of extreme rainfall events are increasing during the last century in Odisha[7,40]. To augment this argument, one can observe from Table 4 that the frequency and number of affected districts have increased during the last decade compared to the earlier decades. The economic loss associated with floods has also increased during 2000–2009, and it has exceeded Rs 10,000 million in 2006, 2007 and 2008 (Figure 2). Again, floods in September 2011 caused damage around Rs 326.6 million in the state[41]. During 1953–2002, an average of 2.449 million people (i.e. 7.41% of India) were affected, and the average value of the damage to crops, houses and public utilities was Rs 817.43 million (i.e. 6.01% of the total damage in India) in Odisha (http://www.indiastat.com).

Materials and methods

Choice of indicators for vulnerability assessment

According to the Intergovernmental Panel on Climate Change (IPCC), vulnerability is defined as '*the degree to which a system is susceptible to or is unable to cope with adverse effects of climate change including climate variability and extremes, and it is the function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity*'[18]. From this, we can infer that vulnerability is the function of exposure, sensitivity and adaptive capacity. A number of proxy indicators were selected to represent these determinants (Table 5). These indicators were selected based on the existing vulnerability studies and the availability of secondary data at the district-level in the state.

Exposure: This is determined by the extent to which the districts face a climatic hazard or stress. For example, exposure can be due to variability in climate parameters or long-term change in climatic conditions (like changes

Table 4. Number of districts affected by floods in Odisha during 1972–2010 (refs 3 and 4)

Year	No.	Year	No.	Year	No.
1972 (July)	5	1990 (May)	1	1997 (August)	13
1975	8	1991 (July)	11	1999 (July and August)	7
1976	6	1991 (August)	7	2001 (July and August)	24
1977 (November)	10	1992 (June)	5	2003	27
1978	12	1992 (July)	10	2004	5
1980	10	1992 (August)	7	2005	15
1981 (June)	1	1994 (July)	16	2006	27
1981 (August)	4	1994 (August)	5	2007 (July)	11
1982 (August/September)	8	1994 (September)	18	2007 (August and September)	15
1984	8	1995 (May)	23	2008 (June and September)	21
1985 (September)	7	1995 (November)	20	2009	17
1985 (August)	11	1997 (June)	4	2010	6
1985 (October)	5				

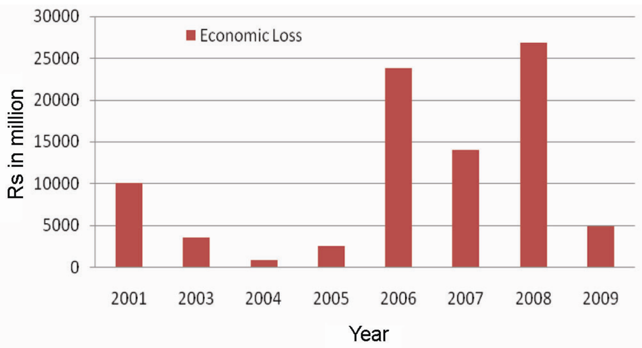

Figure 2. Flood-related economic loss in Odisha during 2001–09 (Rs in millions)[4].

in the intensity of natural disasters). Given the aim of the present analysis, the proxy variables were taken to evaluate district-wise exposure to cyclones and floods as the coastal length, frequency of cyclones and floods and their impact in terms of human mortality, people affected, houses damaged, villages affected and damage to crop lands during 1999–2008; such information for all the districts was accessible during this reference period.

Sensitivity: This is the extent to which an entity is affected, either adversely or beneficially, by the climate extremes[18]. The effect may be direct in terms of damage to crops due to cyclones and floods, or indirect in terms of damages caused by an increase in the frequency of coastal flooding[18]. It is captured by the indicators that represent the intrinsic features of the system, which define the impact of external stressors on a household. Considering an example of vulnerability of the agricultural system to climate extreme, one would do well to remember that the choice of crop variety and seed commits the farmers to certain impact on the farm yield. This could be described as sensitivity of a farmer to climate extreme[42]. The present analysis calculated three types of sensitivity, viz. demographic, agricultural and health. While Bhattacharya and Das[42] calculated both demographic and health sensitivity, Patnaik and Narayanan[11] and Palanisami *et al.*[43] estimated both demographic and agricultural sensitivity.

Previous studies in the context of India have established that population factors have played a major role in increasing damages due to climate extremes in the recent years[44,45], i.e. more number of people are likely to be affected in a district, if it has higher population density. Further, it was also observed that women and children showed higher probability to be vulnerable to climate extremes[46,47]. The demographic sensitivity in the present study is captured by the indicators like share of district population to total population of Odisha, population growth rate during 2001–2008, population density and percentage of rural people, women, children (less than 6 years) and the elderly (above 60 years). It is well known that the agriculture sector in India experiences a relatively high impact from climatic extremes[48,49]. This indicates that a higher vulnerability level could be derived for a region, if more households in that region depend on agriculture for their basic livelihoods. The present study captures agricultural sensitivity through the indicators, like percentage of cultivators, agricultural labourers and net sown area (NSA). Health is affected by climatic extremes through both direct (death of people due to flood and storm surge) and indirect pathways (change in prevalence of waterborne diseases in the aftermath of cyclones and floods, and the increasing rate of malnutrition due to shortage of food). Sensitivity to extreme events would be expected to be higher for those households in a district with poor basic living conditions such as malnutrition and inadequate access to health services[29]. Two proxies represent the sensitivity of health in the present analysis: crude death rate (CDR) and infant mortality rate (IMR). These two indicators broadly show the availability of health infrastructure (this is also captured through some other indicators discussed in the adaptive capacity section) and the inadequate access to health services in a district. This study, therefore, hypothesizes that the proxy variables associated with sensitivity could increase the level of vulnerability.

Table 5. Description of determinants, major components and indicators of vulnerability

Determinants of vulnerability	Components	Proxy indicators	Data year	Expected sign	Data source
Hazard and exposure	Characteristics of cyclone and flood (frequency and magnitude)	Total frequency of cyclones and floods	1999–2008	+	Memorandum of damages and various annual reports on natural calamities published by the Government of Odisha
		Human mortality	1999–2008	+	
		Number of people affected	1999–2008	+	
		Number of houses damaged	1999–2008	+	
		Number of villages affected	1999–2008	+	
		Damage to crop lands (ha)	1999–2008	+	
		Coastal length (km)		+	
Sensitivity	Demographic sensitivity	Share of district population to total population of Odisha	2008	+	Statistical Abstract of Odisha (different years)
		Growth rate of the population during 2001–2008	2008	+	
		Population density	2008	+	
		Percentage of rural population	2008	+	
		Percentage of female population	2008	+	
		Percentage of children (less than 6 years)	2008	+	
		Percentage of old people (above 60 years)	2008	+	
	Agricultural sensitivity	Percentage of cultivator	2008	+	Statistical Abstract of Odisha (different years)
		Percentage of agricultural labourer	2008	+	
		Percentage of net area sown	2008	+	Agricultural Statistics of Odisha
	Health sensitivity	Crude death rate	2008	+	Statistical Abstract of Odisha (different years)
		Infant mortality rate	2008	+	
Adaptive capacity	Economic capacity and equity	Percentage of rural families below poverty line	2008	+	Economic Survey of Odisha (different years), and Statistical Abstract of Odisha (different years)
		Per capita district domestic product	2008	–	
		Percentage of people employed	2008	–	
		Female work participation rate (percentage of females employed)	2008	–	
		Gini-coefficient of land holding	2008	+	
	Technology	Total area covered by irrigation (ha)	2008	–	Agricultural Statistics of Odisha (different years)
		Yield rate of cereals (q/ha)	2008	–	
		Consumption of fertilizer (kg/ha)	2008	–	
	Information and skills	Literacy rate	2008	–	Statistical Abstract of Odisha (different years)
		Female literacy rate	2008	–	
	Infrastructure	Average number of beds available per hospital	2008	–	Statistical Abstract of Odisha (different years), District Statistical Handbooks of various districts
		Percentage of villages electrified	2008	–	
		Total length of rural roads (km)	2008	–	
		Average number of commercial banks per lakh population	2008	–	
		Average number of primary agricultural cooperative societies (PACS) per lakh population	2008	–	
		Percentage of people having membership in PACS	2008	–	
		Total number of small scale industries (SSI) in each district	2008	–	

'+' means increasing vulnerability and '–' means decreasing vulnerability.

Adaptive capacity: This represents the ability of a household to mitigate potential damages from the climate extremes[18]. It can be either specific or generic[50]. The former represents interventions that particularly reduce the impact of extreme events (these interventions include early warning systems and cyclone shelters which help in curbing potential mortality due to cyclones, and building of sea dykes and flood embankments that reduce possible damages from cyclones and floods). It is, however, acknowledged that such information is not available at the district level. The generic adaptation measure refers to the development characteristics such as economic capacity, technology and infrastructure that may increase ability of the system to stand against a wide range of risk and shocks, including cyclones and floods[50]. The present analysis has taken components like economic capacity and equity, technology, information and skills and infrastructure to estimate adaptive capacity of each district.

To capture economic capacity and equity, proxy variables like percentage of people in the BPL (below poverty line) category, per capita DDP (district domestic product), percentage of people employed, female work participation rate and Gini-coefficient of land holding were considered. A study by Moss *et al.*[51] considers GDP per capita and Gini-index as the potential indicators to represent economic condition at a national level. Since agriculture, as outlined above, is the basic source of livelihood for a majority of households in Odisha, the inputs required to improve farm-level production were considered as indicators of technology, e.g. total area covered by irrigation (ha), yield rate of cereals (q/ha) and application of fertilizer (kg/ha). O'Brien *et al.*[52] established that the districts with higher irrigation rates had higher adaptive capacity in India. The yield rate of cereal crops is intended to capture the degree of modernization in the agriculture sector and the access of farmers to production inputs that can be used to buffer the impact of extreme events[29]. Districts with high production per unit area are presumed to be less vulnerable than those with low production. Palanisami *et al.*[43] pointed out that higher productivity could increase the adaptive capacity of rural farm households.

The proxy indicators like literacy and female literacy rate were taken to depict information and skills, while assuming that these indicators reduce the vulnerability level since education enhances the level of awareness and understanding of existing risk and shocks, access to information on potential risk reduction measures, chances of obtaining a formal job and moving out of a risk area[53,54]. In view of this, previous studies established that the level of education is responsible for reducing vulnerability[29,52–55]. In addition, accessibility to well-developed infrastructure enhances the adaptive capacity of households[56]. Various proxy variables were considered to represent the status of infrastructure, e.g. average number of beds per hospital, percentage of villages electrified, total length of rural roads (km), average number of commercial banks per lakh population, average number of primary agricultural cooperative societies (PACS) per lakh population, percentage of people having membership in PACS and total number of small scale industries (SSI). These indicators capture the overall development of infrastructure in different districts of Odisha, which either mitigates direct potential impacts or works as a supportive instrument to enhance adaptive capacity of households. For example, a higher number of beds per hospital could reduce the potential mortality rate during the occurrence of cyclones and floods. The indicators like percentage of villages electrified, total length of rural roads and number of SSI represent the development of a district. The villages which are well connected with district headquarters by concrete road are able to access relief faster than the other villages. Further, the households living in the villages having concrete roads could be easily evacuated during an emergency, which could reduce the death toll due to cyclones and floods. Further, variables like average number of commercial banks and PACS depict the availability of formal institutions that assist households to smooth income and consumption.

The proxy indicators of sensitivity and adaptive capacity were collected for the year 2008. Since data for some of the indicators are not available for this year, they were adjusted based on historical trends. For example, a compounded annual growth rate (CAGR) of an indicator was calculated based on the data available for previous two time-periods, and using the CAGR value, the one for the year 2008 was estimated.

Calculation of vulnerability

There are two ways to analyse indicators: (i) giving equal weight to each indicator and (ii) assigning a weight to each indicator with the help of expert judgement, principal component analysis, correlation with past disaster events and fuzzy logic[57]. The present analysis has given equal weight to each indicator since the appropriateness of giving weights is still dubious as there is no standard weighting method against which each method is tested for precision[27]. Since the indicators are measured in different units, a normalization method was followed in order to aggregate them into a single value, which is shown in eq. (1)[52,58]

$$\text{Index } X_{ij} = \left[\frac{(X_{ij} - \text{Min } X_i)}{(\text{Max } X_i - \text{Min } X_i)} \right], \tag{1}$$

where Index X_{ij} is the index value (i.e. 0 to 1) of the indicator for district j, X_{ij} represents the value of the ith indicator for district, and Max X_i and Min X_i manifest the maximum and minimum value of the ith indicator among all the districts.

Table 6. District-wise vulnerability indices in Odisha

District	Exposure	Rank	Sensitivity	Rank	Adaptation	Rank	Vulnerability	Rank
Angul	0.090	20	0.390	26	0.472	6	0.371	26
Balasore	0.687	1	0.549	5	0.581	21	0.591	1
Baragarh	0.113	18	0.475	18	0.505	10	0.419	23
Bhadrak	0.566	4	0.481	16	0.532	16	0.522	4
Bolangir	0.176	11	0.502	14	0.510	11	0.443	20
Boudh	0.056	25	0.475	19	0.572	19	0.439	21
Cuttack	0.540	7	0.451	21	0.413	1	0.450	18
Deogarh	0.016	29	0.479	17	0.594	25	0.443	19
Dhenkanal	0.125	15	0.408	24	0.515	12	0.403	25
Gajapati	0.117	16	0.530	9	0.589	23	0.478	12
Ganjam	0.430	8	0.557	3	0.425	2	0.470	14
Jagatsinghpur	0.543	5	0.440	23	0.463	5	0.471	13
Jajpur	0.542	6	0.535	8	0.568	18	0.552	3
Jharsuguda	0.010	30	0.287	30	0.499	9	0.333	30
Kalahandi	0.127	14	0.595	1	0.582	22	0.498	9
Kandhamal	0.083	21	0.521	11	0.590	24	0.468	15
Kendrapada	0.677	2	0.527	10	0.524	13	0.555	2
Keonjhar	0.109	19	0.491	15	0.574	20	0.456	17
Khurda	0.283	9	0.324	29	0.431	3	0.367	27
Koraput	0.071	22	0.510	13	0.626	26	0.479	11
Malkangiri	0.026	28	0.548	6	0.670	29	0.504	8
Mayurbhanj	0.185	10	0.540	7	0.532	15	0.467	16
Nabarangpur	0.031	26	0.589	2	0.667	28	0.517	5
Nayagarh	0.132	12	0.404	25	0.543	17	0.417	24
Nuapada	0.060	24	0.520	12	0.677	30	0.505	7
Puri	0.609	3	0.441	22	0.479	7	0.491	10
Rayagada	0.129	13	0.557	4	0.639	27	0.512	6
Sambalpur	0.063	23	0.378	28	0.438	4	0.345	29
Sonepur	0.116	17	0.471	20	0.530	14	0.430	22
Sundargarh	0.027	27	0.381	27	0.488	8	0.363	28
Descriptive statistics								
Min.	0.010		0.287		0.413		0.333	
Max.	0.687		0.595		0.677		0.591	
Mean	0.225		0.478		0.541		0.459	
SD	0.225		0.076		0.073		0.063	

Min, Minimum value; Max, Maximum value; SD, Standard deviation.

The actual index value of proxy indicators of adaptive capacity, except percentage of rural families under BPL category and Gini-coefficient of land holding, is deducted from '1', so that the higher index value denotes lower vulnerability[52,58]. After standardization of all the proxy indicators, the components and determinants of vulnerability (Table 5) and the aggregate vulnerability indices are calculated as

$$M_j = \left[\sum_{i=1}^{n} \text{Index } X_{ij}\right] \Big/ n, \tag{2}$$

where M_j is the component of vulnerability or the determinant of vulnerability or the aggregate vulnerability index; Index X_{ij} is the index value of the ith indicator for district j, and n is the number of indicators considered to represent M_j.

Results and discussion

Table 6 reports vulnerability scores for all the districts of Odisha. Among the vulnerability indices and their determinants, a higher standard deviation (SD) is found in the case of exposure (0.225) compared to sensitivity (0.076), adaptation (0.073) and vulnerability (0.063). But, the average score of exposure (0.225) is less than vulnerability (0.459) and its other two determinants, i.e. sensitivity (0.478) and adaptation (0.541). This suggests that the variation of vulnerability level across all the districts of the state is lower (Figure 3) compared to the exposure, and hence, most of the districts are becoming vulnerable because of high sensitivity and low adaptive capacity. In addition, it is also found that sensitivity and adaptive capacity are highly correlated with vulnerability, i.e. the Pearson's correlation coefficients are 0.829 and 0.534 respectively (Table 7). This implies that sensitivity and adaptive capacity are vital components to derive vulnerability. For example, districts like Nuapada, Nabarangpur, Malkangiri and Rayagada have higher vulnerability value, even though they have lesser exposure to both cyclones and floods. In fact, some of the coastal districts (e.g. Balasore and Kendrapada) also have both high exposure and vulnerability values compared to the

Table 7. Pearson's correlation between determinants and major components of vulnerability

	Exposure	Demography	Agriculture	Health	Sensitivity	Technology	Economic capacity	Information and skills	Infrastructure	Adaptation	Vulnerability
Exposure	1										
Demography	0.649***	1									
Agriculture	0.180	0.567***	1								
Health	–0.640***	–0.249	–0.104	1							
Sensitivity	0.136	0.749**	0.725***	0.365**	1						
Technology	–0.424**	–0.234	0.066	0.283	0.036	1					
Economic capacity	0.743***	0.456**	0.242	–0.577***	0.070	–0.375**	1				
Information and skills	–0.571***	0.078	0.333*	0.76***	0.623***	0.303	–504***	1			
Infrastructure	–0.403**	0.049	0.31*	0.403**	0.390**	0.194	–0.331*	0.711***	1		
Adaptation	–0.374**	0.166	0.500***	0.517***	0.610***	0.419**	–0.131	0.788***	0.826***	1	
Vulnerability	0.541***	0.840***	0.689***	–0.13	0.829***	-0.050	0.47***	0.286	0.331	0.534***	1

***$P < 0.01$, **$P < 0.05$ and *$P < 0.1$.

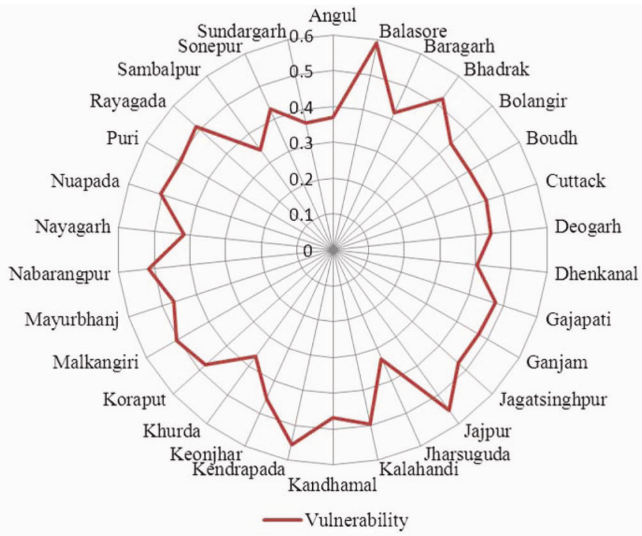

Figure 3. Spider diagram of district-wise vulnerability indices of Odisha.

remaining districts. While calculating correlation coefficient of different components of exposure, sensitivity and adaptation with vulnerability, a positive correlation was found in the case of exposure (0.541), demography (0.84), agriculture (0.689) and economic capacity (0.47); these coefficients are significant at the 1% level. This reveals the fact that exposure, demography, agriculture and economic capacity are the major drivers of vulnerability. But, it should be noted that the influence of demography and agriculture on vulnerability outcome is higher than that of exposure.

Based on the district-level vulnerability indices of Odisha, eight districts have vulnerability level of more than 0.5, namely Balasore, Bhadrak, Jajpur, Kendrapada, Malkangiri, Nabarangpur, Nuapada and Rayagada (Table 8 and Figure 4). Out of them, five districts such as Jajpur, Malkangiri, Nabarangpur, Nuapada and Rayagada are non-coastal districts. In fact, these districts, except Jajpur, have less exposure. But, they have high sensitivity and low adaptive capacity (Table 6), making them more vulnerable. Though the remaining coastal districts like Jagatsinghpur (rank 5), Puri (rank 3) and Ganjam (rank 8) have high exposure, they have less vulnerability score – Jagatsinghpur (rank 13), Puri (rank 10) and Ganjam (rank 14) – because these districts have less sensitivity and/or high adaptive capacity (Table 6). Notably, it has been found that some of the non-coastal districts are highly vulnerable compared to these coastal districts. This suggests that the DRM programme of the state should cover the non-coastal districts. For example, the districts like Malkangiri and Nabarangpur are not covered in the existing DRM programme implemented by the state during 2002–2008 (ref. 30). The present DRM programme in the state mainly focuses on the activities related to massive awareness campaign about preparedness for natural disasters like cyclones and floods (e.g. organizing mass meetings, different competitions like essay, debate and drawing among school students, school safety programmes, wall paintings, explaining dos and don'ts in various disasters, training programmes for village-level selected volunteers). Since sensitivity and adaptive capacity are the major determinants, this study emphasizes on activities to be undertaken through the DRM programme which will enhance the resilience of various households in Odisha, i.e. we should integrate both the development-based activities and the DRM programme. Further, 17 districts have vulnerability level between 0.4 and 0.5, and five districts have vulnerability level less than 0.4 (Table 8 and Figure 4).

Among all the districts of the state, Balasore, Kendrapada and Jajpur occupy first, second and third place in the context of vulnerability score, i.e. 0.591, 0.555 and 0.552 respectively (Table 6). These three districts have high exposure to both cyclones and floods. This indicates that the frequency and intensity of these shocks are high

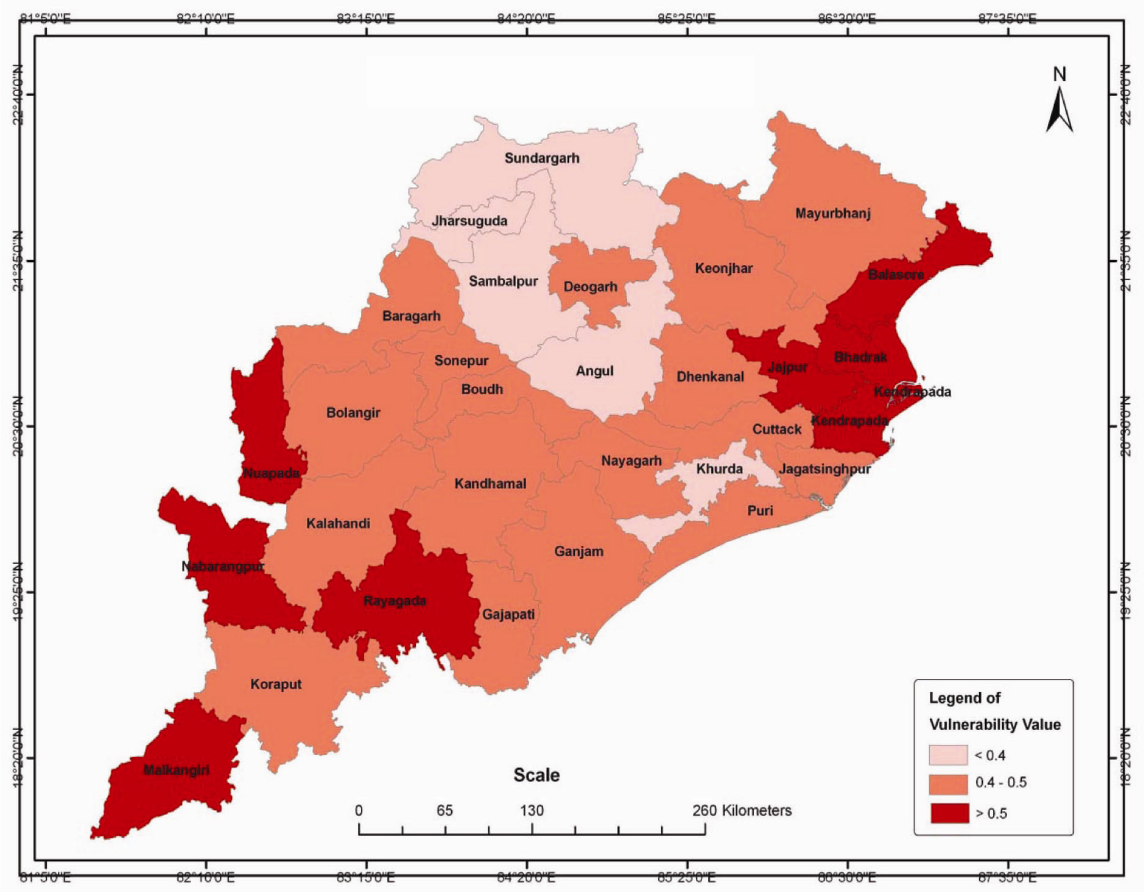

Figure 4. Vulnerability map of Odisha.

Table 8. Classification of districts in Odisha based on vulnerability score

Vulnerability score	District
> 0.5	Balasore, Bhadrak, Jajpur, Kendrapada, Malkangiri, Nabarangpur, Nuapada and Rayagada
0.4–0.5	Baragarh, Bolangir, Boudh, Cuttack, Deogarh, Dhenkanal, Gajapati, Ganjam, Jagatsinghpur, Kalahandi, Kandhamal, Keonjhar, Koraput, Mayurbhanj, Nayagarh, Puri and Sonepur
< 0.4	Angul, Jharsuguda, Khurda, Sambalpur and Sundargarh

in these districts. For instance, these three districts have been affected by at least 20 cyclones and floods during 1994–2010; Balasore district has experienced a higher number of these events, 30 (based on the information collected from Special Relief Commissioner, Government of Odisha, District Emergency Offices, and Government of Odisha[4]). BMTPC[32] reports that the total area (i.e. 100%) of Balasore and Kendrapada districts is prone to wind velocity (50 and 55 m/s) due to the cyclonic storms, and 46.3% area in Balasore and 35.5% in Kendrapada are flood-prone. Balasore has high exposure (0.687 with rank 1) and sensitivity (0.549 with rank 5) and low adaptive capacity (0.581 with rank 21); Kendrapada has high exposure (0.677 with rank 2) and sensitivity (0.527 with rank 10), while Jajpur has low adaptive capacity (0.568 with rank 18) (Table 6).

Conclusion and policy implications

This study calculated district-wise relative vulnerability indices to assign vulnerability rank to each district according to its vulnerability level with regard to cyclones and floods. In doing so, an integrated approach was adopted where vulnerability is the function of exposure, sensitivity and adaptive capacity. A number of proxy indicators were considered in order to capture the determinants of vulnerability. Since the measurement unit for each indicator varies, a normalization procedure was used in order to aggregate them into a single value for comparison.

Calculating the vulnerability indices for all the districts of Odisha, the present study found that Balasore, Bhadrak, Jajpur, Kendrapada, Malkangiri, Nabarangpur, Nuapada and Rayagada have vulnerability levels higher than the other districts of the state. Balasore, Bhadrak and Kendrapada are the coastal districts, while the remaining five districts are non-coastal districts. As highlighted in this article, previous vulnerability studies in the context of cyclone and/or flood have focused mainly on the coastal districts. Notably, the above analysis found high vulnerability score for non-coastal districts compared to other coastal districts like Jagatsinghpur, Puri and Ganjam. Both researchers and the DRM programme of the state should give emphasis on the less-exposed non-coastal districts, in addition to highly exposed coastal districts. Among all the districts, Balasore, Kendrapada and Jajpur occupy first, second and third rank respectively, in terms of vulnerability indices. Sensitivity and adaptive capacity have a role in deriving higher vulnerability score for majority of the districts in Odisha, and its components like demography, agriculture and economic capacity are the major cause for the increasing vulnerability. These components should be considered in the disaster management policy, as the present DRM programme is mostly focused on activities that reduce mortality and the people affected[59], in order to reduce potential vulnerability due to cyclones and floods. This reveals the need for the DRM programme of the state to include development-based activities in addition to disaster-specific risk reduction measures, so that the resilience capacity of the various households will be enhanced.

Caution is required while interpreting the findings of this study. First, the vulnerability indices for the districts have been calculated for a particular time period (i.e. 2008), and this may change while we calculate it for any future time period. Second, the present vulnerability analysis is based on the observed data, and in particular, has not estimated the districts that are likely to be vulnerable in the foreseeable future. Third, this study has given equal weight to each indicator.

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