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Estimating cyclone vulnerability and its linkages with child mortality trajectories along the Bay of Bengal coast of India: a geospatial approach

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Abstract The coastal population of Indian subcontinent experience a variety of coastal hazards, of which cyclone is the most destructive one. The paper analyses the vulnerability level of the east coastal districts of Bay of Bengal stretching for 1400 km by adopting an innovative approach to estimate vulnerability index through hazard exposure, sensitivity, and adaptability measures. Findings reveal that northern districts located close to the apex of Bay of Bengal are more vulnerable to coastal cyclones as compared to the southern part. Districts with a higher degree of coastal vulnerability experience markedly higher neonatal and under-5 mortality. Prevalence of diarrhoea among children, unimproved sanitation facility and unimproved sources of drinking water are revealingly associated with more neonatal and under-5 mortality across coastal districts. Women, children, elderly and the agrarian population are more sensitive to the cyclone. Lack of infrastructure, education and poor health care system hinder adaptive capacity. The study propagates strong disaster planning and improvement of basic facilities, especially immunization coverages of the vulnerable districts of east coast in India.

Keywords Bay of Bengal · Neonatal and under-five mortality · Cyclone · Vulnerability · India

Introduction

The global sea surface temperature has increased in the past half-century due to the global greenhouse gas emission, leading to the intensification of cyclones over time (Deo & Ganer, 2014). Globally, 40% of the world population resides within 60 km from the coast (Kundzewicz, 2003). The Intergovernmental Panel on Climate Change (IPCC) has identified several hotspots in the climate change sensitive regions where livelihood depend on subsistence agriculture, fishing, and aquaculture (UCS, 2011). These vulnerable places experience damage to property, lives, and displacements. Aside from the direct losses, food insecurity, lack of employment opportunities and health impairments are exacerbated by coastal hazards. Additional socioeconomic impacts are mainly accrued by developing nations due to low challenges to adaptation and high mitigation strategies (Wiek et al., 2010). Over the decades, South Asia has experienced recurrent hazards related to tropical cyclones.

In the north Indian Ocean region, Bay of Bengal alone accounts for 7% of all global cyclones of

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the world (Sahoo & Bhaskaran, 2016). This area is identified as a hotspot characterized by high population density, poverty, low development level, and exclusion (Sahoo & Bhaskaran, 2016). Historically, the coastal zones of India have attracted people due to port facilities, prosperity in agriculture, tourism, industries, trades, transport benefits, and habitable ecology (Harley et al., 2006; Rani et al., 2018a, 2018b). However, these regions are vulnerable due to the coincidence of low elevation, storm surges, floods, saline intrusion, coastal erosion (Nicholls et al. 2007), and other environmental challenges leading to infectious diseases and mortality (Dasgupta et al., 2016; Ramasamy & Surendran, 2011).

The coastal population of Indian subcontinent experience a variety of coastal hazards, the most destructive of which is cyclone. With nearly 137 million population (Census of India, 2011) residing along the Bay of Bengal coastal district, the vulnerability is greater than the Arabian Sea coast due to the higher frequency of cyclones (4:1 ratio), low flat coastal terrain, high population density, poor knowledge of the community, inadequate response and preparedness and absence of any hedging mechanism (Rangachari et al., 2011). Most recently, on 20th May 2020, the super cyclone *Amphan* lashed with 155 km/h, as tall as a two-story building on the Eastern coast and state of West Bengal in India (Basheer Ahammed & Pandey, 2021). Strong winds, tidal waves, and heavy rains exacerbated the devastation, causing flooding across the deltaic regions with an estimated economic loss of US$13.5 billion (Baidya et al., 2020). In the following year 2021, another cyclonic storm, *Yaas* intensified in the Bay of Bengal in May and ravaged much of the Bay of Bengal coast. India has witnessed severe cyclones, namely *Laila, Helen, Phailin, Hudhud, Vardah, Ockhi, Titli, Gaja*, *Amphan* and *Yaas* from 2010 to 2021 (Giribabu et al., 2021). Because of the risk of cyclones, the Indian coastal regulation zone (CRZ) has demarcated 500 m from the shoreline as coastal vulnerability zones. However, considering the coastal geomorphology, a buffer of 100 km perpendicular to the shoreline is measured for coastal vulnerability assessments (Kantamaneni et al., 2019). Literature suggests that aquaculture and industrialization have been introduced in these coastal regions to escape subsistence livelihood and poverty, which had been the prime loop to coastal vulnerability (Kumaran et al., 2020).

Previous studies on coastal vulnerabilities

Natural hazard vulnerability has a detrimental impact on human health, especially at conception and ending at the start of the third postnatal year (first 1000 days of life) (Abuodha & Woodroffe, 2010; Hennecke et al., 2004; Klein & Nicholls, 1999; Nowak-Szczepanska et al., 2021; Shaw et al., 1998). Progressively, with the availability of satellite images and radar data, coastal hazard vulnerability assessments have soared (Marghany, 2016; Cazenave & Llovel, 2010; Jiang et al., 2018; Kantamaneni et al., 2019; Nicholls et al. 2007). However, a handful of scientists have conducted vulnerability assessment as a function of geomorphological, socioeconomic, infrastructures and other vectors (Brown et al., 2018; Ružić et al., 2019). The use of convoluted indices to understand the vulnerability has been adopted by many scholars like Cutter et al., 2006, who measured Social Vulnerability Index (SVI) using socioeconomic and infrastructural indicators. Kim and Gim (2020) used the spatial regression model to assess flood vulnerability and adaption along the Java coast (Kim & Gim, 2020). In India, Mazumdar and Paul (2016) and Sharma and Patwardhan (2008) used the principal component method to measure the SVI due to cyclones. Scientists have studied the extreme effect of climate variability on health and mortality trajectories (Grace et al., 2015; Waal et al., 2006). Exposure to cyclones increases the risk of having a preterm birth (Grabich et al., 2016; Sun et al., 2020; Xiong et al., 2008) and consequently plays a critical role in neonatal mortality (Baqui et al., 2013; Simmons et al., 2010). A previous study has observed that tropical storm increases the risk of illness, injuries, and medical needs (Waring et al., 2005). Because of population density, unimproved sanitation and poor health facilities, the risk of disease transmission tends to increase in developing countries. Following Cyclone *Aila* in 2008, gastroenteritis and diarrhoeal disease have been documented in the parts of West Bengal, India (Bhunia & Ghosh, 2011; Panda et al., 2011). Morbidities like acute respiratory diseases and leptospirosis have been reported following a cyclone in Orissa, India, in 1991 (Sehgal et al.2002). Extreme weather events have a significant impact on the health of a child (Bhandari et al., 2020; Neumayer & Plümper, 2007). In the Philippines, female infant mortality was 15.1 times higher than male infant mortality during a natural disaster (Anttila-Hughes & Hsiang, 2013). In addition, a cross-country analysis of 12 developing countries revealed an increase in infant mortality as a result of the cyclone's long-term impact (Miranda, 2019). Because cyclones have the potential to cause infant and under-five mortality, empirical studies suggest that natural hazard-induced child mortality responds to higher fertility rates (Finlay, 2009; Nobles et al., 2015).

The rich body of literature in this field mainly focused on different natural hazard vulnerability assessments or the aftermath of extreme events. Studies in India are rare in this field, particularly those highlighting aggregate measurement of vulnerability based on public data and revealing the association between vulnerability and child health. The present study, which is unique in its approach, aims to estimate vulnerability along the Bay of Bengal's coastal districts, consisting of 45 districts within a 100 km buffer zone across the eastern coastline. We made strides towards integrating vulnerability and its effects on health by considering two crucial health indicators, i.e., neonatal and under-five mortality. The study adds to the body of literature by demonstrating evidence of socioeconomic vulnerability as a function of exposure, adaptation, and sensitivity due to cyclones and their linkages to child mortality in India.

Methods

Study area

Districts within 100 km from the coastline were considered coastal districts according to the definition of Indian meteorological department (IMD) (IMD 2008). A total of 45 districts were selected for this study (Fig. 1). The temperature of the study area exceeds 30º C and the region experience a high level of humidity. Annual rainfall ranges from 1,000 to 3,000 mm. Most of the cyclones here are developed either in the month of April to May (pre-monsoon season) in the apex of the Bay of Bengal coast or October to November (pre-winter season) in the southern part of the Bay of Bengal coast. The coastal populations, particularly in the developing countries are most likely to face coastal hazards.

The Bay of Bengal coastal districts extend from the South 24 Parganas of West Bengal in the North to Ramanathapuram district of Tamil Nadu in the South. The cyclone-prone zone covers 4-States and one-union territory (UT), Puducherry. Odisha distinguishes itself as the most affected state due to cyclonic storms each year. Among all other states, West Bengal has the smallest shoreline, while Andhra Pradesh has the longest. Due to the obscured shape of the coast and a wider continental shelf, the cyclones and coastal floods tend to hit the northward of the Bay of Bengal coastal districts of India and Bangladesh. India is surrounded by the Arabian Sea and Bay of Bengal, whereas the coastline of the Bay of Bengal comprises West Bengal, Odisha, Puducherry, Andhra Pradesh, and the eastern part of Tamil Nadu.

Almost every year, moderate to severe cyclones struck the coastal districts of the Bay of Bengal, which is a major cause of economic loss due to the damages to both physical and human resources. A large proportion of the rural population lives close to the coast and their livelihood mainly depend on agriculture and fishing. In addition, as a result of climate change, the livelihood of coastal communities are affected due to the threat of sea-level rise and cyclones (Oliver-Smith 2009). Although most of the coastal districts are able to recover the damages, still the districts of Odisha and West Bengal are lagging behind.

Operational definition and analysis

Vulnerability is defined as "A function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Brooks, 2003). Total cyclone frequency, severe cyclone frequency, wind speed and shoreline length were considered in the calculation of cyclone exposure. Additionally, we included three components of sensitivity; demographics, agriculture and health. The components that help to adjust to different shocks such as economic capacity and skills & infrastructure were considered to calculate the adaptive capacity as better-off households are able to recover the damages of the cyclones in a short period of time (Abdullah et al., 2016; Burslem et al., 2000) (Table 1**).** The vulnerability index was calculated using the universal normalization technique-

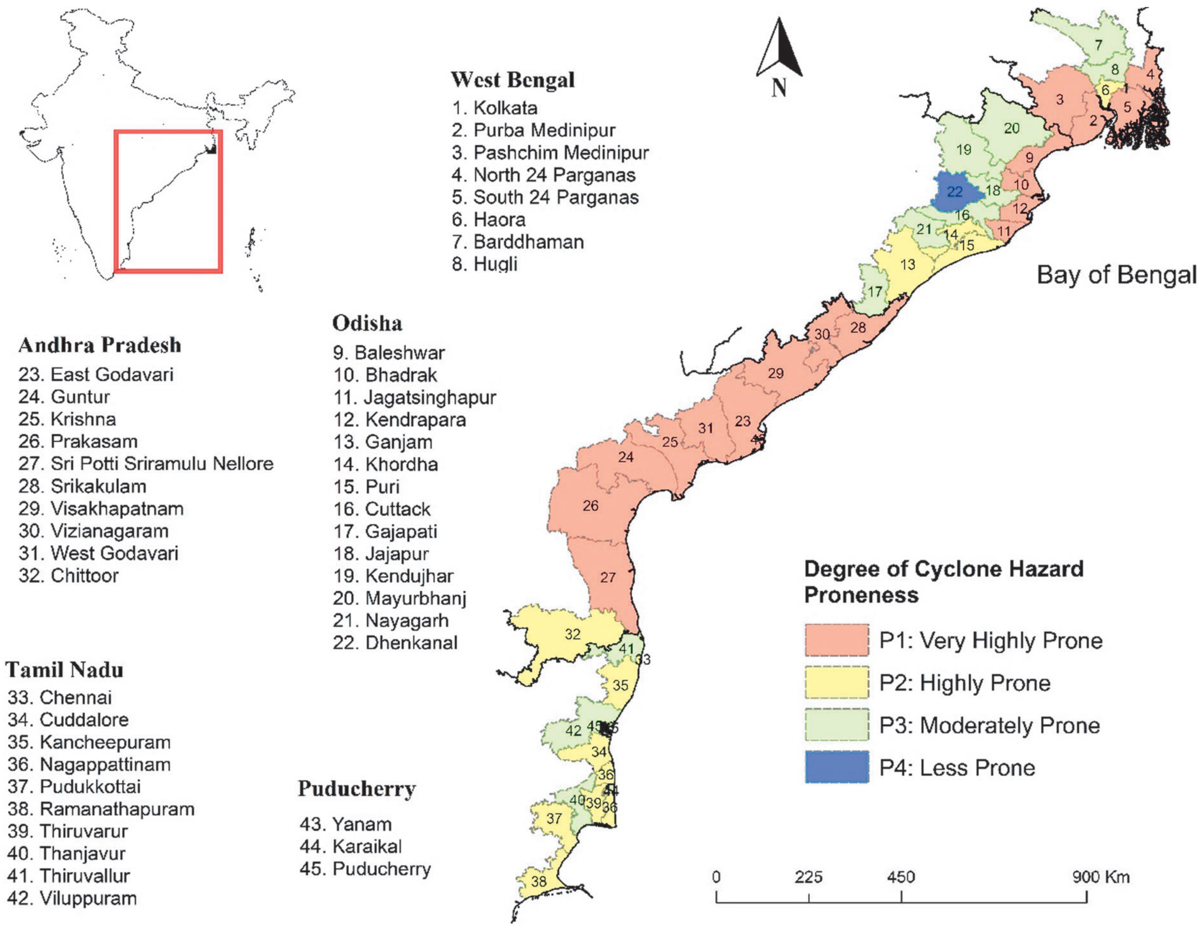

Fig. 1 Bay of Bengal coastal districts of India affected by cyclones (100 km inland buffer). *Source:* Indian meteorological department, Government of India (IMD)

$$X_{ij} = \left[\frac{\left(X_{ij} - MinX_{ij} \right)}{MaxX_{ij} - MinX_{ij}} \right]$$

where X_{ij} refers to the normalized index value of the indicator, i represents indicators, j is the coastal district and $MinX_{ij}$ and $MinX_{ij}$ indicates the maximum and minimum value of the ith indicator among all the coastal districts. The value of the index varies from 0 to 1. Then, the composite vulnerability index was calculated using the equal weighting approach (Soares et al., 2012). After normalizing all the indicators, the vulnerability index was derived as:

$$M_j = \left[\frac{\sum_{i=1}^{n} IndexX_{ij}}{n} \right]$$

where Mj is the vulnerability index Xij is the index value of the ith indicator for district j, and n is the number of indicators considered to represent the index.

The fourth round of the National Family Health Survey (NFHS-4), the landmark Demographic Health Survey (DHS) in India, was used to estimate neonatal and under-5 mortality at the district level, considering the information of 69,971children in the study area (ICF & IIPS, 2017). The mortality rate was calculated using the information of the date of birth of the child, their survival status, and age at death of the deceased child. The synthetic cohort probability approach was applied to estimate the neonatal mortality rate (NMR) and under-5 mortality rate (U5MR) for the ten years preceding the survey using the full birth history information of women aged 15–49. The

Table 1 Description and data source to measure cyclone hazard exposure, sensitivity, adaptive capacity and vulnerability

Determinants of vulnerability	Components	Indicators	Data source
Hazard and exposure	Characteristics of cyclone	Frequency of total cyclone	IMD report of cyclone by Government of India
		Frequency of severe cyclone	
		Wind speed in Knots	
	Coast length	Coastal length in (km)	Measured by authors using GIS
Sensitivity	Demographic sensitivity	Share of district population to total population of the state	Census of India, 2011
		Growth rate of the population during 2001–2011	
		Population density	
		Percentage of rural population	
		Percentage of female population	
		Percentage of children (less than 6 years)	
		Percentage of old people (above 60 years)	
	Agricultural sensitivity	Percentage of cultivator	Census of India, 2011
		Percentage of labourer	
		Percentage of gross sown area	Land use statistics
	Health sensitivity	Crude death rate	Districtsofindia.com
		Percentage of stunting children	National Family Health Survey (NFHS), round 4
Adaptive capacity	Economic capacity	Economic development Index	Mohanty, S. K., Dash, A., Mishra, R. S., & Dehury, B. (2019)
	Skils & Infrastructure	Hospital available per 100,000 population	Data.gov.in
		Road density	Brief Industrial Profile of different districts, Ministry of MSME
		Average number of bank per 100,000 population	
		Total number of small scale industries in each district	
		Electricity	Census of India, 2011
		Pucca house	
		Literacy rate	
		Female literacy rate	

total district population was derived from the Indian Census, 2011.

Scatter plots were used to establish the association between coastal vulnerability and neonatal and under-5 mortality in coastal districts of the Bay of Bengal. Finally, linear regressions, Spatial Lag Model (SLM), and Spatial Error Model (SEM) were used to find out the empirical association between coastal vulnerability and neonatal and under-5 mortality. SLM and SEM helped to adjust the spatial endogeneity and provide a refined measure.

Results

Vulnerability

In India, the number of cyclones, especially severe cyclones, increased considerably over the last decade (Fig. 2b). Meanwhile, a large number of people were displaced as a result of these disasters, notably in 2012 (Fig. 2a), when more than 9 million people were displaced. More than 5 million people in India were displaced by natural catastrophes in

2019, accounting for the highest number of new internal movements in the world (IDMC, 2020).

The districts located in the apex part of the Bay of Bengal were more vulnerable to coastal cyclones than the southern parts (Fig. 3). The highest degree of exposure was observed in South 24 Parganas district of West Bengal. A very high degree of sensitivity was noted in Kendrapara, followed by Gajapati, Thiruvarur and Baleswar because of the higher degree of demographic, agricultural, and health sensitivity. Adaptability was higher in the districts of Chennai and Kolkata. This study demonstrated a high vulnerability index in South 24 Parganas district, followed by Baleswar, Purba Medinipur, Kendrapara, Srikakulam and Bhadrak. Chennai, the maga city of Tamil Nadu state had the lowest vulnerability index due to its higher adaptive capacity.

Neonatal and under-5 mortality

Figure 4 depicts the spatial distribution of neonatal and under-5 mortality rate (per 1000 live births) across 45 coastal districts of the Bay of Bengal. It is worth mentioning that a similar heterogeneity pattern was observed in the case of both NMR and U5MR. The spatial pattern of NMR shows very high occurrence in most districts of Odisha, much higher than the national level, i.e. NMR and U5MR for India were 30 and 50 deaths per 1000 live births in India. On the contrary, a lower NMR was observed in Chennai and Kolkata, the megacities of the study area. However, in the districts of Gajapati, Nayagarh, Prakasam, Kendujhar, Srikakulam, East Godavari, Puri, Jajapur and South 24 Parganas, the NMR and U5MR outpaced the Indian average.

Association of NMR and U5MR with vulnerability

Figure 5 depicts the result of the scatter plot between the coastal vulnerability with neonatal and under-5 mortality rates. The radius of the circles represents the volume of the total population of the district. Districts with higher levels of coastal vulnerability had higher rates of neonatal mortality and under-five mortality. The study found a positive association though the relationship was weaker in the NMR relative to U5MR.

OLS regression was applied to examine the effects of coastal vulnerability on child survival after adjusting other socioeconomic components (Table 2). The coefficient of under-5 mortality was higher with coastal vulnerability index ($\beta = 67.58$, p-value = 0.00) as compared to neonatal mortality ($\beta = 52.3$, p-value = 0.00). Among the covariates, the prevalence of diarrhoea among children was significantly associated with neonatal and under-5 mortality across coastal districts of the Bay of Bengal. In addition, the proportion of using unimproved sanitation facility ($\beta = 0.26$, p-value = 0.04) and unimproved sources of drinking water ($\beta = 0.36$, p-value = 0.03) showed

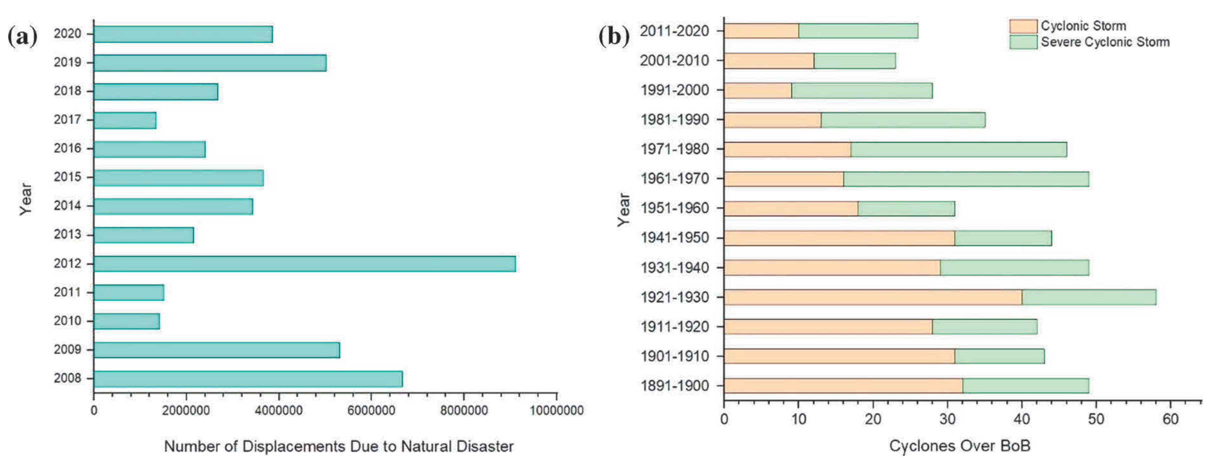

Fig. 2 (**a**) Number of new displacements due to natural disaster in India; (**b**) Frequency of cyclones over Bay of Bengal. *Source:* based on https://www.internal-displacement.org/countries/india.

Fig. 3 Vulnerability, exposure, sensitivity and adaptive capacity in Costal area of Bay of Bengal: District level summary. *Source:* Based on author's calculation

District	State	Vulnerability	Exposure	Sensitivity	Adaptive capacity
Baleshwar	Odisha	0.56	0.59	0.46	0.37
Barddhaman	West Bengal	0.33	0.09	0.30	0.41
Bhadrak	Odisha	0.53	0.51	0.42	0.36
Chennai	Tamil Nadu	0.19	0.15	0.19	0.78
Chittoor	Andhra Pradesh	0.42	0.39	0.36	0.50
Cuddalore	Tamil Nadu	0.38	0.29	0.29	0.44
Cuttack	Odisha	0.42	0.45	0.33	0.52
Dhenkanal	Odisha	0.33	0.03	0.36	0.38
East Godavari	Andhra Pradesh	0.49	0.61	0.33	0.47
Gajapati	Odisha	0.47	0.15	0.47	0.21
Ganjam	Odisha	0.47	0.38	0.41	0.38
Guntur	Andhra Pradesh	0.42	0.27	0.41	0.41
Haora	West Bengal	0.41	0.57	0.19	0.54
Hugli	West Bengal	0.35	0.19	0.32	0.46
Jagatsinghapur	Odisha	0.50	0.52	0.43	0.46
Jajapur	Odisha	0.43	0.31	0.39	0.41
Kancheepuram	Tamil Nadu	0.31	0.35	0.25	0.68
Karaikal	Puducherry	0.32	0.27	0.24	0.57
Kendrapara	Odisha	0.54	0.56	0.47	0.41
Kendujhar	Odisha	0.39	0.04	0.41	0.28
Khordha	Odisha	0.29	0.18	0.27	0.58
Kolkata	West Bengal	0.35	0.57	0.16	0.68
Krishna	Andhra Pradesh	0.48	0.52	0.36	0.45
Mayurbhanj	Odisha	0.44	0.13	0.41	0.23
Nagappattinam	Tamil Nadu	0.43	0.44	0.36	0.51
Nayagarh	Odisha	0.38	0.13	0.40	0.38
North 24 Parganas	West Bengal	0.46	0.63	0.29	0.53
Pashchim Medinipur	West Bengal	0.46	0.35	0.41	0.36
Prakasam	Andhra Pradesh	0.45	0.37	0.38	0.40
Puducherry	Puducherry	0.31	0.20	0.36	0.63
Pudukkottai	Tamil Nadu	0.33	0.09	0.39	0.50
Purba Medinipur	West Bengal	0.55	0.64	0.43	0.42
Puri	Odisha	0.46	0.46	0.39	0.46
Ramanathapuram	Tamil Nadu	0.39	0.31	0.38	0.51
South 24 Parganas	West Bengal	0.57	0.80	0.30	0.40
Nellore	Andhra Pradesh	0.49	0.57	0.35	0.44
Srikakulam	Andhra Pradesh	0.53	0.51	0.44	0.37
Thanjavur	Tamil Nadu	0.39	0.30	0.41	0.55
Thiruvallur	Tamil Nadu	0.25	0.20	0.18	0.62
Thiruvarur	Tamil Nadu	0.42	0.26	0.46	0.45
Viluppuram	Tamil Nadu	0.39	0.20	0.44	0.45
Visakhapatnam	Andhra Pradesh	0.40	0.41	0.33	0.55
Vizianagaram	Andhra Pradesh	0.41	0.20	0.43	0.40
West Godavari	Andhra Pradesh	0.45	0.33	0.44	0.42
Yanam	Puducherry	0.40	0.44	0.31	0.55

Low (< Mean)
Medium (Mean-1 std.dev.)
High (>1std.dev.)

a significant positive association with district-level under-5 mortality rate.

The result of SEM showed a spatial association between coastal vulnerability and NMR—U5MR. Between the two spatially estimated models, the study found a lower AIC value for the SEM model. With respect to neonatal mortality, the coefficient was largest for coastal vulnerability ($\beta = 44.86$, p-value $= 0.00$). Further, the coastal vulnerability was significantly associated with under-5 mortality ($\beta = 52.34$, p-value $= 0.01$). In the spatial lag model, a 10-point increase in unimproved sources of drinking water across the districts was associated with a 3-point increase in U5MR. In addition, diarrhoea among children was significantly associated with NMR ($\beta = 1.05$, p-value $= 0.03$) and U5MR ($\beta = 1.41$, p-value $= 0.00$). Also, unimproved sanitation facilities ($\beta = 0.28$, p-value $= 0.04$) was a strong predictor of NMR ($\beta = 0.25$, p-value $= 0.00$) and U5MR ($\beta = 0.35$, p-value $= 0.00$) in these spatial models. Similarly, a 10-point increase in coverage of child vaccination was associated with a 3-point decrease in NMR and U5MR. We observed that the U5MR model showed a greater AIC value with a pseudo R square value of

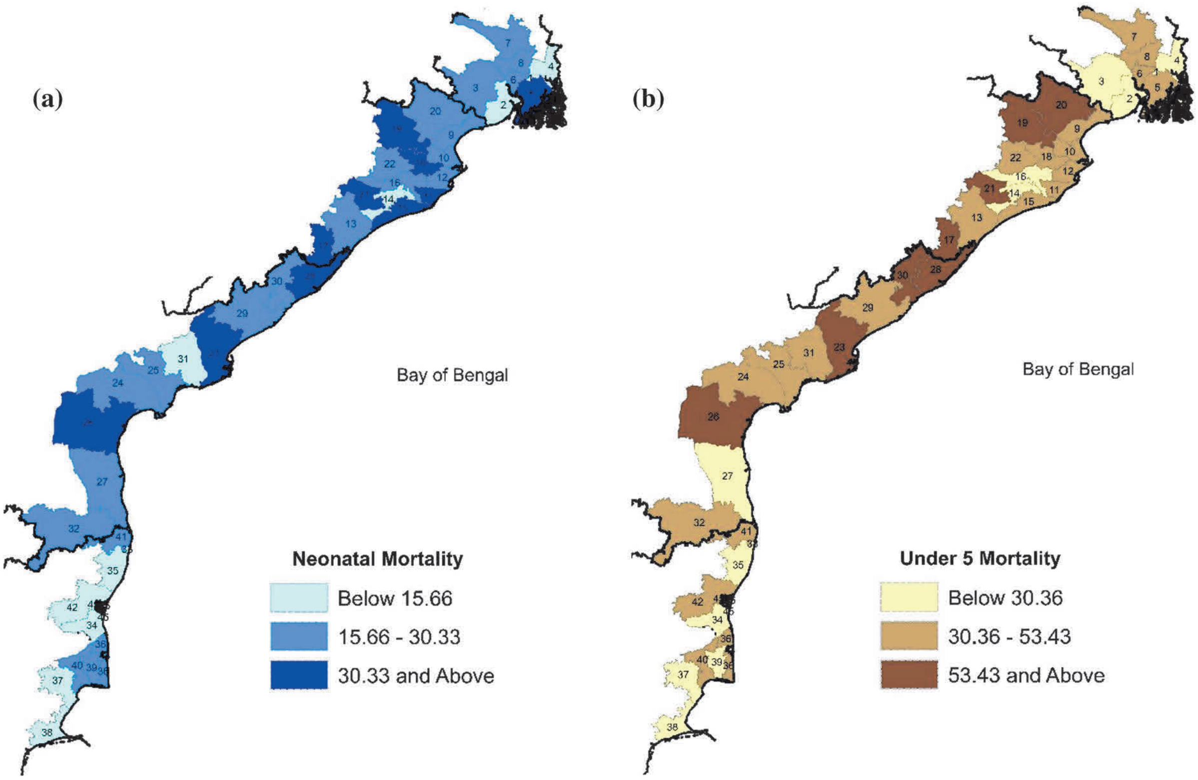

Fig. 4 Spatial distribution of (**a**) neonatal mortality rate; (**b**) Under-5 mortality rate in coastal districts of Bay of Bengal, 2015–16. *Note: Number of districts follows as the base map (Fig. 1) of the study*. *Source:* NFHS4, prepared by authors

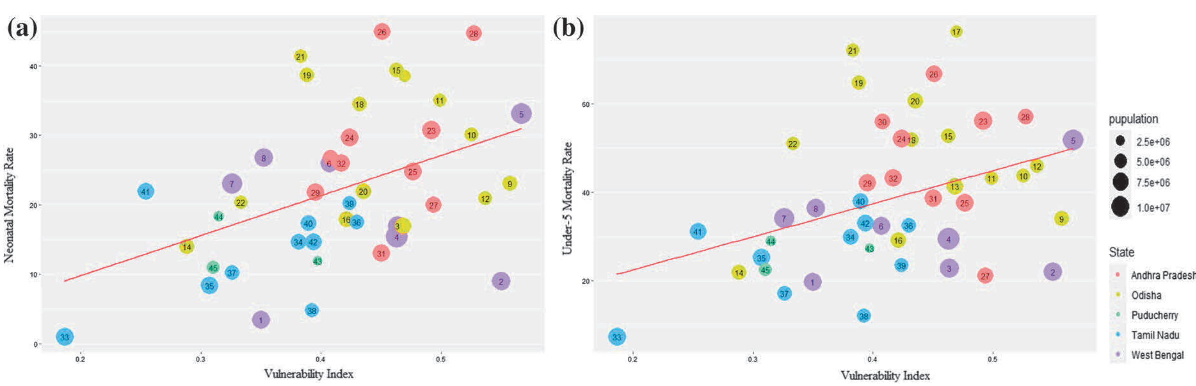

Fig. 5 Graphs visualizing the scatter plots between vulnerability and (a) neonatal mortality and (b) under-5 mortality across the Bay of Bengal coastal districts of India. *Note:* Size *of circle proportional to total population of the district, 2011. Number of districts follows as the base map (Fig. 1) of the study*. *Source:* prepared by authors

Table 2 Estimated Effect of Coastal vulnerability and child mortality in Bay of Bengal coastal districts, India: regression models

	Neonatal mortality			Under-5 mortality		
	OLS	SLM	SEM	OLS	SLM	SEM
Predictors						
Coastal vulnerability	46.98**(17.52)	43.54***(15.98)	44.86***(17.33)	57.84**(22.52)	51.77**(20.77)	52.34**(22.03)
Unimproved drinking water	0.15(0.12)	0.14(0.11)	0.09(0.13)	0.30(0.16)	0.28**(0.14)	0.31(0.16)
Prevalence of diarrhoea	0.52(0.39)	0.61(0.34)	1.05***(0.30)	0.93(0.50)	1.03**(0.44)	1.41***(0.41)
Unimproved sanitation	0.20*(0.10)	0.21**(0.09)	0.25***(0.09)	0.22(0.13)	0.24**(0.11)	0.30**(0.12)
Proportion of Hindu	−0.22(0.16)	−0.24(0.14)	−0.24(0.13)	−0.29(0.21)	−0.34(0.19)	−0.35(0.17)
Proportion of ST	0.06(0.13)	0.03(0.12)	0.02(0.12)	0.32(0.17)	0.27(0.15)	0.26(0.15)
Proportion of full ANC	−0.08(0.14)	−0.06(0.12)	0.07(0.11)	−0.18(0.18)	−0.14(0.16)	−0.05(0.15)
Proportion of no vaccination	−0.24(0.13)	−0.26**(0.12)		−0.31(0.17)	−0.32**(0.15)	−0.32**(0.13)
Constant	16.28(20.19)	13.63(17.87)	2.84(16.29)	33.72(25.94)	30.67(22.88)	24.25(21.74)
ρ		0.15			0.15	
λ			0.48			0.37
AIC	331.53	332.81	327.22	354.11	355.15	351.07
R^2	0.47	0.47	0.56	0.60	0.61	0.64

$^{***}p<0.01$, $^{**}p<0.05$

OLS: Ordinary least square model, *SLM*: Spatial lag model, *SEM*: Spatial Error Model; Standard errors in parentheses

0.64 than the NMR model across 45 coastal districts of Bay of Bengal.

Discussions and conclusion

IPCC has declared that climate change has very high confidence in disease's global burden (Woodward et al., 2014). Further, sea-level rise to one meter in the present century has intensified cyclone affecting the socioeconomic and cultural cohesion through the displacement of coastal communities (Oliver-Smith, 2009). Agriculture, fishery and forestry are the main sources of household income for the people who live in the coastal areas. Almost every year, moderate to severe cyclone hits the coastal districts of the Bay of Bengal, leading to a significant cause of economic and human loss. In this context, our estimates highlight several important issues related to coastal vulnerability and its linkages with neonatal and child mortality in the coastal districts of Bay of Bengal.

The paper analyses the vulnerability level of the coastal districts of the Bay of Bengal of India stretching for 1400 km and supporting a large number of rural populations as well as some important cities and state capitals. Findings reveal that northern districts located close to the apex of the Bay of Bengal are more prone to exposure of vulnerability of coastal cyclones as compared to the southern part. The reasons are varying; first, the topography of the northern part of the Bay of Bengal bordering West Bengal and Odisha is flatter than the southern part where eastern hills stand along the coastline; second, the funnel shape apex of the Bay of Bengal is exactly colliding with the northern coast (along with Bangladesh), that helps intensification of wind speed (Nicholls et al. 2007); third, the urban proportion of southern districts are more and thus it has the better adaptive capacity, as revealed in the estimate. Poor adaptive capacity attributed to the high degree of vulnerability in selected districts is mostly rural, agrarian, and generally located in West Bengal, Odisha, and parts of Andhra Pradesh.

The study establishes that the districts with a higher degree of coastal vulnerability experience a higher neonatal and under-5 mortality rate. Further, under-5 mortality is more strongly associated with the coastal vulnerability index in the districts of the Bay of Bengal as compared to neonatal mortality rate. Exposure to climate shocks like cyclones is harmful to young children as the shocks lead to reduced food intake and increased infectious diseases. In addition to economic hardship, medical access and utilization are also compromised during such catastrophize affecting the children disproportionately (Adair et al., 2013; Alderman et al., 2006; Black et al., 2008; Hoddinott, 2006). Therefore, it is essential to understand whether climate change poses a threat to children's health, and if so, where support is most needed. In the coastal districts, water and waste disposal quality in terms of drinking water and sanitation facility are the major determinants of a child's survival. Drinking water and sanitation help to improve people's overall health and quality of life (Dey et al., 2019; Prüss-Ustün et al., 2019; Semba et al., 2009). The risk of communicable diseases among vulnerable communities is due to the water and unimproved sanitation facilities (Watson et al., 2007). The evidence from *Amphan,* 2020 affected areas of Bangladesh has reported an increase in the number of diarrhea and skin disorders due to the usage of polluted pond water as their primary source of water for varying use. In addition, people also suffered from dysentery, jaundice, and eye irritation after the said cyclone (Rafa et al., 2021). Few studies undertaken in India reveal that excessive precipitation is associated with an increased risk of contracting water-borne diseases such as diarrhea among children under five (Dimitrova & Bora, 2020). Furthermore, the study conducted by Bhattacharjee et al (2010) has reported a greater likelihood of increasing Vibrio fluvialis (diarrhea) in the cyclone-affected areas after the *Aila*, 2009 cyclone. Indeed, the present study substantiates the findings of Dimitrova and Bora (2020) by revealing that in these coastal districts of India, the quality of water and waste disposal in terms of drinking water and sanitation facility are the major determinants of child's survival (Dimitrova & Bora, 2020). So, it is evident that due to coastal cyclones, the water- sanitation facilities are not up to the mark that leads to higher mortality.

WHO and UNICEF recommends measles vaccination and Vitamin-A supplements for children during an emergency (WHO, 2004). In India, after any major disasters, the government organized mass vaccination campaigns to limit the spread of infection and fatality (Mohan et al., 2006). However, Mallik et al (2011) identified major geographical and infrastructural constraints for mass measles vaccination campaigns in the Aila cyclone-affected areas (Mallik et al., 2011). In general, India's healthcare infrastructure, manpower and accessibility are inadequate, especially in remote areas (Shaw & Sahoo, 2020) and this could promote child mortality in vulnerable districts.

The present study has adopted an innovative approach to estimate the vulnerability index. The most common weakness of the pre-existing studies of vulnerabilities in India is the use of satellite data. Here, we used existing credible secondary data from well-established sources to compute the index. Through this measure, considering sensitivity, exposure and adaptive capacity, we identified the problem, quantified it, and assessed the index value in formulating development strategies to reduce the risk and vulnerabilities. In the context of increasing frequency and severity of coastal cyclone, the need of the hour to have better planning and protection strategies for Indian coast to safeguard coastal environment, human health, and livelihoods.

The policies related to climate change and coastal vulnerability in India are lacking in implementation. A recent research on climate change strategies, covering 136 coastal cities in 68 countries, observed the lack of effective climate change adaptation policies with no signs of implementation in nearly half the cases. Six major Indian coastal cities were included in the analysis of which three are from the Bay of Bengal coast, i.e. Chennai, Visakhapatnam and Kolkata. For six Indian cities, only eight policies were identified by the team, which explicit inclusion of plans to prepare for the impacts of climate change; a plan at the national level, six at the state and only one at the local level (for Gujarat in the West Coast of India).

This exhibits the lack of concrete measures at the city government stage (Olazabal et al., 2019).

Overall, current policies in India are not adequate to deal with the challenges of coastal vulnerabilities. The issue of displacement is addressed mostly as a post-disaster response, while there is a serious need for more comprehensive national and state policies on forestalling managed adaptation for at-risk coastal populations. Early response mechanisms and safeguarding households especially those with small children in terms of water sanitation, immunization and safety during such climate catastrophe are essential in areas where cyclone vulnerability is high in India.

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Declarations

Conflict of interests The authors declare that they have no conflict of interests.

Ethical approval The analysis is based on secondary data available in the public domain for research; thus, no approval was required from any institutional review board (IRB).

Consent to participate The analysis is based on secondary data available in the public domain for research; thus, no approval was required from any institutional review board (IRB).

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