Estimating Cyclone Vulnerability and Its Linkages With Child Mortality Trajectories Along the Bay of Bengal Coast in India: a Geospatial Approach

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Research

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Abstract

Background

The coastal population of Indian subcontinent experience variety of coastal hazards of which cyclone is the most destructive one. 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. In the following year 2021, another cyclonic storm, named *Yaas*, intensified in the Bay of Bengal in May, and it has ravaged many parts of the apex of the BoB coast. Over the decades, the devastating tropical cyclones of the Bay of Bengal (BoB) have thrashed thousands of lives and properties.

Methods

An empirical study to assess the coastal population's vulnerability and mortality along the east coastal districts of India is the need of the hour. Using a set of data the paper estimates the hazard exposure, sensitivity, and adaptability. Further, to understand the association between vulnerability and neonatal and under-5 mortality, regressions are applied.

Results

A very high coastal vulnerability risk for poor socio-economic status and lack of infrastructure was observed in certain districts of the BoB coast. Women, children, elderly and agrarian population are more sensitive to the cyclone; while lack of accessibility and infrastructure and poor health care system impact the population's adaptive capacity. A strong association of child mortality with coastal vulnerability is observed in the study area. Other factors that also play marked role in child mortality are prevalence of diarrhoea, lack of improved water and sanitation.

Conclusion

The study, first of its kind in India, has identified vulnerable districts of the east coast to help policymakers take measures for disaster planning and improving the basic facilities for a resilient society.

1. Introduction

The global sea surface temperature (SST) has increased throughout the past half-century due to the global greenhouse gas emission, leading to the intensification of cyclones over time [1]. Globally, 40% of the world population resides within 60 km from the coast, a driver for the coastal vulnerability [2]. The Intergovernmental Panel on Climate Change (IPCC) has identified several hotspots of climate change sensitive region where livelihood depends on subsistence agriculture, fishing, aquaculture [3]. Vulnerable places experience damage of property, lives, and displacements. Aside from the direct losses, insecurity of food, lacking opportunity of employment, and health impairments are exacerbated by coastal hazards. Additional socio-economic impact is mainly accrued by developing nations due to low challenges to adaptation and high mitigations strategies [4]. Over the decades, South Asia has experienced recurrent hazards related to tropical cyclones. The area is identified as a hotspot characterized by high population density, poverty, low development level, and exclusion [5]. In the north Indian Ocean region, Bay of Bengal (BoB) alone accounts for 7% of all global cyclones of the world [6]. Historically, coastal zones of India have attracted people due to port facilities, prosperity in agriculture, tourism, industries, trades, transport benefits, and habitable ecology [7, 8]. However, these regions are vulnerable zones due to the coincidence of low elevation, storm surges, floods, saline intrusion, coastal erosion [9], and other environmental challenges leading to infectious diseases and mortality [10, 11].

The coastal population of Indian subcontinent experience variety of coastal hazards of which cyclone is the most destructive one. With nearly 137 million populations [12] residing along with the BoB coastal districts and higher frequencies of depression-cyclonic storms, the coast is quite vulnerable as compared to the Arabian Sea coast in India due to higher frequency of cyclone (4:1 ratio of cyclones in Bay of Bengal than the Arabian Sea cyclone), low flat coastal terrain, high population density, poor knowledge of community, inadequate response and preparedness and absence of any hedging mechanism [13]. 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 [14]. The devastation was amplified with strong winds, tidal waves, and heavy rains that caused flooding across the deltaic regions, with an estimated economic loss of US$13.5 billion [15]. In the following year 2021, another cyclonic storm, named *Yaas*, intensified in the Bay of Bengal in May, and it has ravaged many parts of the apex of the BoB coast. India has witnessed severe to very severe cyclones: Laila, Helen, *Phailin, Hudhud, Vardah, Ockhi, Titli, Gaja*, *Amphan* and *Yaas* from 2010–2021 [16] As a result of cyclone hazard proneness, the Indian Coastal Zone (CRZ) has demarcated 500 m from the shoreline as coastal vulnerability zones. However, a buffer of 100 km perpendicular from the shoreline is measured for coastal vulnerability assessments considering the coastal geomorphology [17]. Literature suggests that, to escape from subsistence livelihood and poverty, aquaculture and industrialization have been introduced in these coastal regions, which had been the prime loop to coastal vulnerability [18].

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) [19–23]. Progressively, with the availability of satellite images and radar data, coastal hazard vulnerability assessments have soared [9, 17, 24–27]. However, a handful of scientists has conducted vulnerability assessment as a function of geomorphological, socio-economic, infrastructures, and other vectors [28, 29] 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 socio-economic and infrastructural indicators. Kim and Gim (2020) measured flood vulnerability and adaption along the Java coast, integrating the spatial regression model [31]. In India, Mazumdar and Paul (2016) and Sharma and Patwardhan (2008) measured the SVI due to cyclone with the principal component method. Scientists have studied the extreme effect of climate variability on health and mortality trajectories [34, 35]. Maternal exposure to cyclone increases the risk of having preterm [36–38] birth and consequently plays critical role in neonatal mortality [39, 40]. Past study observed that tropical strom increases the risk of illness, injuries and health needs [41].The risk of disease transmission tends to heighten in developing countries due to population density, inadequate sanitation, and poor health facilities. The outbreak of gastroenteritis and diarrhoeal disease has been documented in the parts of West Bengal, India, after Cyclone Aila, 2008 [42, 43]. Other morbidities like acute respiratory diseases, leptospirosis have been reported following a cyclone in Orissa, India, in 1991 [44]. The extreme weather events have a significant impact on the health of a child [45, 46]. Female infant mortality was 15.1 times higher than males in a natural disaster as observed in Philippines [47]. Furthermore, a cross-country analysis of 12 developing countries indicated an increase in infant mortality due to the cyclone's long-term effect [48]. As cyclones have the potential to cause infant and under 5 mortality, empirical studies suggest that natural hazard-induced child mortality positively responds to higher fertility rates [49, 50].

The rich body of literature in this field mainly focused on different natural hazard vulnerability assessments or aftermath of extreme events. Studies in India are rare in this field, especially highlighting aggregate measurement of vulnerability based on public data and revealing the associations of vulnerability and child health. The present study, unique in its approach, aims to estimate vulnerability at coastal districts of the Bay of Bengal, consisting of 45 districts within a 100 km buffer zone along the coastline. We made progress on integrating the vulnerability and its effects on health by considering two crucial health indicators, i.e. neonatal and under-5 mortality. The study adds to the literature by providing additional evidence of socio-economic vulnerability as a function of exposure, adaptation, and sensitivity due to cyclones and its linkages to child mortality in India.

2. Methods

2.1 Study area

Districts less than 100 km from the coast line were considered coastal districts according to the definition of MDI [51]. 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 BoB coast) or October to November (pre-winter season in the southern part of BoB coast.

2.2 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" [52]. Total cyclone frequency, severe cyclone frequency, wind speed and shoreline length were considered in the calculation of cyclone exposure. Additionally, we included three components: sensitivity, demographics, agriculture and health. The components that help to adjust with different shocks like 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 [53, 54] (Table 1). The vulnerability index was calculated using the universal normalization technique-

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

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 *i*th 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 [55]. 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 *i*th indicator for district *j*, and *n* is the number of indicators considered to represent the index.

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 100000 population	Data.gov.in
		Road density	Brief Industrial Profile of different districts, Ministry of MSME
		Average number of bank per 100000 population	
		Total number of small scale industries in each district	
		Electricity	Census of India, 2011
		Pucca house	
Compiled by Authors			

Determinants of vulnerability	Components	Indicators	Data source
		Literacy rate	
		Female literacy rate	
Compiled by Authors			

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 [56]. 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 total population of the districts were taken from the Census of India, 2011.

Scatter plots were used to establish the association between coastal vulnerability and neonatal and under-5 mortality in coastal districts of BoB. 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.

3. Results

3.1 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 [57].

The districts located in the apex part of BoB were more prone to coastal cyclone vulnerability than the southern part (Table 2). The highest degree of exposure was observed in districts 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 Calcutta. This study demonstrated a high vulnerability index in South 24 Parganas district, followed by Baleswar, Purba Medinipur, Kendrapara, Srikakulam and Bhadrak. Chennai had the lowest vulnerability index due to its higher adaptive capacity.

Table 2. Vulnerability, exposure, sensitivity and adaptive capacity in Costal area of Bay of Bengal: District level summary

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-1std.dev.)
High (>1std.dev.)

Source: Based on Author's calculation

3.2 Neonatal and under-5 mortality

Figure 3 depicts the spatial distribution of neonatal and under-5 mortality rate (per 1000 live births) across 45 coastal districts of BoB. It is worth mentioning that a similar heterogeneity pattern remains 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 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, NMR and U5MR surpassed India's average.

3.3 Association of NMR and U5MR with vulnerability

Figure 4 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 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 socio-economic components (Table 3). 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 BoB. 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 a significant positive association with district-level under-5 mortality rate.

Table 3. Estimated Effect of Coastal vulnerability and child mortality in BoB 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)	-0.32*** (0.10)	-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
OLS-Ordinary Least Square Model, SLM-Spatial Lag Model, SEM-Spatial Error Model; Standard errors in parentheses, *** p < 0.01, ** p < 0.05						

The result of SEM showed a spatial association between coastal vulnerability and NMR - U5MR. Of 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 (β = 44.86, p value = 0.00). Further, the coastal vulnerability was significantly associated with under-5 mortality (β = 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 (β = 1.05, p value = 0.03) and U5MR (β = 1.41, p value = 0.00). Also, unimproved sanitation facilities (β = 0.28, p value = 0.04) was a strong predictor of NMR (β = 0.25, p value = 0.00) and U5MR (β = 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 0.64 than the NMR model across 45 coastal districts of BoB.

4. Discussions And Conclusion

IPCC has declared that climate change has a very high confidence in disease's global burden [58]. Further climate change, sea level rise to one meter in the present century has intensified cyclone affecting the socio-economic and culture cohesion through displacement of coastal communities [59]. A large proportion of rural population in India lives near the coastline, depends on agriculture, fishery and forestry. Almost every year, moderate to severe cyclone hits the coastal districts of BoB, leading to 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- child mortality in BoB coast of India.

The paper analyses the vulnerability level of the east coastal districts or BoB coast of India stretching for 1400 km and supporting 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 BoB 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 BoB bordering West Bengal and Odisha are flatter than the southern part where eastern hills stand along the coastline; second, the funnel shape apex of the BoB exactly collides with the northern coast (along with Bangladesh), that helps intensification of wind speed [9]; third, the urban proportion of southern districts are more and thus it has 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 BoB 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 [60–63]. 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 child's survival. The drinking water and sanitation help to improve people's overall health and quality of life [64–66]. The risk of communicable diseases among vulnerable communities is due to the water and unimproved sanitation facilities [67]. The evidence from *Amphan*, 2020 affected areas of Bangladesh has reported an increase in the number of diarrhoea 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 [68]. Few studies undertaken in India reveals that excessive precipitation is associated with an increased risk of contracting water borne diseases such as diarrhoea among children under five [69]. Furthermore, Bhattacharjee *et al* 2010 has reported an increase of Vibrio fluvialis (diarrhoea) along the cyclone affected areas after *Aila*, 2009 cyclone [70]. 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 [69]. 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 [71]. In India, after any major disasters, the government organized mass vaccination campaigns to limit the spread of infection and fatality [72]. However, Mallik et al (2011) identified major geographical, infrastructural constraints for mass measles vaccination campaigns in the Aila cyclone-affected areas [73]. In general, India's healthcare infrastructure, manpower and accessibility are inadequate, especially in remote areas [74] and this could promote child mortality in vulnerable districts.

The present study has adopted an innovative approach to estimate 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 BoB 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 state and only one at local level (for Gujarat in the West Coast of India). This exhibits the lack of concrete measures at the city government stage [75].

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 polices on forestall managed adaptation for at-risk coastal populations. Early response mechanism and safeguarding households especially those with small children in terms of water sanitation, immunization, safety during such climate catastrophe are essential in areas where cyclone vulnerability is high in India.

Declarations

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Contribution statement

Arup Jana: conceptualization, mapmaking, analysis, writing.

Subhojit Shaw: writing and analysis

Aparajita Chattopadhyay: conceptualization, writing, editing.

Ethical approval and 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).

Competing of interests

The authors declare that they have no conflict of interests.

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Availability of data and materials

The datasets used in the study area available at the following links:

NFHS: http://rchiips.org/nfhs/factsheet_nfhs-4.shtml, Census data: https://censusindia.gov.in/

IMD data: https://mausam.imd.gov.in/imd_latest/contents/cyclone.php and MSME report: https://msme.gov.in/.

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Figures

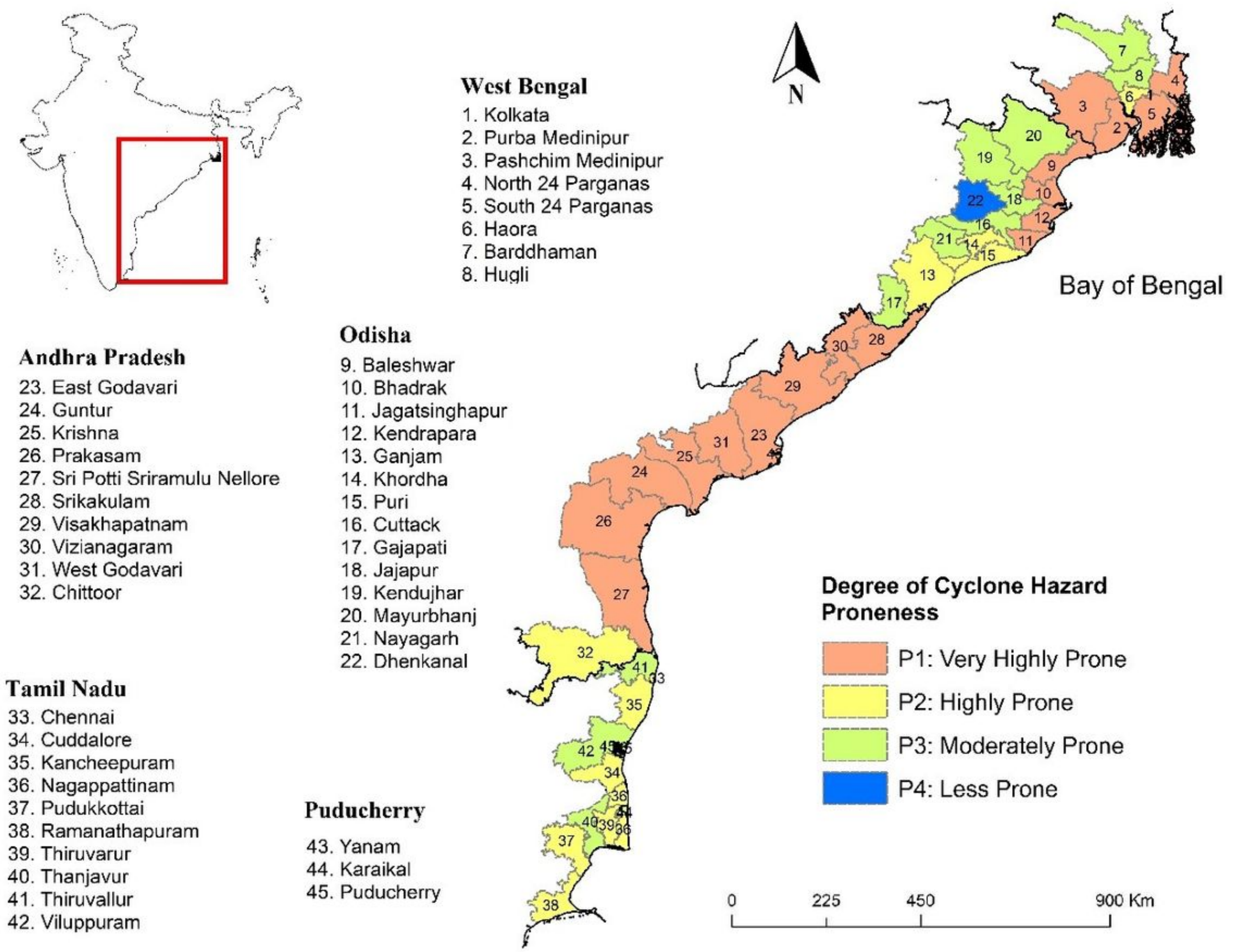

Figure 1

BoB coastal districts of India affected by cyclones (100 km inland buffer). Source: Indian meteorological department, Government of India (IMD)

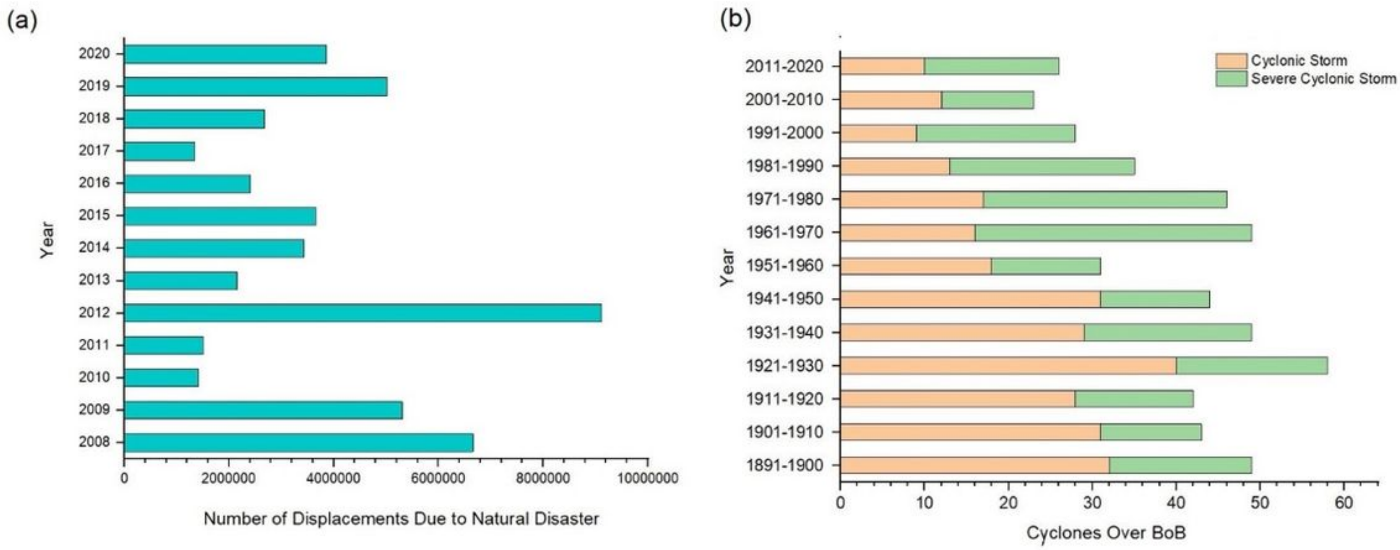

Figure 2

(a) Number of new displacements due to natural disaster in India; (b) Frequency of cyclones over BoB. Source: based on https://www.internal-displacement.org/countries/india ; http://www.imdchennai.gov.in/cyclone_eatlas.htm

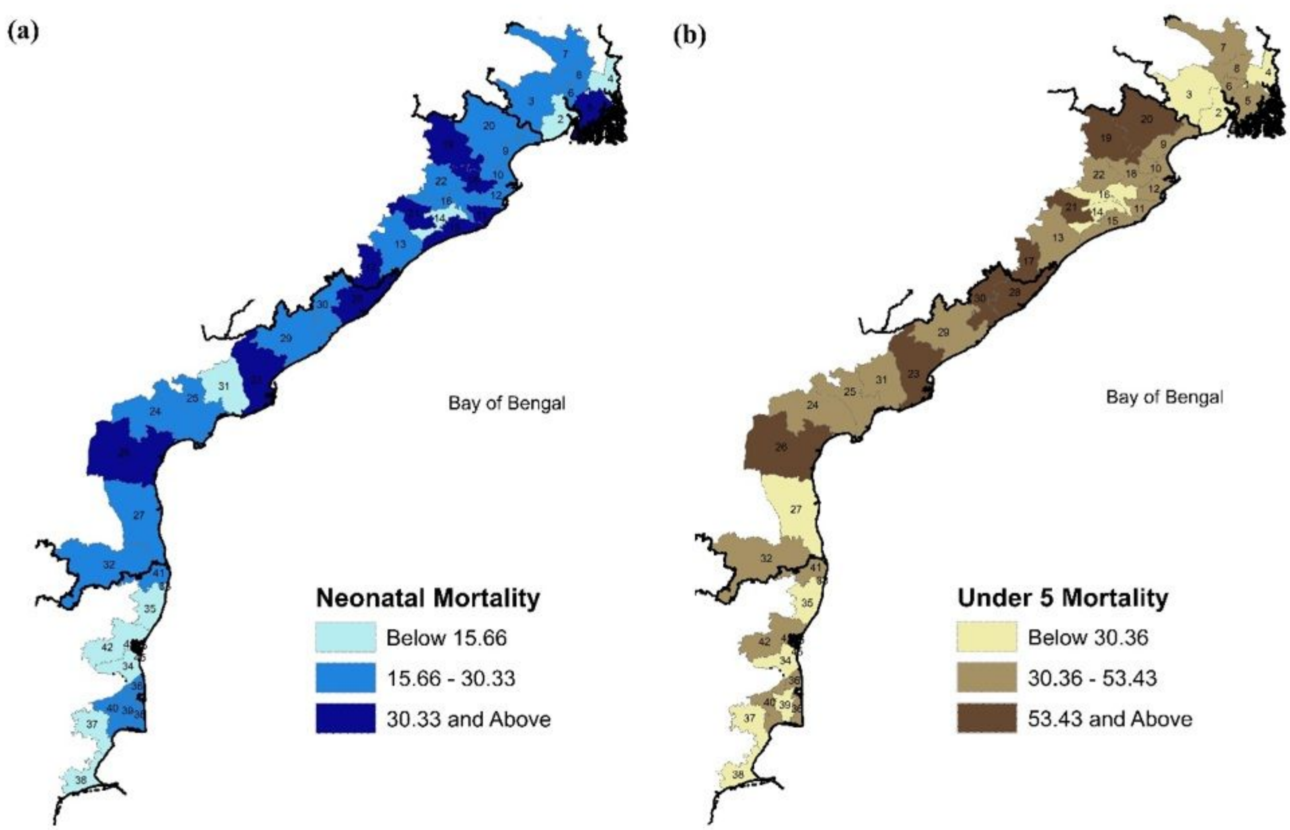

Figure 3

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

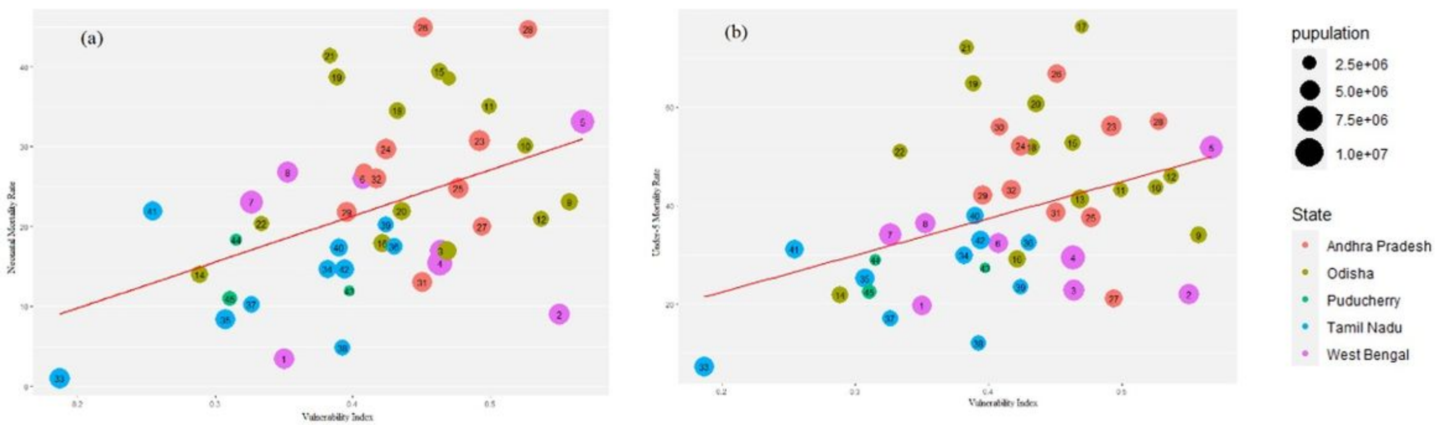

Figure 4

Graphs visualizing the scatter plots between vulnerability and Neonatal mortality (a) and Under-5 mortality (b) across the BoB 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