

An indicator based approach to assess coastal communities' resilience against climate related disasters in Indian Sundarbans

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Abstract The article attempts to develop a five dimensional community resilience assessment framework and a composite resilience index against climate related disasters with special applications to the coastal rural communities' in the developing world. Consequently, it narrates the case study of Indian Sundarbans, which serves as a typical example of a complex & dynamic 'socio-ecological' system characterized by dense mangrove forests, high population density and recurrent climate related disasters. In the present study, 'community resilience' of 19 coastal administrative blocks of Indian Sundarbans were assessed through a systematic questionnaire survey of administrative officials and the composite resilience scores were found to vary between 2.51 and 3.63 in a five point scale. Out of the 19 coastal blocks only one could be classified as high resilient block and the rest were found to be in low to moderate resilience categories. In general, the extreme coastal blocks were found to be less resilient due to their high exposure & developmental deficit, however, at the same time, the study finds strong correlation of institutional interventions & effective coastal zone management in enhancing the overall resilience scores. The study concludes with broad recommendation of integrated planning for disaster & climate resilience in this eco-fragile region where low impact economic development remains at the central.

Keywords Community resilience · Climate related disasters · Resilience indicators · Indian Sundarbans

Introduction

Natural hazards of hydro-meteorological origin are emerging globally as a major concern. Over the last several decades, these disasters have expanded both in frequency & magnitude leading to unprecedented loss of human lives and assets (Costanza and Farley 2007; Auld 2008; IPCC 2012). Much of its impact has been concentrated along the coast. In addition, predictive models reveal that climate change would significantly intensify the coastal hazards including tropical cyclones, rainfall and surge flooding (Knutson et al. 2010; Nicholls and Cazenave 2010). As a consequence, communities living in small islands and low-lying coastal areas will be exposed to an unparalleled risk from sea level rise, stronger storms and other sea-ward hazards (Mimura et al. 2007; McGranahan et al. 2007; Nicholls et al. 2007). Therefore, as we prepare to embrace an era marked by climate uncertainties, fostering disaster & climate resilient coastal communities remain acute and urgent.

Coastal areas are considered as complex socio-ecological systems bounded by its environmental and human limits. In order to assess the sensitivity of such complex systems, 'vulnerability' and 'resilience' are two competing and related concepts widely used over the last four decades. Both of these concepts have been regarded as an effective tool for rapid decision making and prioritized action planning. 'Vulnerability' is generally defined as a function of exposure of any system (e.g., who is at risk/ how severe is the risk etc.); whereas 'resilience' is considered as the capacity to absorb external shocks without significant deformation (Cutter et al. 2008). Despite of some semantic differences, theoretically or in practice, they are considered as 'mutually exclusive'; i.e., 'resilient' systems are less 'vulnerable' and vice versa (Norris et al. 2008; Miller et al. 2010). However, scholars such as Cutter et al. 2008; Cutter 2008; Béné et al. 2012 described 'resilience' as 'pre-event', 'holistic' & 'adaptive concept',

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which is contextual to global consensus for disaster risk reduction and climate change adaptation. In general, ‘resilient communities’ are defined as ‘socio-ecological systems’ that can (1) absorb shocks or recurrent disturbances without significant deformation, (2) recover quickly from an altered state and further can (3) restructure and reorganize itself through adaptive processes and practices (Klein et al. 1998; Adger et al. 2005; Folke 2006; Cutter et al. 2008; Cutter 2008; 2010; Joerin and Shaw 2011; Joerin et al. 2012). Likewise, ‘community resilience’ in coastal areas can be defined as the capacity of a linked ‘socio-ecological system’ to absorb recurrent disturbances without significant functional deformation.

Over the past few years, several researchers have attempted to formulate quantitative as well as qualitative indicators with particular relevance to community resilience against natural disasters (USIOTWSP 2007; Cutter et al. 2008; Cutter et al. 2010; Peacock et al. 2010; Uy et al. 2011; Joerin and Shaw 2011; Joerin et al., 2012; Teo et al. 2013). One particular reason for such predominance of indicator based studies is that, it essentially reduces the complexity of the measuring progress, allows a comparative analysis among the adjacent places and further serves as an important tool for the decision makers (Cutter et al. 2008). Even though, majority of these frameworks were designed to assess community resilience in coastal areas (e.g., USIOTWSP 2007; Cutter et al. 2010; Peacock et al. 2010; Joerin et al., 2012); associated illustrations are mostly drawn against coastal urban areas. Importantly, coastal urban areas differ significantly from coastal rural areas as community dependence on coastal ecosystem services in the later play a crucial role in defining the resilience of a more complex ‘socio-ecological’ system. Rural dependency on coastal resources, particularly in economically depressed coastal areas across the developing world, often makes ‘human-environment’ relation unsustainable. For example, communities living in coastal rural areas characteristically depend on fisheries and agriculture which has direct dependence on the coastal ecosystem services. Consequently, loss of coastal ecosystem services impairs the rural communities’ ability to respond to a crisis (Uy et al. 2011). Therefore, a new set of appropriate indicators are required to assess resilience of the resource dependent rural communities in the low lying coastal areas beside the traditional indicators used in the earlier frameworks (e.g., USIOTWSP 2007; Cutter et al. 2010; Peacock et al. 2010; Joerin et al. 2012).

The paper attempts to develop a set of appropriate indicators along with a comprehensive framework to assess disaster resilience of coastal rural communities, more specifically in the low-lying Asian mega deltas. In the backdrop of these complex ‘socio-ecological’ systems, the article attempts to develop a five dimensional resilience assessment framework encompassing both the structural and non-structural aspects of disaster risk management. The present research narrates a case

study from the Indian Sundarbans in order to gain a comprehensive understanding of local risk exposure, community profile, level and pattern of eco-system exploitation. The study further categorized 19 coastal blocks of this region in terms of their ‘resilience’ against natural disasters & climate hazards. Although, the framework has been customized to the local context, it can be applied to similar coastal rural areas, with or without some minor modifications.

Study area

Geographic & demographic profile of the study area

Indian Sundarbans, a cluster of 103 low-lying deltaic islands, is located in the western fringe of the Ganges Brahmaputra Meghna (GBM) delta under the administrative territory of India (Fig. 1). Geographically, the area is confined between 21°32' to 22°40' Northern Latitude and 88°05' to 89°00' Eastern Longitude and the boundary is demarcated by the river Hooghly on the west, the Bay of Bengal on the south, the Ichamati-Kalindi-Raimongal Rivers on the east and by an imaginary line (Dampier & Hodge Line) in the north (Banerjee 1998). Historically, the entire extent of Indian Sundarban used to be under dense mangrove forest. Over the years, 54 islands were reclaimed for human settlement and the present extent of mangroves only extend to the remaining islands encompassing an area of 2155 sq.km (Forest Survey of India 2011). Most of the study area falls within the territory of an active delta which still undergoes natural erosion and accretion under the influence of innumerable tidal creeks & channels. A network of nearly 4000 km of earthen embankment essentially serves as the key for survival for many of these extremely low lying islands. The region is also severely threatened by relative sea level rise. Official reports suggest that the relative sea level rise in this region is about 5.22 mm/year at the Diamond Harbor Gauge station situated in the western part of the Indian Sundarbans (INCCA 2010).

Indian Sundarbans is spread across 19 Coastal Developmental Blocks (CDB); of which 13 are in the district of South 24 Parganas and 6 are in the district of North 24 Parganas in West Bengal (see Fig. 1, Table 1). From the demographic perspective, the study area host predominately rural population of nearly 4.37 million with a staggering density of 957/sq.km; most of which thrive on coastal agriculture and fisheries. The suffering of these populations is further magnified by inadequacy of resources, dire poverty and remoteness associated with their existence. On an average, approximately 43.5 % of the local communities live under the nationally designated poverty line which is considerably high compared to the national & provincial average.

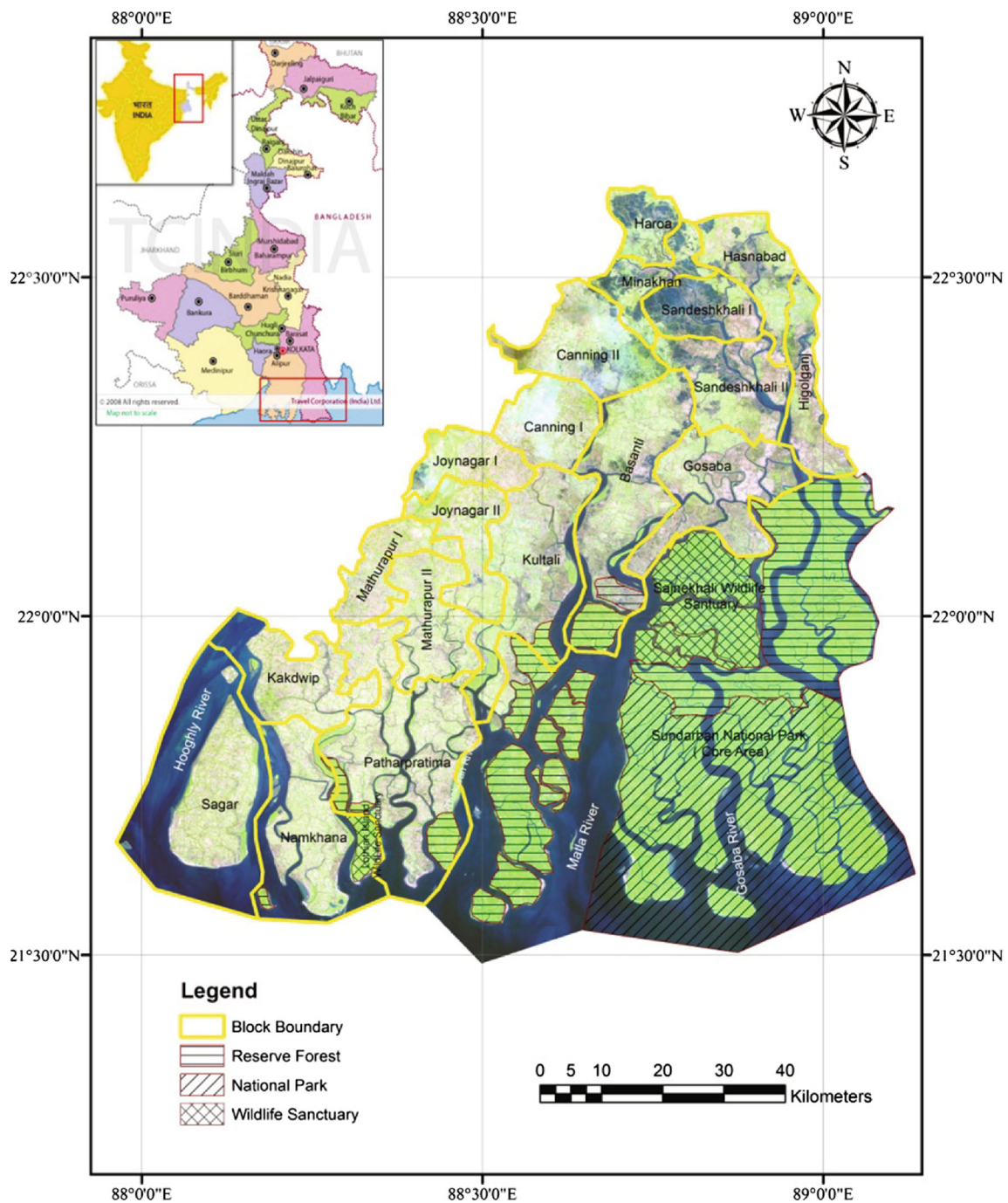


Fig. 1 Location map of Indian Sundarbans

Climate and disaster risk profile of the study area

Indian Sundarbans experience tropical monsoon climate with majority of rainfall occurring within a span of 4–5 months. The average annual rainfall is estimated to be 1661.6 mm (Gopal and Chauhan 2006). Summer in the study area is characterized by excess humidity and occasional thunderstorms in the evening. During the post monsoon season (mid October to mid November), tropical cyclones are extremely common. Bandyopadhyay 1997 estimated that Indian Sundarban has

an average recurrence interval of 3.3 and 2.9 years for ‘severe tropical cyclone’ and ‘tropical cyclones’ respectively. Further, cyclonic storms often result in surge flooding and breach of embankments leading to devastation of the coastal villages and agricultural establishments. However, the risk exposure of the delta is not uniformly distributed and shows extensive spatial variation. For example, prevalent evidences of severe coastal erosion in the small western islands may be a result of fluvial dynamics as well as an increment of relative sea level due to an eastward tilting of the Bengal basin (Stanley and

Table 1 Geographical and socio-economic profile of 19 CDBs in Indian Sundarbans

Name of the CDB	Area in Sq. Km	Census (2001)	Census* (2011)	Density person/km ²	Decadal growth rate	Literacy rate (%)	Below poverty level population (%)
Blocks in South 24 Parganas							
Joynagar I	131.01	219,090	259,980	1984	18.66	66.67	39.57
Joynagar II	186.25	209,145	246,955	1326	18.08	60.09	42.60
Kultali	306.18	187,989	231,855	757	23.33	60.81	46.36
Mathurapur I	147.30	164,650	194,069	1318	17.87	66.00	34.43
Mathurapur II	227.45	198,281	219,541	965	10.72	68.94	39.59
Kakdwip	252.74	239,326	286,325	1133	19.64	71.38	34.91
Sagar	282.11	185,644	211,096	748	13.71	78.92	44.46
Namkhana	370.61	160,627	181,869	491	13.22	79.38	48.17
Pathor Pratima	484.47	288,394	333,687	689	15.71	73.44	49.13
Canning I	187.86	244,627	297,995	1586	21.82	61.23	31.05
Canning II	214.93	195,967	248,521	1156	26.82	52.72	50.32
Gosaba	296.73	222,822	244,721	825	9.83	69.67	38.02
Basanti	404.21	278,592	331,973	821	19.16	58.12	64.89
Blocks in North 24 Parganas							
Hingolgang	238.8	156,400	159,585	668	2.04	70.07	44.50
Hasnabad	153.07	177,521	196,880	1286	10.91	63.45	28.69
Sandeshkhali I	182.3	140,476	164,185	901	16.88	58.45	58.29
Sandeshkhali II	197.21	136,318	160,828	816	17.98	59.31	59.70
Minakhan	158.82	168,965	191,908	1208	13.58	58.65	38.42
Haroa	152.73	182,522	214,248	1403	17.38	62.82	33.73

*Provisional Data

Hait 2000; Gopal and Chauhan 2006). Similarly, all the southern islands of the delta have the highest exposure to tropical cyclones due to their proximity to the sea. In addition, Mitra et al. 2009 observed an inconsistent distribution of salinity across the delta and reported a decrease (1.67 psu/decade) in salinity in the western part and an increased salinity (2 psu/decade) in the eastern part. The decrease in salinity can be due to the melting of Himalayan glaciers thus leading to increased freshwater flow in River Ganges. On the contrary, high rate of sedimentation of the eastern river system and severe environmental pollution (waste water discharge from the city of Kolkata) are identified as major cause behind the increment in the eastern delta. This increased salinity has led to gradual reduction of mangrove diversity, particularly in the eastern part of Indian Sundarbans (Mandal et al. 2010; DasGupta and Shaw 2013).

Methodology

Methodology of this study is divided into two parts, i.e., development of dimensions, indicators and variables that can be applied at a community scale in rural coastal areas and

secondly, to assess the community resilience profile of the study area through methodical application of the framework.

Development of dimensions, indicators and variables

The initial phase of identification of appropriate indicators involves extensive background literature survey dealing with community resilience against natural disasters (e.g., Nicholls and Branson 1998, Adger 2000; Adger et al. 2005; USIOTWSP 2007; Cutter et al. 2008; Cutter et al. 2010; Peacock et al. 2010; Uy et al. 2011; Joerin and Shaw 2011; Joerin et al. 2012; Teo et al. 2013). In order to capture the elements of community resilience in the Indian Sundarbans, the present methodology undertook a 5 × 5 harmonized approach similar to Joerin and Shaw 2011. The final list of major dimensions, indicators and variables were developed after an iterative discussion with the local stakeholders such as local government officials and community groups. The framework considered five key dimensions of coastal resilience i.e., Socio-economic, Physical (Structural), Institutional, Coastal Zone Management (Ecological) and Environmental/Natural resilience. Under each dimension, five major indicators and twenty five variables were framed. A summarized form of the framework is presented in Table 2.

Table 2 Framework for coastal community resilience assessment of Indian Sundarbans

Dimension	Indicators	Variables	Relation to Overall Coastal Resilience	Indicator Type	Data Source	
Socio-economic	Demography	a) Annual Average Growth Rate	-	Q	a) CD (2011/2001)	
		b) Population Density	-	Q	b) CD (2001)	
		c) Age Dependency Ratio	-	Q	c) CD (2001)	
		d) Percent of rural population	-	Q	d) CD (2001)	
		e) Percent backward/tribal population	-	Q	e) CD (2001)	
	Livelihood	a) Percent of below poverty line population	-	Q	Q	a) CD (2011)
		b) Percent of population lives on coastal resources	-	Q	Q	b) DHDR (2009)
		c) Implementation of MGNREGA (Livelihood Guarantee program)	+	Q	Q	c) BDO
		d) Percent of population lives on Eco-tourism	+	Q	Q	d) BDO
		e) Percent of population suffered discontinuation of livelihood aftermath disasters	-	SQ	SQ	e) BDO
	Health	a) Average Life expectancy Birth	+	+	SQ	a) BDO
		b) Doctor: population ratio	-	-	Q	b) BDO
		c) Percent of population having primary health facility	+	+	Q	c) BDO
		d) General condition of Public health	+	+	P	d) BDO
		e) Morbidity of major diseases (Malaria/TB etc.)	-	-	SQ	e) BDO
Social capital	a) Social cohesion	+	+	P	a) BDO	
	b) Acceptance of community leaders	+	+	P	b) BDO	
	c) Frequency of village level meetings	+	+	SQ	c) CL+ BDO	
	d) Occurrence of Conflicts/Riots/ Homicide incidents	-	-	SQ	d) BDO/LPS	
	e) Community participation in shared interests	+	+	SQ	e) BDO	
Education & Awareness	a) Percent of Adult Literacy Rate	+	+	Q	a) Census data	
	b) School dropout rate of children	-	-	Q	b) BDO	
	c) Capacity of existing Primary Schools to cater the demand	+	+	SQ	c) BDO	
	d) Existing community awareness of Disaster & climate change	+	+	P	d) BDO	
	e) Frequency of mass awareness camp run both by NGOs, CBOs etc.	+	+	Q	e) BDO/BDMO	
Physical	Transportation	a) Percent road compared to overall land use	+	Q	a) LULC/DHDR	
		b) Percent of all weather accessible roads compared to existing road network	+	Q	b) LULC/DHDR	
		c) Percent of waterways compared to overall land use	-	Q	c) LULC Map	
		d) Status of Jetties and inter island communication	+	SQ	d) BDO /BDMO	

Table 2 (continued)

Dimension	Indicators	Variables	Relation to Overall Coastal Resilience	Indicator Type	Data Source
Residential infrastructure		e) Availability of emergency vehicle/boats	+	SQ	e) BDO/BDMO
		a) Percent of population with informal (slum etc.) settlements	-	SQ	a) BDO/BDMO
		b) Percent of population in co-operative housing	+	Q	b) BDO/BDMO
		c) Percent of houses living under the avg. flood line	-	Q	c) BDO/BDMO
		d) Percent of population having ownership of their house	+	SQ	d) BDO/BDMO
Electricity		e) Percent of population living extremely close to hazardous activity (port/industry)	-	SQ	e) BDO/BDMO
		a) Percent population having access to electricity	+	Q	a) BDO
		b) Number of hours of average disruption of electricity supply	-	SQ	b) BDO
		c) Service quality (Frequency of dropout or distribution failure etc.)	-	P	c) BDO
		d) Percent population having alternative source of electricity in case of disruption	+	SQ	d) BDO
Tele-communication		e) Implementation of renewable source of energy (Solar/wind etc.)	+	SQ	e) BDO
		a) Percent population having mobile phone	+	Q	a) BDO
		b) Quality of service / network accessibility	+	P	b) BDO
		c) Percent of population having radio/television	+	SQ	c) BDO
		d) Percent of population having internet connection	+	SQ	d) BDO
Water & Sanitation		e) Provision of fishermen tracking systems	+	Q	e) BDO
		a) Percent population having access to safe drinking water	+	Q	a) DSB+BDO
		b) Quality of supplied water (salinity or other chemical contaminant)	+	SQ	b) BDO
		c) Scarcity of drinking water and seasonal variation of water availability	-	P	c) BDO/PHE
		d) Percent population having access to hygienic toilets	+	SQ	d) BDO/PHE
Laws & Policy		e) Implication of waste water disposal and treatment facility	+	Q	e) BDO/PHE
		a) Integration of DRR in developmental activities	+	P	a) BDO/BDMO
		b) Implementation of CRZ Notification (based on number of violations)	+	SQ	b) BDO/BDMO
		c) Administrative initiatives (notification/instructions etc.) of coastal greening	+	SQ	c) BDO/BDMO
		d) Frequency of DRR training organized by the block	+	SQ	d) BDO/BDMO
Coordination		e) Percent of funds allocated to DRR activities	+	SQ	e) BDO/BDMO
		a) Coordination among government departments	+	P	a) BDO
		b) Coordination with political leaders	+	P	b) BDO

Table 2 (continued)

Dimension	Indicators	Variables	Relation to Overall Coastal Resilience	Indicator Type	Data Source		
Emergency response		c) Coordination with NGO (Number of joint program etc.)	+	P	c) BDO		
		d) External assessment (Funding) received	+	P	d) BDO		
		e) Coordination with neighboring blocks	+	P	e) BDO		
		a) Existence of early warning system (extent of risk communication)	+	P	a) BDO/BDMO		
		b) Adequacy of trained emergency response team	+	SQ	b) BDO		
		c) Availability of evacuation centre (Number of Flood/cyclone shelter)	+	Q	c) BDO/DDMP		
		d) Availability of emergency Aids (Food, medicine, water etc.)	+	SQ	d) BDO		
		e) Transparency in Aid distribution process (reported conflict etc.)	+	P	e) BDO		
		Adaptive action		a) Consideration of Climate change & DRR in developmental activity	+	P	a) BDO/BDMO
				b) Development of forestry & Plantation at administrative initiatives	+	P	b) BDO
				c) Implementation of Disaster Insurance / Statutory aids to victims	+	P	c) BDO/DDMP
				d) Implementation flood/erosion control technical measures only	+	P	d) BDO
				e) Implementation of rainwater harvesting scheme	+	P	e) BDO
		Governance		a) Implementation of regular developmental plans	+	P	a) BDO/BDMO
				b) Public Private partnerships in developmental activities	+	SQ	b) BDO
c) Off-disaster activities of Block Disaster Management Authority	+			P	c) BDO/BDMP		
d) Information sharing & risk communication with the community	+			P	d) BDO		
e) Adequacy of manpower in existing block administration	+			Q	e) BDO		
Coastal Zone Management	Embankment & Shoreline	a) Percent of vulnerable shoreline protected by dykes/embankments	+	Q	a) BDO/DDMP		
		b) Average age of embankments	-	SQ	b) BDO		
		c) Strength of Material & design used for building the embankments	+	Q	c) BDO/DDMP		
		d) Frequency of maintenance of embankments	+	Q	d) BDO		
		e) Frequency of reported overtopping incidents	-	SQ	e) BDO		
Mangrove management		a) Percent of mangrove cover compared to block size	+	Q	a) LULC Map		
		b) Percent of people directly depends mangroves (Wood, honey etc.)	-	Q	b) BDO		
		c) Activity of FPC (CBMM) in conservation of mangroves	+	P	c) BDO		

Table 2 (continued)

Dimension	Indicators	Variables	Relation to Overall Coastal Resilience	Indicator Type	Data Source
Coastal Bio-diversity conservation		d) Performance of Forest Department in mangrove conservation	+	P	d) BDO
		e) Frequency of organized mangrove felling in recent past	-	SQ	e) BDO
		a) Frequency of Animal Poaching incidents (tiger, deer etc.)	-	Q	a) BDO
		b) Performance of Forest Department in promotion of Bio-diversity	+	P	b) BDO
		c) Activity of EDC (CbBDCM)	+	SQ	c) BDO
	Coastal Pollution control	d) Reported reduction in species e.g., Fish species, turtle, tiger prawns etc.	-	SQ	d) BDO
		e) Frequency of monitoring overfishing in tidal waters	+	P	e) BDO
		a) Quality of water around the block	+	SQ	a) BDO+RP
		b) Discharge of industrial waste in coastal waters from the block	-	SQ	b) BDO
		c) Discharge of domestic waste in coastal waters from the block	-	SQ	c) BDO
	Coastal land use	d) Occurrence Oil spilling incidents from jetties	-	SQ	d) BDO
		e) Frequency of monitoring of coastal water quality	+	SQ	e) BDO
		a) Percent of coastal sensitive land (500 m) reclaimed for agriculture (10 years)	-	SQ	a) BDO
		b) Extent of fish cultivating pond compared to block land use	-	Q	b) BDO
		c) Extent of coastal land diversion for settlements/infrastructure	-	SQ	c) BDO
Environmental/Natural	Frequency of natural disaster	d) Extent of mining and other drilling activities	-	Q	d) BDO
		e) Extent of coastal land rehabilitation (Greenbelt etc.)	+	Q	e) BDO
		a) Frequency of flood occurrence and degree of damage	-	SQ	a) BDO/BDMO
		b) Frequency of cyclone occurrence and degree of damage	-	SQ	b) BDO/RP
		c) Extent of Coastal erosion and degree of damage	-	SQ	c) BDO/RP
	Climate components	d) Frequency of heavy tidal inceptions causing substantial damage	-	SQ	d) BDO/R
		e) Extent of Earthquake & Tsunami vulnerability* (Cummins,2007)	-	SQ	e) RP
		a) Extent of physical impact caused by sea level rise	-	SQ	a) BDO/RP/R
		b) Relative rate of sea level rise in the block	-	SQ	b) RP/EI
		c) Reduction of availability of freshwater (surface+subsurface)	-	SQ	c) RP
	Geo-physical components	d) Extent of rise in river water salinity	-	SQ	d) RP
		e) Extent of mangrove deterioration (loss of species) due to salinity	-	SQ	e) RP/EI
		a) Decadal loss of shorelines/permanent inundation area	-	SQ	a) RP/R
		b) Extent of change in tidal patterns leading to river piracy/damage to dykes	-	SQ	b) BDO/BDMO
		c) Extent of Natural accretion (bio-shielded coastline)	-	SQ	c) SQ
Bio-geochemical components	d) Extent of natural subsidence due to compaction	-	SQ	d) SQ	
	e) Protective measures (bouldering/cementing) to control erosion	+	SQ	e) BDO/BDMO	
	a) Extent of contamination of ground water in coastal aquifers (e.g., Arsenic)	-	SQ	a) RP/R/BDO	
	b) % of total population affected by such contaminated water	-	SQ	b) BDO	

Table 2 (continued)

Dimension	Indicators	Variables	Relation to Overall Coastal Resilience	Indicator Type	Data Source
Environmental safeguard measures		c) Extent of chemical pollution in mangrove food chain	-	P	c) RP/EI
		d) Extent of loss of soil fertility (agricultural impact) due to sea level rise	-	P	d) BDO
		e) Mitigation level of existing chemical contamination	+	P	e) BDO
		a) Extent of Integration of Natural hazard Maps in planning	+	P	a) BDO
		b) Implementation of Environmental Protection Act	+	P	b) BDO
		c) Extent of Control in Deep aquifer pumping	+	P	c) BDO
		d) Extent of monitoring and Maintenance of environmental database	+	SQ	d) BDO
		e) Involvement of Scientific communities in Environmental R & D	+	SQ	e) BDO

Relation to Overall community resilience: (-) Denotes the specific indicators is indirectly proportional to overall community resilience, i.e., increase of particular component will lead to reduction of overall resilience score. (+) Denotes the specific indicators is directly proportional to overall community resilience, i.e., increase of particular component will lead to increment of overall community resilience
 Abbreviations: CD Census Data, DHDR District Human Development Report, BDO Block Development Office/Officer, CL Community Leaders, BDMO Block Disaster Management Officer, DSB District Statistical Handbook, RP Research Papers, R Reports, EI Expert Interview, CBMM Community based Mangrove Management, CBBDCM Community based Bio-diversity Conservation and Management, FPC Forest Protection Committee

Significance of social and economic resilience to natural disasters has been widely recommended in all the four important policy research domains i.e., disaster risk reduction, climate change adaptation, environmental management and poverty reduction (Thomalla et al. 2006). Particularly, when the communities are extremely dependent on natural resources, social and ecological resilience normally follows a synergistic and co-evolutionary pathway (Adger 2000). Thus, it can be derived that socio-economic resilience of coastal rural communities consists of community competency and sustainable resource utilization. In the present framework, indicators and variables used to measure 'socio-economic resilience' include 'Demography', 'Livelihood', 'Health' and 'Education & Awareness'. In addition, inclusion of 'social-capital' contributes in the understanding of 'network and ties' within and outside the community which can significantly enhance its capacity to counter external stress (Murphy 2007). Strong social bonding among the communities may lead to faster recovery (Nakagawa and Shaw 2004). Hence, these five indicators contribute to measure the intrinsic capacity of the community (community competency) with respect to an external stress and further, it also facilitates faster disaster recovery (De Bruijn 2004). Variables under these indicators have also been carefully chosen after extensive literature review (Table 2) (Cutter et al. 2010; Peacock et al. 2010; Joerin and Shaw 2011). In addition to this, some site-specific variables such as 'Below Poverty Level (BPL)' population and implementation of 'Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)' etc. was also included in this present framework.

Communities, be it rural or urban, depend on series of infrastructural facilities. Resilient infrastructure systems, particularly electricity, water and other public services are crucial for minimizing the disaster impacts (McDaniels et al. 2008). Discontinuation of public essential services leads to poor rescue and relief operations and impedes recovery. Therefore, physical or structural resilience needs to be robust and dynamic. Unfortunately, rural communities, especially in the developing countries, mostly lack modern infrastructural facilities such as potable water, improved public transportation, electricity etc., which makes them susceptible to shocks and stresses. In the present framework, physical (structural) resilience assessment indicators are largely derived from Cutter et al. 2008, and Joerin and Shaw 2011 which recommends transportation, residential infrastructure, electricity, telecommunication and water infrastructure & sanitation as major indicators of physical resilience. Although, these indicators are equally applicable to urban areas, variables like 'all weather accessible roads' and 'percent of houses living under the avg. flood line' are definite coastal issues and are proxy for the seasonal (monsoonal) vulnerability of the study area.

Coastal rural areas, in general, consist of two primary institutions, i.e., social institutions and resource management

institutions. These two institutions have major functional role in community development as well as ecological conservation. These can be further segregated into two specific categories, i.e., formal and informal institutions. For example, in India, village level institutions known as *Panchayets* are formal institutions that were established under the constitutional requirements to promote village level 'self governance'. *Village Panchayets* function under the supervision of the Block level administration and are primarily responsible for village development. However, a number of other informal institutions such as farmer's group, fishermen's group, forest protection group and faith based organizations have also profound impact on the communities; particularly to promote disaster risk reduction and community based adaptation measures. Therefore, the indicators and variables incorporated under the institutional dimension were largely designed against the socio-political understanding of the study area. In general, the variables intend to measure the institutionalization of disaster risk reduction, climate change adaptation as well as the existing risk response mechanism of the local government. Primarily, it intends to analyze the institutional capacity of the block level administration to handle a crisis situation. Additionally, it also incorporated some specific variables to measure administrative tribulations such as corruption; lack of financial capability and lack of coordination. Although, at times, these are considered as negligible factors, yet have the potential to become highly corrosive to social and economic resilience during catastrophic times.

'Coastal Zone Management' is an integrated process that combines a complex set of social, economic and environmental information for sustainable development of the coasts (Vandermeulen 1998). Numbers of researchers have mentioned that the annihilation of coastal ecosystem services such as mangroves or coral reefs can be attributed to human induced unsustainable development of coastal areas. Therefore, the present framework consist a distinct dimension of 'Coastal Zone Management' which includes the 'management' of both the biotic and abiotic coastal resources. Among the five major indicators used in this framework, four has strong ecological significance (i.e., Mangrove management, Bio-diversity conservation, Aquatic pollution control and Coastal Land use). Additionally, embankment and shoreline management largely defines the survivability of the communities in the low lying delta areas of the Indian Sundarbans (Table 2). All the variables that were framed under the coastal zone management have some relevance to the ecological performance of the exotic Sundarbans mangroves.

The last component of natural or environmental resilience mostly corresponds to the block's exposure to specific coastal and terrestrial hazards including coastal erosion, relative sea level rise, salinity and arsenic contamination. Importantly, each community has different scale of exposure to natural hazards and distribution of risks is not uniform. Hence, the

degree of natural/environmental resilience corresponding to each block is different from others. In addition, a specific indicator 'environmental safeguard action' was introduced to incorporate precise actions that are being undertaken in order to counter the environmental threats arising from natural, biogeochemical and geo-physical factors.

In this present framework, 125 variables have been categorized into three types (Table 2), i.e., Quantitative (Q), Semi-quantitative or 'proxy' variables (SQ) and perspective variables (P). While quantitative variables are directly supported by a dataset, the semi-quantitative variables, are essentially supplemented by a relevant dataset, although not directly related (e.g., Data corresponds to percent of population suffered livelihood discontinuation aftermath disasters can be closely estimated from the number of person applied for temporary jobs following the last encountered disaster). The perspective variables are complicated as no benchmark is available and the assessment depends on the apprehension of the respondent (administrators/experts). One way to improve the precession of such variables is to follow a set of sub-questions that can define the overall goal of the indicators (e.g., activity of Forest Protection Committee in mangrove conservation can be segregated to further sub questions such as area mangrove that has been planted by the committee, survival rate of plantation, number of annual meeting etc.).

Data collection and computation of the coastal community resilience index

A questionnaire was formulated based on the above framework with five dimensions, 25 indicators and 125 variables. Community development blocks (CDBs); the lowest administrative units were targeted to carry out the present study. Field survey was conducted in all the 19 CDBs of Indian Sundarbans during June/July 2013 and a follow-up survey in January/February 2014 and responses were gathered mostly in an interview mode. Block Development Officers (BDOs) [the administrative head of the CDBs] were approached with the questionnaire. As Block Development Offices are bestowed with the responsibility of dealing with all the local level development issues, they contain a wide range of socio-economic data ranging from census, livelihood, land use, public health etc. Other associated administrative officers (e.g., Block Disaster Management Officer, Fisheries and agricultural officer etc.) were also interviewed simultaneously to reach a conclusion, particularly for the perspective variables. A Likert scale of 1 to 5 was used to rate each variable (i.e., scoring of the variables); where '1' refers to 'very poor' and 'five' was designated as 'Very Good'. For quantitative indicators, '5' actually represents the best practices and/or examples. For e.g., the average coastal population density in low elevated coastal areas is 114/sq.km (Small and Nicholls 2003), therefore if the density of the block is less than 114/sq.km, it is

assigned 'five' depicting very high resilience. For most of the variables, the likert scales were designed according to the national, regional and international best practices/standards.

Another important aspect of the present framework is the prioritization of components (variables, indicators as well as dimensions) for each administrative block. Therefore, the framework introduced a weightage scale ranging from 1 to 5. The respondents were asked to prioritize the impact of a particular component by weighing between 1 (Not Important) and 5 (Very significant). For example, under demography (indicator), the respondents can prioritize each of the five variables [i.e., Annual Average Population Growth Rate (v_1), population density (v_2), age dependency ratio (v_3), percent of rural

population (v_4), percent of Backward/Tribal Population (v_5)]. The weighted score of demography is calculated as

$$\text{Score}_{Demography} = \frac{w_1v_1 + w_2v_2 + w_3v_3 + w_4v_4 + w_5v_5}{w_1 + w_2 + w_3 + w_4 + w_5} \quad (1)$$

Where, $v_{n(n=1 \text{ to } 5)}$ represents the score of the variables and $w_n (n=1 \text{ to } 5)$ represents the assigned weightage to each variable.

Weighted mean score of each dimension is calculated from the indicator scores obtained using Eq. 1. For example, the weighted mean score of socio-economic dimension is calculated by the weighted average score of each of the indicators under it.

$$\text{Weighted Mean Score}_{Socio-economic} = \frac{w_1i_{Demography} + w_2i_{Livelihood} + w_3i_{Health} + w_4i_{Education} + w_5i_{Social Capital}}{w_1 + w_2 + w_3 + w_4 + w_5} \quad (2)$$

Where i_n represents the score of indicators obtained from Eq. 1 and $w_n (n=1 \text{ to } 5)$ represents the assigned weightage to each indicator.

Finally, composite resilience score was calculated from the weighted mean score of the five dimensions i.e., socio-economic, physical, institutional, Coastal Zone Management (CZM) & Natural/Environmental (Eq. 2).

$$\text{Composite Resilience Score} = \frac{w_1d_{socio-economic} + w_2d_{physical} + w_3d_{institutional} + w_4d_{CZM} + w_5d_{Natural}}{w_1 + w_2 + w_3 + w_4 + w_5} \quad (3)$$

Where, d_n represents the weighted mean score of each dimension obtained from Eq. 2 and $w_n (n=1 \text{ to } 5)$ represents the assigned weightage to each dimension.

Based on the composite resilience scores, the blocks were segregated into five different groups – very low, low, moderate, high and very high resilient by equal interval classification method using ArcGIS 10.2.1. The ranges were classified as Very High (>4.0), High ($4.0>3.5$), Moderate ($3.5>3.0$), Low ($3.0>2.5$) and Very Low ($2.5>2.0$) using the obtained upper (3.6) and lower limits of (2.51) of composite resilience. Similar method of classification was used for segregating the blocks under each of the five dimensions.

Result & discussion

Overall status of community resilience in Indian Sundarbans

Table 3 & Fig. 2 outlines the summarized version of community resilience of 19 coastal blocks of Indian Sundarbans. Out

of the 19 blocks, only one (Mathurapur I) can be designated as a high resilient block, whereas 7 blocks are found to be moderately resilient and rest 11 blocks are found to experience low resilience (Fig. 2f). To detect which of the five components impart significant impact on the overall resilience score, a simple correlation analysis was carried out. The result suggests that the composite score is significantly influenced by mainly three factors, i.e., Institutional resilience ($r=0.80$), Environmental & Natural resilience ($r=0.77$) along with Coastal Zone Management ($r=0.70$). Understandably, composite resilience follows an inversely proportional relationship with the exposure, i.e., communities with low environmental & natural resilience (i.e., high exposure) are less resilient i.e., prone to disaster impacts. Also, 'Community resilience', in general, improves with the effective coastal zone management and this observation is in line with the documented evidences from several researchers working on socio-ecological systems (e.g., Adger et al. 2005). In regards to the institutional resilience, local institutions play a significant role in promoting coastal communities' resilience. This is mostly because of the effective collaboration within and among the local level administration, precisely with the community members.

Table 3 Evaluation of community resilience in Indian Sundarbans

	Location	Socio-Economic	Physical	Institutional	Coastal Zone Mgt.	Environmental & Natural	Composite Score	Assigned Resilience Category
Mathurapur I	MM/S	3.31	3.41	3.55	3.95	3.92	3.63	High
Joynagar I	MM/S	2.76	3.50	3.41	3.59	4.09	3.47	Moderate
Haroa	MM/S	3.35	3.24	3.73	3.52	3.47	3.46	Moderate
Namkhana	EC/A	3.22	3.42	3.09	2.92	3.16	3.16	Moderate
Joynagar II	MM/S	2.71	2.87	3.32	2.94	3.92	3.15	Moderate
Mathurapur II	MM/S	3.43	2.74	3.48	3.13	2.78	3.11	Moderate
Canning II	MM/S	2.54	2.86	3.12	3.20	3.72	3.09	Moderate
Kultali	C/A	2.58	2.68	3.35	3.56	3.20	3.07	Moderate
Minakhan	MM/S	2.78	3.46	3.13	2.68	2.93	3.00	Low
Basanti	C/A	2.78	2.53	3.43	2.80	3.34	2.97	Low
Sagar	EC/A	3.35	2.54	2.73	3.02	3.10	2.95	Low
Hingolganj	C/A	3.06	2.51	2.70	3.37	2.91	2.91	Low
Sandeshkhali II	EC/A	2.31	3.10	2.28	3.37	3.02	2.81	Low
Patharpratima	EC/A	2.70	2.50	3.18	2.99	2.66	2.81	Low
Hasnabad	C/A	3.01	3.17	2.72	2.68	2.17	2.75	Low
Canning I	C/A	2.93	2.82	2.50	2.42	3.02	2.74	Low
Kakdwip	EC/A	2.55	2.75	2.76	2.62	2.94	2.72	Low
Sandeshkhali I	C/A	2.86	2.42	2.85	2.93	2.07	2.63	Low
Gosaba	EC/A	2.42	2.14	2.29	2.92	2.80	2.51	Low

MM/S Middle Mature Stable Delta, C/A Coastal Active Delta, EC/A Extreme coastal Active Delta

Conversely, socio-economic ($r=0.47$) and physical resilience ($r=0.67$) was found to contribute moderately to overall community resilience.

Socio-economic resilience

Socio-economic resilience of the study area is found to be uniformly poor and can be generally categorized between very low and low. Among the five indicators, demography, health and livelihood are the key concern for this region (see inset of Fig. 2a). Population density in blocks such as Joynagar I (1984/sq. km), Canning I (1586/sq.km) are alarming where as annual growth for blocks of Kultali, Canning I & Canning II crosses 2 %/year; significantly high for predominantly rural areas. As depicted in the Fig. 2a, blocks with high coastal exposure i.e., Pathar Pratima, Kakdwip, Kultali, Basanti, Gosaba & Sandeshkhali II experience significantly low socio-economic resilience. This is presumably due to physical isolation and excessive dependence on coastal resources. The present study coincides with the post 'Cyclone Aila' recovery period and loss of livelihood due to saline water intrusion in coastal agricultural lands has been particularly prominent in the extreme coastal blocks. A gradual trend of depleting ecosystem services was also observed in Gosaba, Pathar Pratima, Sandeshkhali I & II where the local fishing communities expressed their concern over the depleting

fishing resources. Although no specific scientific studies have been conducted, further interrogation with the communities revealed that the fish catch has been decreased approximately by 30 % over the last decade. Excluding some of the interior blocks such as Mathurapur I, Mathurapur II and Joynagar I, livelihood choices are exceptionally limited. Low literacy rate further play a crucial role as it limits the livelihood options. Blocks with low literacy rate Sandeshkhali I & II, Basanti also experience low socio-economic resilience and characteristically depend on fishing or agriculture. However, the discussion needs a special mention of Sagar Block. This particular block has been exemplified as a critical hazard prone area by number of researchers (e.g., Bandyopadhyay 1997; Gopinath and Seralathan 2005; Gopinath 2010). In this present assessment, despite of its close proximity to the sea and high exposure, it shows somewhat better socio-economic resilience. This can be attributed to several causes such high literacy rate and diversified economic opportunities from religious & eco-tourism. The island of Sagar is one of the well known Hindu pilgrimages which annually hold a mass gathering and bathing ceremony. Religious tourism, therefore, is a major income source for the local communities (Edward and Lakshmi 2010). Although, the entire delta of Sundarbans has an untapped potential of eco-tourism, it was hindered by lack of transportation and necessary infrastructural facilities. Similar to Sagar, blocks such as Gosaba, Namkhana, Pathar Pratima

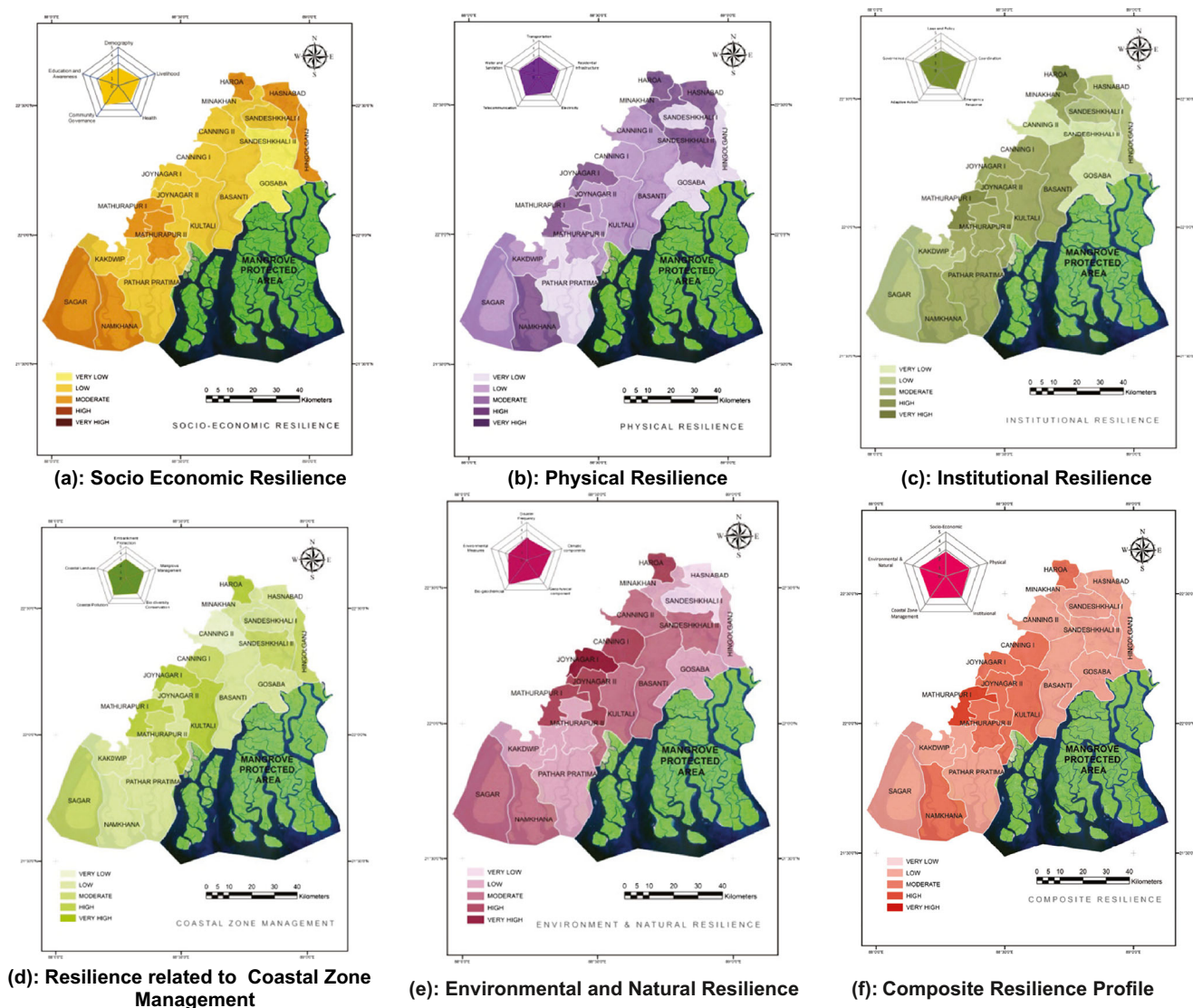


Fig. 2 Resilience profile of Indian Sundarbans. **a** Socio Economic Resilience **b** Physical Resilience **c** Institutional Resilience **d** Resilience related to Coastal Zone Management **e** Environmental and Natural Resilience **f** Composite Resilience Profile

has extensive mangroves & its exotic bio-diversity to offer; however, the growth of tourism sector is extremely limited.

Physical resilience

Spatial variation of physical resilience follows the similar trend of socio-economic resilience and scores between poor to moderate scale (Fig. 2b). Among the five indicators used to assess the physical resilience, transportation and electricity are the key concern for this region (see inset of Fig. 2b). Rural communities in the developing world, in general, lack the robustness in the infrastructural arrangements which make them prone to natural hazards. The case of the Indian Sundarban is also no exception. This is mostly because of predominantly earthen housing structures, non-availability of

potable water, absence of rural electrification and primitive transportation. Connectivity of the extreme coastal blocks of Indian Sundarban remains the foremost challenge. Blocks such as Pathar Pratima, Gosaba, and Hingolganj have extremely limited accessibility and mostly rely on semi motorized boats, locally engineered rickshaws etc. Conversely, interior blocks such as Joynagar I, Mathurapur I, Canning I, Hasnabad and Haroa are somewhat well connected by railways and formal public transportation network. Among the extreme coastal blocks, Namkhana and Sagar shows moderate resilience due to the occurrence of formidable road conditions within the block which essentially improves the overall connectivity and provides ample scope for infrastructural development. Physical isolation and island conditions also severely impair the domestic electricity connections & uses. This fact

emphasizes the reason behind significant negative correlation between coastal exposure and physical resilience. For example, less than 5 % of the communities living in blocks such as Sagar, Gosaba, Basanti, Pathar Pratima, and Kultali have formal electricity connections. However, things are fast changing for the last couple of years as the remote islands are presently being connected to the main supply grids. On the contrary, cyclone 'Aila' in 2009 has triggered some positive changes like building 'emergency cyclone shelter' in the delta and also some government grants to build resilient public houses. Surprisingly, despite of wide spread poverty and unavailability of domestic electricity supply, more than 60 % of the population use mobile phones. Information sharing through mobile messaging has also been started on trial basis in blocks such as Canning I & II, Basnati, Sandeshkhali I & II, however, the formal early warning systems available in each block remain mostly non-functional.

Institutional resilience

Despite of the same administrative framework, institutional resilience in the study area varies widely among the blocks (Fig. 2c). Even though, a minor relationship exists between the proximity to the administrative headquarters and the institutional resilience of a particular block; yet, it is difficult to conclude that the coastal blocks which are distantly located are institutionally less resilient. However, interior blocks such as Haroa, Joynagar I, Mathurapur I have the better capacity in terms of responding to disaster due to improved availability of necessary human and logistic resources. Among the five indicators used to measure institutional resilience, implementation of laws/policies and adaptive actions are under performed for majority of the blocks (see inset of Fig. 2c). Many of the bordering blocks with Bangladesh such as Hasnabad, Hingolganj experience problems in maintaining law and orders. One critical observation during the field study was that the general public opinion often goes against the existing institutional mechanism. Consequently, a severe lack of trust persists among the communities. Particularly, in the aid and emergency responses, people who are politically powerful (community leaders) are accused of manipulating aid distribution system in the past. Such cases were prominent in Gosaba, Namkhana, and Sagar blocks (Mukhopadhyay 2009). However, apart from the emergency response, disaster resilience also includes the broader aspect of risk reduction i.e., 'adaptation'. For example, despite the wide spread damage to coastal agricultural land in the previous cyclones, any of the village level institutions in blocks like Gosaba, Pathar Pratima, Namkhana, Sandeshkhali I & II is yet to initiate flood or disaster insurance scheme. Although, a good number of NGOs are working on specific aspects of ecological conservation, existence of developmental NGOs and their activities are fairly limited. In addition, several block offices are under

resourced in terms of physical capacity and necessary manpower.

Coastal zone management

Active management of coastal resources and sustainable environmental practices largely reduces the risks from coastal hazards (USIOTWSP 2007). In coastal rural areas, a robust ecosystem can provide the best possible resistance to coastal hazards. This was evident from number of previous coastal disasters, especially the Indian Ocean Tsunami in 2004. Case studies in the aftermath of the Tsunami revealed that mangroves and other coastal forests protected rural communities from the devastating waves (e.g., Kathiresan and Rajendran 2005; Danielsen et al. 2005). The name Sundarbans is synonymous to the exuberant mangrove species of *Heritiera fomes* and represents a vibrant coastal ecosystem. In the present study, obtained scores demonstrated that interior blocks in the middle mature delta like Mathurapur I and Joynagar I manages their coastal zones more effectively (Fig. 2d). However, it is also necessary to mention that their coastal exposure is limited to small channels and creeks. On the contrary, resilience scores obtained for the extreme coastal blocks like Gosaba, Namkhana, Pathar Pratima, Basanti and Kakdwip were found to be significantly low. Out of the five components used to measure CZM resilience (inset of Fig. 2d), the most crucial has been the embankment management. Embankment essentially serves as the critical coastal infrastructure for this tide-dominated delta. Blocks such as Gosaba, Namkhana, Pathar Pratima, Basanti, Sandeshkhali I & II survive on semi-engineered earthen embankments; failure of which results in immediate flooding. Unfortunately, the embankments are over 100 years old with occasional repairing and reconstruction. During the cyclone 'Aila' in 2009, nearly 472 km of embankment was severely damaged and/or destroyed leading to instant flooding of these blocks. On the other hand, since the communities of these blocks mostly depend on coastal resources, unsustainable methods coupled with overfishing have led to significant decrease in fish population in the estuarine creeks. In addition, collection of prawn seeds by nets of fine mesh is a predominant form of rural livelihood in Gosaba, Basanti, Sandeshkhali I & II. This is an ecologically destructive practice with severe impact on the aquatic bio-diversity. Further, unsustainable practices of fishing & aquaculture through large scale conversion of coastal land have also been observed in the eastern part of the delta, especially in blocks like Minakhan, Hasnabad and Haroa. Importantly, aquaculture has strong implications in local economy and serves as a lucrative livelihood

option for the local communities, yet, it also poses significant environmental challenge for this eco-fragile delta.

Environmental and Natural Resilience

Environmental/Natural Resilience is associated with the geographical location and geophysical characteristics that determine the disaster risk exposure of a particular block. In the present study, resilience score obtained under the Environmental / Natural dimension (Fig. 2e) closely corresponds to the existing scientific understanding of disaster and climatic risk profile of Indian Sundarbans. In general, interior blocks are resilient compared to the extreme coastal blocks as the later face more severe risk from cyclonic storms and associated storm surges. Out of the five indicators, disaster frequency and geophysical components are of primary concern for this region (see inset Fig. 2e). For example, extreme coastal blocks such as Gosaba, Sandeshkhali I, Patharpratima and Kakdwip experienced low resilience scores due high disaster frequency from a variety of coastal hazards such as heavy tidal inceptions, storms and surge flooding. The western block of Sagar shows moderate resilience despite of the fact that part of the block is severely prone to coastal erosion. This can be related to the existence of large sand dune systems, coastal protective plantations and some recently developed engineered sea dykes in Sagar islands. Additionally, despite of it locations in arsenic contaminated lower Gangetic basin, majority of the blocks remain contamination free. However, this is apparently because of the exploitation of deep aquifers instead of the shallow aquifers. Swallow water aquifers, which contain arsenic in the Bengal basin, are not used by the communities due to the presence of salinity. Yet, as per the available government documents, significant number of public tube wells located in Hasnabad and Hingolganj Blocks are found to possess high arsenic levels leading to their low natural resilience.

Conclusion & recommendation

Integration of social, ecological, human and natural factors in overall resilience assessment significantly enhance our ability to understand the severity of a possible disaster and subsequently to prepare for it. It further helps to carefully plan and execute pre-disaster developmental activities in order to minimize the impacts of a future disaster. The desired endeavor of this particular study was to link the current socio-economic, scientific and ecological knowledge through an appropriate resilience assessment framework. Further, it also tried to incorporate administrator's perspectives, identify the key functional areas to enhance disaster & climate resilience of the communities living in Indian Sundarbans. All these

components are crucial in terms of framing Integrated Coastal Zone Management Plan (ICZMP) for this critically vulnerable coastal area. The study also briefly addressed the interrelatedness of these components and tried to identify the synergic relationship between the components. In general, it has been observed that community resilience in Indian Sundarban follows an inversely proportional relationship with coastal exposure (Environmental/Natural resilience), i.e., 'resilience' tends to decrease with the proximity to the sea. Understandably, due to its immediacy to sea, extreme coastal areas are at the forefront of the impact caused by climate induced disasters; however, this is being further escalated by significant developmental deficit, limited livelihood opportunities, inadequate institutional arrangements and improper coastal zone management. Therefore, under the existing scenario, it can be concluded that more than half of the population in Indian Sundarbans have little or negligible capacity to cope with an external stressor.

It is apparent that the entire delta of Sundarbans will continue to remain at the forefront of climate & disaster risks. Regional consequences of tropical cyclones, surge flooding and coastal erosion may continue to rise under the influence of global climate change. Therefore, in order to improve the existing level of community resilience, several structural and non-structural measures are necessary. Such measures may differ depending on the geographical location of the blocks. However, beside the structural measures, there is a strong requirement for community level 'adaptation' which needs to be incorporated through gradual institutional interventions. Further, adaptation requirements are higher in the extreme coastal blocks compared to the interior blocks due to their exceptionally limited coping capacity. In order to achieve such goals, the local level institutions must be empowered, trusted and given adequate training and resources to initiate the adaptation planning. On the other hand, community infrastructures such as transportation and communication need to be strengthened which will largely promote diversification of livelihood and creation of new employment opportunities. Importantly, the Indian Sundarban remains at the centre of a dilemma since it is widely believed that any large scale development would adversely affect the fragile ecosystems of the delta. Yet, basic infrastructural development is prerequisite for resilience to climate disasters. However, developmental process needs to be balanced with ecological consideration. An ideal adaptation model to enhance the community resilience of Indian Sundarbans should effectively integrate & optimize both physical (infrastructural) and ecological resilience through comprehensive planning at regional & sub-regional level. Low impact economic developments perhaps hold the key to resilience in this eco-fragile region.

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References

- Adger WN (2000) Social and ecological resilience: are they related? *Prog Hum Geogr* 24(3):347–364
- Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-ecological resilience to coastal disasters. *Science* 309(5737):1036–1039
- Auld H (2008) Disaster Risk Reduction under Current and Changing Climate Conditions. *WMO Bull* 57(2):118–125
- Bandyopadhyay S (1997) Natural environmental hazards and their management: a case study of Sagar Island, India. *Singap J Trop Geogr* 18(1):20–45
- Banerjee A (1998) Environmental Population and Human Settlements of Sundarban Delta. Concept Publishing Company, New Delhi
- Béné C, Wood RG, Newsham A, Davies M (2012) Resilience: new utopia or new tyranny? Reflection about the potentials and limits of the concept of resilience in relation to vulnerability reduction programmes. *IDS Work Pap* 2012(405):1–61
- Costanza R, Farley J (2007) Ecological economics of coastal disasters: Introduction to the special issue. *Ecol Econ* 63(2):249–253
- Cutter S (2008) A framework for measuring coastal hazard resilience in New Jersey communities-White Paper for the Urban Coast Institute
- Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E, Webb J (2008) A place-based model for understanding community resilience to natural disasters. *Glob Environ Chang* 18(4):598–606
- Cutter SL, Burton CG, Emrich CT (2010) Disaster resilience indicators for benchmarking baseline conditions. *J Homel Secur Emerg Manag* 7(1)
- Danielsen F, Sørensen MK, Olwig MF, Selvam V, Parish F, Burgess ND, Suryadiputra N (2005) The Asian tsunami: a protective role for coastal vegetation. *Science (Washington)* 310(5748):643
- DasGupta R, Shaw R (2013) Changing perspectives of mangrove management in India—An analytical overview. *Ocean Coast Manag* 80:107–118
- De Bruijn KM (2004) Resilience indicators for flood risk management systems of lowland rivers. *Int J River Basin Manag* 2(3):199–210
- Edward JP, Lakshmi SA (2010) Coastal Issues and Management Strategy for Sagar Island in Bay of Bengal. *Recent Res Sci Technol* 2(5)
- Folke C (2006) Resilience: The emergence of a perspective for social-ecological systems analyses. *Glob Environ Chang* 16(3):253–267
- Forest Survey of India (2011) State Forest Report-2011
- Gopal B, Chauhan M (2006) Biodiversity and its conservation in the Sundarban Mangrove Ecosystem. *Aquat Sci* 68(3):338–354
- Gopinath G (2010) Critical coastal issues of Sagar Island, east coast of India. *Environ Monit Assess* 160(1–4):555–561
- Gopinath G, Seralathan P (2005) Rapid erosion of the coast of Sagar island, West Bengal-India. *Environ Geol* 48(8):1058–1067
- INCCA (2010) Climate change and india; A 4 × 4 Assessment, available online at <http://www.moef.nic.in/downloads/public-information/fin-rpt-incca.pdf>
- IPCC (2012) Summary for Policymakers. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, pp 1–19
- Joerin J, Shaw R (2011) Mapping climate and disaster resilience in cities in Community, Environment and Disaster Risk Management, Emerald Publications, UK, 6, 47–61
- Joerin J, Shaw R, Takeuchi Y, Krishnamurthy R (2012) Action-oriented resilience assessment of communities in Chennai, India. *Environ Hazards* 11(3):226–241
- Kathiresan K, Rajendran N (2005) Coastal mangrove forests mitigated tsunami. *Estuar Coast Shelf Sci* 65(3):601–606
- Klein RJ, Smit MJ, Goosen H, Hulsbergen CH (1998) Resilience and vulnerability: Coastal dynamics or Dutch dikes? *Geogr J*. 259–268
- Knutson TR, McBride JL, Chan J, Emanuel K, Holland G, Landsea C, Held I, Kossin JP, Srivastava AK, Sugi M (2010) Tropical Cyclones and Climate Change. *Nat Geosci* 3:157–163
- Mandal RN, Das CS, Naskar KR (2010) Dwindling Indian Sundarban mangrove: the way out. *Sci Cult* 76(7–8):275–282
- McDaniels T, Chang S, Cole D, Mikawoz J, Longstaff H (2008) Fostering resilience to extreme events within infrastructure systems: characterizing decision contexts for mitigation and adaptation. *Glob Environ Chang* 18(2):310–318
- McGranahan G, Balk D, Anderson B (2007) The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environ Urban* 19(1):17–37
- Miller F, Osbahr H, Boyd E, Thomalla F, Bharwani S, Ziervogel G, Nelson D (2010) Resilience and vulnerability: complementary or conflicting concepts? *Ecol Soc* 15(3):11
- Mimura N, Nurse L, McLean RF, Agard J, Briguglio L, Lefale P, Payet R, Sem G (2007) Small islands. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 687–716
- Mitra A, Gangopadhyay A, Dube A, Schmidt AC, Banerjee K (2009) Observed changes in water mass properties in the Indian Sundarbans (northwestern Bay of Bengal) during 1980–2007. *Curr Sci* 97(10):1445–1452
- Mukhopadhyay A (2009) Cyclone Aila and the Sundarbans: An Enquiry into the Disaster and Politics of Aid and Relief (<http://www.mcrg.ac.in/pp26.pdf>)
- Murphy BL (2007) Locating social capital in resilient community-level emergency management. *Nat Hazards* 41(2):297–315
- Nakagawa Y, Shaw R (2004) Social Capital: A Missing Link to Disaster Recovery, *Int J Mass Emergencies Disasters*, 5–34
- Nicholls RJ, Branson J (1998) Coastal resilience and planning for an uncertain future: an introduction. *Geogr J* 164(3):255–258
- Nicholls RJ, Cazenave A (2010) Sea-Level Rise and Its Impact on Coastal Zones. *Science* 328:1517–1520
- Nicholls RJ, Wong PP, Burkett VR, Codignotto JO, Hay JE, McLean RF, Ragoonaden S, Woodroffe CD (2007) Coastal systems and low-lying areas. *Climate Change 2007*. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 315–356
- Norris FH, Stevens SP, Pfefferbaum B, Wyche KF, Pfefferbaum RL (2008) Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *Am J Community Psychol* 41(1–2):127–150
- Peacock WG, Brody SD, Seitz WA, Merrell WJ, Vedlitz A, Zahran S, Harris C, Stickney R (2010) Advancing resilience of coastal localities: developing, implementing, and sustaining the use of coastal resilience indicators: A final report. Hazard reduction and recovery center. final report for NOAA CSC grant no. NA07NOS4730147
- Small C, Nicholls RJ (2003) A global analysis of human settlement in coastal zones. *J Coast Res* 584–599

- Stanley DJ, Hait AK (2000) Holocene depositional patterns, neotectonics and Sundarban mangroves in the western Ganges-Brahmaputra delta. *J Coast Res* 26–39
- Teo M, Goonetilleke A, Ziyath AM (2013) An integrated framework for assessing community resilience in disaster management. In Proceedings of the 9th Annual International Conference of the International Institute for Infrastructure Renewal and Reconstruction, Risk-informed Disaster Management: Planning for Response, Recovery and Resilience
- Thomalla F, Downing T, Spanger-Siegfried E, Han G, Rockström J (2006) Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. *Disasters* 30 (1):39–48
- U.S. Indian Ocean Tsunami Warning System Program (USIOTWSP) (2007) How Resilient is Your Coastal Community? A Guide for evaluating coastal community resilience to tsunamis and other coastal hazards. U.S. Indian Ocean Tsunami Warning System Program supported by the United States Agency for International Development and partners, Bangkok, Thailand
- Uy N, Takeuchi Y, Shaw R (2011) Local adaptation for livelihood resilience in Albay, Philippines. *Environ Hazards* 10(2):139–153
- Vandermeulen H (1998) The development of marine indicators for coastal zone management. *Ocean Coast Manag* 39(1): 63–71