Coastal Ecosystem and Changing Economic Activities and Vulnerabilities along Chinese and South Asian Coasts

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HIGHLIGHTS

- Traditional economic activities of coastal communities are moving away from fisheries and agriculture.
- The change is due to declining fish stock, cyclones, storm surges, soil water intrusion and water stress.
- Low income from traditional livelihood, competition for land, and pollution load has also contributed to the change.
- Related policies are creating short-term alternative livelihood options.
- Threats to current coastal economic activities will be exacerbated in the region due to climate change.

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ABSTRACT This field-based study documents the changing pattern of economic activities along selected coastal stretches in South Asia in Bangladesh, India, Sri Lanka and China. Economic activities vary with coastal ecosystem types and service flows. In the first phase, field study sites were identified based on multiple meetings and discussions with policy makers in each of the countries and they continued to be part of scientific discussions within an ecology-economy framework through the project lifetime. In the second phase, for Bangladesh, India and Sri Lanka, further in-depth enquiry and analyses were carried out to understand the perception of various economic stakeholder groups of natural and anthropogenic threats in the coastal regions and the resultant vulnerability and risks. Possible future climate scenarios for the study sites were developed to assess the nature of future climate risks to various ecosystem-based economic activity groups.

KEYWORDS *coastal ecosystem, coastal economic activities, changing livelihood, threats, vulnerability, risk.*

1. Introduction

Very high population density characterises South Asia and China coasts. At the global level, coastal population densities are almost three times larger than that of inland areas (UNEP, 2005) with an exponential rise over the years (Barbier et al., 2008). In their study of coastal regions at the global scale, Martínez et al. (2007) have estimated the ecological, economic and social importance of coasts. The wide variety of economic activities, which prevail along the coasts, has either direct or indirect connectivity with the coastal ecosystems through its provisioning of a diverse range of goods and services (Burke et al., 2001). Globally, coastal ecosystems have been experiencing rapid alteration (Barbier et al., 2008; UNEP, 2006; Turner et al. 1998; Martínez et al. (2007)) by either human-induced risks or natural forces (Adger, 2000; Klein, Smit, Goosen, & Hulsbergen, 1998). "Coastal ecosystem" refers to the direct interface between ocean, land and atmosphere, extending seawards to about the middle of the continental shelf and inland, which includes all areas strongly influenced by their proximity to the ocean (UNEP, 2005). LOICZ (2011) identified multiple stresses arising from local- to global-scale drivers that have significant

impact on coastal regions. The Millennium Ecosystem Assessment (UNEP, 2005) has demonstrated that ecosystems have been significantly altered by anthropogenic activity. For South Asian countries, there is a need for better understanding of the extent of human dependence on ecosystem services to assess the vulnerability and risk of coastal ecosystem-based economy. Asian countries like Bangladesh, China, India and Sri Lanka share almost 3 percent of the global coastline and experiencing fast changes over the past four to five decades (Burke et al., 2001). Multiple stressors are inducing coastal habitat modification resulting in degradation of ecosystem services and posing a severe threat to the ecosystem-based economic

Study sites	Population density (per sq. km)	Length of coastline and ecosystem types	Natural threats
Bangladesh: Part of Chittagong and Cox's Bazar 21°23'16" to 21°46'26" N latitude and 91°50'34" to 92°07'50" E longitude	Bangladesh: 964 [a] Coastal Bangladesh: 744 [b] Study Site: 2011 (Cox's Bazar) [c], 887 (Maheshkhali) [c]	Cox's Bazar, 26 km Maheshkhali, 77 km Muddy beach, sandy beach, sand dunes, salt-marshes/salt pans, mangroves and estuary	Tornado, cyclone, tsunami, storm surges, sea level rise, monsoonal precipitation, sea water intrusion, coastal erosion
China: Tianjin Binhai New Area 38°34' to 40°15' N, latitude and 116°43' to 118°04' E longitude	China: 140 [d] Coastal China: 467 [d] Study Site: 994 [e]	153.2 km Mostly muddy coast, estuary, intertidal zone, a few sandy beaches	Sea level rise, storm surge, air temperature rise, sea water intrusion
India: Digha-Sankarpur 21°37'N and 87°32'E	India: 420 [f] Coastal India: 164 [g] Study Site: 517 [h]	17 km Sandy, muddy coast with sand dune, estuary, forest	Cyclones, wind storms, sea level rise, storm wave surge, natural erosion
Sri Lanka: Koggala Area in the Habaraduwa DS division 6°0' N, 80° 20' E	Sri Lanka: 323 Coastal Sri Lanka: 320 Study Site: 877	10 km Wide sandy beaches, lagoons, mangroves, estuary, barrier beach and submerged reef	Sea water intrusion, invasion of sea grass species into lagoon, growth of invasive species
World	52 [i]	3,56,000 kms [a] Evergreen needle-leaf forest, evergreen broad-leaf forest, deciduous needle-leaf forest, deciduous broadleaf forest, mixed forests, closed shrublands, open shrublands, woody savannas, savannas, grasslands, permanent wetlands, sandy shores, coral reefs, mangroves, sea grass, coastal shelf, swamps–floodplains, estuaries (Martinez et al., 2007)	Temperature rise (air and seawater), storms, waves, floods (due to sea level, runoff), rising water tables (sea level), erosion (due to sea level, storms, waves), salt water intrusion (sea level, runoff), biological effects (all climate drivers) (IPCC, 2007)

TABLE 1. Four Study Sites
Feasibility Study reports by country partners: a-The World Factbook, CIA, accessed on Aug 15, 2011; b-Islam, M.R. (ed.), 2004. Where Land Meets the Sea: A Profile of the Coastal Zone of Bangladesh, The University Press Limited, Dhaka; c-Population census-2011, Community report, Zila: Cox's Bazar (June 2012); d-China Statistical Yearbook 2011; e-Tianjin Statistical Yearbook 2012; f-data.worldbank.org/indicator/EN.POP.DNST; 2011; g-UN, 2005. Human Development Report. International Cooperation at a

activities in the region. Studies have shown that vulnerability will vary with time, space and among social groups (O'Brien, Sygna, & Haugen, 2004; IPCC, 1997). The objective of this study is to add to existing literature with a better understanding of the coastal ecosystem types in the four countries in Asia and how and why economic activities are changing over time, relating them to ecosystem service flows and market forces. How communities perceive various sources of threats to their economic activities and what climate-model-based predictions can inform about the risks to current economic activities are some of the questions that have also been touched upon within the limited space of this article.

Anthropogenic Threats	Traditional economic activities	New economic activities
Industrial pollution, poisonous chemicals and even radioactive elements discharged from ship breaking activities	Fishing, fish business, fish drying, small scale business (grocery shop, tea stall), agriculture, betel leaves trading, hawking, photography, aquaculture	Fish drying, hotel and restaurant, shrimp fry, shop business, speed boat driving, beach concert, hawking on the beach, shrimp farming and salt production
Decline in fisheries and low marine environmental quality due to severe pollution from industries in catchment area (waste discharged into the sea)	Mariculture, fishing, sightseeing, education	Leisure, vacation, game, experience, golf, business, meeting, disney park
Drainage and sewerage network, disposal of liquid and solid waste, unauthorised construction of hotels on the beach violating Coastal Regulation Zone (CRZ) regulations, poor protection against wave action particularly during high tide (ingress of tidal water), beach erosion and lowering of beach level	Agriculture, fishing, small-scale business (grocery shop, vegetable seller, tea stall), salt-making, manual van driving, aquaculture, fishing net business, fish business, betel leaves trading, folk singing, masonry, blacksmith	Hawking on the beach, motorbike rides, horse-riding and photography on the beach for tourists, shell-crafting, motorised and manual van-driving, hotels, resorts and restaurants
Encroachment of mangroves, industrial pollution in the form of liquid and solid waste	Agriculture, lagoon fishing, coastal fishing, fish trading, cottage industry, carpentry, small business	Export and hotel industry, tourist guest houses, cinnamon industry, souvenir shops, tourist transportation services
Coastal development (ports, urbanisation, tourism-related development, industrial sites), destructive fisheries (dynamite, cyanide, bottom trawling), coastal deforestation (especially mangrove deforestation), mining (coral, sand, minerals, dredging), civil engineering works, environmental change brought about by war and conflict, aquaculture-related habitat conversion, eutrophication from land-based sources (agricultural waste, sewage, fertilisers), pollution: toxins and pathogens from land-based sources, pollution: dumping and dredge spoils, pollution: shipping-related, alien species invasions, overexploitation of resources (MEA, 2005)	Activities related to urban, industry, mining, agriculture/forestry/aquaculture and fisheries, commerce and transportation (LOICZ, 1998)	

Crossroads: Aid, Trade and Security in an Unequal World; h-Census of India, 2011; i-Population Reference Bureau, 2012 World Population Data Sheet, available at: http://www.prb.org/Publications/Datasheets/2012/world-population-data-sheet/data-sheet.aspx.

2. Methodology

The multi-country study was carried out in two phases: the first phase comprised field studies in four countries: Bangladesh, China, India and Sri Lanka. The second phase covered the same countries except China. In each country, we selected changing coastlines induced by economic activity, developmental policy and population pressure. Using semi-structured questionnaires[1] the natural and anthropogenic threats faced in the study sites by various stakeholder groups categorised by primary economic activity were identified through individual face-to-face interviews. The coverage of surveys varied from 330 in India to 175 in Sri Lanka. Besides direct stakeholders, officials at various levels of policy-making and implementation, and (where existing) economic activity associations were also covered. Some participatory focused group discussions were arranged for policy makers along with the research team to enhance mutual understanding. Various characteristics of the study sites are shown in Table 1. The sites also represent varied coastal ecosystem types and thus different service flows and economic activities. In the second phase, in the three countries of South Asia, various economic groups were interviewed individually with a goal to understand the various threats and related individual level perceived risks[2], and how effective they consider the adaptive measures taken by the local administrative bodies against natural events. The same field survey instrument was used to facilitate cross-country comparison. The data are mainly from individualised face-to-face primary field surveys from various economic categories in India, Sri Lanka and China. Field visits in Phase 1 were mainly organised to obtain information on socio-economic and demographic characteristics of people living in these sites, and the changing patterns in economic activities over the years. The main focus of the second phase of the survey was to identify important threats (natural and anthropogenic) to different economic activities and ecosystem types, to help with the assessment of vulnerability using the IPCC 1997 method. Surveys in both phases were conducted between 2012 and 2014. We adopted the risk-resilience framework (Figure 1) based on literature to frame various questions for our field survey. Various threats in coastal areas driven by environmental change and human activities (Adger et al., 2005) impact coastal ecosystem-based economies through their vulnerability to multiple threats, risk perception and level of resilience determined by adaptive capacity, sensitivity and exposure—the three components of vulnerability (IPCC, 2013). Exposure is the magnitude and duration of climate-related events (Gabor & Griffith, 1980; Adger, 1999). Sensitivity is the degree to which the system is affected (Timmerman, 1981; IPCC, 1997) by the exposure. Adaptive capacity is the system's ability to withstand or recover from the exposure. Adaptation involves reducing risk and vulnerability, seeking opportunities and building the capacity of nations, regions, cities, various stakeholders and natural systems to cope with stresses, as well as mobilising that capacity by implementing decisions and actions. Adaptation options can be implemented to modify either the drivers or exposure and vulnerability or both (IPCC, 2013). Risk in this study refers to the potential for adverse effects on human lives, livelihoods, health status, economic, social and cultural assets, services (including environmental), and infrastructure. Risk can also be subjective in the sense that the likelihood and outcomes are based on the knowledge or perception that a person has about a given situation (IPCC, 2013). Resilience (Timmerman, 1981; Adger, 2000; Dolan & Walker, 2004) is a concept that takes into account how systems, communities, sectors, or households deal with disturbance, uncertainty and surprise over time, and it is characterised by both adaptability and transformability. The schematic of the complex links of interdependence among vulnerability, risk and other components as mentioned above are presented in Figure 1.

Climate change projections for the three countries of South Asia are being done using IPCC AR4 Projections based on PRECIS A1B Scenario and IPCC AR5 Projections using SMHI RCP4.5 Scenario.

1 The full questionnaire can be accessed on request. The method provided scope to get narratives from the respondents along with answers to structured questions.

2 Individual level risk assessments are available in detail with the corresponding author and are omitted here for presentation in limited space.

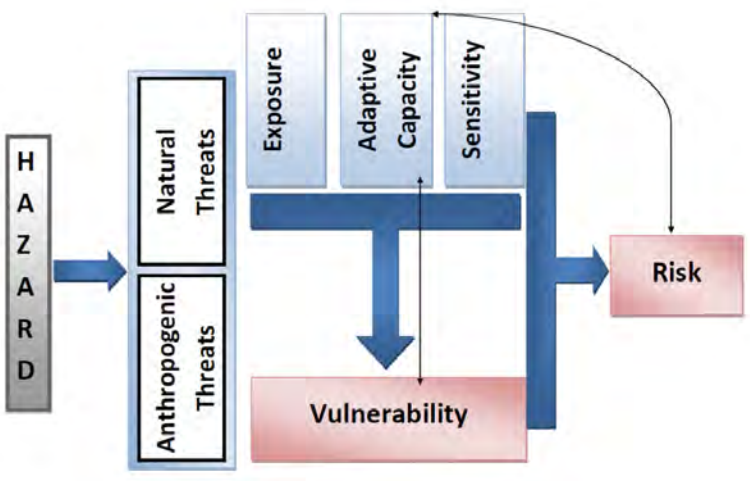

FIGURE 1. Components of the Vulnerability, Risk and Resilience Assessment Framework.

3. Results and Discussions

In all the four countries, Bangladesh, China, India and Sri Lanka, coastal study sites are facing population pressure with population density levels significantly higher than national averages (Table 1). A variety of ecosystem fisheries and agriculture dominated the traditional livelihood pattern, but new activities are heavily biased towards tourism-related activities and services. In Bangladesh, the agricultural productivity of traditional mono-cropping is declining due to the lack of cultivable land, poor sandy soils, the risk of flooding and saline water intrusion, lack of irrigation facilities and sand storms, conversion of agricultural land, expansion of saltpan-shrimp farming and infrastructural development in the tourism sector. Farmers are moving to marine fish catch as it is emerging as a higher value added activity with relatively higher market price with changing demand.

According to the farmers in India and Sri Lanka, expenditure on agricultural inputs is increasing, leaving a smaller margin of income over expenditure. Stress on water availability and increasing salt water intrusion are also reported by some as reasons. Traditional activities are considered as laborious activity. Decline in fish catch is also a reason for the move away from traditional activities. In China, high-end tourism services are increasing. In Tianjin, the natural marine fishery resources declined dramatically due to overfishing, land-based pollution, habitat destruction, coastal development and utilisation, etc. The government is also encouraging coastal tourism through incentive design.

The Bangladesh study site has been facing devastating cyclones, landslides and storm surges. Around 49% of the sampled population opined that coastal storms are a major threat for the coastal community. Two important anthropogenic threats reported by 50% of respondents are due to wastewater discharge from hotels and vehicles running on fossil fuels on the beach. Seawater intrusion affecting agriculture, salt-shrimp farming and fish drying (22% reported), while such impacts were reported the least on hoteliers. Cox's Bazar sea beach and ecosystem are under great threat from erosion due to unplanned development of resort area by cutting hills, establishment of shrimp hatcheries along the seashore, deforestation, over-fishing, salt fields, hill cutting for unplanned construction and tourism activities. Coastal storms pose medium risks for salt-shrimp farming, hotel industry, fish drying and shop business.

The Chinese study site has different characteristics. Tianjin sea waters belong to Bohai Sea, which is an enclosed sea with limited power of self-purification and fragile ecological environment. Coastal waters are polluted mainly by inorganic nitrogen and active phosphate. About 2,870 sq km do not meet national sea water quality standards, and among them, about 380 sq km are categorised as less clean, about 630 sq km lightly polluted, about 760 sq km, and about 1100 sq km seriously polluted. The Tianjin coastline is used for fishery, transportation, tourism, sewage dumping and there is reclamation as well. Of the major economic activities, marine fisheries (i.e. for fishing and mariculture) is an important one. Mariculture has received a lot more attention than before. With strict marine fishing regulations and declining natural fishery resources, shallow sea and beach mariculture were developed to increase mariculture production. The coastal zone of Tianjin is among the most vulnerable areas in China. Sea-level rise and storm surges remain a major problem. As sea-levels rise, the defence capability of breakwater gradually declines. Of all influencing factors, the largest contributor is land subsidence, which makes ecosystem-based economic activities in the region quite vulnerable. Opinions expressed by the respondents show that the traditional economic activities such as agriculture and fisheries are more vulnerable to natural hazards than new economic activities.

For India, responses show that three major threats to coastal economic activities in Digha-Sankarpur-Mandarmoni region are coastal storms (54%), sea water intrusion during high tides (78%) and coastal erosion (79%). After factoring in risk, horse-riding and fishing using manual boats and deep sea fishing using trawlers are perceived to be most threatened economic activities. Due to coastal storms, a substantial proportion of the respondents have reported to have experienced very significant loss of fixed assets and income among different types of risks. Sea water intrusion during high tides has led to very significant loss of roads, embankments and other public resources, according to a considerable proportion of the respondents. The survey findings showed that the majority of the households have not heard of climate change and were not aware that this could cause an increasing threat in the future. Interventions by local administration through adaptive measures are not equitably distributed across economic groups.

The long term trends in annual and seasonal-precipitation, as well as maximum and minimum temperature over the study sites of South Asia (India, Bangladesh and Sri Lanka) at daily time scales has been analysed to arrive at current baseline climatology and climate change projections. Characteristics of climate change projections for the study sites show:

- Mean annual maximum and minimum temperature rise by mid-century is projected to be the highest for India (1.5°C to 2°C min, 1.0°C to 1.4°C max).
- Mean annual rainfall is projected to decrease marginally towards the mid-century for India while increase for Bangladesh and Sri Lanka. Maximum increase is projected in Bangladesh. By IPCC AR5 projections with SMHI RCP4.5 Scenario, increase is projected to be the maximum for Sri Lanka.

The predictions become relevant for current trend towards increasing tourism-related activities as it can become affected in future with reduced recreational time window on the beach and with increasing coastal erosion and flooding.

4. Concluding remarks

Field experience shows that various anthropogenic and market changes are driving people away from traditional livelihood options in coastal areas. But, natural hazards are also exacerbating the changes. Taking a risk reduction strategy, people are moving towards new economic activities mostly related to tourism, which is also supported by the government in all the countries. However, we realise there is need for further research on strengthening the risk assessment study of new economic activities with alternative climate scenarios, alternative adaptation strategies designed for managing the risks, cost

assessment of alternative adaptation strategies with risk reduction potential, and efforts are necessary for capacity building of different policy makers for better informed policy decisions relating to ecosystem vulnerability to various threats and possible adaptive strategies to reduce this vulnerability.

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References

Adger, W. N. (1999). Social vulnerability to climate change and extremes in coastal Vietnam. *World development, 27*(2), 249–269.

Adger, W. N. (2000). Social and ecological resilience: are they related? *Progress in Human Geography, 24*(3), 347–364.

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., & Rockström, J. (2005). Social-ecological resilience to coastal disasters. *Science, 309*(5737), 1036–1039.

Barbier, E. B., Koch, E.W., Silliman, B. R., Hacker, S. D., Wolanski, E., Primavera, J . . . Reed,. D. J. (2008). Coastal ecosystem-based management with nonlinear ecological functions and values. *Science, 319*(5861), 321–323.

Burke, L., Kura, Y., Kassem, K., Revenga, C., Spalding, & M., McAllister, D. (2001). Pilot Analysis of Global Ecosystems: Coastal Ecosystems, World Resource Institute Report, Washington, DC.

Dolan, A. H., & Walker, I. J. (2006). Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal Research*, 1316–1323.

Gabor, T., & Griffith, T. K. (1980). The assessment of community vulnerability to acute hazardous materials incidents. Preliminary paper #56. University of Delaware, Disaster Research Centre.

IPCC. (1997). The regional impacts of climate change: an assessment of vulnerability. Summary for policymakers. Intergovernmental Panel on Climate Change. Cambridge University Press. United Kingdom.

IPCC. (2013). Climate change 2013: The physical science basis. Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. United Kingdom.

Klein, R. J., Smit, M. J., Goosen, H., & Hulsbergen, C. H. (1998). Resilience and vulnerability: coastal dynamics or Dutch dikes? *Geographical Journal*, 259–268.

LOICZ. (2011). Megacities and the coast: Transformation for resilience—a preliminary review of knowledge, practice and future research.

Martinez, M.L., Intralawan, A., Vazquez, G., Perez-Maqueo, O., Sutton, P., & Landgrave, R. (2007). The coasts of our world: Ecological, economic and social importance. *Ecological Economics 63*:254–272.

O'Brien, K., Sygna, L., & Haugen, J. E. (2004). Vulnerable or resilient? A multi-scale assessment of climate impacts and vulnerability in Norway. *Climatic Change, 64*(1), 193–225.

Timmerman, P. (1981). Vulnerability, resilience and the collapse of society: a review of models and possible climatic applications. Environmental Monograph #1. Institute for Environmental Studies, University of Toronto, Canada.

Turner, R. K., Lorenzoni, I., Beaumont, N., Bateman, I. J., Langford, I. H., & McDonald, A. L. (1998). Coastal Management for Sustainable Development: Analysing Environmental and Socio-Economic Changes on the UK Coast. *The Geographical Journal, 164*(3), 269–281.

UNEP. (2005). Millennium Ecosystem Assessment Synthesis Report. UNEP.

UNEP. (2006). Marine and Coastal Ecosystems and Human Well-being Synthesis Report.UNEP.