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Socio-Economic Vulnerability of Mangrove Ecosystems to Climate Change in South Asia: A Case Study of the Indus and Ganges Deltas

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ABSTRACT: The present study is intended to understand the socio-economic vulnerability under a changing climate for coastal communities that are dependent on mangroves ecosystems in two important South Asian deltas: the Indus and Ganges-Brahmaputra. We use the Composite Vulnerability Index (CVI) approach to draw a general picture of vulnerable communities. We try to answer some key questions to understand how climate change is impacting mangrove ecosystems and dependent communities. Our assessment shows that these coastal communities are highly sensitive and exposed to climate change-driven threats. Further, poor access to basic facilities, inadequate income diversification, and low education levels are negatively affecting adaptive capacity of local populations. However, the communities' nature of dwelling, their strong family networks, and their ability to migrate on a timely basis when the need arises contribute to their adaptive capacity.

KEYWORDS: *Composite Vulnerability Index, climate change, exposure, sensitivity, adaptive capacity*

Introduction

Mangroves are an important component of our natural ecosystems. They feed and breed an amazing diversity of economically and ecologically important flora and fauna (Valiela, Kinney, Culbertson, Peacock, & Smith, 2009; Walters et al., 2008) that generate livelihoods for dependent communities. However, the overdependence of mangroves on coastal waters and of local communities on mangrove resources, makes them highly vulnerable to slight changes in temperature, rainfall, or sea level, that are likely to result from climate change (Ellison, 2012). This is particularly true for South Asian mangroves (Belkin, 2009).

For the purpose of our study, mangrove forests in deltas of two major South Asian rivers were selected: the Indus River in Pakistan and the Brahmaputra in Bangladesh. Although the two rivers flow thousands of miles apart, they are common in that millions of lives and major socio-economic systems are dependent on them.

The Indus River Delta hosts 97% of the total mangroves forest in Pakistan. Besides providing local ecosystem services, Indus Delta mangroves generate handsome revenues which add to the national exchequer. It is estimated that they provide a breeding ground to approximately 90% of the total shrimps that are exported from Pakistan (Sivakumar & Stefanski, 2011).

Similarly, the Ganges-Brahmaputra Delta (also known as Sundarban Delta) on the farther end of South Asia supports the largest single block of tidal halophytic mangrove forest in the world. The rich and unique diversity of life that the Sundarban mangrove forests support, and the threat imposed to them by overexploitation, led UNESCO to declare the Bangladeshi portion (6,000 km^2) as a world heritage site in 1997 (UNESCO, 2010).

The research undertaken in this study was guided by the following key research questions: a) how do climate change stress factors impact both mangrove ecosystems and dependent communities, especially at the local level? b) What are the possible indicators of both the sensitivity of mangrove systems and dependent communities to such stresses? c) What is the coping potential of communities? d) What should be the key adaptation options for increasing community resilience?

Study Area

Two districts around each of the mangrove forests were selected for field research. They share the following features: (i) close proximity to mangrove forests; (ii) small and scattered settlements, usually around the fringes of creeks; (iii) high local dependence on mangrove resources (for livelihood generation and/or domestic consumption); and (iv) vulnerability to natural disasters, presently or in the past.

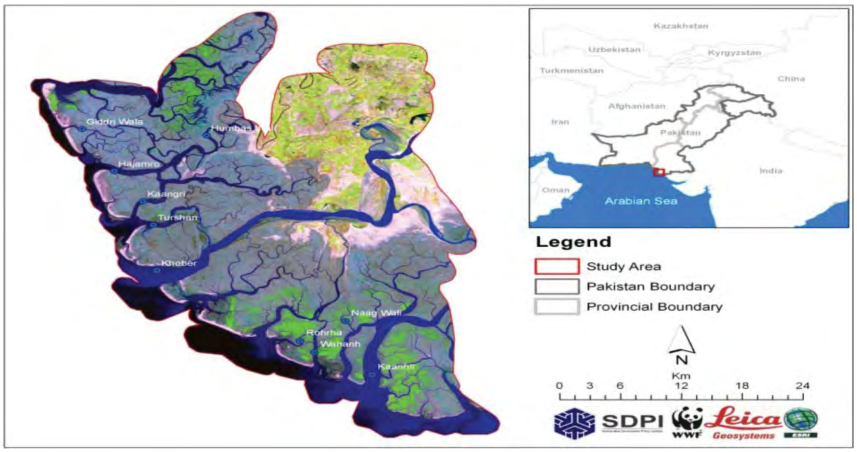

Figure 1. The Study Area – Keti Bandar, Indus Delta, Pakistan.

Indus Mangroves

In Pakistan, the study was primarily carried out in the Keti Bandar area of Thatta district (Figure 1). The area is characterised by mangroves, mudflats, creeks and rich biodiversity. Currently, it constitutes 42 *dehs* (cluster of villages) with a total population of 12,000 and covers 60,969 hectares (Khatoon & Akbar, 2008). The area has been prone to natural disasters in the past. Local populations generate most of their income from fishing (77%) (Dehlavi & Adil, 2012) and agriculture (Hai & Khursheed, 2011).

Sundarban Mangroves

The study on Bangladeshi Sundarban mangroves was carried out in Khulna district. The primary area of research was a sub-district (or upazilla) named Dacope (Figure 2), where the total population is 152,316 and covers 99158 hectares hectares (Bangladesh Bureau of Statistics, 2012). It is surrounded by the Nalian

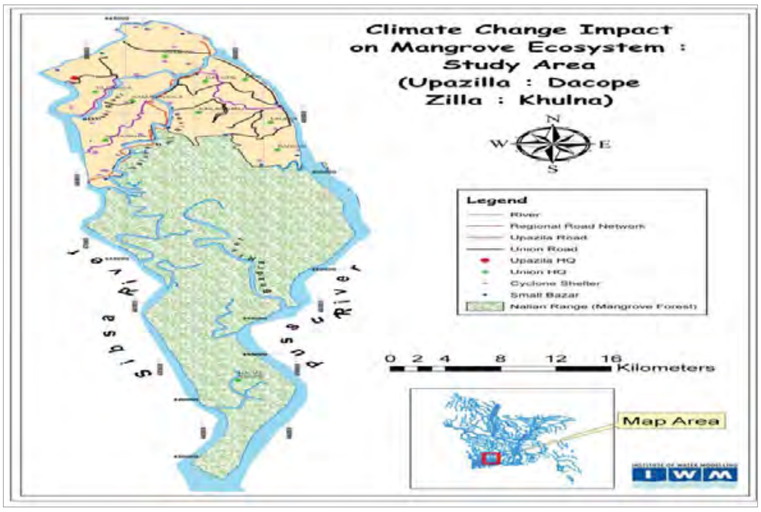

Figure 2. The Study Area – Upazilla: Dacope Zilla, Khulna, Bangladesh.

Range and the Pussur River (Figure 2). The area has reportedly experienced environmental problems that ranged from salinity intrusion and water-logging to extreme weather events such as cyclonic storm surge and droughts.

Data used

The study relies on a mix of qualitative and quantitative data for indicators of exposure (E), sensitivity (S), adaptive capacity (A), and their variables, as listed in Tables 2 and 3. Primary data for S and A was collected from field surveys (during April 2013 in Pakistan; and May, 2013 in Bangladesh). It is complemented by secondary data that guided the direction and, later on, analysis of the research process. Data on indicators was collected from national surveys and relevant government and private centres. The data for the sub-index E was obtained from the Meteorological Departments of Pakistan and Bangladesh for the periods of 1951–2010 and 1986–2008, respectively.

Methodology

In the present study, the Composite Vulnerability Index (CVI) provides an indicator-based estimation of socio-economic factors of the coastal area in relation to environmental and climatic parameters (Eriksen, Adger, Brooks, Kelly, & Bentham, 2004; Gornitz, Daniels, White, & Birdwell, 1994; Heltberg & Bonch-Osmolovskiy, 2011).

All the considered variables, presenting particular sub-index S, E and A, were normalised using Equation 1 (UN-ECLAC, 2003):

$$\acute{X} = \frac{(X - X_{min})}{(X_{max} - X_{min})} \ldots Eqn. (1)$$

Where X is any considered variable, Xmax is the maximum value of the variable and Xmin is the minimum value of the variable among its investigated sample. The normalised variables were used to calculate the respective sub-indices (Exposure, Sensitivity and Adaptive Capacity) using Equations 2 to 4 respectively. The index values have been analysed through component analysis after categorising the normalised indices at different levels to ensure the consistency in the results (Comer et al., 2012; Hammill & McCandless, 2013). Consequently, four categories of vulnerability levels have been developed to categorise the impact of indices of three components i.e., exposure, sensitivity, and adaptive capacity against vulnerability (Table 1). Finally, the CVI is calculated by using Equation 5.

$$\bar{E} = \frac{1}{6}\left[\sum_{x=1}^{x=4} \frac{1}{12}\left[\sum_{m=1}^{m=12} \acute{E}_{x,m}\right] + \frac{1}{2}(\acute{E}_5 + \acute{E}_6) + \acute{E}_7\right] \ldots Eqn. (2)$$

$$\bar{S} = \frac{1}{4}\left[\frac{1}{3}\left\{\sum_{x=1}^{x=3} \acute{S}_x\right\} + \frac{1}{2}\left\{\sum_{x=4}^{x=5} \acute{S}_x\right\} + \frac{1}{4}\left\{\sum_{x=6}^{x=9} \acute{S}_x\right\} + \frac{1}{4}\left\{\sum_{x=10}^{x=13} \acute{S}_x\right\}\right] \ldots Eqn. (3)$$

$$\bar{A} = \frac{1}{8}\left[\sum_{x=1}^{x=4} \acute{A}_x + \frac{1}{2}(\acute{A}_5 + \acute{A}_6) + \frac{1}{2}(\acute{A}_7 + \acute{A}_8) + \frac{1}{2}(\acute{A}_9 + \acute{A}_{10}) + \frac{1}{2}(\acute{A}_{11} + \acute{A}_{12})\right] \ldots Eqn. (4)$$

$$CVI = \frac{1}{3}[\bar{E} + \bar{S} + (1 - \bar{A})] \ldots Eqn. (5)$$

Where $\acute{E}_x$, $\acute{S}_x$, $\acute{A}_x$ are all the normalised variables belonging to Exposure, Sensitivity and Adaptive Capacity sub-indices and scaled accordingly (see Tables 2 and 3).

Results and Discussion

Our analysis of exposure indicators shows that the higher index values for climatic parameters in both regions. This increasing incidence of abrupt changes in the temperatures, precipitation, and SST can trigger many bio-physical processes in the coastal areas and can impact on mangroves vegetative and reproductive growth (mostly negatively due to abrupt decline in temperature). The most significant of these could include habitat loss, reduced food yield, and increased salinity. In the case of Bangladesh, increased salinity of deltaic waters is already a major problem.

Rises in SSTs also increase vulnerability.

Index value Scale	Exposure/ Vulnerability	Sensitivity/ Vulnerability	Adaptive Capacity/ Vulnerability	CVI
0.0≤CVI≤0.3	Low/ Low	Low/Low	Low/ Very high	Low
0.31≤CVI≤0.5	Medium/ Medium	Medium/ Medium	Medium/ High	Medium
0.51≤CVI≤0.7	High/ High	High/ High	High/ Medium	High
0.71≤CVI≤1.0	Very High/ Very High	Very High/ Very High	Very High/ Low	Very High

Table 1. Categorisation of vulnerability levels (Adopted and transformed from Comer et al., 2012 and Hammill & McCandless, 2013).

Moreover, inadequate fresh water flows in both study areas have resulted in highly sensitive/vulnerable and it has also impacted agriculture and fisheries production allowing sea water intrusion. This value reflects a very high impact on the economy of the community that depends entirely on fisheries.

Further, considering the relation between the exposure to and the cost of climatic disasters, the respective variables showed high index values, as the climatic disasters are quite frequent in these areas. The fact that communities were not financially supported during and after the disasters that made them highly sensitive/vulnerable, owing to a high rate of poverty in the area. Water and sanitation was inadequate in the two study areas, directly affecting health and nutrition.

It was obvious that the lack of income diversification, high dependency ratio, low education levels, and lack of adequate basic facilities all contributed towards low adaptive capacity. Not surprisingly, these factors also contributed to communities' high vulnerability and low resilience in both mangrove deltas. However, it is promising that these local communities have strengths in that their nature of dwelling, their family networks, and their ability to migrate efficiently when the need arises. These factors contribute to their enhanced adaptive capacity to climate change.

Adaptations Options and Conclusions

Improving access to basic facilities is key to enhancing adaptive capacity of dependent communities in responding to climate change. It is recommended that governmental authorities in both regions prioritise improving access to basic facilities such as safe and clean drinking water, sanitation, and environmental hygiene. This should be done in support with local municipal authorities. Also linked to this is the need to invest in building climate-compatible shelters that are disaster-resilient.

There is a need for substantive investment in education sector in the study areas. Its benefits would include: a) access to more/better economic opportunities; b) skill diversification; c) decreased dependency ratio (assuming that more household members enter the workforce); and d) informed climate change responses at the household level.

Based on the study, there is a need for key adaptation options that can provide useful climate change intervention strategies for the two study areas. Functions of such would include: (1) Provision of safe drinking water and sanitation facilities; (2) Ensuring environmental flows; (3) Safeguard from the climatic disasters and settlements out of the risky areas; Improving education access; and (4) Capacity development for climate preparedness and innovations:

Scientific and local knowledge regarding climate change needs to be enhanced and coordinated. Such knowledge further needs to be integrated into policy procedures for informed climate-preparedness planning. Closely linked to this is also the need to strengthen institutional capacities of local development departments (e.g. municipal and management authorities) working in coastal areas. There is also a great need for improving inter-departmental coordination for more coordinated and efficient disaster preparedness and response.

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