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Fostering coastal resilience to climate change vulnerability in Bangladesh, Brazil, Cameroon, and Uruguay: a cross-country comparison

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Abstract

This paper describes a comparative study of four different cases on vulnerability, hazards and adaptive capacity to climate threats in coastal areas and communities in four developing countries: Bangladesh, Brazil, Cameroon, and Uruguay. Coastal areas are vulnerable to sea level rise (SLR), storm surges and flooding due to their (i) exposure, (ii) concentration of settlements, many of which occupied by less advantaged groups, and (iii) the concentration of assets and services seen in these areas. The objective of the paper is twofold: (i) to evaluate current evidence of coastal vulnerability and adaptive capacity, and (ii) to compare adaptation strategies being implemented in a sample of developing countries, focusing on successful ones. The followed approach for the case evaluation is based on (i) documenting observed threats and damages, (ii) using indicators of physical and socio-economic vulnerability, and adaptive capacity status, and (iii) selecting examples of successful responses. Major conclusions based on cross-case comparison are (a) the studied countries show different vulnerability, adaptive capacity and implementation of responses and (b) early warning systems are key to increase climate resilience. A recommendation is that efforts in adaptation planning in coastal areas should be intensified so as to reduce the vulnerability of coastal communities.

Keywords Climate change adaptation. Coastal risk. Sea-level rise. Storm surges. Vulnerability. Hazards. Resilience.

1. Introduction

The impacts of climate change are felt by societies in a variety of areas and through a variety of perspectives: socially, culturally, and physically, through a country's natural resources (Tompkins and Adger 2004). In many ways, it often affects densely populated coastal areas and community settlements with more intensity than inland areas ways (Adger 2000; Smith 2011; Neumann et al. 2015).

The Earth is getting warmer and the global temperature is projected to rise by at least 2°c from 2050 to 2100 (Moss et al. 2010). Along the way, this warming process may substantially damage or even destroy ecosystem services which are vital to both nature and human societies. Against such a backdrop, and faced with increasing population growth in these coastal communities and settlements, it is likely that damages not to only to the environment and coastal resources (Henderson-Sellers et al. 1998) but also to property will take place. In response to this situation, the Paris Agreement was negotiated and later ratified by more than 110 countries (UNFCCC, November 2016) to curb the growing concern over global warming. The main objective of the Paris Agreement is to bring the current temperature down well below 2°c by 2050, and inter alia, to protect coastal areas.

As a result of climate change, coastal systems, communities, and settlements are more exposed and sensitive to growing threats from rising sea levels (SLR), storm surges, tropical cyclones, high seas, and the increased frequency of floods leading to erosion, inundation, loss of habitat and infrastructure, land-use change, and damage to ecosystems (UNEP 2005; Knutson et al. 2010; Barbier et al. 2011; Hirabayashi et al. 2013; Arkema et al. 2013; Masselink and Gehrels 2014; Wong et al. 2014; de Moel et al. 2015).

Some of the common impacts of climate change and hazards on coastal populations include (i) loss and damages to property, infrastructure, agriculture, coastal forests, transport systems and tourism, (ii) food security and health access, are affected because they are at the front line of most of the climate disasters, (iii) the poor people, most significantly in developing countries, are frequently forced to migrate, due to increases in the price of food and lower incomes because they largely depend solely on smallholders and agriculture for their livelihood (Dale et al. 2001; Church et al. 2006; Cutter et al. 2006; Barnett and Adger 2007; Brouwer et al. 2007; Morton 2007; Frumkin et al. 2008; Wong et al. 2014).

The need to integrate climate change adaptation and future planning increasingly resonates in environmental science and policy arenas, particularly in regions that need to accommodate socio-economic growth and are seriously threatened by the impacts of climate change (Adger et al. 2005a; 2005b), such as coastal and delta regions (van der Voorn et al. 2017).

In the absence of significant adaptation measures, coastal ecosystems will continue to be impacted by a changing climate (Wong et al. 2014). This is particularly true in the low-elevation coastal zone "LECZ" (McGranahan et al. 2007; Jetz et al. 2007; Neumann et al. 2015; Liu et al. 2015). Confronting these stresses and impacts which affect the conditions through which people live in harmony with their environment, resources, and economic assets may require new approaches to managing these coastal areas. Making water systems more adaptive and resilient to climate change impacts is an important global climate change adaptation strategy, which needs to be downscaled to the regional level (Shaw et al. 2009; Sheppard et al. 2011).

In this paper, it is argued that the assessment of adaptation success has to also rely on implementation and effectiveness criteria rather than solely on plans (Villamizar et al. 2016) which complement innovative global climate adaptation strategies, particularly at the local scale.

There is a paucity of studies which look at the links between coastal vulnerability and hazards in various countries. Against this background, the objective of the paper is twofold: (i) to evaluate current evidence of coastal vulnerability from a set of developing countries, and (ii) to compare adaptation strategies focusing on new and successful ones. The cases presented in this paper provide illustrative examples of regional responses to climate change, rendering coastal areas more resilient and adaptive, which are in line with the global change adaptation strategy: four completely different and distinct countries: (i) Bangladesh (South-East Asia), (ii) Brazil (South America), (iii), Cameroon (Central Africa) and (iv) Uruguay (South America). More emphasis will be put on Bangladesh often called the “adaptation capital of the world” because of its exciting progress as one of the most climate vulnerable countries of the world (Irfanullah 2013; 2016).

2. Approach and Methods

2.1. Literature review for documenting observed threats, hazards, damages and responses

As part of the methodology used to ascertain the impacts of climate change to the coastal areas of Bangladesh (Bd), Brazil (Bz), Cameroon (Cr) and Uruguay (Uy), a literature review regarding local coastal dynamics, threats and impacts, and the population at risk was conducted, wherein local and government stakeholders' perceptions were also considered.

Some of the issues assessed were: coastal hazards; the response strategies to deal with coastal erosion; the key environmental hazards and vulnerable areas; climate change and its institutional considerations; the local government's responsibility to respond to hazards; response strategies to hazards; and environmental governance and planning. In addition, an investigation of the variables and barriers pertaining the implementation of adaptation measures was undertaken.

2.2. Study sites and case studies

The overall climate vulnerability and threats to the coastal areas of the studied countries: Bangladesh (Bd), Brazil (Bz), Cameroon (Cr) and Uruguay (Uy) are herewith presented, focusing on the threats and impacts, regional or sectoral issues at each country as follows:

- A multiple climate threat case (tropical cyclones, river- and sea-flooding, SLR) over the highly exposed and densely populated Bangladeshi coast (Figure 1).

- A synergic climate threat, multi-sectoral (agriculture, industries, tourism, natural resources) case along the coastline of the Limbe, Douala and Kribi municipalities in Cameroon because of growing population (Figure 2).
- A synergic climate threat and mismanagement beach erosion case in Brazil, the Ilha Comprida (long island), within the Iguape-Cananéia-Paranaguá Estuarine-lagoonal System in the southern end of the São Paulo State coast (Figure 3).
- A synergic climate threat and management touristic beach erosion case in Montevideo, Uruguay (Figure 4).

These elements were used since they offer a fairly broader insight into some of the variables that pertain each study area.

2.3 Coastal physical and socio-economic vulnerability

The approach followed to assess Coastal vulnerability are related to I) exposure due to (i) Low Elevation Coastal Zone-LECZ (less than 10 m above mean sea level-AMSL, McGranahan et al. 2007), (ii) the ratio of a national coastline to that of a country's border, (iii) population density (PD) (UNEP 2005), and (iv) threats (hazards and SLR), II) sensitivity, because many settlements are occupied by less advantaged groups (Cutter et al. 2006), and III) adaptive capacity associated with socio-economic status and governance (Villamizar et al. 2016).

Although climate vulnerability is not necessarily closely related to socio-economic and human development indicators, the per capita parity purchase power (PPP) GDP is included in the United Nations Human Development Index (HDI) together with education and health indicators (UNDP 2015), as well as in the coastal vulnerability index (CVI) (UNEP 2005).

2.4 Indicators and index of coastal vulnerability and adaptive capacity status

The UNEP coastal vulnerability index (CVI, range: 0-1) classifies vulnerability as low (CVI < 0.1), moderate (0.1 < CVI < 0.5) or high (CVI > 0.5) based on adaptive capacity indicators of exposure, impacts and vulnerability (UNEP 2005). According to Villamizar et al. (2016) a five class system gives a better discrimination (e.g. very low:

CVI <0.1, low 0.1 < CVI <0.2, moderate: 0.2 <CVI <0.5, high <0.5 CVI <0.8, and very high CVI > 0.8).

Vulnerability: f [(PD) + (ND) + (1-FC) + (GE) - (HDI)]

where:
PD= population density, ND= high probability of natural disasters, GE= geographic exposure, (1-FC) = low forest cover, and HDI= human development.

The Global Climate Risk Index (CRI) analyses to what extent countries have been affected by the impacts of weather-related events from 1996–2015 (Kreft et al. 2017).

The Notre Dame Gain Index (ND-Gain) (http://index.gain.org/) measures vulnerability (exposure, sensitivity, and adaptive capacity) and readiness (a country's ability to leverage investments and convert them into adaptation actions) when it comes to climate change impacts. The analysed sectors are ecosystem services, food, health, human habitats, infrastructure (including coastal hazards and SLR) and water. For instance, the ND-Gain exposure indicator measures the nature and degree to which a system is exposed to extreme events. Governance readiness captures the institutional factors that enhance the application of investment for adaptation (e.g. political stability, regulatory quality, and rule of law).

The rankings of exposure, socio-economic status, and adaptive capacity status shown for each country downloaded from the internet (e.g. United Nations, World Bank) give the relative place for each one among the world’s nations. They are useful for cross-comparison. All of them are post-2015 data.

For the purpose of an estimation of quantitative vulnerability the following equation was used:

Vulnerability = Exposure x 2 + Sensitivity – Adaptive Capacity.

3. Coastal Vulnerability and hazards: gathering evidence from Bangladesh, Brazil, Cameroon and Uruguay

3.1. Physical and socio-economic vulnerability

This section looks into the current evidence of physical, human and management vulnerability, socio-economic, development, and governance status, and climatic threats and hazards through combining data from different sources, including literature and downloads, from Bangladesh, Brazil, Cameroon, and Uruguay.

The four developing countries analysed herein are classified according to different sources (ND-Gain 2016; UN 2016; World Bank 2016a; 2016b) as follows (table 1): Bangladesh is a least developed country or LDC (low development); Cameroon is a low-income country (middle-low development); Brazil is a middle-high-income country (upper-middle development), and Uruguay is a high-income country (upper-middle development).

Table 1

Socio-economic differences are reflected in the vulnerability status (table 2).

Table 2

From the indicators shown in Tables 1 and 2, an increase of vulnerability, threats and impacts are anticipated, and there is likely to be a decrease in coping capacity from Uruguay, Brazil, Cameroon and Bangladesh. In fact, Brazil and Uruguay show better socioeconomic and development indicators (e.g. GDP, poverty, equity, HDI) than Cameroon and Bangladesh, while Uruguay shows a good functioning of government, governance for readiness and prosperity indicators (19th, 32nd, 28th respectively). Cameroon, meanwhile, shows very poor indicators (126th, 166th, and 127th). Nevertheless, when it comes to the CVI and CRI indices, Cameroon is the least vulnerable country in terms of coastal geography (physical exposure) and is less impacted compared to Bangladesh, which is very highly vulnerable and faces significant impact. Brazil and Uruguay lie in the middle.

The ND-Gain overall index shows that Brazil and Uruguay are much less vulnerable than Cameroon and Bangladesh. In regards to readiness, the order and values are similar to those of socioeconomic, development and governance indices, with Uruguay being the best placed (47th) while Brazil and Cameroon are ranked lower than expected (93rd and 161th respectively). Cameroon's low ranking contradicts the CVI and CRI indices, which might be related to exposure and governance readiness respectively.

When it comes to exposure, only Uruguay is well placed among the four studied countries (45th). The other studied countries, however, are below the global average (Brazil 104th, Cameroon 114th, and Bangladesh 145th) which corroborates with all other indices. In terms of governance readiness, Uruguay is well-placed (32nd) and Cameroon is among the world's worst (166th). Cameroon's vulnerability and adaptive capacity seem to be both over and underestimated due to governance indicators. This fact is not equated at CVI but reflected at the CRI. The low CVI exposure of Cameroon is due to the low death toll associated with coastal hazards (DTAP), PD, and GE. Bangladesh showed the highest DTAP, PD and GE, and CVI. A severe cyclone storm accompanied by tidal surges up to 9 m, battered the coastal areas of Bangladesh in April 1991 (Chowdhury et al. 1993), which accounted for the very high DTAP of UNEP CVI calculations (not included at the CRI 1996-2015).

The HDI, the ND-Gain government for readiness and the Prosperity Index (LPI) give an overall and coastal vulnerability measure (exposure, sensitivity, and adaptive capacity) with regards to climate change and climate-related hazards. A quantitative estimation of exposure, adaptive capacity and vulnerability were made (Table 3) from the indicators shown in Tables 1 and 2.□

Table 3

3.2 Coastal vulnerability, hazards, and impacts from the four countries

Let us start with examples of the coastal vulnerability and hazards from the four countries, based on the data gathered.

3.2.1 Bangladesh (Bd)

Bangladesh has been experiencing frequent disasters such as tropical cyclones, storm surges, floods, coastal erosion, and salinity intrusions. These disasters have caused heavy losses of life and property over the years that has consistently jeopardised local development activities (Figure 1). The frequency and intensity of these extremes have increased significantly in recent decades (MoEF 2008; Rehan Dastagir 2015). Bd ranks as the world's 6th most flood-prone country because its topography is mostly low and flat. Two-thirds of its territory is less than 5 meters ASL being susceptible to flooding in the delta of three large rivers – the Brahmaputra, the Ganges and the Meghna, while, in lower lying coastal areas, there is a significant risk of tidal flooding during storms (UNDP 2004; Brouwer et al. 2007; MoEF 2008). Overall, Bd is the world's 6th most vulnerable to climate change (Kreft et al. 2017), the 2nd by death toll (Kreft et al. 2017), and is the most vulnerable country in the world when it comes to tropical cyclones (Rehan Dastagir 2015).

Figure 1

In an "average" year, one-quarter of the country is inundated by river flows related to the South Asian Monsoon rainfalls. Once every 4 to 5 years, however, there is a severe flood that may cover over 60% of the country and cause loss of life, damage to infrastructure, housing, agriculture, and the livelihoods of many citizens. It is the poorest and most vulnerable who suffer most because their houses are often in more exposed locations (MoEF 2008).

An analysis of 30-year trends of SLR in the coastal areas of Bd shows a range of 6-21mm/year (CCC 2016). A quarter of Bangladesh's coastline could be inundated under a SLR scenario of 0.9 m. Because of a changing climate, its vulnerability to severe monsoon floods increases significantly due to intensified cyclonic storm surges (World Bank 2010) increasing ocean salinity intrusion, and shoreline retreat (CCC 2006). These effects could displace 30 million people from their homes and farms (CCC 2009).

A severe tropical cyclone hits Bangladesh, on average, every 3 years. During these severe cyclones, wind storm surges reach up to seven metres high, resulting in extensive damage to houses, and a significant loss of life to humans and livestock in coastal communities (MoEF 2008; CCC 2009; Saroar and Routray 2012). The extreme cyclone storm of 1991 (with tidal surges of up to 9 m) resulted in a very high death toll and a huge number of affected people (DTAP) included at the CVI.

From 1999 to 2014 Bangladesh has slowly and consistently improved its vulnerability standing regardless though, Bangladesh's readiness has only consistently improved since 2004 (ND-Gain 2016).

3.2.2 Brazil (Bz)

About 35% of Brazil's coastline is undergoing erosion (Neves and Muehe 2010) requiring measures of recovery and containment. The loss of Brazilian beaches can be attributed to SLR and the increased frequency and intensity of storm surges coupled with unplanned coastal development (Marengo 2007). These coastal hazards are further compounded by the lack of appropriate coastal management legislation and governance arrangements (Souza 2009).

The Bz southern coast is among the most exposed in South America to storm surges, waves and SLR America (Losada et al. 2013) being affected by the occurrence of increased S and SW winds during La Niña years (Pereira and Klumb-Oliveira 2015).

Despite the Brazil’s socio-economic improvement (e.g. the reduction of poverty, table 1) and the small number of people living in LECZ (7%, table 2), the functioning of Brazil’s government is below the world's average, worsening its indicators of vulnerability and readiness. An example of coastal vulnerability, hazards, and urbanisation in South-eastern Brazil is that of Ilha Comprida (Figure 2) (Modesto and

Serrao-Neumann, in press). It is a summer tourist destination with increased urbanisation and a rise in new residents over the last few decades (Mendonça 2007). However, Ilha Comprida lacks adequate urban planning and there is little consideration of coastal erosion and inundation (Queiroz and Pontes 1999).

Figure 2

Human interventions in the estuarine system exacerbate coastal erosion and inundation on the northern part of the island (Ponta Norte) (Becegato and Suguio 2007), while changes in salinity and sedimentation (Cunha-Lignon 2001; Mahiques et al. 2009) destroy residences, natural vegetation, and force the retreat of residents and visitors.

3.2.3 Cameroon (Cr)

Climate change is currently impacting the coast of Cameroon by way of erosion, changes in wind, SLR and in the intensity of the storm surges and flooding. All of these hazards lead to the destruction of coastal ecosystems (Figure 3). Nevertheless, Cameroon's coastline has never suffered a disaster that has resulted in any deaths. The local coastal communities and settlements are threatened by projected SLR from 0.13 to 0.56 metres by 2090, leading to the displacement of 580,300 people and the destruction of 39,000 homes (Fonteh et al. 2009). This projection corroborates with the percentage of people living in LECZ (table 2).

Figure 3

Despite the economic significance of Cameroon's coastline, unsustainable utilisation, poor management and the negative impacts of climate change pose serious challenges to its sustainable development (Ngoran et al. 2016). Cameroon relies greatly on its agriculture, industries, tourism, and natural resources that are focused upon the 402 km long coastline of the Limbe, Douala and Kribi municipalities. This focus has led to a rising population in the region.

Hazards in the Limbe flood-prone coastal area have led to the destruction of properties Molua (2009), whereas the mangroves (1,957 km^2, Ellison and Zouh 2012) are over-exploited for economic purposes. For instance, from 1974-2009, their depletion reached -53 % (from 3 to 1.4 km^2) in peri-urban Douala, a loss that has been accelerating since 2003. Mangroves help to sustain livelihoods in the region (e.g. provision of sand for construction, trees, and logs that serve as fuel for smoking fish).

3.2.4 Uruguay (Uy)

A long-term SLR≥ 1 mm/year has been observed along the Uruguayan micro-tidal (amplitude < 0.5 m) coastline (Figure 4), which has accelerated to 2-3 mm/year since 1971 (Magrin et al. 2007; Nagy et al. 2007; 2013; Verocai et al. 2015; 2016). According to Losada et al. (2013), flooding levels of 5 mm yr^{-1} change (storm surge + SLR) are observed. Up to 30% of Uruguay's population is exposed to a SLR of 1 m (Nagy et al. 2014a; 2014b; 2015) with 13% of the population living in LECZ (Villamizar et al. 2016). Wind-induced flooding may reach 1 to 3 m AMSL (Verocai et al. 2015). The estimated cost of flooding + 0.3, 0.5, and 1 m represents 2%, 4%, and 12% of 2008 GDP, respectively (ECLAC 2011; Nagy et al. 2015).

The loss of sandy beaches is related to severe storm surges, along with La Niña events, unplanned coastal development, and SLR SLR (Gutiérrez 2010; Gutiérrez et al. 2015; 2016). Sandy beaches are key for the tourism sector that contributed 8.8% to the country's GDP in 2014 (WTCC 2015).

The long-term balance of sandy beaches in Montevideo has been associated with ENSO-related wind anomalies from 1948 to 2010. Natural erosion is related to storm surges alongside La Niña events and enhanced SW erosive winds. A threshold of significant and extreme sandy beach erosion is estimated to be 1.8 m and 3.5 m AMSL (1-year to 50-year recurrence intervals respectively) (Gutiérrez and Panario 2005; Gutiérrez et al. 2015; 2016; Nagy et al. 2015).

Figure 4

4. Discussion

4.1. Towards adaptive capacity: key concepts from the case studies

The concepts of adaptation, adaptive capacity, vulnerability, resilience, and exposure are interrelated and they have broad applications in the science of global environmental change (Smit and Wandel 2006) as a whole, and to coastal areas in particular. Climate change adaptation (CCA) is a process of proactive adjustment to the negative impacts of climate change, as well as the exploitation of potential opportunities: "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities" (UKCIP 2014). Adaptation is a process of changes that allows reducing negative consequences and is a result of the combination of elements of resilience, vulnerability and adaptive capacity (Marques and Modesto 2014). Adaptation is required to alleviate the worst effects of climate change and to help build resilience, especially for the poorest and for those who live in the most vulnerable regions of the world (Costello et al. 2009; World Bank 2011; De Souza et al. 2015).

Adger et al. (2005a) highlighted that "adaptation can involve both building adaptive capacity thereby increasing the ability of individuals, groups, or organisations to adapt to changes, and implementing adaptation decisions, i.e. transforming that capacity into action".

Resilience "is the capacity of a community or society to adapt when exposed to a hazard" and is central to an understanding of vulnerability. Resilience is a community's ability to resist or change "in order to reach and maintain an acceptable level of functioning and structure". Also, resilience is determined by two measures of peoples' livelihoods: (a) the assets they possess and (b) the services provided by external infrastructure and institutions (Prasad et al. 2009).

Planning proactive actions that consider the impacts of climate change reduces the need for a reactive response to damage caused by extreme events. Moreover, the costs to handle the post-event event may be much higher and less effective (Wong et al. 2014).

Constraints to adaptation include several factors such as gaps in databases and monitoring networks (Magrin et al. 2007). For instance, there is no long-term series of tide data available in Brazil (Neves and Muehe 2010).

There are synergies between CCA and disaster risk management (DRM) with regard to risk drivers, policy instruments and actors, and the IPCC has called for further linking the two agendas for development and planning (IPCC 2012; 2014; Schinko et al. 2016).

The following case studies describe the trends identified in the study.

4.2 Bangladesh

Over generations, the people of Bangladesh have adapted to the risks of flooding, cyclones, storm surges, and the salinisation of fresh water. These all cause the loss of biodiversity, as well as losses and damage to infrastructure and local livelihoods associated with being an "LECZ densely populated river deltas" (MoEF 2008; Lwasa 2015).

At the national level, Bangladesh has developed the National Adaptation Program of Actions (NAPA) in 2005 and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) in 2009. Under the BCCSAP, the Climate Change Action Plan has envisioned to implement 44 programs covering six thematic areas including comprehensive disaster management, livelihood and food security, climate resilient infrastructure, and capacity building and institutional strengthening by 2009 to 2018.

About 6,000 km long coastal embankments and polders, 2,000 cyclone shelters and 9,000 km of coastal green infrastructure have been implemented to enhance the resilience of coastal community and settlements (MoEF 2008; Brammer 2014; Dewan et al. 2015). Coastal embankment and drainage infrastructure projects build resilience by preventing tidal flooding, salinity intrusion, and facilitating the outflow of water. Cyclone shelters build resilience by providing refuges for communities from storm surges caused by tropical cyclones and coastal flooding. Furthermore maintaining a sustained flow regime in coastal rivers throughout the dry season, coupled with the flushing of brackish water zones with increased volumes of freshwater with the link canals on the Ganges River will help to build community resilience against increasing trend of coastal salinisation (Ahmed 2004; 2005; 2010; IWM & CEGIS 2007)

Due to the lack of community ownership and participatory monitoring some adaptation projects, for instance, pond-sand filter and rainwater harvesting have failed to bring any transformation change in safe sanitation behavior although made some incremental effects in safe drinking water (Harun and Kabir 2013).

There are community-based adaptation programmes and early warning systems aimed at building resilience against hydro-meteorological coastal hazards (MoEF 2008; Ahmed 2010; Saroar et al. 2015). Bangladesh has pioneered community-based adaptation (CBA) to reduce vulnerability to climate change since 2000. Currently with the UNDP and DFID support Bangladesh has been implementing five CBA projects for building community resilience (UNDP, undated). These are being shared with other developing countries.

As a result of the increasing frequency and intensity of hazards, Ecosystem-based Adaptation (EbA) strategies are already beginning to emerge for the known and anticipated long-term impacts of climate change. In fact, these are a mix of planned and spontaneous interventions that involve multiple actors cooperating in a challenging socio-economic landscape (Anbumozhi et al. 2012; IPCC 2014; Lwasa 2015). For instance, the gap between the logistics and the monitoring of weather data for the modelling and fitting of climate systems (Rehan Dastagir 2015) is a problem when it comes to adapting to a changing climate. Climate change adaptation is closely linked with Poverty Reduction (≈ 39%, MoEF 2005) which remains high but has been reduced (≤ 30%, table 2).

4.3 Brazil

Since 1988 in Brazil, there has been a National Coastal Management Plan aimed at adapting human activities to support the capacity of local ecosystems. In May 2016, the Brazilian Government instituted the Climate Change Adaptation National Plan (PAO 2016) with the aim to promote the reduction of the national vulnerability to climate change and to help manage the risks associated with this phenomenon.

The experience of the coastal island of Ilha Comprida and its environmental hazard and adaptation options illustrates how government authorities do not have management plans in place to address current and future risks, and that current responses to hazards are mostly carried out on an individual level (Modesto and Serrao-Neumann, in press).

"In practice, governments still tend to concentrate on emergency response and recovery and have been slow to adopt an integrated disaster prevention and preparedness approach" (Hardoy and Pandiella 2009).

There is still a need to increase the adaptive capacity of local communities "individuals bear the full financial costs of dealing with coastal hazards threatening their properties, and they ultimately lead the response once these hazards have occurred" (Modesto and Serrao-Neumann, in press).

4.4 Cameroon

Cameroon Vision 2035 identifies climate change as one of the two major challenges facing Cameroon's economy. However, the country depends greatly on international aid for the implementation of adaptation programmes. The National Observatory on Climate Change aims to: "establish relevant climate indicators for monitoring environmental policy; carry out prospective analyses to provide a vision on climate change, to provide weather and climate data to all sectors concerned and to develop annual climate balance of Cameroon; educate and promote studies on the identification of indicators, impacts, and risks of climate change; collect, analyse and provide policy makers, national and international organisations information on climate change in Cameroon" (Nachmany et al. 2015).

The government of Cameroon has established a National Cell of Climate Change which has institutionalised disaster risk reduction (DRR) activities in line with the priorities of the Sendai Framework for Action 2015-2030 (CMEF 2005). The introduction of Community-Based Disaster Management Personnel and guidelines would support the threatened communities to enhance their preparedness and response for DRR (Diko 2012).

According to Din et al. (2016), indigenous knowledge about climate change in the coastal region of Cameroon (e.g. perception and understanding of related natural phenomenon, and cultural belief systems) is crucial for local sustainability practices (diversification), survival and coping strategies.

Most of the touristic coastal sites in Limbe, Douala, and Kribi are eroded by SLR and flash floods, and the most common local adaptation measure is the building of embarked walls along the coast.

4.5 Uruguay

Uruguay shows good adaptive capacity (table 2) and adaptation plans reported through national communications to the UNFCCC (UNCCC 2016). These initiatives place the country among the 10% overall top "leader countries" in adaptation (Lesnikowski et al. 2015).

Nevertheless, several authors (Nagy et al. 2015; Gutiérrez et al. 2016) found that there was a deficit of successful coastal adaptation; in this regard, Villamizar et al. (2016) suggest that the assessment of adaptation should be based on the results of implemented actions rather than on plans.

Most of the successful implemented experiences in Uruguay mix top-down and bottom-up approaches focused on knowledge and early warning of ENSO events, soft engineering (green infrastructure), scenario planning for "futures", and EbA (Nagy et al. 2014a; 2014b; 2015; in press; Conde et al. 2015; Gutiérrez et al. 2015; 2016; UNCCC 2016; Carro et al. 2017; Nagy and Gutiérrez 2017).

4.6 Classical and innovative adaptation strategies

The adaptation actions presented in this paper might be grouped into classical and new (innovative) strategies (Table 4). The former includes socio-economic development-SED (GDP, Eq, Pov, Social Capital), top-down plans, integrated coastal management, capacity building, institutional strengthening, response against hazards and disasters, and hard engineering solutions. The new strategies include (i) bottom-up scenario planning, future visions (Nachmany et al. 2015; Irfanullah 2016; Nagy and Gutiérrez 2017); CBA and climate risk management-CRM (Ahmed 2010; Lwasa 2015), (ii) top-down OWD, and (iii) "ground actions close people" EbA-green infrastructure in Bd and Uy (Ahmed 2010; Irfanullah 2013; Carro et al. 2017).

Table 4

4.7 How could vulnerability factors change in the studied countries?

Among the indicators presented in Table 3, the external forcings (OH, MH, SLR) are uncontrollable on the short-time scale at the local level. The intrinsic vulnerability (P, EE) and socio-economic status (e.g. HDI, Pov) could hardly be managed, whereas GDP, Eq, and GR could be ameliorated in the short-time

Several adaptation strategies are relevant in the studied countries (i) capacity building and knowledge, (ii) awareness, (iii) institutional strengthening and planning, (iv) observation, early warning systems and modelling (OWM), (v) Community-based (CBA) and Ecosystem-based (EbA) Adaptation, and (vi) hard/soft engineering solutions which might be fostered with appropriate efforts in the short- to mid-term.

The increase in vulnerability standing in Bangladesh from 1999 to 2014 demonstrates the usefulness of taking appropriate actions, regardless though, its readiness has only consistently improved since 2004 (ND-Gain 2016) coinciding with the first NAPA in 2005 (Irfanullah 2016). This was made possible through (i) reducing poverty (Pov), (ii) increasing capacity building, knowledge, and awareness, (iii) institutional strengthening and planned interventions, (iv) enhancing OWM, (v) implementing innovative CBA and EbA, and (vi) hard/soft engineering solutions (Ahmed 2005; 2010; MoEF 2005; IWM & CEGIS 2007; Saroar et al. 2015; Lwasa 2015).

The relative poor adaptive capacity of Cameroon is attributable to intrinsic vulnerability (i) increase in PD, (ii) increase in EE, (iii), poor GR, (iv) high Pov and (v) low GDP (CMEF 2005; Nachmany et al. 2015; Ngoran et al. 2016; this article), all of which are difficult to improve in the short-term. Sustained SED and planning for futures (e.g. Cameroon Vision 2035) could improve GDP, Pov, Eq, PD, EE, as well as knowledge and OWM in the mid-term.

The relative low vulnerability of Brazil and Uruguay are not enough to arrest beach erosion. This is mainly related to mismanagement, uncontrolled external forcings, increased PD and EE. In the case of Brazil there is poor GR, partly compensated by community efforts (Modesto and Serrao-Neumann, in press; this article), whereas in

Uruguay, despite better GR, community efforts are still less developed despite increasing pilot CBA and EbA initiatives (Nagy et al. 2014a; 2014b; 2015; Conde et al. 2015; Villamizar et al. 2016).

It is argued that investments in awareness, knowledge, ground actions close to people, and OWM are the most cost-effective improvement achievable in all cases in the short- and mid-term (e.g. 2020-40).

The classical strategies (Table 4) are not enough to arrest the impact of extreme hazards nor are flexible and adaptive enough to cope with an uncertain and changing future. The new strategies such as such as bottom-up scenario planning - when critical drivers can't be controlled (Moore et al. 2013) and future visions (Faldi et al. 2014; van der Voorn et al. 2017) should be more adaptive to face uncertainty. The implemented participatory CBA, EbA and climate risk management-CRM, and soft engineering strategies are showing good results (Ahmed 2010; Wong et al. 2014; Lwasa 2015), which need to be tested under changes and hazards at each country.

5. Conclusions and lessons learned

5.1 Conclusions

There is a paucity of studies, which look at the links between coastal vulnerability and hazards in developing countries in an integrated way. Therefore, this paper has provided a contribution to the current state of knowledge, combining data from four completely different and distinct developing nations whose coastal areas are impacted by climate change: Bangladesh, Brazil, Cameroon, and Uruguay. As countries of the world move towards pursuing the implementation of the UN Development Goals (SDGs) two of them: namely "Life Below Water" (SDG 14) and "Life on Land" (SDG 15) are impacted by climate change and coastal areas are an intersection of them.

There is a gap between indices and reality in regards to vulnerability, hazards, and adaptation in Bangladesh (better adaptation) and mainly in Cameroon (lower adaptation); Uruguay shows consistent results for the three factors, whereas Brazil lies in the middle, with mixed human and socio-economic indices.

Among the four case studies, Bangladesh is the most exposed country to hazards, with high sensitivity and vulnerability, and increasing adaptive capacity over the last decade; Cameroon shows low exposure, high sensitivity, moderate vulnerability, significant impacts and poor adaptation; Brazil shows moderate exposure, low sensitivity, moderate vulnerability and adaptation; Uruguay shows moderate exposure, low sensitivity, and vulnerability, high adaptive capacity. However, the last two countries are threatened by storm surges due to less than optimally implemented measures.□

Climate hazards trigger the vulnerability of coastal areas to impacts of climate change, regardless of the county's economic standing and ongoing planned adaptation measures and strategies.□

Bottom-up Community Based and Ecosystem-based Adaptation, and Disaster Risk Reduction Management approaches are being developed.

Institutional National cells, plans (NAPAs), scenario planning and visions for futures are becoming advisory and policy planned adaptation programmes.

Gaps in databases and monitoring networks still are a major constraint to adaptation.

5.2 Lessons learned

One of the first lessons learned from the data gathered on this paper is that although the sources of exposure and of potential hazards are similar for all studied coastal countries, the levels of vulnerability and impacts in each one differs greatly, largely because of magnitude of threats, geo-physical setting, economic standing, and systems of governance.

Secondly, despite some adaptation failures, the success of new adaptation strategies such as CBA and green infrastructure in coastal Bangladesh over the last decade are promising and exemplary, especially if they are contrasted with the very high level of exposure.

Thirdly, the case studies have shown that in absence of national comprehensive adaptation plans, local communities tend to initiate their own adaptation activities. These are mostly reactive in nature and therefore do not yield long-term benefits to them.

Moreover, it has emerged that in all four countries, regardless of the country's economic standing, the consequences of climate change induced hazards, in absence of robust adaptation planning, could render the choice to live on the coast in all four countries a risk to livelihoods and to property.

Moving forward through the development of new adaptation strategies such as participatory planning for futures, CBA, EbA, green infrastructure, and improved early warning systems seems promising but needs monitoring, learning, and evaluation.

Finally, the experiences from the paper seem to indicate the fact that an integrated and flexible climate risk management (CRM) is needed which coordinates and integrates climate-related DRR with adaptation to climate change and to climate variability. To achieve this goal there is a need to i) broaden stakeholder engagement, ii) enhance knowledge, forecasting, monitoring, modelling, and early warning systems, iii) develop hazard-focused climate risk analysis and continuous updates of normal limits, and iv) assess the failures and successes of implemented policy, as well as soft and hard measures.

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