Catena 170 (2018) 36–50

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Beyond the tradition: Using Fuzzy Cognitive Maps to elicit expert views on coastal susceptibility to erosion in Bangladesh

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ARTICLE INFO

Keywords:
Accretion
Coast
Erosion
FCM
Susceptibility

ABSTRACT

This paper portrays the application of Fuzzy Cognitive Maps (FCMs) to elicit expert views on current condition and future scenario of coastal susceptibility to erosion in Bangladesh. The geomorphological characteristic of the coastal area is highly dynamic where land erosion and accretion with different rates are constant phenomena. This research focuses on three coastal zones: western, central and eastern that comprise the entire coastal area of the country. Using 'Mental Modeler' software this study quantified experts' judgements on the issue and developed FCMs by way of arranging workshops. At the basis, this study identified 33 factors of susceptibility to erosion for current baseline conditions. Considering future projections of hydro-climatic phenomena, this study accentuated potential factors of susceptibility to erosion for future scenario under three time-slices: near-future (2020), future (2050) and far-future (2080). The results generated from FCMs show that some factors such as sedimentation, soft and unconsolidated soils, shelf bathymetry, funnel shape of the Bay of Bengal, wave action, river discharge, monsoon wind, cyclone and storm surges, excessive monsoon rain, high tidal energy, variations of tidal range and sea level rise are highly influential that yielded higher centrality scores for both current and future susceptibility of the area to erosion. The experts' interpretations demonstrate that the future susceptibility to erosion might be higher in the central zone compared to the western and eastern zones of the coastal area. This is the first time that FCM based approach was applied to evaluate expert views on coastal susceptibility to erosion for the country. This study suggests coastal managers, planners and policymakers to consider the current and future factors of susceptibility of coastal lands for taking specific measures options. This study is also significant from socio-economic and demographic contexts of any densely populated coastal area like Bangladesh.

1. Introduction

Coastal areas of the world are identified as important zones for human settlement where about 21% of world population lives within 100 km distance of the coasts (Du-Gommes et al., 1997; Brooks et al., 2006; IPCC (Intergovernmental Panel on Climate Change), 2007a). These areas are marked as buffer zones between land and sea that are physically dynamic in nature (Hanson and Lindh, 1993). Coastal erosion is taking place in about 70% of world's beaches in different forms (Ghosh et al., 2015). It is reported that the magnitude and frequency of climate induced coastal disasters are increasing as a result of global warming and consequent sea level rise (Choi et al., 2016). This situation might increase the future rate of erosion in coastal areas of the world. However, the coastal area of Bangladesh is highly dynamic where erosion and accretion of land is a continuous process. The coastal area of the country is densely populated (949 persons/km^2) that comprises 32% of the total land area and 28% of the total population (Islam, 2004). Hence, interpretation of susceptibility to erosion in the coastal area is an important task for Bangladesh society.

The susceptibility of the coastal area to erosion depends on a number of factors (often termed as forces). Some are endogenic forces (from interior of the earth) such as the shifting of river channels by earthquake and some are exogenic forces (on the earth surface) such as the changes in geomorphology (Sarker et al., 2011). The driving forces can also be categorized as physical factors and human induced factors. The physical factors ranging from earthquake, sedimentation and sea level rise to wave action, rainfall, prevailing south-western wind, soil compaction, vegetation cover, and storm surges etc. whereas, human induced factors ranging from construction of embankments, polders and dykes to deforestation, cross dam and modification of river flow etc. (Goodbred et al., 2003; Brammer, 2014). The variation of susceptibility to erosion in different parts of the coastal area relies on the combined strength of these physical and human-induced factors and hence the factors do not act in a simple static way. Very often, one of

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https://doi.org/10.1016/j.catena.2018.06.003
Received 22 October 2017; Received in revised form 26 May 2018; Accepted 1 June 2018
0341-8162/

the factors might be a dominating driving force for a region, which might not be common for another area of the coast.

However, the effects of climate-driven factors such as water discharge, rainfall, wind speed, tidal variation and mean sea level etc. are found to be varied in the coastal area of the country for the last few decades (Huq et al., 1999). Hence, the rate of changes in coastal lands could further be increased by future changes in climate and associated sea level rise. For instance, rapid geomorphological changes are taking place in the Meghan estuary of the central coastal zone (Karim and Mimura, 2006; MoEF (Ministry of Environment and Forests, Bangladesh), 2007) that might be the result of such changes. Furthermore, future sea level rise could accelerate erosion in relatively older lands of major islands in the Meghna estuary (Brammer, 2014). The changes in future drivers could lead to the changing morphological pattern as well as current susceptibility of the coastal area to erosion in future. However, there is still a great uncertainty in research as to how exactly the drivers of land dynamics (e.g. erosion and accretion) are influenced by the rising sea level (Huq et al., 1999). It is also uncertain how the coastal areas of Bangladesh will respond with future changes of climate scenarios.

Coastal susceptibility to erosion has largely been studied by applying different approaches, methods and techniques such as GIS based Decision Support Systems, Dynamic Computer Modeling and Coastal Vulnerability Index (Ramieri et al., 2011). Since a number of physical and human-induced parameters are associated with coastal susceptibility to erosion, it is uncertain how precisely the aforementioned methods address the factors of coastal susceptibility to erosion. Furthermore, the evaluation of individual contributions of parameters in computer-based models require a number of sensitivity tests that would necessitate more time and manpower for computations. However, to expand knowledge on the issue beyond the traditional approach of generating computer-assisted models bears significant reasons. In reality, scientific knowledge essentially generate from humans which can largely be influenced by social, cultural and political values (Edge, 1995). The scientific 'truth' generally falsify the previous truth (Popper, 1963) and hence, exist more than one truth in the scientific community on any concerned issue (Kuhn, 1962). Expert views are important to expand knowledge on a dynamic system (Morgan et al., 2001). Expert judgements are considered to be more diverse in nature (Hansson and Bryngelsson, 2009) that may lead to ascertain a comprehensive representation of a system. Moreover, individuals at local levels have their 'hazard perception threshold' (Kates, 1971) that depends on their knowledge, perceptions and experiences on any hazards. Additionally, scientists and experts are considered as most highly trusted sources of information (Hargreaves et al., 2003; CLAMER, 2011) since, their knowledge is based on shared understanding of established facts and theories (Breakwell, 2007).

There are two types of 'temporal repertoire' in the scientific community regarding how the experts think about future (van-Asselt et al., 2010). The first group follows historic determinism in which, future can be determined by considering the past and present whereas, the second group follow futuristic difference in which the future is disconnected from past. In particular, most of the reports that addressed climate uncertainties are inclined to central tendency of model values (Kunreuther et al., 2013) and hence are not as critical for the governments as a full exploration of uncertainty (Oppenheimer et al., 2007). In contrast, the process of presenting expert views by subjective probability elicitations is an established approach (Spetzler and Stael, 1975) in which individuals' probabilistic idea can be converted into numbers (Jenkinson, 2005) as well as allow individuals to rate the levels of uncertainty on the given idea (Zickfeld et al., 2007). However, addressing future by way of generating cognitive maps is more participatory in nature that represents individual's unique knowledge structure (Kearney and Kaplan, 1997). Cognitive maps facilitate to address multiple viewpoints of different experts since, the ideas and viewpoints on a particular issue are reasonably different among experts (Zickfeld et al., 2010). Additionally, changes in knowledge are an intrinsic human nature where existing mental construct can be replaced by the assimilation of new knowledge (Boyle, 1969). Mental models carry essence in that the decisions people take, can largely be determined by the cognitions and perceptions they have in their mind (Breakwell, 2007). Mental models are good representations of datasets that derive from reasoning (Oberauer, 2006) and hence, able to provide a reliable ground for evaluating perceptions. Moreover, cognitive approach has been used for previous researches to evaluate the perceptions and understanding of individuals on climate change and hazards (Bostrom et al., 1994; Lowe and Lorenzoni, 2007). However, the nexus between future climate scenarios and coastal susceptibility to erosion has yet to be evaluated by applying cognitive approach at local, regional as well as global levels.

In recent years, Fuzzy Cognitive Mapping (FCM) has become a popular participatory method. It has been used in fields ranging from fisheries management to agricultural development, climate vulnerabilities, environmental problems and policy design (Gray et al., 2014a). The benefits of using the approach are attached to the popularity of using 'bottom-up' approach and their ability to incorporate a range of individuals, community and expert into an accessible and standardized format (Gray et al., 2014b). Although Fuzzy Cognitive Map (FCM) based modeling approach is highly suitable for future studies (Jetter and Kok, 2014), only a few studies (Amer et al., 2011; Biloslavo and Dolinsek, 2010; Jetter and Schweinfort, 2011; Salmeron et al., 2012; Soler et al., 2012; van-Vliet, 2011) are identified in the field of climate change and natural disasters. Most of the studies were mainly devoted to focus future states of wind and solar energy and land cover changes. There is, however, still a great scope of using FCM based mental modeling approach for future climate change, hazard and disaster related issues (Gray et al., 2014b). The adoption of experts' judgements by FCMs insights into not only the details of the problem but also identify the causal relations among and between both physical and human-induced driving forces (Jetter and Kok, 2014; Moschoyiannis et al., 2016).

This study applied FCM based approach to evaluate experts' judgements on the current components associated with the coastal susceptibility to erosion in Bangladesh. This study then identified potential factors of future susceptibility of the coastal area to erosion with an aim to address the impacts of future changes in climate drivers on erosion susceptibility in the area for different time-slices. This research addressed the implicit assumptions of experts' opinions into explicit causal-relations among and between a number of physical and human induced components of current and future susceptibility of the coastal area to erosion. The study supports discussion on the interrelationships between different components of coastal susceptibility to erosion that would be useful for coastal managers and policymakers in managing coastal lands.

2. Data and methodology

2.1. Study area

The coastal area of Bangladesh possesses dynamic coastal lands along with diverse coastal characteristics identified by IPCC (Intergovernmental Panel on Climate Change) (2007a, 2007b). The total coastal area covered is 47,200 km^2 (MoEF (Ministry of Environment and Forests, Bangladesh), 2007) which encompasses the land area (including islands), internal rivers, Meghna estuary and near shore water bodies (Fig. 1). Pramanik (1988) first divided the coastal area into three zones (i.e. western, central and eastern) by evaluating geomorphological characteristics of the area (Shibly and Takewaka, 2012). These three zones cover approximately 27,150 km^2, 12,040 km^2 and 8010 km^2 of the coastal lands respectively. The coastal area can also be segmented into two parts: interior coast (23,265 km^2) and exterior coast (23,935 km^2), considering the exposure to the Bay of Bengal