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GIS coupled multiple criteria decision making approach for classifying urban coastal areas in India

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ABSTRACT

Coastal area classification in India is a challenge for decision makers due to unclear directions in implementation of coastal regulations and lack of scientific rational about existing classification methods. To improve the objectivity of the coastal area classification is the aim of the present work. A Geographical Information System (GIS) coupled Multi-criteria Decision Making (MCDM) approach is developed in this work to provide scientific rational for classifying coastal areas. Utility functions are used to transform the physical coastal features into quantitative membership values. Different weighting schemes for coastal features are applied to derive Coastal Area Index (CAI) which classifies the coastal areas in distinct categories. Mumbai, the coastal megacity of India, is used as case study for demonstration of proposed approach. Results of application of GIS-MCDM approach showed the clear demarcation of coastal areas based on CAI is possible which provides a better decision support for developmental and planning authorities to classify coastal areas. Finally, uncertainty analysis using Monte Carlo approach to validate the sensitivity of CAI under different scenarios was carried out.

1. Introduction

India, surrounded by Arabian Sea, Bay of Bengal and Indian Ocean with a 7500 km long coastline is inhabited by nearly 25% of population within the vicinity of 50 km towards the coast (Nayak, Chandramohan, & Desai, 1992). Indian coastal states support national economy with developmental activities (largest in the South Asian Region) and numerous marine resources located in 2.02 million km^2 Exclusive Economic Zone (EEZ). At another hand, these states are under extreme pressure of natural hazards because of vulnerable geographical locations (Alcántara-Ayala, 2002; Smith & Petley, 2008) and anthropogenic development (Nair & Gopinathan, 1981; Ramesh, Lakshmi, George, & Purvaja, 2015). India harbors some of the world's fastest growing coastal megacities such as Mumbai and Kolkata, with Chennai joining the league shortly.

The implications of coastal cities are pollution and natural hazards which are inevitable and the effect can be destructive in urban coastal regions with huge population (Cenci et al., 2015; Nayak et al., 1992; Newton, Carruthers, & Icely, 2012). Specifically (Vaz, 2014), reports that in Mumbai there is observed transformation of 36% of mangrove eco-system area to urban land since 1973 due to urbanization. Along with urbanization there is industrial belt development along the Indian coasts causing effluent discharges from cities and industrial belts (Datta, Chakraborty, Jaiswar, & Ziauddin, 2010; Ramachandran, 1999; Shirodkar et al., 2009). On the east coast, increased metal concentration in the coastal waters of Pondicherry as reported by Govindasamy and Azariah (1999) was a result of the effluent discharges of nearly 16 major and minor industries.

1.1. Coastal regulations in India

Coastal area classification for developmental activities in urban areas is a challenging task due to conflicts among associated stakeholders. Different countries have various mechanism to manage their coastal resources with the help of policies. These policies are aimed at creating balance between human development and coastal biodiversity. Similar efforts have been made by State and Central Government in India to direct the development in the coastal areas using regulatory frameworks. One of the most prevailing regulation is Coastal Regulation Zone (CRZ) policy (Krishnamurthy, DasGupta, Chatterjee, & Shaw, 2014). The Ministry of Environment, Forest and Climate Change (MoEF & CC) had issued the Coastal Regulation Zone (CRZ)

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Notification, 1991 under the Environment (Protection) Act, 1986 and there have been continuous amendments in this notification since then. The CRZ notification was issued with a vision of sustainable development and conservation of marine resources.

Present coastal regulations (CRZ, 2011) has issues related to implementation at administrative level and violations at private/government level. Considerable variations have been observed in the application and interpretation of coastal regulations in various Indian states (Sonak, Pangam, & Giriyan, 2008). Lack of clarity and definitions in CRZ regulations has led to subjective interpretations. This subjectivity stems from the basic definitions used to classify the coastal areas. For example, in prevailing CRZ regulation, areas come in CRZ-I are ecologically subtle areas like mangroves (if area more than 1000 square meters, a buffer area of 50 m shall be provided), corals, sand dunes, salt marshes, bird & turtle nesting grounds, horse shoe crab habitats, sea grass beds, mudflats and the area between Low Tide Line and High Tide Line and it's hard to demarcate these areas independently. Chouhan, Parthasarathy, and Pattanaik (2016) reported the violation of coastal regulations in Mumbai city leading to the destruction of ecosystem and biodiversity in coastal region due to rapid uneven population growth and developmental activities. Parthasarathy (2011) discussed the land encroachment issues and its associated effects on coastal communities in Mumbai. Ignorance of coastal communities existence by administrations has resulted into commercial exploitation and loss of biodiversity despite the coastal communities are meant to be protected according to CRZ (2011) regulations (Krishnamurthy et al., 2014). Absolute gap at institutional level for CRZ implementation has been reported by academicians and expert's working in the area of coastal resource management in India (R Dhiman, June 2015, Personal Communication).

There is a need to bring all the priorities related to the development, natural disasters and environment in decision-making related with Indian coastal cities (Srinivas & Nakagawa, 2008). All these issues related to futile regulations, policy violations and fragile institutional framework urge the requirement for management of coastal resources in a sustainable manner which is possible through suitable planning and policy improvement. Quantitative decision analysis is one of the suitable approaches answering strategic or policy decisions with large uncertainties and multiple conflicts (Zhou, Ang, & Poh, 2006). Therefore, present work focuses on improvement for coastal area classification methods in Indian cities through advancement in decision analysis.

1.2. Use of GIS and MCDM for area classification

Geographical Information System (GIS) tool is a set of computer hardware and software which is used to process and store the spatially referenced data to derive information (Burrough & McDonnell, 1998). One of the key application of GIS is land suitability analysis (Collins, Steiner, & Rushman, 2001) targeting the identification of appropriate spatial configurations for upcoming land uses based on specific criteria and requirements (Brail & Klosterman, 2001). Specific land suitability applications of GIS include urban and regional planning (Baud, Scott, Pfeffer, Sydenstricker-Neto, & Denis, 2015; Janssen & Rietveld, 1990), selecting site for public and private sector facilities (Longley, Goodchild, Maguire, & Rhind, 2005), habitant selection for animal and plant species (Schmoldt, Kangas, Mendoza, & Pesonen, 2001), environmental impact assessment (Gontier, Mörtberg, & Balfors, 2010), coastal vulnerability assessment (Le Cozannet et al., 2013; Mani Murali, Ankita, Amrita, & Vethamony, 2013).

GIS is acknowledged as an appropriate decision support tool for analyzing and solving problems with integration of spatially referenced data (Brown & Kyttä, 2014). Major limitation of GIS to be designate as complete decision support tool is that, GIS doesn't incorporate preferences (evaluation criteria/alternatives) of decision makers (Malczewsk, 1999). Coupling GIS with Multiple Criteria Decision Making (MCDM) approach provides better decision support and has been widely practiced (Malczewski, 2006). A detailed literature survey by Keefer, Kirkwood, and Corner (2004) has highlighted the significant growth in use of decision analysis approach for decision making in interdisciplinary areas. One of the most suitable fundamental decision analysis approach is MCDM (Feizizadeh & Blaschke, 2014). Coupling of GIS with MCDM can transform the geographical data and combine the preferences from decision makers (value judgments) to derive the information for decision making (Drobne & Lisec, 2009). Capabilities of GIS coupled MCDM methods can be utilized for benefits of advancement in theoretical and applied research areas (Malczewski, 2004).

In literature, we observed numerous applications of coupling GIS with MCDM in the area of agricultural resource management (Ananda & Herath, 2003a), natural resource management (Mendoza & Martins, 2006), urban planning (Bryan, 1988), forest management (Ananda & Herath, 2003b), environmental management (Howard, 1991; Munda, Nijkamp, & Rietveld, 1993), energy policy analysis (Greening & Bernow, 2004), wetland management (G A; Mendoza & Martins, 2006), selection of storm water management options (Gogate, Kalbar, & Raval, 2017) and food security (Renwick, 2015). Alves, Coelho, Coelho, and Pinto (2011) interestingly demonstrates development of coastal zone risk map with the help of vulnerability modelling for the northwest Portuguese Coastal Zone.

Some of literature studies have attempted Analytical Hierarchical Process (AHP) methods for development of disaster resilient index to assess coastal communities (Orencio & Fujii, 2013), conservation of coastal areas in Iran (Pourebrahim, Hadipour, Mokhtar, & Taghavi, 2014), comprehensive framework for coastal reclamation in China (Feng, Zhu, & Sun, 2014), optimizing strategies for protection of coastal landscape (Baby, 2013), protection priority in coastal environment of Taiwan (Chang, Liou, & Chen, 2012) and coastal vulnerability assessment (Sudha Rani, Satyanarayana, & Bhaskaran, 2015). However, utility based and compensatory approaches have not been attempted so far for management of coastal areas in Indian coastal cities.

1.3. Problem definition

The above literature suggests that there is lack of quantitative scientific rational method applied presently in India for classifying coastal areas. The present work attempts to fulfill this gap by developing a coastal area classification method based on GIS coupled MCDM approach. Main objective of this research is to develop area classification method which is technically robust and easy to use for decision making in coastal planning. Such a decision-making method will synergies developmental activities and environment conservation in coastal cities of India by appropriately classifying coastal areas using quantitative approach.

2. Methods

Present study relies on application of GIS and MCDM for coastal areas. A case study is used to demonstrate the application of the method. Results obtained from the case study are validated and rigorous sensitivity analysis was performed. The overall methodology followed in this work is represented in Fig. 1. Next sub-sections describes the case study and the methods in details.

2.1. Study area

We selected Mumbai, Indian coastal megacity as primary study area for validation of coastal area classification method using GIS coupled MCDM approach. Coastal area of Mumbai has high environmental value territory exposed to anthropic activities. Furthermore, this coastal area is subjected to major urban issues related to water shortage, seasonal monsoonal flooding, untreated pollution discharge in adjacent creeks, direct solid waste dumping in mangroves (Pacione, 2006). Severe coastal pollution leading to depletion of coastal ecosystem made