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Fuzzy risk assessment modelling of East Kolkata Wetland Area: A remote sensing and GIS based approach

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ABSTRACT

East Kolkata Wetland Area (EKWA), a Ramsar site, is suffering from long-term resource exploitation and land-use change. This paper presents a Fuzzy-based Risk Assessment Model (FRAM) using Remote Sensing and GIS tools to identify the areas with varying intensity of wetland conversion risk within EKWA. Model was developed through rule-based Fuzzy Inference System. 'Wetlands conversion rate', 'Canal proximity', 'Road proximity', 'Population density', 'Population growth rate', 'Infrastructure status', 'Livelihood status', and 'Social status' were the eight selected input indices for the model.

The model was validated at two stages. For stage one, Fuzzy c-Means (FCM) classified satellite data for 2012 and 2014 were compared to detect the landuse change. In stage two, model relevance over thirteen study sites was studied through questionnaire-based field survey. It was found that FRAM has efficiently modelled and mapped the various levels of wetland risk zones of EKWA.

1. Introduction

Wetlands, for their multifaceted functionalities and issues of their conservation, have engaged the attention of scientific communities as well as a multitude of special interest groups in last few decades. The ecological and societal benefits, commonly known as ecosystem services, are the direct or indirect contributions that these ecosystems make to the well-being of human populations (United States Environmental Protection Agency, 2009). They form a basic part of livelihood support for the local wetland dependent communities. However, the relationship between wetlands and human society has changed significantly over time (Maltby, 2006). The wetland areas have experienced long-term and continuing resource exploitation and land-use change. The risk assessment of these stressed ecosystems is highly required, so that appropriate conservation and management measures can be taken in time. The application of risk assessment has been widely done for the protection of our environment or any ecosystem in recent times (Martínez-Santos et al., 2008; Chen et al., 2010; Wang and Chen, 2010; Weihong et al., 2011). Ramsar Convention on Wetlands, the global intergovernmental treaty that promotes wetland conservation worldwide, has given due importance to wetland risk assessment techniques. Para 10 of Resolution VII.10 of Ramsar Convention puts forward the 'Wetland Risk Assessment Framework' for predicting and assessing change in ecological character of wetlands.

The convention has further proposed a Geographical Information System (GIS)-based framework as a potentially useful technique for characterizing risks in wetlands. Risk assessment is a complex process that depends on comprehensive data collection, integration, and analysis of various ecological, social, and economical variables. Its database must encompass spatial extent and information on risk types, the occurrence probability and frequency, enormity and intensity of risk-related social and economical factors, and their proximity to human environment. In this regard, GIS has facilitated efficient data management, representation, and analysis of these variables at one platform irrespective of their various sources. Satellite-based Remote Sensing has been widely used for mapping and monitoring wetland resources (Ozesmi and Bauer, 2002; Phillips et al., 2005; Ramachandra and Kumar, 2008; Frohn et al., 2009; MacKay et al., 2009; MacAlister and Mahaxay, 2009; Nagabhatla et al., 2010; Zhao et al., 2010; Klemas, 2011). By integrating Remote Sensing and GIS tools various wetland studies were conducted that scale from developing multi-purpose wetland inventory to conducting spatial simulation

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(Joshi et al., 2002; Rebelo et al., 2009; Durga Rao et al., 2009).

Risk assessment is generally performed using models. Modelling any phenomena whether natural or man-made is challenging because it contains certain level of uncertainty in terms of time, data availability and reliability, consistency of input functions, and technological know-how's. In an ecosystem based modelling uncertainty is a major concern, as ecosystem is not a fixed structure that is fully deterministic 'hard' system, but a soft, fuzzy system with vague boundaries. Observation error for ecological process is higher than physical ones, since they are difficult to measure (Straskraba and Mauersberger, 1988). Traditionally most of the models were threshold-based, which was leading to information or data loss. In recent times, fuzzy logic has emerged as an important approach in ecological risk modelling (Comas et al., 2008; Liu and Lai, 2009; Camastra et al., 2015). They are fruitful in modelling the complex systems and processes of environment (Smith, 1997; Gemitzi et al., 2006; Prato, 2007; Casper et al., 2007). It has the answer to all the problems related the inaccuracy of land-cover classifications (Woodcock and Gopal, 2000), boundary imprecision or vagueness (Leung, 1987) and modelling a process like human reasoning (Kandel, 1986). Fuzzy logic developed on fuzzy set theory attempts to generate a consistent representation of an inconsistent reality (Fisher and Unwin, 1995). It uses an uncertainty gradient having values between zero (no membership) and one (full membership) that imitates the nature of imprecise data and makes it a prime candidate for inclusion in a model framework (Zadeh, 1965; Quelch and Cameron, 1994; Davis and Keller, 1997). Wetland risk assessment needs a modelling approach, which can efficiently handle the non-linear relationships existing among its dependent variables. Fuzzy Inference System has advantage in this respect that works on the vague relations and can build model based on experts' knowledge and individuals. This operates on classification and decision making process (Yanar and Akyiirek, 2004; Sami et al., 2014). Nevertheless, the application of fuzzy inference system in wetland risk modelling is still at infant stage. Thus, in this study, fuzzy based approach has been incorporated in the wetland risk model to include human knowledge and experience in the form of linguistically defined variables into GIS-based spatial analysis. This study presents a comprehensive wetland risk assessment model based on rule-based Fuzzy Inference System.

For the present study, East Kolkata Wetland Area (EKWA) is selected as the study area, which was recognized as a "Wetland of International Importance" by the Ramsar Convention in August 2002. Shrinkage in spatial extant of the wetlands in EKWA has been noticed in the last few decades (Parihar et al., 2013). Sited at the margin of a densely populated city, Kolkata, the wetlands have faced the axe of city expansion. Where development and wetlands coexist, there are often potential or realized risks, which must be addressed for the survival of the wetlands (Lyon, 2001). Therefore, recognizing the vulnerability of the wetlands towards conversion, it is of great significance to identify the areas with high risk. This will help in developing the management strategies for wetland conservation and the area's integrated development. Henceforth, in this study an attempt has been made to identify the areas with varying intensity of wetland conversion risk within EKWA by Remote Sensing - GIS integrated FRAM.

2. Methodology

2.1. Study area

EKWA, an unbeatable resource for being a unique resource recovery system, encompasses an area of about 125 sq km., and is located along the eastern part of the Kolkata city [approximately between 22°25′ to 22°40′ latitude North and 88°20′ to 88°35′ longitude East] in the state of West Bengal, India (Fig. 1). It consists of 37 *mouza* [administrative revenue collection units that include

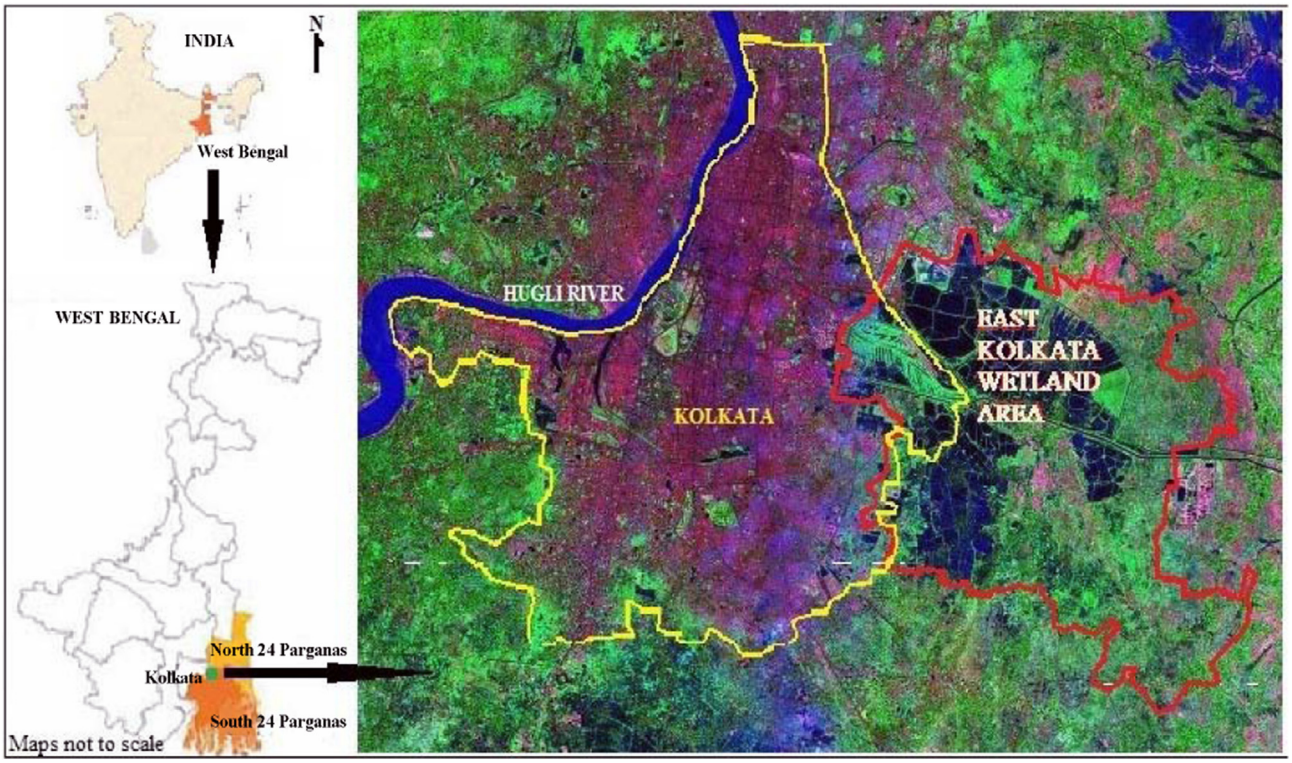

Fig. 1. Location of East Kolkata Wetland area (EKWA).