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Geospatial scenario based modelling of urban and agricultural intrusions in Ramsar wetland Deepor Beel in Northeast India using a multi-layer perceptron neural network

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ABSTRACT

In recent decades, the world has experienced unprecedented urban growth which endangers the green environment in and around urban areas. In this work, an artificial neural network (ANN) based model is developed to predict future impacts of urban and agricultural expansion on the uplands of Deepor Beel, a Ramsar wetland in the city area of Guwahati, Assam, India, by 2025 and 2035 respectively. Simulations were carried out for three different transition rates as determined from the changes during 2001–2011, namely simple extrapolation, Markov Chain (MC), and system dynamic (SD) modelling, using projected population growth, which were further investigated based on three different zoning policies. The first zoning policy employed *no restriction* while the second *conversion restriction* zoning policy restricted urban-agricultural expansion in the Guwahati Municipal Development Authority (GMDA) proposed green belt, extending to a third zoning policy providing *wetland restoration* in the proposed green belt. The prediction maps were found to be greatly influenced by the transition rates and the allowed transitions from one class to another within each sub-model. The model outputs were compared with GMDA land demand as proposed for 2025 whereby the land demand as produced by MC was found to best match the projected demand. Regarding the conservation of Deepor Beel, the Landscape Development Intensity (LDI) Index revealed that wetland restoration zoning policies may reduce the impact of urban growth on a local scale, but none of the zoning policies was found to minimize the impact on a broader base. The results from this study may assist the planning and reviewing of land use allocation within Guwahati city to secure ecological sustainability of the wetlands.

1. Introduction

Wetlands, the natural or artificial transition zones between land and water, play a vital role in a region's landscape by controlling floods, protecting shorelines, and purifying water in addition to groundwater recharge. However, because of unplanned urban growth and land conversions wetlands in most urban and suburban areas are in danger (Bhattacharyya and Kapil, 2009; Han et al., 2012; MEA, 2005; Prasad et al., 2002). As an indicator, the global extent of freshwater wetlands and lakes covering only a small percentage of the land surface, especially in South Asia and South America, has been reported to have declined by 6% in just 14 years (from 1993 to 2007) due to continuous and disordered urban growth (Prigent et al., 2012). To better protect these wetlands, several studies on wetland monitoring, restoration, and management are currently under way (Grayson et al., 1999; Mitsch and Wang, 2000; Richardson et al., 2011), and a number of international treaties, such as, the Ramsar convention and Millennium Ecosystem Assessment, have been introduced focussing on "wise use" and "ecosystem services" of the wetlands (MEA, 2005; Ramsar, 2006).

For effective management of wetland in urban areas, it is of utmost importance to consider land use conversions and activities associated with human population at the basin scale (Hermoso et al., 2012; Ramsar, 2010). Despite the strengthening body of literature in wetland conservation planning and urban growth modelling, the integration of the two is still lagging (Jia et al., 2011). For instance, the elements of an urban ecosystem such as urban river systems, urban landscapes, and green spaces have been researched and implemented (Tong et al., 2007; Crane and Kinzig, 2005), while urban wetland planning has yet remained limited (Tilton, 1995; Mitsch and Gosselink, 2000; BenDor et al., 2008). To

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address the complex relationship between urban growth and wetland conservation, one of the best approaches is the comparison of probable future scenarios (Geneletti, 2012; Thapa and Murayama, 2012; Trisurat et al., 2010; Verburg et al., 2002; Zacharias et al., 2005). These scenarios can be exploratory and/or normative, and are typically developed based on criteria such as relevance, credibility, legitimacy, and creativity (Kok and Van Vliet, 2011; Kok et al., 2011). However, in the development of scenarios it is vital to keep in mind that they should allow for a comparison with alternatives and the implication of uncertainties associated with probable future urban growth around the wetland or other concerned ecosystems, so that they can contribute to the spatial urban planning system (Geneletti, 2012; Kok and Van Vliet, 2011).

At the same time, the selection of models for projecting future land use is also crucial, and to this end, various land change models have been developed to mimic the dynamic process of land use/land cover (LULC) change (Agarwal et al., 2002; Brown et al., 2004; Silva and Wu, 2012; Mas et al., 2014). Generally, these models can be classified as: (1) empirical and statistical models, such as Markov Chain (MC), regression model, etc. (Bell, 1974; Clark, 1965); (2) dynamic models, such as cellular automata (CA) model, agent-based model, weights of evidence, artificial neural network (ANN), system dynamic (SD) models, etc. (Dai et al., 2005; Matthews et al., 2007; Mohmand et al., 2011; Pijanowski et al., 2002; Thapa and Murayama, 2011; Ti-yan et al., 2007); (3) integrated models, such as CLUE (conversion of land use and its effects) and DynaCLUE, etc. (Verburg et al., 2002; Verburg and Overmars, 2009). Among these, integrated models are capable of accurately representing the complex phenomenon of land use change. Nevertheless, as pointed by Mas et al. (2014), these models do not incorporate the past changes in the calibration, since they are typically based on the logistic regression between the LULC and explanatory factors. Secondly, some integrated models produce poor goodness of fit if the change potential function is not sigmoidal (Mas et al., 2014). Therefore, in recent years, several hybrid models composed of empirical/statistical and dynamic models, such as ANN and MC (Thapa and Murayama, 2012), MC, CA, and regression (Arsanjani et al., 2013), MC and regression (Geneletti, 2012), CA and fuzzy logic (Wu, 1998), CLUE and SD (Luo et al., 2010), etc. have been integrated to depict the complex phenomenon of urban growth.

The non-linear spatial–temporal relationship between land use types and driving factors encompasses many components such as population growth, geographic conditions, policies, socio-economic interventions, topography, economy, morphology, etc. Such non-linear relationships can be addressed smartly by an ANN framework as evidenced by Thapa and Murayama (2012), Pérez-Vega et al. (2012), etc. ANN employs a machine learning approach, which uses model-free functions, and are able to handle complex non-linear functions with the consideration of complex relationship between variables. Such approaches are expected to produce a better fitting between the change potential and explanatory variables, since they utilizes 50% of the samples for calibration and 50% for validation, until the expected accuracy is obtained. While ANN is able to answer "which pixels to change" based on the network developed from land use change and driving factors, it is unable to decide "how much to change". Therefore, specific land use demands have been estimated by empirical and dynamic models such as MC, SD, etc. in several previous studies (Luo et al., 2010; Ti-yan et al., 2007). However, as land use trends also change forward, backward, left or right, most of the studies reveal deficiencies in considering and comparing uncertainties in land use demands. After all, Geneletti (2012) included two different land use change rates and compared zoning policies; however, no accuracy estimation was presented in this case.

The current study addresses the issues of integration of land use modelling and wetland planning through a case study in northeast India, aiming at empirically exploring how the supposition of diverging land use demands and zoning policies will affect the future of a threatened Ramsar wetland. Among the variety of models and approaches available for modelling, and thus describing the mechanism of LULC change, this study employs an ANN based approach because of its ability to model and quantify complex behaviour and patterns (Pijanowski et al., 2002) by considering nonlinear relations between the driving factors and land use change. The predictive power of ANN was coupled with an empirical and dynamic land use demand estimation derived from extrapolation, MC and SD. Zoning policies are the regulations which permit, prohibit or prefer a certain land use in the periphery of the ecosystem. These exploratory scenarios were evaluated in view of the goal of fulfilling the criteria of conserving the ecosystem while allowing urban and agricultural expansion.

The study area under consideration is Deepor Beel, a Ramsar wetland threatened by unplanned urban and agricultural expansion in the city area of Guwahati, India. The wetland is not only shrunk in size, but also eutrophicated due to constant discharge of pollutants and fertilizers from the surrounding area. Therefore, for the conservation of the wetland, this is of utmost importance to consider different zoning policies, in addition to the different land demands required to accommodate the future population growth in the Guwahati city. The method used in this study complements earlier works which focused on sustainable planning and management of natural resources in the periphery of developing cities around the world.

1.1. Deepor Beel in Guwahati City, India

Guwahati city acts as the gateway and transit point for communication and transportation of seven sister states of the northeastern region of India. Shifting the capital of Assam from Shillong to Guwahati in 1972 has increased its importance manifold. People from all northeastern states have migrated to Guwahati for jobs, business and education. This has resulted in a rapid and unplanned growth of the city with a total population of about 968,549 (2011 census). Additionally, the city has geographically very limited space of about 328 km^2 (metropolitan area) surrounded by several steep sided granite hillocks, as shown in Fig. 1. In the early 70s, only a few multi-storey buildings existed in the city outside the downtown area. But during the last decade, many high-rise buildings have been built juxtaposed to each other due to the acute shortage of space. Many natural water bodies have been filled up for construction of houses increasing their vulnerability to earthquake and urban flooding hazards.

Deepor Beel, a freshwater lake located about 10 km southwest of Guwahati, is one of the large and important riverine wetlands in the Brahmaputra valley of lower Assam (Fig. 1). In 2002, it was recognized as one of the most significant wetland systems in the world under the Ramsar International Convention on wetlands as reported by the World Wildlife Fund (WWF) on fulfilment of 5 out of 8 Ramsar criteria (RIS, 2002). It is believed that the wetland is an abandoned channel of the Brahmaputra river situated in a wide U-shaped valley rammed between two cliffs on the north and south (MoEF, 2008). A perennial stream originating from the Basistha basin runs through the wetland and finally joins the Brahmaputra river at Khanamukh. The wetland stands 4–5 m deep during the monsoon season and up to about 1 m deep in the dry season, where the major sources of water to the wetland are monsoon precipitation and some inflows from Bharalu and Kalmani rivers (tributaries of the river Brahmaputra) adjoining the wetland (RIS, 2002).

Deepor Beel is listed as one of the threatened Ramsar sites, which has undergone degradation in biological aspects, water quality, and quantity and spatial extent (RIS, 2002). The Ministry