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Assessment of environmental factors causing wetland degradation, using Fuzzy Analytic Network Process: A case study on Keoladeo National Park, India

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ABSTRACT

Different factors play important roles in sustaining ecological balance and socio-economic stability of a region. Wetlands have crucial impact on preserving the ecology of a particular region. Wetland ecosystem is influenced by many factors that affect the bio-diversity and ecological balance to different degrees. The most common threats to wetlands are generally water scarcity, changing biodiversity and human intervention. Assessing the condition of a wetland involves the impact of environmental, ecological and socio economic factors which are mostly imprecise and uncertain in nature. Opinions of experts in several related fields are considered and subsequently importance of a particular environmental process in the wetland biosphere is expressed linguistically. Fuzzy Analytic Network Process (FANP) is one of the well-known procedures to assess the relative importance of different factors. In this paper, a model is developed using different wetland factors and sub-factors responsible for ecological degradation of Keoladeo National Park (KNP), India. Fuzzy Analytic Network Process (FANP) is applied to assess the relative importance of different factors responsible for preservation and restoration of ecological balance of KNP. The strategies of preservation and restoration of wetlands are sub-divided into several sub-goals. The network analysis of different factors explains their relative degrees of influence on the ecological system of KNP. Based on these findings, this paper suggests further enhancing the water supply, optimizing the land use structure and strengthening wetland protection laws.

1. Introduction

Wetlands play an important role in biochemical transformation, production of flora and fauna with decomposition of organic matter and sustains biological diversity (Clarkson et al., 2003). According to Ramsar convention on wetland (1971) (www.ramsar.org), *wetland ecosystem* is defined as 'areas of marsh, fen, peat land or water bodies, natural or artificial, permanent or temporary. They also comprise of static or flowing, fresh, brackish or saline water bodies including areas of marine water, the depth of which at low tides does not exceed six metres'. Urbanization and rapid industrialization cause wetland degradation and disruption of ecological balance (Zedler and Kercher, 2005). Furthermore wetlands are sensitive ecosystems facing deterioration in ecological balance as a result of human intrusion (Janssen et al., 2005). Assessment of a wetland ecosystem is to analyze the possible effects on the changing biodiversity of the particular wetland under environmental factors on a regional scale (Chen et al., 2010).

The major threats to proper management of wetlands are excessive usage of technology and lack of knowledge among different stakeholder's viz. farmers, conservationists and recreationists. The prime constraints to analyze the present condition of a wetland are difficulties in quantifying the influence of economic, environmental and recreational factors (Herath, 2004). In the last two centuries, rapid industrial development and unexpected growth of eco-tourism has led to human encroachment of wetlands and coastal regions (Butler, 1980). The growth of real estate in India is one of the vital risk factors for ecological stability of a wetland. Also climate change and global warming occurring along coastal and different densely populated wetland areas are causing serious ecological imbalance (Santiago, 2006).

The policy-makers plan to restore wetlands using scientific approaches, in spite of rapid industrialization which supports eco-tourism in wetland areas (Nobre, 2011). Alien invasive grasses and

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shrubs have negative impacts on local aquatic flora and fauna, upsetting the natural balance of the ecosystem. Pollution in wetlands is a growing concern in ecological diversity. The wetlands throughout the world and their ecosystems are suffering from environmental degradation like water scarcity, species' extinction, disruption of breeding grounds, imbalance in sediment load and nutrient filtration (Ramsar Convention Secretariat, 2004).

A fair bit of work has been done so far in this area. Chen et al. (2011) proposed information based network environmental analysis for ecological risk assessment in wetland. Cui et al. (2015) measured the potential impacts of rise in sea levels on the coastal wetlands in Yangtze Estuary by adopting SPRC model and spatial assessment method. Guo et al. (2012) carried out a scientific assessment of wetland ecosystems, integrating clusters of geochemical indicators of soil into a framework of ecosystem in Zoige Wetland of southwest China. In the Indian perspective, a novel research scheme based on the usage of geospatial technology has been demonstrated for biodiversity conservation and wetland management using landscape ecological metrics (Garg, 2015). Evaluation of wetland stability and risk factors of ecosystem needs some criteria and indicators which are both qualitative and quantitative in nature. Ecosystem assessment consists of a multi-criteria decision making (MCDM) problem involving social and environmental aspects through a series of evaluation indices which cannot be measured directly (Burgman, 2005). MCDM methods incorporate concerns about multiple conflicting, complex factors and sub-factors in management planning processes (Liu, 2007). Malekmohammadi and Blouchi (2014) studied ecological risk assessment applying MCDM and Geographic Information system (GIS) and subsequently developed zoning maps to identify and analyze the risky stress factors. The best method to evaluate problems that involve a number of uncertain factors are Analytical Hierarchy process (AHP) (Saaty, 1980) and Analytical Network process (ANP) (Saaty, 1996). Zhang et al. (2013) applied AHP approach for evaluation of wetland ecosystem stability in Yinchuan Plain, China. It fails to develop the inter-dependence and intra-dependence among factors, which can only be overcome by ANP methodology.

In real life, ecological aspects of some wetlands depend on socio-economic and environmental factors which are generally vague and uncertain in nature and hence we have considered a fuzzy classification rather than precise quantification. This paper is aimed at assessing the wetland ecosystems using an analytical network process (ANP) approach in a fuzzy environment. The criteria layer is composed of wetland function values, wetland environmental constraints and socio-economic factors. First, we study the construction method of the wetland ANP in fuzzy nature. Then we calculate the relative weights and the overall ranking of indices. And lastly the results of the weights are analyzed to figure out the intensities of the main factors affecting wetland ecological sensitivity level. These results provide decision support to wetland conservation management and sustainable regional development. For the sake of a case study, this paper has considered Keoladeo National Park (KNP) in Rajasthan, India, taking help of notes from Perennou and Ramesh (1987) for wetland assessment. Sudhakar Reddy et al. (2010) did assessment and monitoring of spatio-temporal changes in Keoladeo National Park, Rajasthan using geoinformatics. In this paper, we have applied fuzzy Analytical Network Process (FANP) for sensitivity level and ecological degradation analysis of the Keoladeo National Park which falls under the category of risk-prone wetland ecosystems in India.

The structure of the paper is as follows: In Section 2, basic concepts of fuzzy theory and fuzzy number, fuzzy-ANP, extent analysis method with proposed methodology are discussed. In Section 3, an assessment hierarchy framework is formed for a wetland assessment considering a case study on Keoladeo National Park taking risk factors and sub-factors. In Section 4, results and discussion session are dealt with. Section 5 presents conclusion and future research scope in the related field.

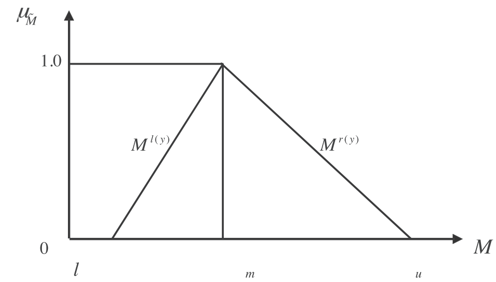

Fig. 1. A triangular fuzzy number, $\tilde{M}$ (Kahraman et al., 2003).

2. Methodology

2.1. Fuzzy theory and fuzzy numbers

Fuzzy sets theory deals with uncertainty due to imprecision and vagueness, using human linguistics expressing complex relationship of a system (Zadeh, 1965). Fuzzy theory is defined as a class of objects with a continuum grade of membership, which assigns a level of membership to each object, ranging between zero and one (Kahraman et al., 2003). A fuzzy number is a fuzzy set $\widetilde{A} = \{(x, \mu_A(x)), x \in R\}$, where x takes values on the real line, $R: -\infty < x < +\infty$ and $\mu_A(x)$ is a continuous mapping from R to the closed interval $[0, 1]$. Among different types of membership functions used in fuzzy logic, three types are most common: monotonic, triangular and trapezoidal (Taha and Rostam, 2011). The triangular fuzzy numbers (TFN), represented by (l, m, n), are more convenient in application due to their computational simplicity and information processing in fuzzy environment (Tang, 2009). The TFN best suits the nature of expert's linguistic evaluation and utilized in MCDM studies. Each TFN is denoted by linear representations on its right and left sides such that its membership function μ can be defined as follows (Patil and Kant, 2014):

$$\mu\left(\frac{x}{\widetilde{M}}\right) = \begin{cases} 0, & x < l \\ \dfrac{x-l}{m-l}, & l \le x \le m \\ \dfrac{u-x}{u-m}, & m \le x \le u \\ 0, & u > x \end{cases}$$

See Fig. 1.

2.2. Fuzzy analytic network process

The analytic network process (ANP), generalization of analytic hierarchy process (AHP), is a multi-criteria assessment tool for decision structuring and analysis (Saaty, 1996). Although AHP represents a linear hierarchical structure in a top-to-bottom form, it is not suitable to deal with non-linear networks among factors at the same level. Many complex decision problems cannot be structured hierarchically as they involve dependence among factors or sub-factors of same level in a hierarchy. Saaty (1996) suggested the use of AHP and ANP to solve problems of independence and dependence among factors or sub-factors, respectively. The ANP approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher or lower (Saaty and Takizawa, 1986). The ANP technique includes two parts, control hierarchy or network of criteria and sub-criteria that control the feedback networks and networks of influence that contain those criteria and their clusters formed by logical