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# Environmental vulnerability assessment using Grey Analytic Hierarchy Process based model

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ABSTRACT

Environmental management of an area describes a policy for its systematic and sustainable environmental protection. In the present study, regional environmental vulnerability assessment in Hirakud command area of Odisha, India is envisaged based on Grey Analytic Hierarchy Process method (Grey–AHP) using integrated remote sensing (RS) and geographic information system (GIS) techniques. Grey–AHP combines the advantages of classical analytic hierarchy process (AHP) and grey clustering method for accurate estimation of weight coefficients. It is a new method for environmental vulnerability assessment. Environmental vulnerability index (EVI) uses natural, environmental and human impact related factors, e.g., soil, geology, elevation, slope, rainfall, temperature, wind speed, normalized difference vegetation index, drainage density, crop intensity, agricultural DRASTIC value, population density and road density. EVI map has been classified into four environmental vulnerability zones (EVZs) namely: 'low', 'moderate' 'high', and 'extreme' encompassing 17.87%, 44.44%, 27.81% and 9.88% of the study area, respectively. EVI map indicates that the northern part of the study area is more vulnerable from an environmental point of view. EVI map shows close correlation with elevation. Effectiveness of the zone classification is evaluated by using grey clustering method. General effectiveness is in between "better" and "common classes". This analysis demonstrates the potential applicability of the methodology.



## 1. Introduction

Environmental vulnerability zone identification is an important step for a sustainable environmental protection framework. It is defined for an area based on relative likelihood of getting affected due to a set of environmental factors. Surrogate information are used to infer the probability of environmental vulnerability. Environmental vulnerability zones provide an imprecise assessment of environmental protection based on remote sensing and conventional data. Environmental management of an area could be envisaged by adopting qualitative and quantitative analysis of various natural, environment and human factors. There are three major approaches available for predicting environmental vulnerability for an area: i) index based overlay method, ii) process based mathematical model, and iii) statistical inference analysis. In the present study, first approach is implemented in terms of environmental vulnerability index (EVI). EVI is an imprecise measure of vulnerability. A methodology is developed for environmental vulnerability assessment based on the Grey–AHP method.

Environmental vulnerability zones are delineated based on indirect inference analysis of influencing factors/features. Presence of large number of influencing features in the analysis increase the complexity. Fraster et al. (2006) described the methods of analysis of participatory process based identification of sustainability indicators for sustainable environmental management. This work show results of long and complex sustainability indicators for social, environmental and economic issues. An approach for assessing environmental vulnerability is discussed by Kvaerner et al. (2006) by the using standard environmental impact assessment (EIA) procedure. This approach provided more subjectivity linked to vulnerability assessments. Regional environmental vulnerability assessment is performed by Wang et al. (2008) using remote sensing & GIS techniques. Finally, results are correlated with altitude. Eco-environmental vulnerability assessment using fuzzy analytic hierarchy process (FAHP) for the Danjiangkou reservoir area, China is presented by Li et al. (2009). This method is developed by combing fuzzy set theory and decision making system in GIS framework. Tran et al. (2010) worked on environmental vulnerability pattern assessment based on stressor resource overlay, state-space analysis, and clustering analysis methods. Marine environmental vulnerability mapping using GIS based on neuron-fuzzy techniques is presented by Navas et al. (2011). This method mainly focuses on the three-dimensional hydrodynamic model validation. A study on environmental vulnerability

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quantification and measurement based on environmental vulnerability index (EVI) is presented by Skondras et al. (2011). It measures potential risk only (anthropogenic and natural risk). Johnson et al. (2012) worked on heat–health vulnerability assessment based on remote sensing & GIS techniques utilizing census data and remotely sensed variables. This approach considers land surface temperature (LST), normalized different vegetation index (NDVI) and normalized different built-up index (NDBI) factors. Watershed-based environmental vulnerability mapping for the Mid-Atlantic region is presented by Tran et al. (2012). It utilizes a concept of self-/peer-appraisal approach. Ecological vulnerability evaluation in environmental impact assessment based on geographic information system technique is described by Liao et al. (2013). These results are classified into 5 levels by zonal statistical analysis. Romero et al. (2013) performed oil environmental vulnerability mapping for the Santos Basin region, Brazil. Yoo et al. (2014) presented environmental vulnerability assessment for local scale conditions in Jakarta, Indonesia. This methodology mainly focuses on conceptual diagram composed of exposure and sensitivity analysis. Socioeconomic and environmental vulnerability assessment of river systems in China based on multidimensional perspective is available in Varis et al. (2014). This approach is based on six stress factors (e.g., hazards, water stress). Traditionally, effectiveness of environmental vulnerability zone delineation is evaluated from the elevation vs. environmental vulnerability index (EVI) plot (Wang et al., 2008). A positive correlation loosely indicates the effectiveness. However, direct quantification of effectiveness is not unique.

The analytic hierarchy process (AHP) is a powerful multi-criteria decision tool. However, effectiveness evaluation of AHP is not available. In the present work, a Grey Analytic Hierarchy Process (Grey-AHP) is proposed for the effectiveness evaluation of environmental vulnerability zone delineation. Environmental vulnerability assessment needs socioeconomic and geospatial data. The present work utilizes thirteen natural, environmental and human factors, i.e., soil, geology, elevation, slope, rainfall, temperature, wind speed, NDVI, drainage density, crop intensity, agricultural DRASTIC, population density and road density. The proposed methodology is applied to the Hirakud command area in Odisha, India.

## 2. Study area

Hirakud command area is situated in the western part of Odisha, India. The study area (Fig. 1) is bounded by North Latitudes 20° 53′:21° 36′ and East Longitudes 83° 25′:84° 10′ and falls in the survey of India Toposheets 64O, 64P and 73C. The total area of 2260 km$^2$ consists of five administrative blocks of Sambalpur District, six administrative blocks of Bargarh District, two administrative blocks of Suvarnapur District and one administrative block of Bolangir District (Dhar et al., 2015).

## 3. Material and methods

### 3.1. Data used

To identify the environmental vulnerability zones in the study area, thirteen feature maps (soil type, geology, elevation, slope, rainfall, temperature, wind speed, normalized difference vegetation index, drainage density, crop intensity, population density, road density and agricultural DRASTIC) are prepared from satellite imagery and field/conventional data. Elevation, slope and drainage density maps are prepared from the CARTOSAT 1 [CARTOSAT-1 PAN (2.5 m)] data. Rainfall data [grid data (0.25°, daily)] are collected from the Aphrodite Water Resources (http://www.chikyu.ac.jp/precip/) site. Temperature and wind speed data [grid data (1°, daily)] are collected from the NASA (National Aeronautics and Space Administration) Prediction of Worldwide Energy

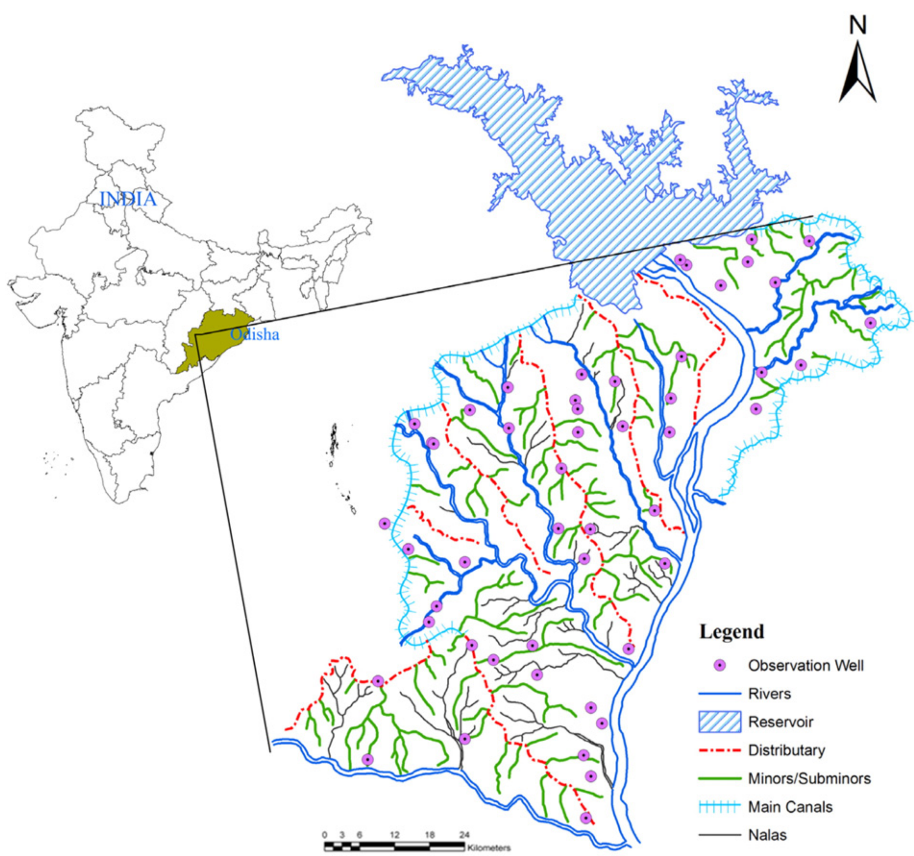


**Fig. 1.** Location map of the study area (Hirakud Canal Command).