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Assessment of impact of shrimp farming on coastal groundwater using Geographical Information System based Analytical Hierarchy Process

P. Nila Rekha *, R. Gangadharan, P. Ravichandran, P. Mahalakshmi, A. Panigrahi, S.M. Pillai

Central Institute of Brackishwater Aquaculture 75, Santhome High Road, R.A. Puram, Chennai 600 028, India

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ABSTRACT

Impact assessment of shrimp farming on groundwater needs selection of representative sampling units. In the coastal region, complex sources invariably influence the groundwater flow and its quality. This warrants multicriteria evaluation techniques consequent to which Geographical Information System (GIS) based Analytical Hierarchy Process (AHP) was used for the selection of groundwater sampling units in an effort to assess the impact of shrimp farming. Thematic maps of eight base layers viz. distance from the aquaculture ponds, drainage pattern in the study area, lineament, soil texture, slope, landuse/landcover, geomorphology and lithology were prepared using ARCGIS 10 as these were the main factors that could impact groundwater quality. Information on the relative importance of the evaluation criteria was obtained by assigning weights to each criterion defined by pairwise comparison for all the above eight factors. Pairwise comparison revealed that the consistency ratio was less than the threshold value (0.1) indicating perfection in comparison of each evaluation criterion. Eight criteria of distance, seven criteria of drainage, three criteria of lineament, seven criteria of soil, eight criteria of landuse, three criteria of slope, seven criteria of geomorphology and five criteria of geology were computed and combined to develop a priority classification map related to the influence of brackish water aquaculture on the salinisation of the groundwater in an effort to precisely assess the impact. On analysis, 29 sampling well locations were identified with three priority classes viz., (i) high priority (10), (ii) moderate priority (13) and (iii) low priority (6). Groundwater samples from all these sampling units were collected bimonthly starting from October 2011 till June 2013 and analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), and chloride (Cl). Results revealed no significant relationship of groundwater quality as per the priority classification. Hierarchical cluster analysis clearly elucidated the variation of different water quality parameters being independent of the location of aqua farms indicating multiple sources for variation. From the spatial distribution map, it could be concluded that groundwater quality is independent of shrimp farming.

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* Corresponding author.
E-mail addresses: rekha@ciba.res.in, nila_71@yahoo.com.in (P. Nila Rekha).

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1. Introduction

Aquaculture is one of the fastest growing food producing sectors and contributes over 47% of world fish supplies for human consumption (FAO, 2009) and is perceived as having the greatest potential to meet the growing demand for aquatic food. In addition, aquaculture has great potential for alleviation of poverty and generation of wealth for the people living in coastal area especially in developing countries. Over 500 million people in developing countries depend directly or indirectly on fisheries and aquaculture for their livelihoods (FAO, 2009). At the same time, aquaculture development also brought significant environmental issues and management problems to share access to the coastal resources. Environmentalists elsewhere pointed out both the positive and negative impacts of shrimp farming (Newport and Jawahar, 1995; Phillips et al., 1993). Positive impacts of shrimp farming are economic benefits, utilisation of marginal lands and water for economic benefits whereas the negative impact is due to the conversion of important coastal ecosystems like lakes, mangroves and agricultural lands to aquaculture farms (Boyd and Gross, 1999; Perez et al., 2003; Rosenberry, 1998), salinisation of drinking water resources adjacent to shrimp farms (Patil et al., 2002), nutrient loading of coastal water bodies and estuaries (Lacerda et al., 2006) and multi-user conflicts. Occasionally, the range and severity of these effects have often been exaggerated mainly owing to the high visibility of the aquaculture sector, failure to distinguish between actual and hypothetical hazards (Jerald, 1996) and projection of piecemeal studies which were location specific. This warrants a comprehensive and holistic impact assessment study and the watershed approach would be ideal and appropriate for any land and water based activity as it is considered to be basic hydrogeological spatial functional unit (Munafò et al., 2005; Tideman, 2000). The present study is a genuine attempt in this regard.

Among the impact assessment studies reported, Grant et al. (1995) evaluated the impact of shellfish aquaculture on benthic communities. Ward (2000) studied on the effect of shrimp farming on the hydrography and water quality of El Pedaegaland San Bernardo estuaries. Boyd and Green (2002) prepared a status report on coastal water quality monitoring in shrimp farming areas and conducted a consortium programme on shrimp farming and the environment. A close perusal of literature survey revealed that although the impact of shrimp farming on various aspects has been studied, the impact of shrimp farming on groundwater quality and salinisation has not been dealt adequately. which prompted us to undertake this study. There has been an apprehension among the environmentalists that aquaculture activities might influence the hydrology and hydrochemistry of groundwater aquifers. In the absence of proper scientific data this study was undertaken to evaluate the impact of shrimp farming on groundwater quality.

Geo-spatial environmental impact assessment (EIA) technique using GIS and remote sensing offers a better option to evaluate the impact on both spatial and temporal variability (Patil et al., 2002). The usefulness of remote sensing and GIS in assessing landuse changes in and around shrimp farming area has been attempted by many researchers (Kapetsky et al., 1987; Nath et al., 2000; Salam et al., 2003) at different places viz. Thailand (Tripathi et al. 2000), Mexico, Bangladesh (Hossain and Das, 2010; Paul and Vogl, 2011) and in Sepetiba, Brazil (Scott and Ross, 1999). Rajitha et al. (2007) has given a comprehensive review of application of GIS and remote sensing for aquaculture in India. GIS facilitates efficient storage, management and analysis of spatial and non-spatial data (Burrough and McDonnell, 1998; Kapetsky et al., 1987). Collectively, RS and GIS can serve as analytical and prediction tools for planning aquaculture development and also to test the consequence of various development decisions before their use in the landscape (Aguilar-Manjarrez and Ross, 1995; Burrough, 1986). Many of the studies cited above have demonstrated the capability of spatial modelling in identifying the appropriate sites for aquaculture.

Environmental impact assessment (EIA) is an intrinsically complex multi-dimensional process involving multiple criteria and multiple actors and AHP is one of the most reliable and widely used methodologies for multicriteria decision making. The two most widely used procedures are the weighed linear combination (WLC) and the Boolean overlay operations (such as intersection (AND) and union (OR)). There are, however, some fundamental limitations associated with the use of these approaches in a decision making process mainly due to lack of a theoretical foundation in deciding the weights which are often rather arbitrarily assigned without taking the comparison among the criteria and classes into consideration. This limitation can be overcome by using the Analytical Hierarchy Analysis (AHP) method (Saaty, 1977, 1980; Saaty and Vargas, 1993). The AHP is a multi criteria technique which has been incorporated into the GIS-based spatial modelling procedures (Carver,1991; Marinoni, 2004). The APH gained high popularity due to the ease in obtaining the weights, its capacity to integrate heterogeneous data consequent to which it is applied in a wide variety of decision making problems. Multicriteria evaluation provides a systematic, transparent approach that increases objectivity and generates results that can be reproduced. It considers both qualitative as well as quantitative information and combines them by decomposing ill-structured problems into systematic hierarchies to rank alternatives based on a number of criteria (Chen et al., 2007). It has been applied in many fields of research, including nature, economy and society (Krajnc and Glavic, 2005; Lai et al., 2012; Lie et al., 2004; Ramanathan and Ganesh, 1995). The AHP is also a means of eco-environment quality evaluation, the ecological environment being a large and multi-layer system (He et al., 2004; Hill et al., 2005; Janseen, 2001; Kang, 2002; Klungboonkrong and Taylor, 1998; Kurttila et al., 2000; Solnes, 2003; Yedla and Shrestha, 2003). This method has been applied for selecting suitable sites for prawn farming, Crab farming in Bangladesh (Hossain and Das, 2010), selection of groundwater monitoring location in Korea and identification of artificial recharge locations (Kim, 2010). However, till now no study has been reported using GIS based AHP to assess the impact of shrimp farming on groundwater.