Aquaculture 448 (2015) 491–506

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

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

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ARTICLE INFO

Article history:
Received 21 August 2014
Received in revised form 14 May 2015
Accepted 16 June 2015
Available online 20 June 2015

Keywords:
Shrimp farming
Groundwater
Coastal watershed
Salinisation
Geographical Information System

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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http://dx.doi.org/10.1016/j.aquaculture.2015.06.025
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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.

Selection of representative sampling unit is the first and primary task for any environmental monitoring for impact assessment studies. It is all the most important for a groundwater monitoring network in coastal areas as there are complex sources influencing the groundwater flow and its quality (Rekha et al., 2004, 2011). Taking random samples would not yield a realistic picture as it is a crude method of sampling. Similarly, strategic sampling, in which samples equidistant from shrimp farms are taken will not be properly represented. As it appears logically correct and easier, strategic sampling method which is usually followed will not be representative especially for groundwater samples. Sampling location requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area. For groundwater monitoring site, it is necessary to integrate data from various terrain characteristics using geographic information system techniques (Bahuguna et al., 2003; Kumar et al., 2007; Sinha et al., 1990). In the present study, GIS based AHP was applied to select appropriate sampling locations for assessing the impact of shrimp farming on groundwater quality. However, only a limited number of studies have taken the approach of specifically mapping for suitable monitoring sites (Kim et al., 2005), and as such there is no integration of multi-criteria analysis using the Analytical Hierarchy Process Method associated with GIS techniques to derive suitable monitoring sites for groundwater. This is a new approach which is adopted for selection for monitoring groundwater site for environmental impact assessment of shrimp farming.

The main objective of this study was to develop a sampling methodology to assess the impact of shrimp farming on groundwater using GIS based AHP method and to ascertain whether the area under study was actually impacted by shrimp farming.

2. Materials and methods

2.1. Watershed approach

The present study was based on the watershed approach which is holistic. Watershed is a basic geo-hydrological unit intrinsically addressing the complex multi-dimensional process of the environmental impact assessment and gives the realistic and cumulative effects more precisely even in coastal areas. Tamil Nadu is endowed with rich natural resources such as coastal zones in the form of brackish water/estuaries for shrimp culture.

2.2. Study area

In order to precisely assess the impact of shrimp farming, it is imperative to select an area where aquafarming has been in vogue for quite some time. Accordingly, the present study area which is located between 11°30′N to 11°20′N latitude and 79°38′E to 79°48′E longitude in Cuddalore district, Tamil Nadu, (Fig. 1) was selected as aquaculture was being practised from early nineties. Since it was proposed to assess the impact on the watershed, basis three adjacent coastal mini-watersheds covering the shrimp farming regions of Cuddalore district which falls in Survey of India toposheets no. 58 M/15 & 16 were delineated using ARC GIS.10

The brackish water resource of Tamil Nadu is about 56,000 ha. in which 18,000 ha. is identified as potential areas for farming. At present, shrimp aquaculture has been developed in 12 maritime districts of Tamil Nadu and approximately about 6500 ha is under culture as per

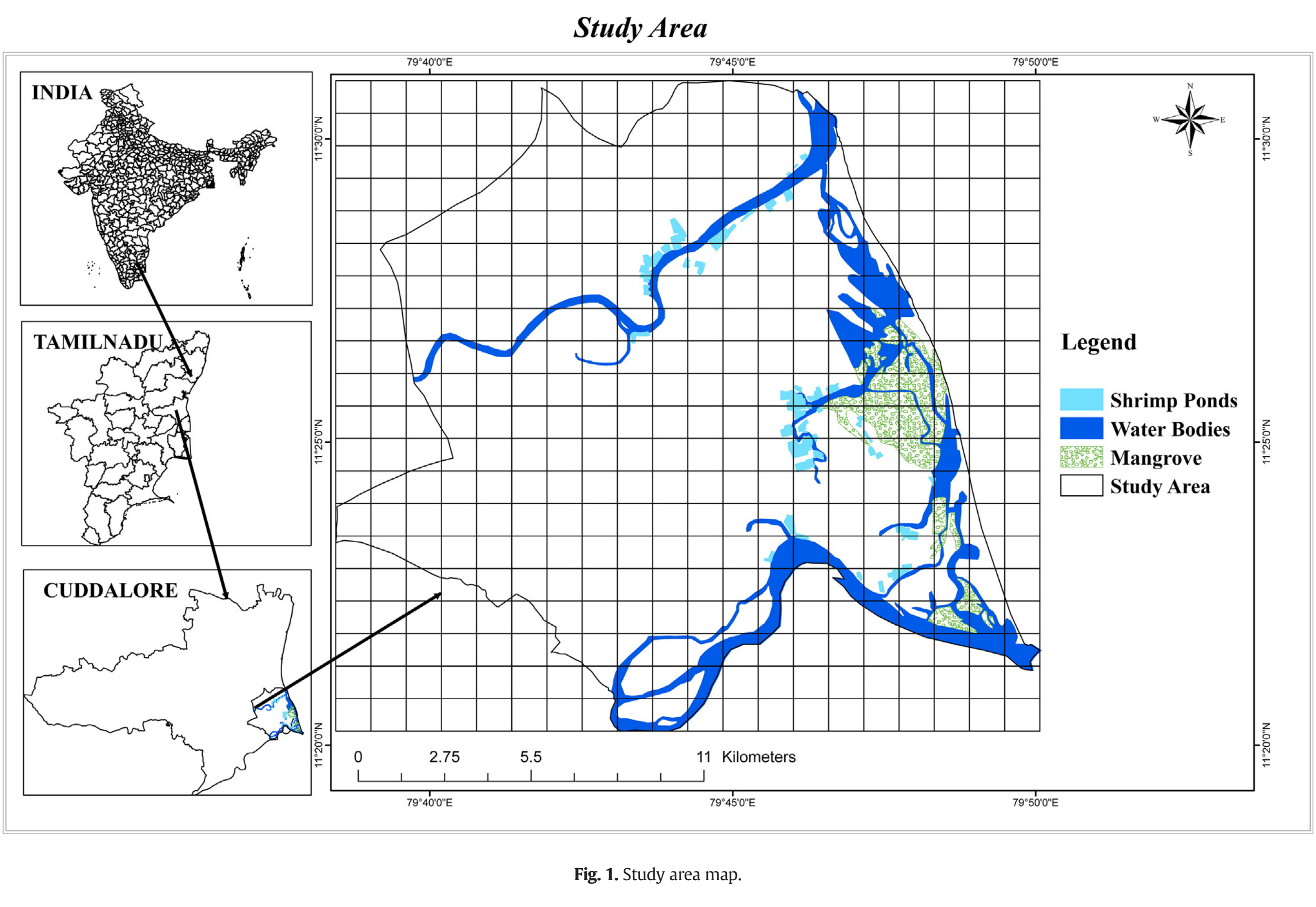


Fig. 1. Study area map.

recent estimates of MPEDA (2013). The total extent of the study area was about 246 km^2 and about 390 ha area was covered by shrimp farms during 2012 which were scattered as six clusters. Aquaculture has been developed in the area gradually with 3 to 4 ha during 1992 and expanded slowly with *Penaeus monodon* as the culture species. Since then, it has been an extensive system of farming with a stocking density of 6–10/m^2. Later on, disease problems and the environmental issues have threatened the very existence of culture but aquaculture thrived with the introduction of *Litopenaeus vannamei* in 2009. Presently, 90% of the farming is devoted to *L. vannamei* culture with the maximum stocking density of 60 no./m^2

The geology of the area consists of sedimentary formations, which include sandstone, clay, alluvium, and small patches of laterite soils of quaternary age. The study area has a hot tropical climate. The temperature gradually increases from the end of February to May (the hottest month) to between 33 °C and over 45 °C in the interior. In the coldest month (January), 25 °C is recorded in the coastal regions. Most of the rainfall occurs during the southwest monsoon (June–September). The normal rainfall for the period ranges from 1007–2362 mm. Average annual rainfall recorded in the area is 1558 mm year with a maximum contribution from the North East monsoon. The water level is observed at 1 to 7 m and 10 to 35 m below the ground level in the unconfined and confined aquifers respectively.

2.3. Selection of criteria influencing groundwater quality

For the selection of monitoring wells, all probable criteria which could have an influence the ground water quality due to aquaculture, have been considered based on previous studies. The main-criteria and its corresponding sub-criteria involved in groundwater monitoring site were selected with the help of 21 experts which included both aquaculture and groundwater experts. With their suggestions and field study, the following eight criteria have been selected viz., distance from shrimp farms, drainage pattern in the watershed, location of lineament, soil quality especially soil texture, land use, slope, geomorphology and lithology.

2.4. Data used

Since eight criteria have been selected, eight thematic maps were prepared for analysis purpose. The source data used for this study are given in Table 1.

- Using Landsat TM image of 2006 the geomorphology map was prepared and the classes/units were identified as per the guidelines laid down by Integrated Mission for Sustainable Development (NRSA, 1985) and Rajiv Gandhi National Drinking Water Mission (NRSA, 2007) and validated with limited field checks.
- The landuse map was also prepared using the same image and also checked with the image of 2012. The major landuse pattern includes shrimp farms, cropland, fallow land, forest area, forest plantations, barren area, land with and without scrubs following the guidelines of NRIS (National Resources Information System). Shrimp farming areas were identified by rectangular shape in light white colour and cropland including those for Rabi and Kharif crops were identified by light medium red tone, fine/medium texture varying in size, often rectangular in shape. The forest and forest plantation had a light reddish brown tone with white patches and fine to medium texture with irregular shape and varying size.
- The distance map was prepared using the buffer analysis tool of ARC GIS 10. The distance of the sample location from the shrimp farms was derived through calculations.
- The drainage map had been prepared from Toposheets at 1:50,000 scale by importing, registering and screen digitizing all the drainage units viz., the river, I order and II order streams.
- Lineament was captured from the image of Landsat TM (Thematic Mapper) & ETM (Enhanced Thematic Mapper Plus) for the years of 1977, 1980, 1991 and 2001 from USGS, USA through visual interpretation by comparing spatial variation in tone, colour, texture, association etc. The digitally processed colour composite provided sufficient information about lineaments.
- The soil texture map (2011) had been collected from Agricultural Engineering Department of the Government of Tamil Nadu.
- The slope map was prepared based on the Digital Elevation Model (DEM) which was derived using contour information from the SRTM. A Shuttle Radar Topography Mission (SRTM) 90 m Digital Elevation Model (DEM) of the study area downloaded from the website of Consortium for Spatial Information at: http://srtm.csi.cgiar.org/, was used as primary data for making hydrological features.
- The lithology map (2010) was collected from the Geological Survey of India.

Table 1
List of data sources used.

S.No.	Source	Acquisition date	Scale/path & row
1	Landsat TM (LT51420522006230BKT00)	18/8/2006	Path: 142 row: 52
2	Landsat ETM LE71420522012143PFS0**0**	22/05/2012	Path: 142 row: 52
3	Landsat TM & ETM (LM21530521977171TGS03)	20/06/1977	Path: 153 Row: 52
4	Shuttle Radar Topography Mission	2000	90 M
5	Survey of India — Toposheet	2003	1:50,000
6	Geological survey of India — Lithology map	2010	1:25,000
7	Agricultural Engineering Department, Tamil Nadu — Soil texture map	2011	1:25,000

2.5. Weighing of criteria in AHP method using GIS

The weights (or relative importance) of main-criteria and its corresponding sub-criteria under consideration were defined by pairwise comparison method (Saaty and Vargas, 2000). The overall goal of identification of sampling location began with consideration of eight main- criteria and its corresponding sub-criteria. The entire study area of 400 sq.km was divided into a grid of size of 1 km × 1 km and each grid was taken as the unit of comparison for all the eight thematic layers. A comparison matrix M (L × L) was built for each criteria in which L is the number of either main-criteria or its corresponding sub-criteria being compared. To fill the matrix M, Saaty (1987) proposed the use of a one to nine scale to express the preference of the expert and intensity of that preference for one element over the other (Table 2: Scale for pairwise comparison). According to this scale, the available values for the pairwise comparisons are members of the set (9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9). This matrix is a positive and reciprocal matrix, that is, $r_{ij} > 0$ and $r_{ji} = 1/r_{ij}$ for i,

Table 2
Scale for pair wise comparison.

Intensity of relative importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance
Reciprocals of above non-zero numbers	If the activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared to i.

Source: Saaty (2000).

j = 1, 2, …, L. The experts have to perform (L/2) (L-1) comparisons for a category of L evaluation criteria. To be specific, the identified criteria (either main or sub-criteria) were presented in pairs using all possible combinations. After identification of the possible pairs, 21 experts weighed the factors together during an informal meeting organised using a structured interview schedule in the straight ranking method. Suitable weights were assigned to each thematic feature after considering their characteristics depending upon their degree of influence. Experts agreed on the weight as a consensus was reached during the discussion as per the majority method Guzzo (1982). The final weightage value of each criterion was entered into the GIS environment and converted to grids by interpolation, maintaining the same geographic extent. The grids of each criteria were multiplied with the respective weights, calculated in the pair-wise comparison matrix and then evaluated by adding all the criteria so that $Grid_{result} = \Sigma\ (grid_i \times weight_i)$. Likewise, eight thematic maps were prepared. Similarly, for the main objective of identification of different priority zones, all these eight parameters were compared pairwise and their scores were integrated and analyzed using the weighted aggregation method in GIS environment using the ARCGIS 10, AHP module. Accordingly, the whole study area was classified into three distinct priority areas viz. high, moderate and low priority. Details of the methodology adopted, have been depicted clearly in the flowchart (Fig. 2).

2.6. Monitoring of groundwater quality and spatial distribution

Groundwater samples from identified sampling units as per the AHP method were collected bimonthly starting from October 2011 till June 2013 and analyzed for pH, EC, TDS, and Cl as per standard procedure (APHA, 2005). The average values were taken and their spatial distribution depicted through GIS software. The spatial distribution of groundwater quality would help in visualising the exact scenario and in ARCGIS 10, it is carried out using Inverse Distance Weighing (IDW) method which is a multivariate interpolation technique used to interpolate spatial data based on the concept of distance weighting. It can be used to estimate the unknown spatial data from the known data of sites that are adjacent to the unknown site (Goovaerts, 2000)

2.7. Statistical analysis

2.7.1. One way ANOVA

One way ANOVA was carried out to determine the significance among ground water quality variables in the three priority classification.

2.7.2. Multivariate statistical analysis — hierarchical cluster analysis

Cluster analysis is a method for placing objects into more or less homogeneous groups so that the relation between the groups is revealed. A number of studies used this technique to successfully classify groundwater samples (Meng and Maynard, 2001; Williams, 1982). Hierarchical clustering joins similar observations and then successively connects the next similar observations to these. First the matrix of similarities between all pairs of observations is computed. The pairs having the highest similarities are then merged and the matrix is recomputed. Classification of samples according to their parameters is known as Q-mode classifications. In the present study, Q-mode hierarchical cluster analysis (HCA) was used to classify the samples into distinct hydrochemical groups. The Ward's linkage method (Ward, 1963) was used in this analysis. A classification scheme using Euclidean distance for similarity measurement, together with Ward's method for linkage, produces the most distinctive groups where each member within the group is more similar to

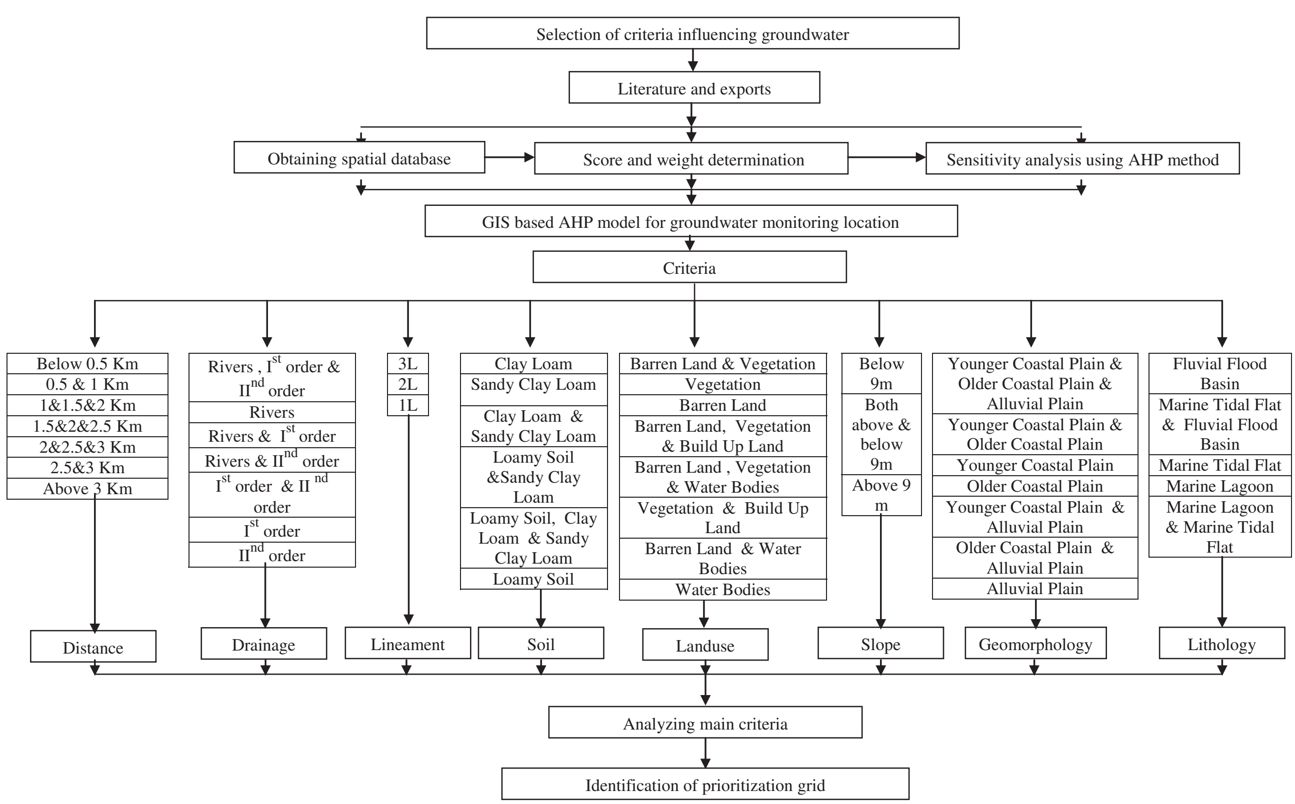


Fig. 2. Methodology flow chart of GIS based AHP model.

its fellow members than to any member outside the group (Guler et al., 2002).

3. Results and discussion

3.1. Thematic maps

3.1.1. Distance from shrimp farms

Out of the eight criteria, distance from shrimp farms was considered as the most important criterion for selecting the monitoring location to ascertain whether the groundwater is affected by the presence of shrimp farms or not. The distance was separated into 0.5 km, 1 km, 1.5 km, 2 km, 2.5 km and 3 km buffer from shrimp farms (Fig. 3a). From the figure, it is clearly evident that shrimp farming activities were concentrated in two locations, the first one near Vellar River and the second scattered in the watershed. In total, six clusters of shrimp farms were observed with a total area of 390 ha under shrimp farming. There were 101.86 ha with 62 ponds, 38.76 ha with 23 ponds, 100.98 ha with 46 ponds, 68.90 ha with 60 ponds, 89.50 ha with 140 ponds and 8.73 ha with 20 ponds in the six clusters respectively. Sub-criteria for distance from shrimp farming were made based on nearness of each individual grid to the shrimp farms. The grid in which 0.5 km buffer distance falls was considered the more influencing grid followed by 0.5 &1 km buffer grid, 0.5&1&1.5 km buffer grid, 1&1.5 & 2 km, 1.5&2& 2.5 km, 2&2.5&3 km, 2.5&3 km and >3 km grids respectively making the subcriteria for this parameter eight. The consistency ratio (0.095)

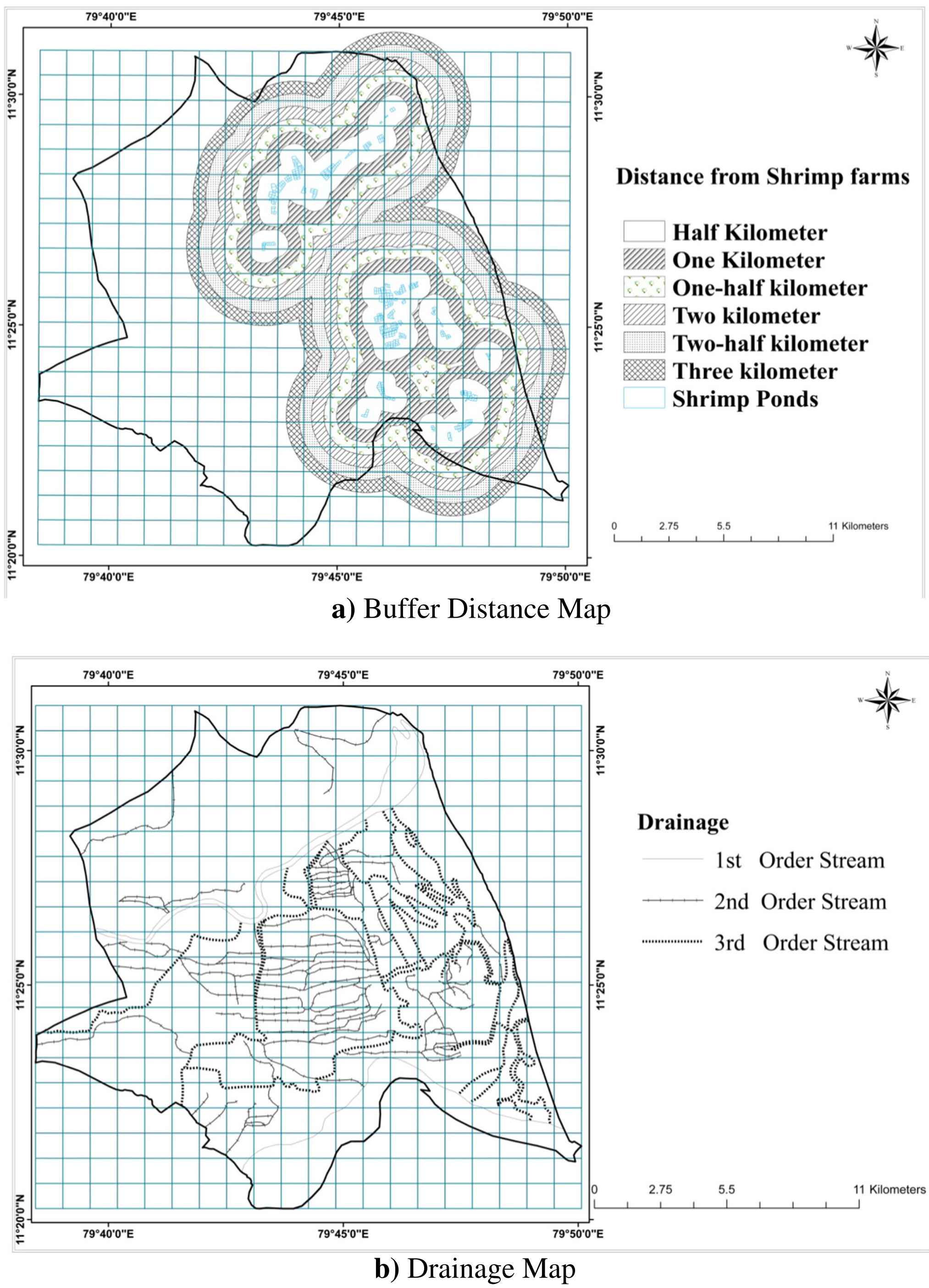
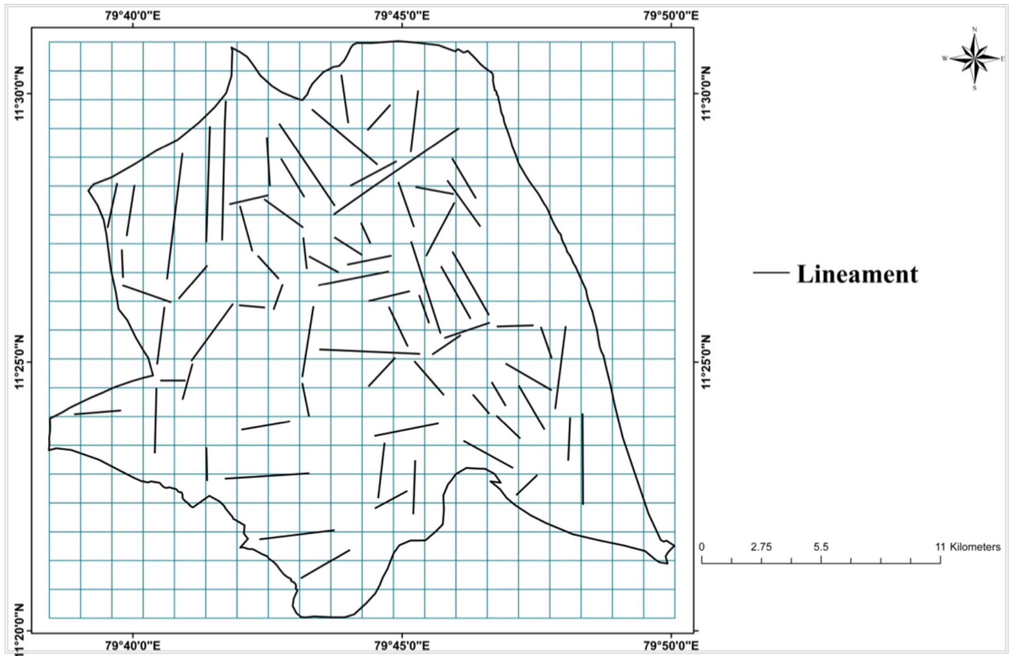
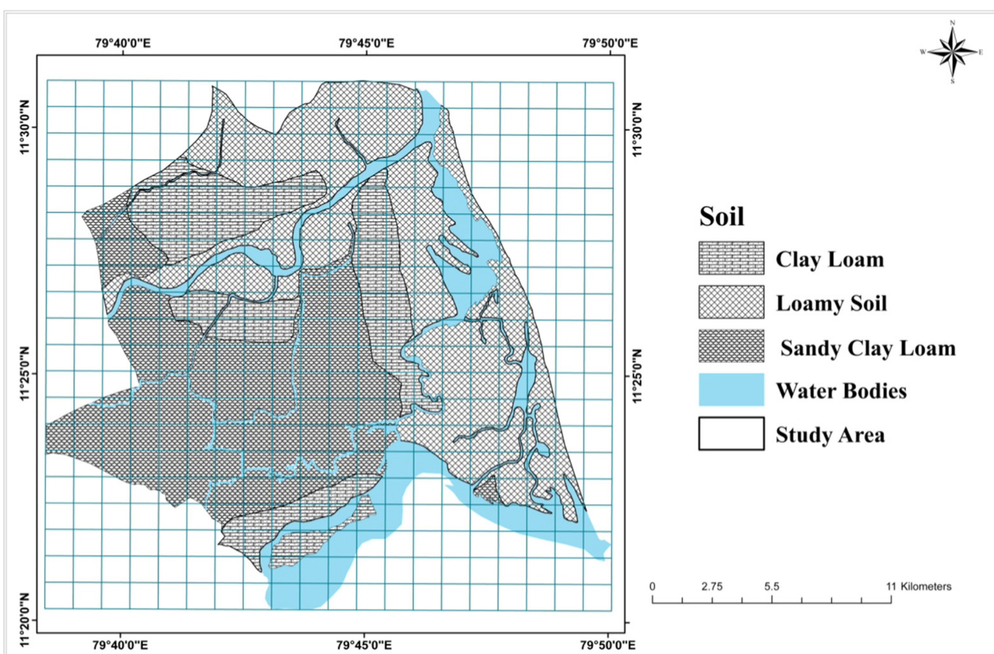


Fig. 3. Thematic layers.



c) Lineament Map



d) Soil Texture Map

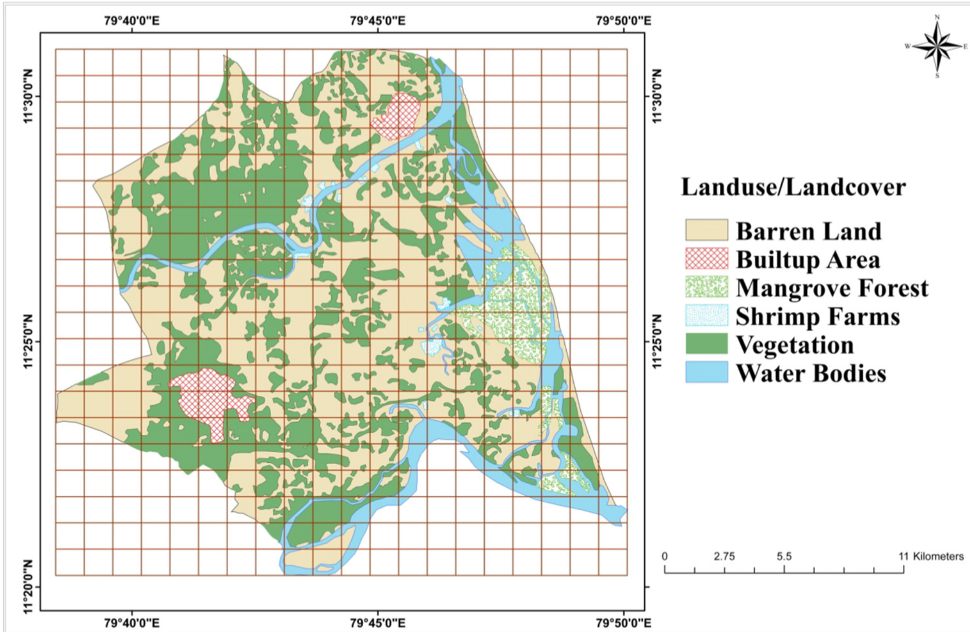
Fig. 3 (*continued*).

is lesser than 0.1 indicating a reasonable level of consistency in the weighing procedure. Criterion weightage for distance from shrimp farms are 0.257, 0.212, 0.169, 0.102, 0.063, 0.041, 0.030 and 0.014 for 0.5 km, 0.5&1 km, 0.5&1&1.5 km, 1&1.5 & 2 km, 1.5&2& 2.5 km, 2&2.5&3 km, 2.5&3 km and above 3 km grids respectively as given in Table 3.

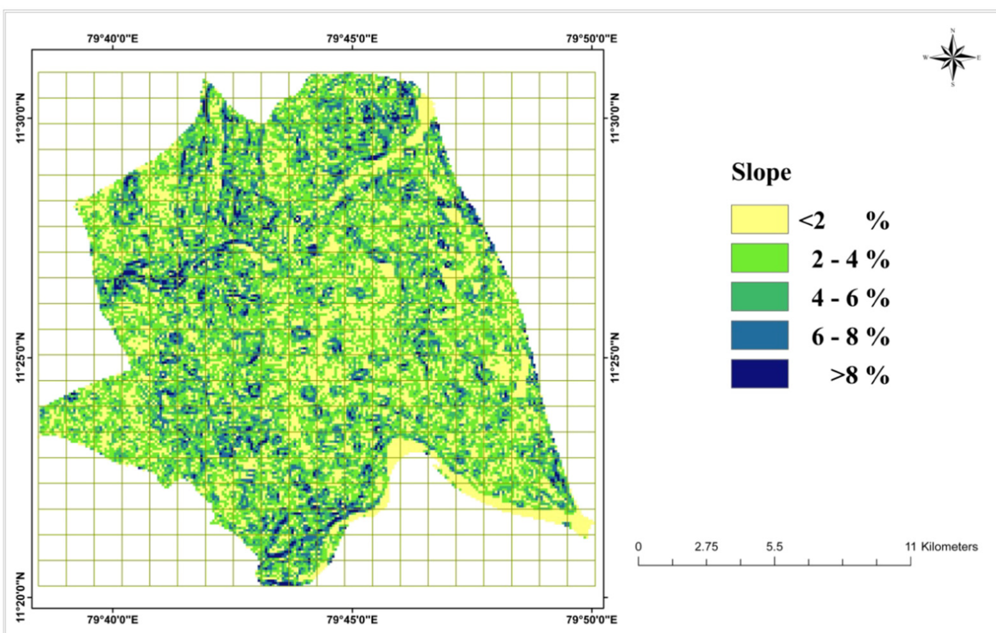
$$\begin{aligned}\text{Distance from shrimp farms grid} = {} & \text{Grid}_{0.5\text{ km}} * 0.257 + \text{Grid}_{0.5\&1\text{ km}} * 0.212 + \\ & \text{Grid}_{0.5\&1\&1.5\text{ km}} * 0.169 + \text{Grid}_{1\&1.5\&2\text{ km}} * 0.102 + \\ & \text{Grid}_{1.5\&2\&\ 2.5\text{ km}} * 0.063 + \text{Grid}_{2\&2.5\&3\text{km}} * 0.041 + \\ & \text{Grid}_{2.5\&3\text{km}} * 0.030 + \text{Grid}_{\text{above 3km}} * 0.014\end{aligned} \quad (3.1.1)$$

3.1.2. Drainage

The second important factor considered was the drainage, as it plays an important role in the process of recharging the subsurface layers and influences the groundwater quality (Krishnamurthy et al., 2000). The Survey of India (SOI) toposheet was used and surface drainage map was prepared (Fig. 3b). It could be observed that the study area was covered by parallel drainage system with Vellar river in northern side and Coleroon river in southern side and its tributaries distributing throughout the study area and hence I order and II order streams along with the river were considered as the drainage features. Rivers are the prominent drainage unit in the watershed followed by Ist order stream and then 2nd order stream. In other words, rivers are wide and deep, the possibility



e) Landuse Map



f) Slope Map

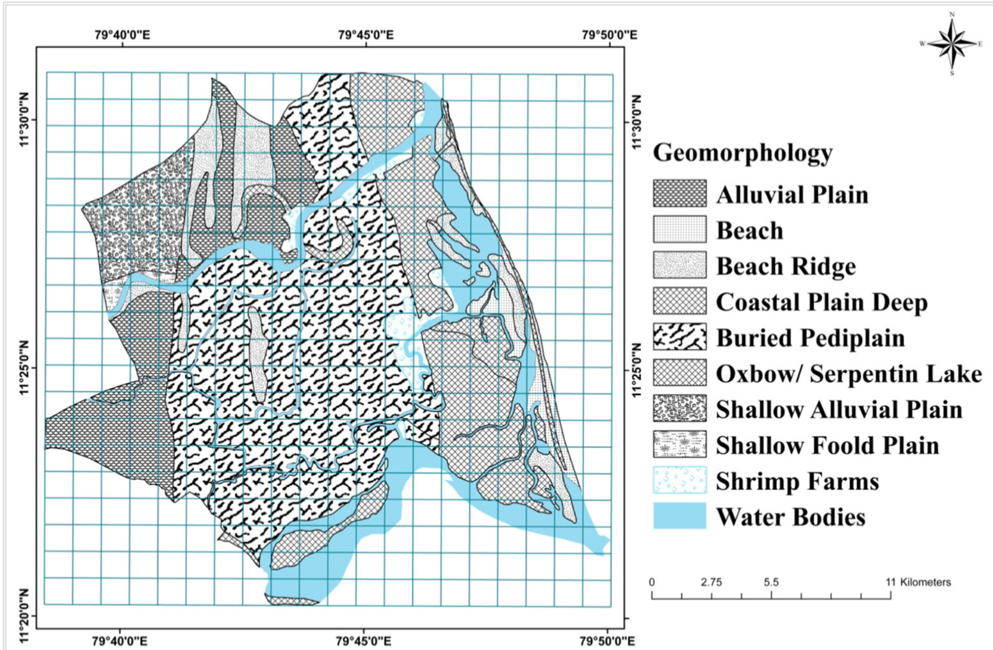
Fig. 3 (*continued*).

of recharge being high. The grid in which all the three drainage features was observed viz. River & Ist & IInd was considered as the most influential grid followed by River, River & Ist, River & IInd, Ist & IInd, Ist and IInd, respectively and accordingly all combinations were considered for pairwise comparison, Accordingly this parameter has seven sub-criteria. The weightages obtained were 0.306, 0.249, 0.194, 0.133, 0.060, 0.033 and 0.025 for River & Ist & IInd, River, River & Ist, River & IInd, Ist & IInd, Ist and IInd respectively. Thus the subcriteria were seven and the consistency ratio (0.038) < 0.1 indicating perfect comparison (Table 3).

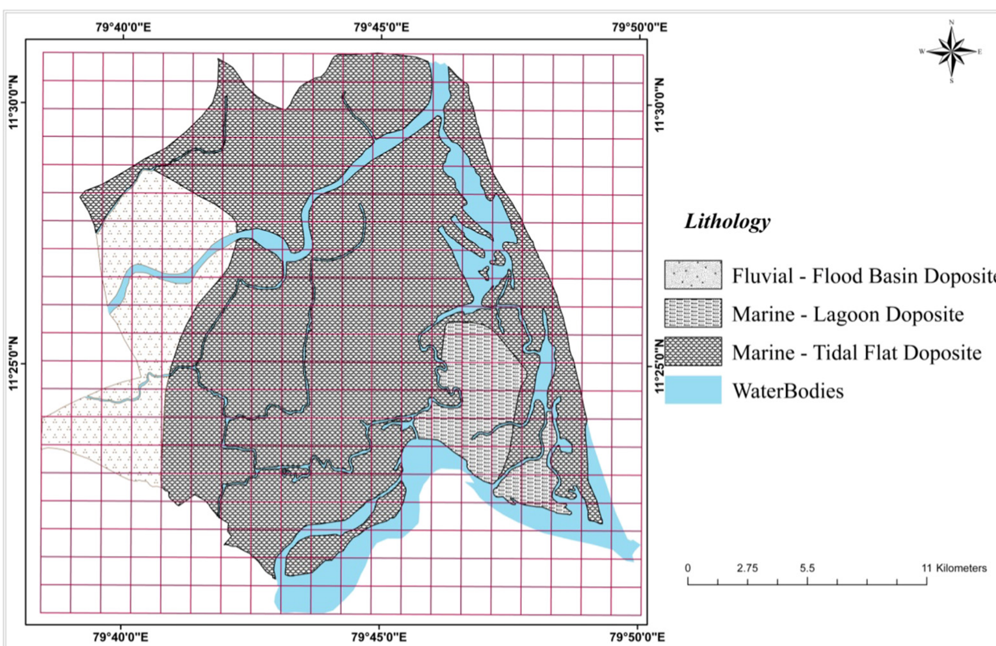
$$\text{Drainage grid} = \text{Grid}_{\text{River \& Ist \& IInd}} * 0.306 + \text{Grid}_{\text{River}} * 0.249 + \text{Grid}_{\text{River \& Ist}} * 0.194 + \text{Grid}_{\text{River \& IInd}} * 0.133 + \text{Grid}_{\text{Ist \& IInd}} * 0.060 + \text{Grid}_{\text{Ist}} * 0.033 + \text{Grid}_{\text{IInd}} * 0.025 \quad (3.1.2)$$

3.1.3. Lineament

The third factor considered was lineament. Lineaments are linear features developed by the tectonic activity; reflect a general surface manifestation of underground fractures, with inherent characteristics of porosity and permeability of the underlying materials (Subba Rao, 2006). Lineaments provide the pathways for groundwater movement and are hydro-geologically very important (Sankar, 2002). The lineament map (Fig. 3c) shows that the lineaments are more on the north-eastern side and close to the coast of the study area. Moreover, the directions of lineament are towards N–S, NW–SE, NE–SW and E–W as clearly depicted in the map. The grid having more than three lineaments was considered having more influence, the weightage given being 0.735 followed by two lineaments in a grid (weightage: 0.199) and thereafter for a lone lineament (weightage: 0.065). (Table 3) Thus the subcriteria



g) Geomorphology Map



h) Lithology Map

Fig. 3 (*continued*).

were three and the consistency ratio was 0.070 < 0.1. indicating perfect comparison.

$$\text{Lineament grid} = \text{Grid}_{3L} * 0.735 + \text{Grid}_{2L} * 0.199 + \text{Grid}_{1L} * 0.065 \quad (3.1.3)$$

3.1.4. Soil

Soil characteristics play an important role in the infiltration of water to the groundwater and hence are considered as the fourth important factor influencing groundwater. The rate of infiltration largely depends on the grain size of soil. The initial infiltration and transmission of surface water into an aquifer system is a function of soil type and its texture (Anbazhagan et al., 2005). In the study area, the soil texture varied from sandy clay loam (SCL), clay loam (CL) and loamy soil (LS) (Fig. 3d) with sandy soil enhancing recharge to the groundwater and clay inhibiting the water movement. A perusal of the figure reveals that near the coast, loamy sand is dominant whereas sandy clay loam was dominant in the whole watershed. Clay loam was found only in small patches. Criterion weightages for the seven subcriteria were 0.331, 0.239, 0.186, 0.113, 0.075, 0.034 and 0.022 for CL, SCL, CL&SCL, LS&CL, LS&SCL, SC&CL&CLS and LS respectively. The calculation value of l_{max} is

Table 3
Subcriteria weights by paiwise comparison

Criteria	Sub-criteria	Weight	Lamda	Consistency index	Random index	Consistency ratio
Distance	0.5 km	0.257	8.932 ≥ 8	0.133	1.4 for L = 8	0.095
	0.5–1 km	0.212				
	0.5, 1.0 & 1.5 km	0.169				
	1.0, 1.5 & 2 km	0.102				
	1.5,2.0 & 2.5 km	0.063				
	2.0, 2.5 & 3.0 km	0.041				
	2.5 & 3.0 km	0.030				
	above 3.0 km	0.014				
Drainage	River Ist + IInd	0.306	7.309 ≥ 7	0.051	1.35 for L = 7	0.038
	River	0.249				
	River & Ist	0.194				
	River & IInd	0.133				
	Ist + IInd	0.060				
	Ist	0.033				
	IInd	0.025				
Lineament	3 L	0.7352	3.041 ≥ 3	0.020	0.52 for L = 3	0.039
	2 L	0.1994				
	1 L	0.0654				
Soil texture	CL	0.331	7.271 ≥ 7	0.045	1.35 for L = 7	0.034
	SCL	0.239				
	CL & SCL	0.186				
	LS & CL	0.113				
	LS & SCL	0.075				
	SC, CL & CLS	0.034				
	LS	0.022				
Landuse	BL & V	0.278	8.574 ≥ 8	0.082	1.4 for L = 8	0.059
	BL	0.246				
	V	0.178				
	BL,V & BUL	0.113				
	BL,V & WB	0.079				
	V & BUL	0.058				
	BL & WB	0.030				
	WB	0.018				
Slope	Below 9	0.7352	3.041 ≥ 3	0.020	0.52 for L = 3	0.039
	Both Below And Above 5	0.1994				
	Above 9	0.0654				
Geomorphology	YCP, OCP & AP	0.359	7.608 ≥ 7	0.101	1.35 for L = 7	0.075
	YCP & OCP	0.240				
	YCP	0.145				
	OCP	0.110				
	YCP & AP	0.070				
	OCP & AP	0.051				
	AP	0.025				
Lithology	FFB	0.425	5.434 ≥ 5	0.109	1.11 for L = 5	0.098
	MTF & FFB	0.305				
	MTF	0.172				
	ML	0.068				
	ML & MTF	0.030				

(L: lineament) (soil texture = CL: clay loam, SCL: sandy clay loam, LS: loamy sand) (landuse = BL: barren land, V: vegetation, W: water bodies, BUL: builtup land) (geomorphology = YCP: younger coastal plain, OCP: older coastal plain, AP: alluvial plain) (lithology = FFB: fluvial flood basin, MTF: marine tidal flat, ML: marine lagoon).

7.271 ≥ 7 and degree of inconsistency value is 0.271. The CI value is 0.045 and value of RI is 1.35 (L = 7). The consistency ratio is 0.034 < 0.1 the ratio indicates the comparison was perfect (Table 3).

$$\text{Soil grid} = \text{Grid}_{CL} * 0.331 + \text{Grid}_{SCL} * 0.239 + \text{Grid}_{CL\&SCL} * 0.186 + \text{Grid}_{LS\&CL} * 0.113 + \text{Grid}_{LS\&CL} * 0.075 + \text{Grid}_{SC\&CL\&CLS} * 0.034 + \text{Grid}_{LS} * 0.022 \quad (3.1.4)$$

3.1.5. Land use

The landuse influences the behaviour of water flow on terrain surface and the recharge process and was considered as the fifth parameter. The landuse map was prepared by visually identifying the texture pattern, association and the spectral signatures of the different surface features on the Landsat TM. The major landuse pattern in the study area (Fig. 3e) includes vegetation (V), barren land (BL), builtup land (BUL) and water bodies (WB) in addition to shrimp ponds and mangrove forest. The total geographical area of the study was 246 km^2. The net area under vegetation was 62 km^2, which occupies 25.38% of the total area. Vegetation includes land for growing crops and has been identified by light medium red tone, fine/medium texture varying in size often rectangular in shape. The mangrove forest was 23 km^2 which is 9.16% and the land for purposes other than agriculture such as building, pathways and roads are classified as builtup land which cover 19 km^2, which occupies 7.73%. Land which cannot be brought under cultivation unless at a high cost is classified as barren and occupies an area of 97 km^2 representing 39.44%. Barren land is recognized by grey tone texture, water bodies in blue and builtup land in rectangular or irregular shape. In total, a geographical area of only 6 km^2 comes under shrimp farming constituting 2.44%. The shrimp farming system in the study area is extensive to semi-intensive only and has been initiated in Killai area of the watershed in early nineties which later expanded slowly. The watershed is in a rainfed area and agriculture was carried out based on the rainfall availability. Aquaculture is a financially lucrative venture, yielding profits ranging from 50 to 80% rate of return per annum, much beyond the returns that can be expected from any other activity in this coastal area. Unemployed coastal folk and agriculturists are offered jobs in aqua farms for wages that far exceed those in other farming activities in the study area and as a new activity, it evoked curiosity and interest among the farmers. Thus, in the study area, till date, aquaculture has expanded to 400 ha. In addition to aquaculture, agriculture is also widely practised in the watershed. The land use map clearly reveals the activities in the watershed and only 2% of the study area comprises aquaculture. In addition to aquaculture, agriculture is the dominant activity in the watershed. Wherever agriculture is not feasible, aquaculture was found to be profitable since the investment for initiation of aquaculture is higher compared to agriculture. The weightage for the landuse pattern was 0.278, 0.246, 0.178, 0.113, 0.079, 0.058, 0.030 and 0.018 for BL&V, V, BL, BL&V&BUL, BL&V&WB, V&BUL, BL&WB and WB respectively. The calculation value of l_{max} is 8.574 ≥ 8 and degree of inconsistency value of RI (1.4 for L = 8). The consistency ratio is 0.059 < 0.1 which indicates a reasonable level (Table 3).

$$\text{Landuse grid} = \text{Grid}_{BL\&V} * 0.278 + \text{Grid}_{V} * 0.246 + \text{Grid}_{BL} * 0.178 + \text{Grid}_{BL\&V\&BUL} * 0.113 + \text{Grid}_{BL,V\&WB} * 0.079 + \text{Grid}_{V\&BUL} * 0.058 + \text{Grid}_{BL\&WB} * 0.030 + \text{Grid}_{WB} * 0.018 \quad (3.1.5)$$

3.1.6. Slope

Digital Elevation Model (DEM) is derived using contour information from the SRTM for estimation of slope in degrees as it is the sixth parameter. DEM is a digital representation of continuous variation of topographic surface with the elevation or ground height above any geodetic datum. Generation and application of DEM for hydrological studies have also been widely published (Ludwig and Schneider, 2006; Walker and Willgoose, 1999). The slope analysis was carried out in the watershed and is divided into three subcriteria according to slope value (Fig. 3f). Criterion weightages are 0.735, 0.199 and 0.065 for three sub-criteria of below 9 m, both above& below 9 m and above 9 m in the grid. More weightage is given for the lower portion of the 9 m grid. The calculation value of l_{max} is 3.072 ≥ 3 and degree of inconsistency ratio is 0.070 < 0.1, the ratio indicating a reasonable level (Table 3).

$$\text{Slope grid} = \text{Grid}_{\text{Below 9m}} * 0.735 + \text{Grid}_{\text{Both above \& below 9m}} * 0.199 + \text{Grid}_{\text{Above 9m}} * 0.065 \quad (3.1.6)$$

3.1.7. Geomorphology

The seventh parameter geomorphology, exercises a significant control over the groundwater region. Significant geomorphic units were identified based on their image characteristics that include coastal plain, flood plain and alluvial plain (NRSA, 2000). The synoptic view of satellite data provide a wealth of information about configuration of various landform characteristics based on varied spectral signatures. Geomorphologic studies coupled with hydro geological and structure/lineaments have been proven to be very effective for locating groundwater movements (Bahuguna et al., 2003). The study area (Fig. 3g) consisted of younger coastal plain (YCP), older coastal plain (OCP) and alluvial plain (AP) and for this parameter, there were seven sub-criteria. For CI calculation, lmax (7.608) is always ≥ the number of evaluation criteria under consideration (7) for positive, reciprocal matrix and the degree of inconsistency value was computed as 0.608. The CI value was 0.101 and RI was 0.52 (L = 3). The consistency ratio was 0.075 < 0.1, the ratio indicating a reasonable level. More weightage is given for YCP&COP&AP grid and weightage for each criterion were 0.359, 0.240, 0.145, 0.110, 0.070, 0.051 and 0.025 for YCP&COP&AP, YCP&COP, YCP, COP, YCP&AP, COP&AP and AP grids respectively (Table 3).

$$\text{Geomorphology grid} = \text{Grid}_{YCP\&COP\&AP} * 0.359 + \text{Grid}_{YCP\&COP} * 0.240 + \text{Grid}_{YCP} * 0.145 + \text{Grid}_{COP} * 0.110 + \text{Grid}_{YCP\&AP} * 0.070 + \text{Grid}_{COP\&AP} * 0.051 + \text{Grid}_{AP} * 0.025 \quad (3.1.7)$$

3.1.8. Lithology

The final criterion of consideration was lithology, as it is a major water controlling factor represented by the geographic distribution of different rock formations. Occurrence and distributions of aquifers largely depend on local lithology and has been ascertained by the scientific community (McArthur et al., 2001; Nickson et al., 2000; Zheng et al., 2004). The study area was (Fig. 3h) mainly surrounded by sedimentary formation and it consists of fluvial flood basin (FFB), marine tidal flat (MTF) and marine lagoon (ML). Sub-criteria for lithology were five and more weightage is given for fluvial flood basin grid. The calculation value of RI is 0.52 (L = 3). The consistency ratio was 0.070 < 0.1 the ratio indicating the comparison was perfectly consistent. Criterion weightage were 0.425, 0.305, 0.172, 0.068 and 0.030 for FFB, MTF & FFB, MTF, ML and ML & MTF grids respectively (Table 3).

$$\textit{Lithology grid} = \text{Grid}_{FFB} * 0.425 + \text{Grid}_{MTF\ \&\ FFB} * 0.305 + \text{Grid}_{MTF} * 0.172 + \text{Grid}_{ML} * 0.068 + \text{Grid}_{ML\ \&\ MTF} * 0.030 \quad (3.1.8)$$

The sub-criteria weightage using pair-wise comparison method was perfect for all the eight thematic layers.

3.2. Main criteria — selection of sampling grids

The main criteria of selecting the grids that could be impacted more by aquaculture activity was the main objective of this study. Accordingly, for selecting the sampling locations the pairwise comparison matrix and the relative importance of each criterion derived are shown (Table 4). The criterion weights obtained were 0.303, 0.223, 0.131, 0.107, 0.095, 0.067, 0.047 and 0.028 for distance from shrimp farms, drainage, lineament, soil, landuse, slope, geomorphology and lithology respectively. The consistency ratio 0.086 < 0.1 indicating a reasonable level

$$\text{Grid influenced by aquaculture} = \text{Grid}_{Distance} * 0.303 + \text{Grid}_{Drainage} * 0.223 + \text{Grid}_{Lineament} * 0.131 + \text{Grid}_{Soil} * 0.107 + \text{Grid}_{Landuse} * 0.095 + \text{Grid}_{Slope} * 0.067 + \text{Grid}_{Geomorphology} * 0.047 + \text{Grid}_{Lithology} * 0.028. \quad (3.2)$$

The analysis shows that the total study area covered about 218 grids in which only 67 grids could be influenced by aquaculture. To be precise, only 11 grids were under high priority, 42 grids were under moderate priority and 14 grids were under low priority. The presences of wells in these grids were ascertained by field survey and accordingly 29 sampling well locations were identified for sampling. There were ten wells from high priority grids, thirteen wells from moderate and six wells from low priority grids (Fig. 4).

This methodology of combining the AHP with GIS for selecting appropriate sampling locations appears realistic for assessing the impact of shrimp farming on coastal groundwater resources. Sampling a site for a comprehensive and realistic impact assessment involves integration of information from various sources. There are many criteria, both qualitative and quantitative, upon which the representative wells were selected and is therefore, a multiple criteria decision-making (MCDM) process. The attributes of different criteria are to be derived from both spatial and non-spatial information under diverse conditions. Geographic information systems (GIS) are best suited for handling a wide range of data from different sources for a quick and cost-effective assessment. This study therefore presents a spatial modelling procedure for a fast and realistic impact assessment of shrimp farming on groundwater using available biophysical information in a GIS environment. The modelling exercise revealed that the spatial model produced appropriate sampling locations which could be applied in similar scenarios to assess the impact of shrimp farming on other coastal watersheds. Therefore, this method could be invaluable to policy makers involved in regional eco-environmental quality evaluation,

Table 4
Pair-wise matrix for selection of sampling grid consistency ratio (C.R): 0.086.

Criteria	Distance	Drainage	Lineament	Soil	Landuse	Slope	Geomorphology	Lithology	Weight
Distance	1	2	2	3	5	5	7	8	0.303
Drainage	1/2	1	3	5	3	3	3	5	0.223
Lineament	1/2	1/3	1	3	2	2	2	4	0.131
Soil	1/3	1/5	1/3	1	3	3	2	4	0.107
Landuse	1/5	1/3	1/2	1/3	1	4	2	5	0.095
Slope	1/5	1/3	1/2	1/3	1/4	1	3	3	0.067
Morphology	1/7	1/3	1/2	1/2	1/2	1/3	1	2	0.047
Lithology	1/8	1/5	1/4	1/4	1/5	1/3	1/2	1	0.028

especially taking the mini/microwatershed as the basic evaluation unit. This concept of micro/miniwatershed based impact assessment is appropriate because it could allow decision makers to clearly understand the current status of the integrated quality of their regional eco-environment with all the stake holders who are using the resources like agriculture, settlement, salt pan, forestry, fisheries and tourism etc. It also would help administrators to resolve problems relating to regional eco-environmental improvement in a single stroke as this is spatial and gives a synoptic view and status to prioritize the action plan for the watershed.

3.3. Groundwater quality and its spatial distribution

The average pH, EC TDS and the chloride ion concentration in all the sampling wells as per the priority class have been presented in Table 5. It is observed that the pH ranged from 7.82 to 8.32. It is seen that in locations where the aquaculture influence would be of high priority, the pH ranged from 7.82 to 8.12 with a mean value of 7.96. In moderate priority locations, it ranged from 7.93 to 8.32 and the sample collected from the low priority location ranged from 7.85–8.08. This indicates that there is not much difference between the priority areas and the pH values are well within the WHO (1993) and ISI (1983) standards. The pH range observed indicates the alkaline nature of the groundwater. The coastal aquifer is alkaline in general, as earlier reported by Chidambaraam et al. (2010). The spatial distribution map (Fig. 5a) clearly shows that the shrimp farm location and pH values are independent. The results also revealed that TDS fluctuated widely from 320 to 3120 ppm. It should also be noted that the maximum and minimum values were observed in moderate priority. The TDS ranged from 581–2520 ppm (high priority) 320–3120 ppm (moderate priority) and 660–1808 ppm (low priority area) respectively. The results reveal that the groundwater quality is not as per the priority classes. Electrical conductivity (EC) of water is considered to be an indication of the total dissolved salt content. The EC ranged from 890 μS/cm to 3880 μS/cm (high priority) and from 480 μS/cm to 4810 μS/cm (moderate priority). Sample location for low priority ranges from 1015 μS/cm to 2780 μS/cm. The spatial distribution map of TDS (Fig. 5a) and the chloride ion (Fig. 5b) clearly reveals that higher values and shrimp farming location were independent. The results demonstrate that chloride ranged from 138.45 to 1158.75 mg/l, 42.60 to 1448.40 mg/l and 127.80 to 745.50 mg/l for high, moderate and low priority thereby indicating no specific trend as per the priority class. Aiuppa et al. (2000) reported that water with high concentration of chloride could be of sea water origin. The statistical analysis using one way ANOVA reveals that groundwater quality is not significantly different as per the priority class and it is more or less similar. The chloride ion occurs in natural waters in fairly low concentrations, usually less than 100 mg/l, unless the water is brackish or saline (Fetter, 1999). The value of chloride ranges between 42.66 and 1156.31 mg/l. The spatial distribution of chloride concentration in the present study clearly shows increased concentration in some pockets which is independent of shrimp farming activity. From these results, it is quite evident that the coefficient of variation between

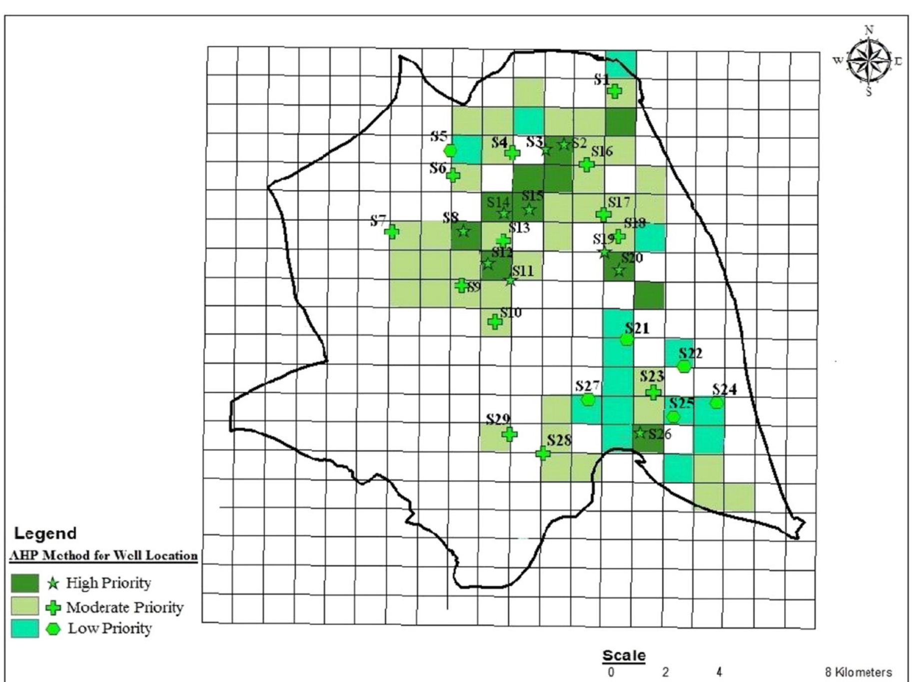


Fig. 4. Sampling location identified using GIS based AHP.

Table 5
Groundwater quality in the study area.

Parameters	Groundwater quality in the study area																WHO (1993)	
	Total study area				High priority				Moderate priority				Low priority				Maximum accept limit (mg/l)	maximum allowable limit (mg/l)
	Min	Max	Avg	Std	Min	Max	Avg	Std	Min	Max	Avg	Std	Min	Max	Avg	Std		
pH	7.67	8.33	8.02	0.17	7.74	8.32	8.01[a]	0.19	7.80	8.33	8.07[a]	0.15	7.67	8.08	7.91[a]	0.15	6.5	8.5
EC (μs/cm)	418.11	6792.00	2305.25	1476.92	899.80	6792.00	2220.71[a]	1696.49	418.11	4841.00	1907.26[a]	1151.55	923.70	5811.70	2875.17[a]	495.06	-	-
TDS (mg/l)	247.7	4395.6	1501.66	1000.87	576.8	4395.6	1413.03[a]	1114.4	247.7	3242.6	1249.93	774.86	613.75	1656.17	1091.95[a]	1755.81	500	1500
Cl (mg/l)	118.72	1758.62	570.86	162.14	264.21	1596.30	589.60[a]	383.66	118.72	974.56	408.49[a]	235.52	268.91	1758.62	768.80[a]	545.28	200	600

[a] Same superscript indicates that there is no significant ($p < 0.05$) difference among different priorities.

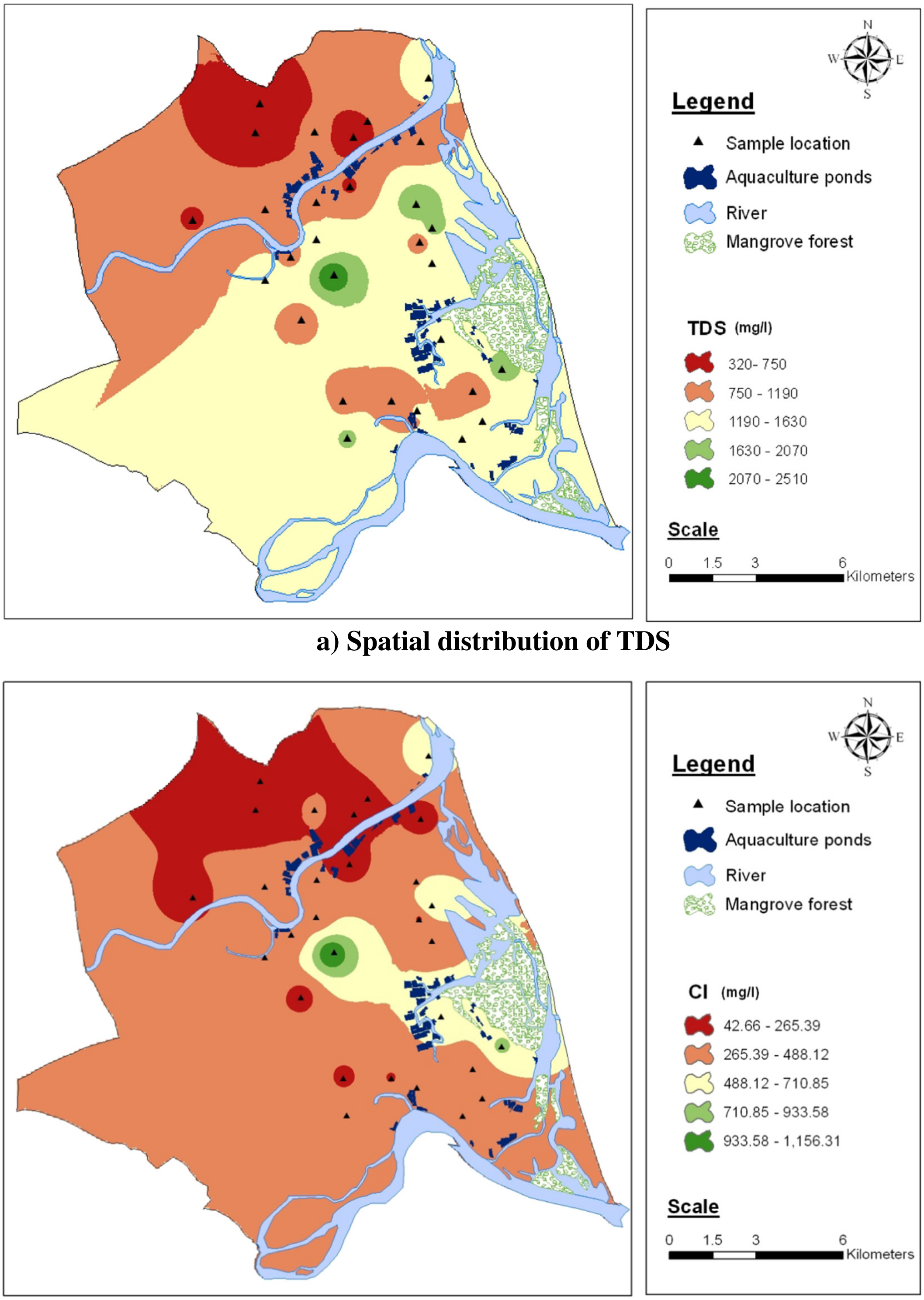
the values is greater indicating multiple sources of influence on the groundwater quality. There is a wide variation in lithology, hydrogeology and hydrochemistry of the coastal aquifers. Similar observations were reported by Mondal et.al (2012) and Chidambaraam et al. (2010) in their studies in the coastal aquifers of Pondichery and Cuddalore, respectively. The coastal aquifer by nature is influenced by multiple sources. If shrimp farming alone is the sole reason for groundwater quality changes, it would have been as per the priority class which is not the case here. Localized patches of saline water are encountered in the shallow aquifer regions in the study area which is mainly due to the mineralization as reported by Central Groundwater Board (2009), Government of India. The report also reveals that the groundwater quality is slightly saline due to the natural hydrogeochemical conditions existing at this place and there is the presence of brine in the deep aquifer near Porto Novo. This emphasizes the fact that aquaculture has been initiated in in situ salinity areas and there is no palpable influence of shrimp farming on groundwater quality.

3.4. Hierarchical cluster analysis

The results of the hierarchical cluster analysis are depicted in the form of a dendrogram (Fig. 6). The Ward's method was used and the Euclidean distance was selected as the measure of similarity. The Euclidean distance is represented on the horizontal axis of the dendogram. It gives the similarity between two clusters and it is observed that each group represents different hydrochemical environments (Khan, 2008). From the figure, it is evident that there were two major clusters. Cluster I was subdivided into two clusters (Ia & Ib) and cluster Ia was again subdivided into two more clusters which include 13 sampling wells such as S23, S27, S16, S4, S19, S10, S29, S8, S15, S7, S3, S5 and S6 with 45% and it would have a preeminent water quality as it had the lowest concentrations of EC, TDS, pH and Cl. These sites are mainly dominated by agriculture activity and are shaped into one group. The other group is dominated by agriculture and aquaculture activity. Samples belonging to cluster Ib is composed of the wells S20, S24, S9, S13, S26, S11, S1, S18, S22, S2, S21, S28, and S17 and concerns 45% have judicious value of EC, TDS, pH and Cl. In this S20, S24, S9, S13, S26, S11 and S1 are located as one group of cluster and these sites are essentially dominated by aquaculture activity. Sample locations S18, S22, S2, S21, S28, and S17 formed near the sea and creek were grouped together as a separate group of cluster in cluster Ib and it has comparatively slightly elevated values of EC, TDS, pH and Cl. Cluster II is represented by the wells S25, S14, and S12 and occupies 10% of the water samples. It has the highest concentration of EC, TDS, pH and Cl. These sites were predominantly located in the vicinity of creek. Hierarchical clustering joins the most similar observations and then successfully the next most similar observation (Chen et al., 2007). It is clearly evident that the clusters are not formed as per the priority classification and it was grouped together by influence of salinity values in groundwater.

In early days, aquaculture was synonymous to *P. monodon*. It is an extensive system of farming with the stocking density of 6–10/m^2. Later, disease and environmental issues hampered the growth of aquaculture during 1995 to 1997. It may not be an exaggeration to opine that the very existence of shrimp culture has been threatened with the environmental issue. Introduction of *L. vannamei* in Indian aquaculture during 2009 through SRF stock opened up a new vista in aquaculture. Seafood export from India crossed 1 million tonnes for the first time and the earning crossed $ 4.5 billion during 2013–14 (MPEDA, 2013). Presently, 90% of the farming is with *L. vannamei* with a maximum stocking density of 60 no./m^2 as allowed by the regulatory authority.

It is observed in the study area that both agriculture and aquaculture co-exist with natural boundary of a road or a trench to flush the saline water immediately next to the shrimp farms. Paddy cultivation is also being undertaken in the watershed. It is obvious that where coastal



a) Spatial distribution of TDS

b) Spatial distribution of Cl

Fig. 5. Spatial distribution map.

aqua farms exist on clayey soils, the soil salinity did not exceed the permissible limits in adjacent agricultural farms. The salinisation of groundwater and agricultural land depends entirely on the soil texture and profile. Even where there are no shrimp farms, the land and groundwater are saline at some pockets. This could be due to the geological condition as earlier reported by closeness of the sea and regular tidal flushing, seepage, humid climate and meagre and narrow freshwater tables in the coastal belt. As per the report of the Central Groundwater Board, India, 2009, the groundwater is of marine origin and the in situ salinity exists in patches in the watershed. The quality of ground water in the fissured formation in some local pockets shows slightly higher mineralisation. There is no evidence of shrimp farming causing salinisation in the study area. However it would be desirable to have an isotope analysis of the groundwater for confirmation of this notion.

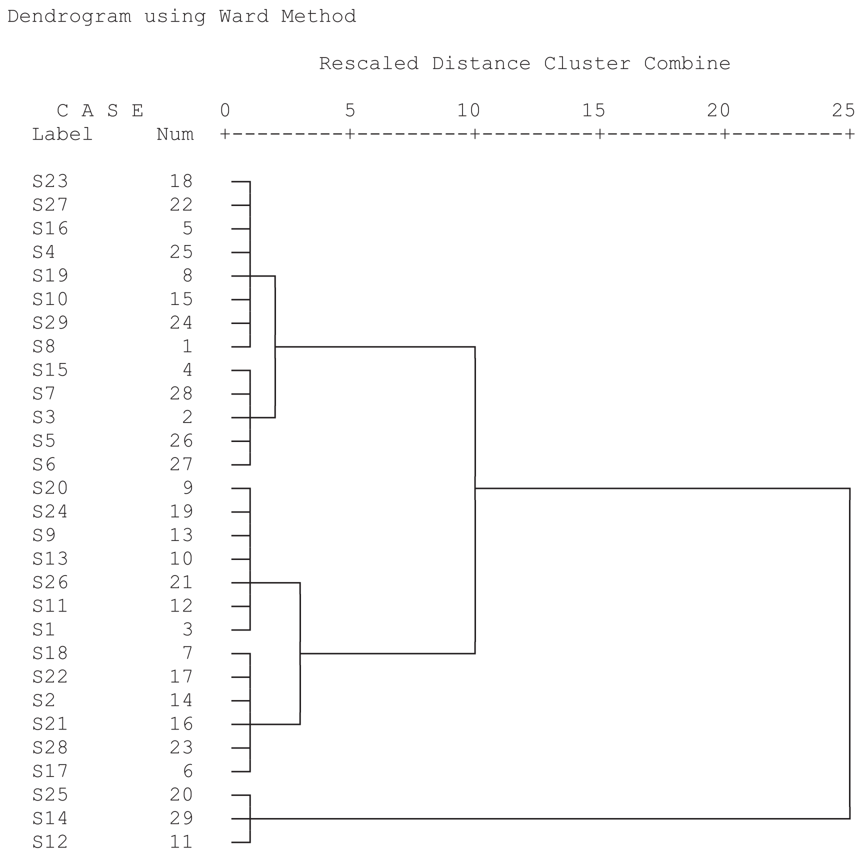


Fig. 6. Cluster analysis.

4. Conclusion

The main objective of this study was to develop a methodology for ascertaining the impact of shrimp farming on shallow groundwater. Selection of representative sampling location is the primary task and GIS based Analytical Hierarchical Process was attempted. Eight thematic layers were integrated as inputs to a GIS based Analytical Hierarchy Process (AHP) a built-in tool with ArcGIS 10.0 software. This evaluation study utilised the GIS capability of spatial analysis and the AHP capability of multilayer analysis. Grid based spatial modelling was carried out and priority areas viz, high medium and low were identified with 29 sampling locations. Continuous monitoring of the groundwater quality from these identified wells did not significantly vary as per the priority classification implying that groundwater quality is independent of shrimp farming impacts. Wide variation in quality indicated multiple sources for groundwater variations. The spatial distribution revealed isolated pockets of elevated salinity away from shrimp farms confirming the natural existence of in situ salinity in certain patches of the watershed. Cluster analysis revealed clusters not as per the priority classification. It could therefore be concluded that shrimp farming does not influence groundwater quality in the area studied.

Acknowledgment

The first author wishes to place her deep sense of gratitude to Dr. A. G. Ponniah, Director, CIBA for his encouragement and assistance to carry out this study. The research grant funded by the Ministry of Water Resources (MoWR) Government of India is gratefuly acknowledged.

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