

Assessment of groundwater vulnerability mapping using AHP method in coastal watershed of shrimp farming area

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Abstract Groundwater regions in coastal aquifers are highly vulnerable with increase in urbanization, industrialization and sea water intrusion. The present study attempts to evaluate the vulnerability of groundwater in a coastal watershed of shrimp farming areas. The study area is categorized in the GIS-based AHP environment into three ranges (high, medium, and low vulnerability) using various groundwater parameters such as electrical conductivity (EC), total dissolved solids (TDS), sodium percentage (Na%), total hardness (TH), Revelle coefficient, sodium adsorption ratio (SAR), permeability index (PI), and residual sodium carbonate (RSC) and their recommended limits. GIS-based AHP weighted index overlay analysis technique has been proven to be a powerful tool to evaluate the distribution of groundwater vulnerability in the study area. The high vulnerable areas were noted in downstream with a strong contamination of the seawater intrusion along the coastal zone and in proximity of the river. Multivariate statistical techniques are also applied to identify and assess the groundwater vulnerability of the study area. The factor analysis revealed that groundwater quality is strongly affected by rock–water interaction, saline water intrusion, and anthropogenic activities. The spatial distribution map of factor-scores showed the gradual variation in groundwater geochemistry

from the western part (upstream) to the eastern part (downstream) of the river. The results from the present study revealed that shrimp farming areas have very least or no impact on the groundwater of the region.

Keywords Groundwater · Vulnerability · Shrimp farming · GIS · AHP method · Coastal aquifers

Introduction

The groundwater vulnerability in coastal environments is a major issue which governs the groundwater quality. The quality of groundwater is mainly determined by the amount of various chemical elements both major and trace, present in it, and ascertained by the ability to use it for domestic purpose. With the increasing population along the coastal environments, the demand for groundwater and their potential resources is in upstream demand. Groundwater aquifers being the major source of water supply along the coastal regions have been subjected to either over exploitation or contamination. The over exploitation may either be for domestic usage or industrial purposes. This ultimately results in lowering of groundwater table which in turn increases the salinity of groundwater due to the intrusion of sea water (Sathish et al. 2011). On the industrial side, it is complicated by a large number of potential sources of contamination found in a coastal area. Mapping of groundwater vulnerability has become an important factor for the rational management of groundwater resources and subsequent land use planning. Also, the shrimp farms which utilise the saline water either from sea or creek creates apprehension among environmentalists about its role in salinity of groundwater along the coastal aquifer. In the recent years, aquaculture has been gaining more importance in the coastal areas as the potential economic resources with

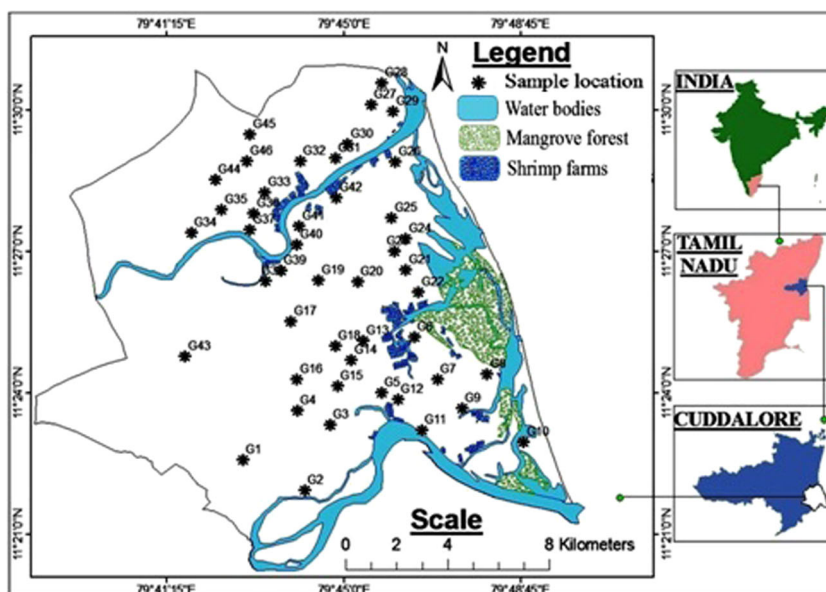
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Fig. 1 Map showing the location of the study area



the increase in demand for fishery food products. Due to this, the areal distribution of shrimp farms along the coastal regions utilizing the saline water for fisheries productions has increased to considerable extent. Shrimp farms could be a major concern for the groundwater vulnerability including saline water intrusion along the coastal aquifers (Briggs 1993). This trend shows upward progress over the years. Various researches have showed that proper scientific investigations can aid in mitigating this consequences of the shrimp farms on the coastal aquifer (Rekha et al. 2013). The major success in the implementation of the aquaculture projects without adverse effect on the environment and groundwater system depends on the adherence to the better management practices in term of site selection and its impact on the aquifer system (Mahalakshmi et al. 2014). This could benefit both the coastal environment and economic scenarios to the great possible extent.

The application of the Geographical Information System (GIS) for studying the groundwater vulnerability is wide spread (Anbazhagan and Nair 2004; Shahid and Nath 2002; Phukon et al. 2004; etc.). In India, where the coastal aquifer salinization has been a major issue, GIS studies in combination with the geochemical analysis proved vital in assessing groundwater quality and are greatly attributed to their resource management. Over the years, GIS has been an effective tool for studying the spatial distribution of various geochemical elements and contaminants to estimate groundwater quality (Babiker et al. 2007). They provided useful information to protect groundwater resources and to evaluate the potential methods for water quality improvement with changes in agricultural practices and land use applications. Groundwater vulnerability maps are prepared to ascertain the level of contaminants in the groundwater environment. Such maps have proved to be a popular tool in

Table 1 Scale for pair wise comparison (Saaty 1987)

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.

assessing the groundwater quality management and to identify throughout the world (Worrall and Kolpin 2004). They are used to examine the susceptibility of the aquifer system for pollution from various sources. Thus, the vulnerability of groundwater to different pollutants or to seawater intrusion constitutes the subject of analysis in several studies (Cardona et al. 2004; Lobo and Chachadi 2005; Rajankar et al. 2009; Ramakrishnaiah et al. 2009). In groundwater geochemistry, multivariate statistical analysis offers a powerful means of identifying similarities among the variables present in the chemical composition of groundwater (Vega et al. 1998; Bengraïne and Marhaba 2003). The application of AHP method in combination of GIS is relatively less (Kaliraj et al. 2013). But the approach is getting importance in the recent years. The notable application of AHP method includes the works of Chowdhury et al. (2010), Machiwal et al. (2011), and Kaliraj et al. (2013) for groundwater investigations and Mahalakshmi et al. (2014) for the selection of aquaculture sites.

The present paper outlines the results obtained in characterizing the groundwater around the shrimp farming areas by the combination of GIS with AHP technique and multivariate geochemical analysis. The parameter includes electrical conductivity (EC), total dissolved solids (TDS), percentage of sodium (Na%), total hardness (TH), revelle coefficient, sodium adsorption ratio (SAR), permeability index (PI), and residual sodium carbonate (RSC). The GIS-based spatial analysis with AHP weighted index overlay analyses is used to infer the source of groundwater contaminants. They are used to

prepare the groundwater vulnerability maps of the region. The suitability of groundwater around shrimp farming areas used for domestic and agricultural purposes can be determined from such maps.

The study area

The study area forms of part of eastern coastal region of southern India (Fig. 1). The area lies between 11° 30' N to 11° 20' N latitude and 79° 38' E to 79° 48' E longitude. The study region covers total aerial distribution of about 213 km² out of which shrimp farms occupy approximately 3 km². The area has a tropical climate with the highest and lowest temperatures recorded in May and January, respectively. The area receives annual rainfall of 1600 mm in average from the North East Monsoon, which is cyclonic in nature. It can be attributed to the development of low pressure in the Indian Ocean and Bay of Bengal. The area is well covered by eastern coastal plain, which predominantly constitutes the flood plain of fluvial origin from the sediments of Vellar and Coleroon river systems. They generally flow from west towards east following the general geomorphic relief of the terrain, and their flow pattern is mainly sub parallel. The eastern coastal part of study area is characterized by Pichavaram backwater.

The study area consists of sedimentary formations which include sandstone, clay, alluvium, and small patches of laterite soils of quaternary age. The area is characterized with the extensive built-up of alluvium consisting of mixtures of sand, silt, and clay in the delta portions in and around the watershed with thickness varying from 10 to 15 m. The

Table 2 Maximum and minimum ranges of the geochemical parameters of the groundwater samples collected for the study compared with WHO (2004, 1993) and ISI (1983) standards

S. No	Concentration of ions in the groundwater samples				WHO (1993, 2004)		ISI (1983)		
	Min	Max	Avg.	Std	Maximum accept limit (mg/l)	Maximum allowable limit (mg/l)	Highest desired limit (mg/l)	Maximum permissible limit (mg/l)	
	Total study area								
	Parameters*								
1	Ca	58.89	143.73	95.48	20.82	75	200	75	200
2	Mg	39.85	110.45	69.29	13.86	50	150	30	100
3	Na	36.85	298.36	143.48	55.57	–	200	–	–
4	K	1.09	34.96	13.50	8.37	45	–	–	–
5	Cl	197.45	956.27	451.01	167.96	200	600	250	1000
6	Br	0.23	15.14	3.42	3.01	45	–	–	–
8	NO ₃	1.83	49.17	10.70	9.80	45	–	–	–
7	SO ₄	7.90	97.43	44.13	20.64	200	400	–	–
9	HCO ₃	243.86	477.07	371.30	48.48	–	–	–	–
10	CO ₃	14.00	65.25	35.37	12.70	45	–	–	–
11	pH	7.69	8.57	8.04	0.20	6.5	8.5	6.5–8.5	6.5–9.5
12	EC	561	6366	2168	1189	–	–	–	–
13	TDS	404	4163	1425	804	500	1500	500	2000

*Ca, Mg, Na, K, Cl, Br, NO₃, SO₄, HCO₃, CO₃, and TDS in mg/l; EC in µs/cm

Table 3 Characterizing the groundwater of the study area from the studied parameters

Category	Grade	No. of sample	Percentage of sample	Sub criteria weightage in AHP method	Consistency ratio
EC values ($\mu\text{s}/\text{cm}$) (Wilcox 1955; Subramani et al. 2005)					
Excellent	<250	–	–	0.031	0.093
Good	250–750	2	4	0.058	
Permissible	750–2000	27	59	0.157	
Doubtful	2000–3000	9	20	0.271	
Unsuitable	>3000	8	17	0.482	
TDS content (mg/l) (Desjardins 1988)					
Fresh water	<500	3	7	0.044	0.042
Moderately fresh brackish water	500–1000	12	26	0.026	
Slightly brackish water	1000–5000	31	67	0.036	
Moderately brackish water	5000–15000	–	–	0.143	
Very brackish water	15000–35000	–	–	0.249	
Sea water	35000–42000	–	–	0.501	
Percentage of Na (Wilcox 1955)					
Excellent	<20	1	2	0.043	0.093
Good	20–40	25	54	0.133	
Permissible	40–60	18	39	0.210	
Doubtful	60–80	2	4	0.263	
Unsuitable	>80	Nil	Nil	0.352	
Revelle coefficient (Roger 1941)					
Very low salinity	<1	20	43.48	0.070	0.037
Low salinity	1–1.5	17	36.96	0.186	
Medium salinity	1.5–2	5	10.87	0.261	
High salinity	>2	4	8.70	0.483	
TH (Total hardness) (WHO 1983)					
Good	<100	Nil	Nil	0.074	0.008
Doubtful	100–500	20	43	0.186	
Unsuitable	>500	26	57	0.740	
SAR (Sodium absorption ratio) (Richards 1954)					
Excellent	<10	46	100	0.085	0.019
Good	10–18	Nil	Nil	0.140	
Doubtful	18–26	Nil	Nil	0.233	
Unsuitable	>26	Nil	Nil	0.542	
PI (Permeability Index) (Raghunath 1987)					
Class I	>18	Nil	Nil	0.072	0.044
Class II	18–70	40	86.96	0.143	
Class III	70–120	6	13.04	0.301	
Class IV	<120	Nil	Nil	0.484	
RSC (Residual sodium carbonate) (Richards 1954)					
Good	<1.25	45	98	0.068	0.043
Doubtful	1.25–2.5	1	2	0.275	
Unsuitable	>2.5	Nil	Nil	0.657	

quaternary formations consist of sediments of fluvial, fluvio-marine, and marine facies, which include fine to coarse-grained sand, silt, clay, laterite, and lateritic gravels. In the coastal tract, except at the confluence point of river, wind-blown sands of 1.5–3 km width occur commonly in the form of low and flat-topped sand dunes. The study area

indicates the presence of alluvial sand and sandstones up to a depth of 50 m below ground level. The groundwater occurs in both unconfined and confined conditions in alluvial and sandstone formations, respectively. The shallow aquifers are the target of the groundwater vulnerability. They are predominantly unconfined and some confined areas. It can

be recharged directly from natural rain infiltration; surface water body leakage; and irrigation return water.

Analytical methodology

Groundwater samples were collected from 46 representative wells after well inventory survey for 2 years from October 2011 to October 2013, once in 2 months. The samples were collected mainly from shallow aquifers (40–100-ft depth) after 10 min pumping. The pH, EC, and TDS of water samples were measured immediately in situ. Latter, the samples were analysed for their chemical constituents such as the sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), nitrate (NO₃), bicarbonate (HCO₃), and carbonate (CO₃) in laboratory. The results were compared with the standard guideline values as recommended by the World Health Organisation (WHO 2004, 1993; ISI 1983).

Groundwater vulnerability parameter

The groundwater vulnerability maps were prepared from the collected groundwater samples in and around the shrimp farming areas. In the present study, eight important physical parameters of groundwater including EC, TDS, Na%, TH, Revelle coefficient, SAR, PI, and RSC were considered. The EC, TDS, and Revelle coefficient (the ratio of [Cl-]/[HCO₃+CO₃]) were used to evaluate the magnitude of seawater intrusion and the contamination of coastal aquifers (Bowen 1986; Chachadi and Lobo-Ferreira 2005; Roger 1941). Na%, TH, SAR, PI, and RSC were used for determining the suitability of groundwater for irrigation based on an assessment of the content of sodium compared to the total cations in the system. The values were estimated as suggested by

Raghunath (1987) and Doneen (1948) to establish the suitability of groundwater quality for drinking and irrigation purposes following the WHO (1993, 2004) and ISI (1983) standards.

AHP overlay methodology

The spatial distribution maps of the analysed parameters were prepared using AHP weight method. Systematic weightage was allocated to each parameter, and the overlay analysis was performed in the GIS platform. Qualitative or quantitative indices were derived from the key factors which determine the groundwater vulnerability processes (Connell and van den Daele 2003). For spatial analysis, inverse distance weighing (IDW) method was applied to generate the raster graphical output for the parameters. The raster graphical output would be suitable for the overlay analysis which would give high spatial variability of multi-attributes (Babiker et al. 2007). The weights (or relative importance) of main-criteria and its corresponding sub-criteria under consideration were defined by pair wise comparison method (Saaty and Vargas 2000). to identify the most significant factors with higher weight and vice versa. Different features for each theme were assigned with weights on a scale of 1 to 9 according to their relative influence on groundwater vulnerability (Saaty 1987) (Table 1). The consistency ratio (CR) is obtained by dividing the consistency index by the random index. The consistency ratio is designed in such a way that if CR<0.1, the ratio would indicate a reasonable level of consistency in the pairwise comparisons; if, however, CR≥0.1, the values of the ratio were indicative of inconsistent judgments (Mahalakshmi and Ganesan 2009).

Fig. 2 The spatial distribution of electrical conductivity values within the study region

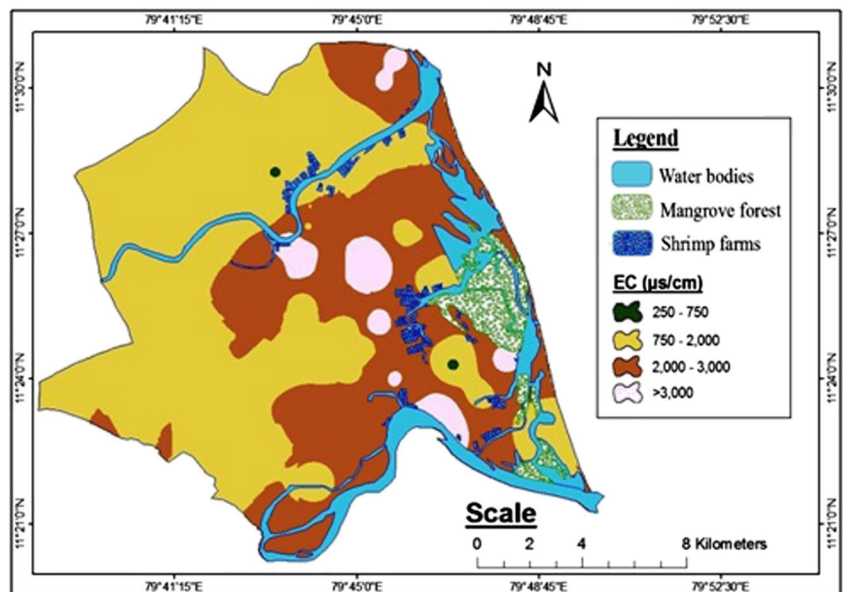
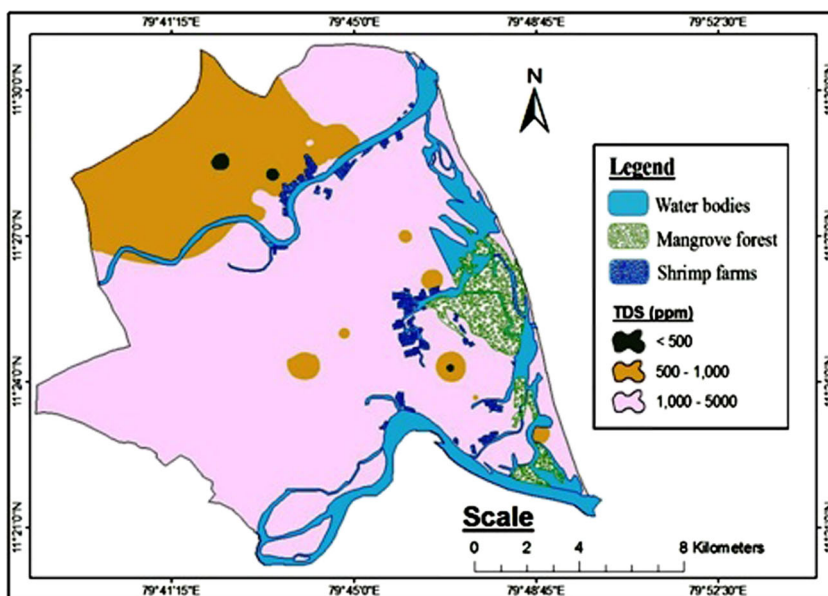


Fig. 3 The spatial distribution of total dissolved solid within the study region



Statistical methodology

The factor analysis was carried out to reduce the large inter-related variables by retaining the significant variability in the resulted groundwater datasets (Singh et al. 2005). This technique allowed the identification of the possible sources that influence water systems for reliable management of water resources as well as rapid solution for groundwater pollution problems (Kazi et al. 2009). Factors extracted by varimax rotation gave values close to -1, 0, and +1 suggesting respectively the negative, zero, and positive contribution of a variable toward a factor (Briz-Kishore and Murali 1992). The factor increased with the increase in level of particular factor (Lawrence

and Upchurch 1983). While 0 represents average impact, -1 denoted the high impact, and +1 denoted the least affected regions (Giridharan et al. 2009).

Results and discussion

Major ion distribution

The statistical measures such as minimum, maximum, average, median, mode, and standard deviation of the geochemical parameters are reported in Table 2. The abundance of the major ions in groundwater of the study area is in the following order: Na>Ca>Mg>K=Cl>HCO₃>CO₃>SO₄>NO₃>Br.

Fig. 4 Map showing the spatial distribution of the sodium percentage within the study area

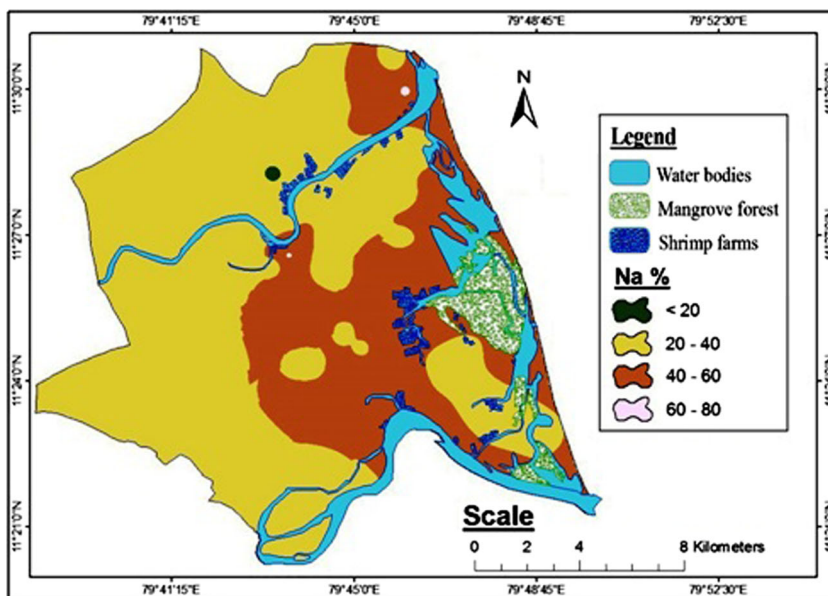
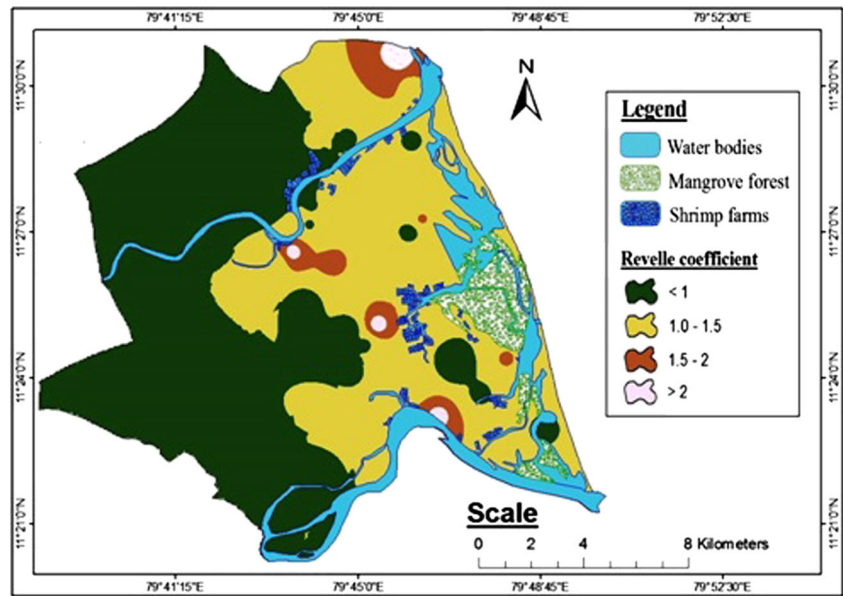


Fig. 5 The spatial distribution map of the Revelle coefficient for salinity hazard



The pH of the groundwater in the study area ranges from 7.69 to 8.57 with a mean value of 8.04. All samples have pH values more than 7, indicating alkaline nature of the samples.

Parameter used for groundwater vulnerability

Understanding the quality of groundwater is as important as its quantity, because it is the main factor determining its suitability for drinking, domestic, agricultural, and industrial purposes. In the present study, the groundwater of the study area is characterized into various categories defining their suitability for utility. The results are summarized in Table 3. The spatial distribution maps are prepared based on the distribution of the discussed parameters within the study area. From

the spatial distribution, the quality of the groundwater around the shrimp farms is ascertained. This suggested the significance of studied parameters and is used to estimate the detailed impact of the shrimp farms on the surrounding groundwater system.

Significance of electrical conductivity

EC values are considered important in determining the usage of water. Groundwater with high EC values is not suitable for both irrigation and drinking purposes (Davis and DeWiest 1966; Freeze and Cherry 1979). The spatial distribution map of the weighted EC values (Fig. 2) suggested that the salinity distribution of the groundwater in the study area ranges from

Fig. 6 The spatial distribution map of total hardness in the study area

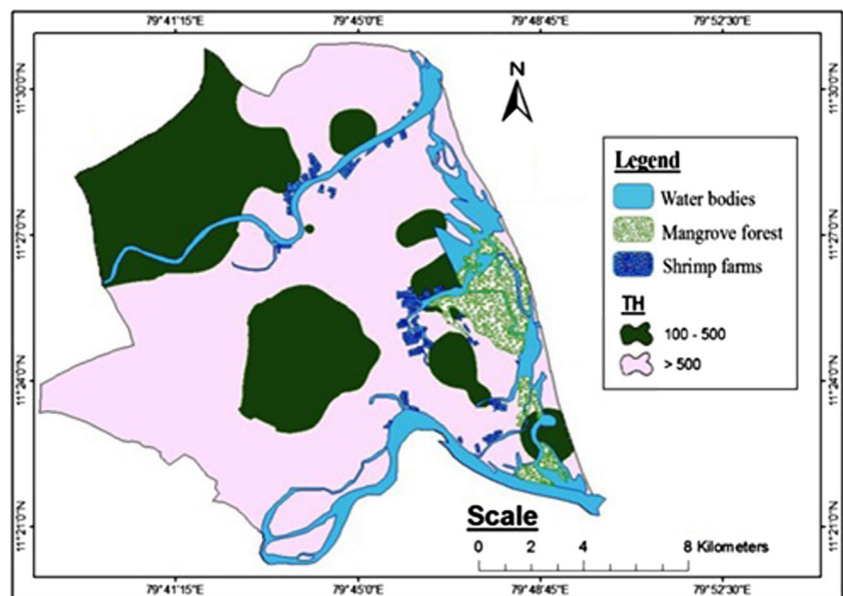
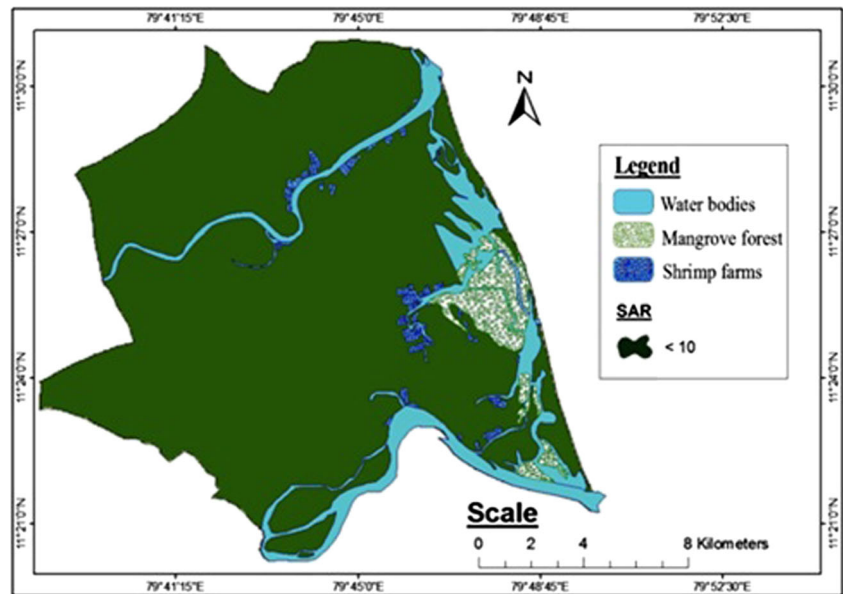


Fig. 7 The spatial distribution of sodium adsorption ratio within the study area



561 to 6366 $\mu\text{s}/\text{cm}$ with an average value of 2168 $\mu\text{s}/\text{cm}$. The results of the EC values are given in Table 3. The spatial distribution of the EC values suggested that most of the western region falls within the permissible category, where shrimp farm area is 1.27 km^2 . The regions with higher EC (unsuitable category) are located away from the shrimp farms area and cover 0.15 km^2 . The values indicated that the salinity of groundwater increases towards coastal side.

Total dissolved solid

The TDS value of the groundwater in the study area ranges from 404 to 4163 mg/l with an average value of 1388 mg/l .

The spatial distribution map of TDS for the study area (Fig. 3) shows that the major distribution is slightly brackish water to fresh as in Table 3.

As observed from the collected groundwater samples in Fig. 3, the area has about 67 % of slightly brackish water of TDS value 1000–5000 (mg/l), with 26 % of moderately fresh brackish water at the northern portion of the study area, where the shrimp farm area occupy 2.54 km^2 . Few fresh water samples (<500 mg/l) were encountered at both north western and south eastern side near to shrimp farming area. The groundwater categories of TDS range from 500 to 1000 mg/l representing moderately fresh water conditions and are present in north western side and in

Fig. 8 The spatial distribution of permeability index within the study area

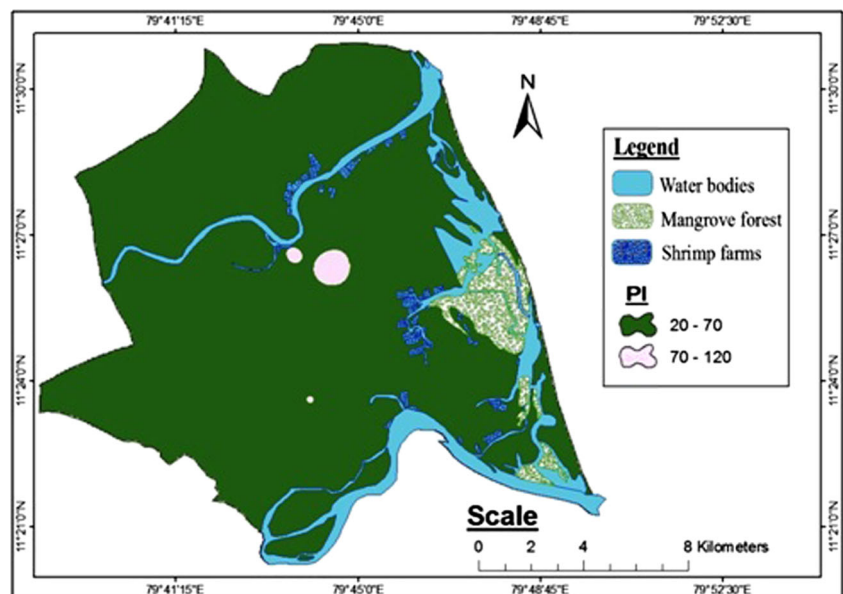
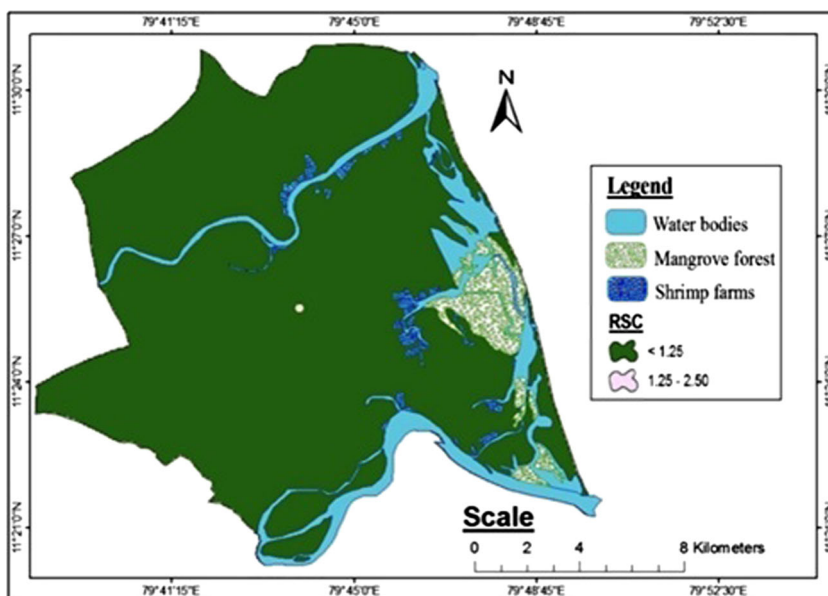


Fig. 9 The spatial distribution map of residual sodium carbonate in the study area



few parts of central and south eastern part of the study area, with 0.49 km² of the area covered by shrimp farming activities.

Sodium percentage

The Na% is one of the important factors for estimating the irrigation water quality and salinity of the groundwater. If the concentration of sodium is high in irrigation water, it will reduce the soil quality by reducing soil permeability (Collins and Jenkins 1996; Saleh et al. 1999). Based on the percentage of the sodium (% of Na), the groundwater of the area is characterized for its quality. Out of the five categories classified by Wilcox (1955), four level of Na% are prominent in the study area (Fig. 4).

The maximum and minimum values of Na% ranges from 17 to 62 meq/l with the average value of 38 meq/l. The spatial distribution map of the Na% depicted that a major part of the study area surrounding the shrimp farms is well within the

permissible limits (40–60 %) while shrimp farms covering 1.60 km². Next to that, good categories (20–40) are found along the western region with a 1.42 km² covered by shrimp farming area. Other categories are dispersed scarcely within the study area. This signified that the shrimp farms have no or very least impact on the Na% of the groundwater on the region (Fig. 4).

Revelle coefficient

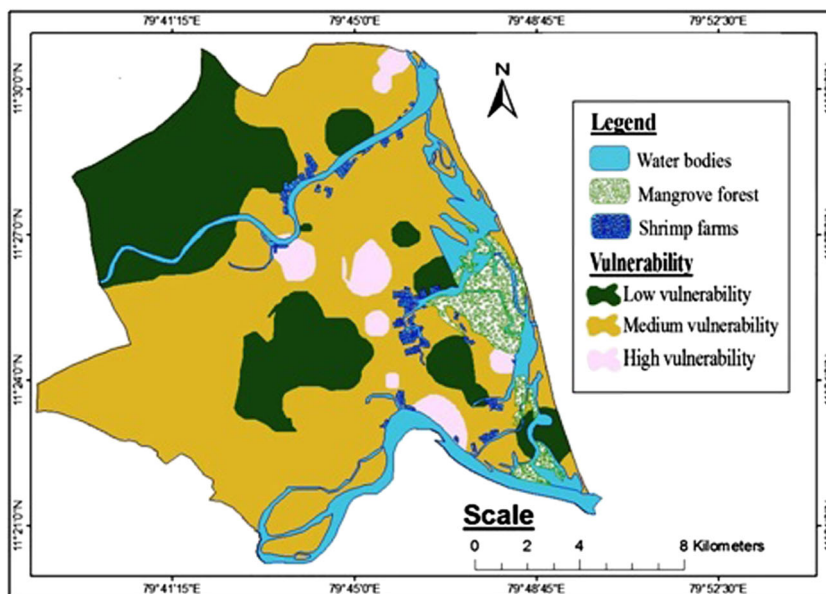
Revelle coefficient is calculated to determine the salinity hazard of the region based on Cl^-/HCO_3^- ratio (Roger 1941), and the results are shown in Table 3. The revele coefficient ranges from 0.5 to 2.5 mg/l with mean 1.1 mg/l. The spatial distribution map of revele coefficient (Fig. 5) is identical with that of the EC distribution suggesting that the western portion of the study area away from the coast is very low saline with the revele values <math>< 1</math>, where the area covered by shrimp farming area is

Table 4 Overall pair-wise comparison matrix of multi-criteria for selection of groundwater vulnerability

Criteria	EC	TDS	NA%	Revelle coefficient	TH	SAR	PI	RSC	Weight
EC	1	2	2	2	2	2	4	9	0.238
TDS	1/2	1	2	2	2	2	2	3	0.168
NA%	1/2	1/2	1	2	3	2	4	6	0.171
Revelle coefficient	1/2	1/2	1/2	1	3	3	3	6	0.150
TH	1/2	1/2	1/3	1/3	1	2	4	6	0.113
SAR	1/2	1/2	1/2	1/3	1/2	1	2	3	0.078
PI	1/4	1/2	1/4	1/3	1/4	1/2	1	4	0.055
RSC	1/9	1/3	1/6	1/6	1/6	1/3	1/4	1	0.026

Consistency ratio (CR)=0.067

Fig. 10 The vulnerability map of groundwater in the study area



0.60 km². The salinity increased towards the coast to high saline region on the eastern side with revelle coefficient ranging 1–1.5. Few high saline areas (revelle coefficient >2) surrounded by medium saline regions (revelle coefficient 1.5–2) are noted near to the creek of south eastern, central part, and near to the sea of northern eastern side of study area, where shrimp farming area is very less. The impact of aquaculture on the groundwater is found to be feeble, suggesting that there is no major impact of the shrimp farms on the study region.

Total hardness

The total hardness of the groundwater chiefly depends on the Ca and Mg ion concentration and hence signifies the relative amount of these elements on the groundwater (Todd 1980). The classification of groundwater within the study area using total hardness (TH) is based on WHO (1983) standards and is given in Table 3. Majority of the groundwater samples fall in the hard water category with the hardness values ranging from 330 to 814 mg/l with an average value of 526 mg/l. Most of the samples fall within the two dominate categories, the unsuitable groundwater quality being the major portion with TH greater than 500 mg/l. The doubtful category found dominated in the north eastern and central part of the study area. The region surrounding the shrimp farming area has mixed concentration of both categories signifying the low impact of the aquaculture in the groundwater (Fig. 6).

Sodium adsorption ratio

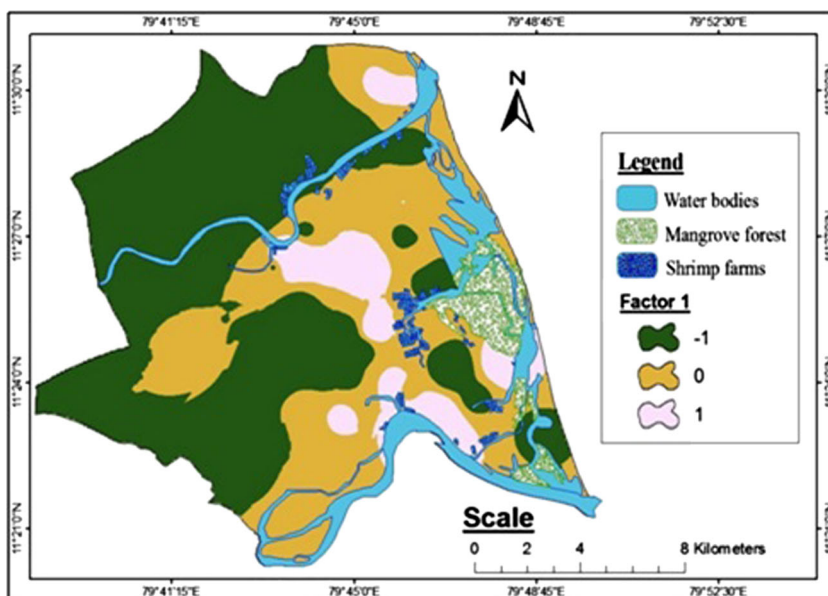
SAR is the measure of sodium/alkali hazards in the groundwater for irrigation purpose which expresses the

relative activity of Na⁺ in the soil as calculated by Karnath (1987). The results in Table 3 showed that sodium adsorption ratio ranges from 0.80 to 4.24 meq/l with mean value of 2.36 meq/l. The spatial distribution of SAR suggested that, majority of the study area is low in sodium hazard water (Fig. 7). This implies that the groundwater within the study area is not affected by the shrimp farms with respect to sodium hazard.

Table 5 Factor analysis for each studied parameters and their significance

Variable	Component				Communalities
	1	2	3	4	
EC	0.96	-0.17	0.04	-0.08	0.96
TDS	0.96	-0.18	0.04	-0.08	0.96
pH	-0.12	-0.29	0.04	0.36	0.85
Na	0.87	-0.12	0.08	-0.24	0.84
K	0.45	0.58	-0.21	-0.14	0.60
Ca	0.80	-0.05	-0.03	0.31	0.74
Mg	0.77	0.01	-0.10	0.49	0.84
Cl	0.96	-0.19	0.02	0.02	0.96
Br	0.87	-0.26	0.01	-0.22	0.87
NO ₃	0.30	0.68	0.24	0.42	0.78
SO ₄	0.46	0.58	-0.26	-0.02	0.61
HCO ₃	0.11	0.42	0.27	-0.03	0.27
CO ₃	0.21	0.36	0.68	-0.48	0.86
Eigen value	6.08	1.70	1.34	1.00	
Percent Var	46.80	13.10	10.31	7.72	
Cummulative %	46.80	59.90	70.21	77.93	

Fig. 11 Spatial distribution of factor 1 variance in the study area



Permeability index

PI is an important factor which influences the quality of irrigation water, in relation to soil for development in agriculture. In the study area, the PI values range from 23 to 82 meq/l with mean value of 54 meq/l. The PI of the area is classified based on Raghunath (1987), and the results are shown in Table 3. The majority of the groundwater samples in the study area are represented in class II with few samples falling in class III category. The spatial distributions map of PI for the study area shows that shrimp farm area has no impact on the permeability of soil (Fig. 8).

Residual sodium carbonate

The RSC of the groundwater is estimated according to Richards’s classification (1954). From Table 3, it can be understood that only one sample (G17) falls within the doubtful category while remaining all the sample are within good category with RSC values ranging from -9.24 to 1.50 and mean value of -3.83 . The spatial distribution of RSC (Fig. 9) shows that the entire study area falls under good categories (<1.25) with very small part in the central part come under doubtful categories. Also, all shrimp farm area comes under good categories indicating

Fig. 12 Spatial distribution of factor 2 variance in the study area

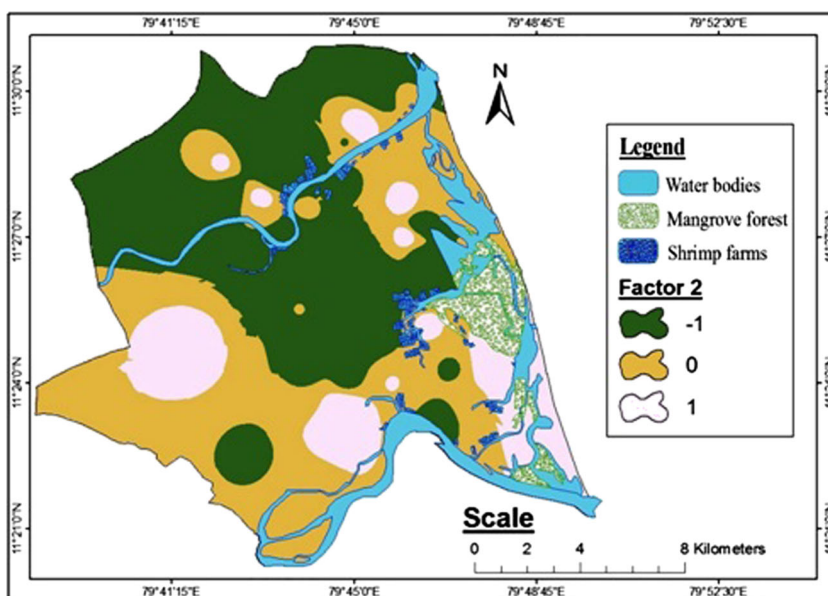
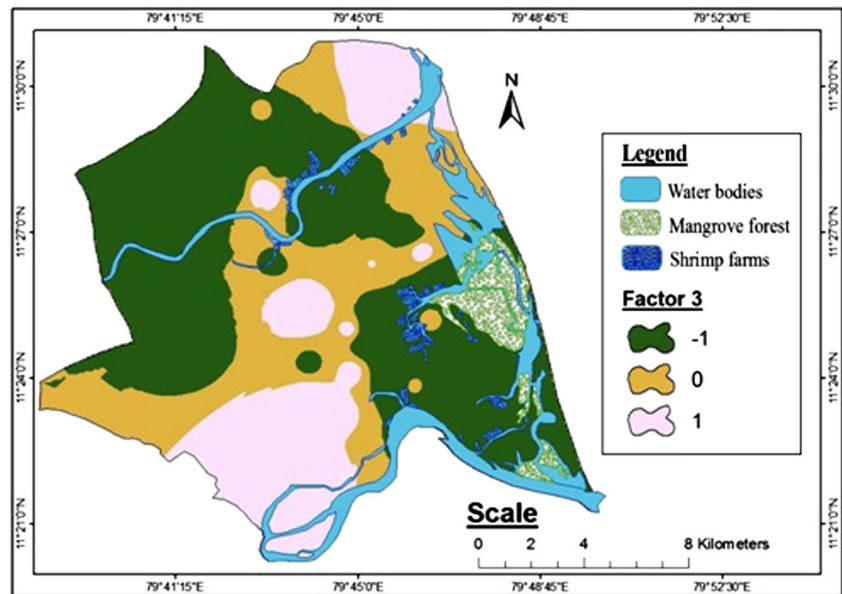


Fig. 13 Spatial distribution of factor 3 variance in the study area



that there is no impact of shrimp farms on RSC of the groundwater system.

Determination of groundwater vulnerability

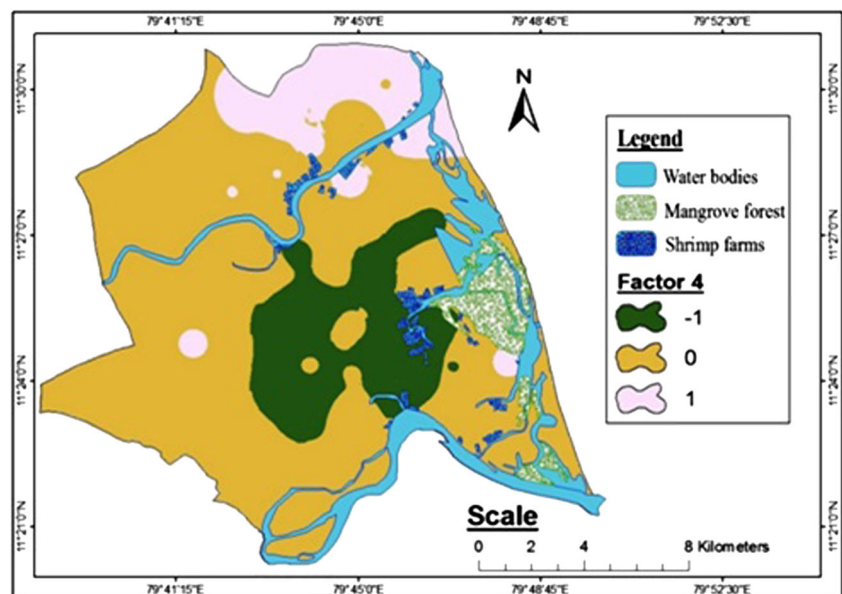
The systematic analysis of AHP techniques on weighted parameters has produced a suitable groundwater zone map in raster format using raster calculator module in GIS environment. The pairwise comparison matrix and the relative importance of each criterion derived are shown in Table 4. The criterion weights obtained are 0.238, 0.168, 0.171, 0.150, 0.113, 0.078, 0.055, and 0.026 for EC, TDS, Na%, revelle coefficient, TH, SAR, PI, and RSC, respectively. The

relative weightage of raster map is obtained by classifying the study area into high, moderate, and low vulnerable zones of groundwater (Fig. 10). The results suggested that 11.92 km² of the study area falls in higher vulnerability which has about 0.15 km² of shrimp farm area. This clearly suggested that the agriculture activities within the area are independent from shrimp farming area.

Factor analysis

Four factors are extracted to statistically represent the contributions influencing chemical composition of groundwater (Table 5). For factor loadings, a high loading is defined as

Fig. 14 Spatial distribution of factor 4 variance in the study area



greater than 0.75, and a moderate loading is defined as 0.40–0.75. Loadings of less than 0.4 are considered insignificant (Mor et al. 2006). In the present study, R-mode factor analysis is chosen which provides several positive features that allow the interpretation of the data set more scientifically.

Factor I consisted of Na, Cl, Br, Ca, Mg, TDS, and EC which contributed about 46 % of the variance. It has the high loading of above parameters thereby indicating the higher proportionate levels of these ions along the coastal groundwater. This suggested the significant effect of seawater mixing within the groundwater aquifer (Park et al. 2005). The areal distribution of the factor scores is shown in Fig. 11. Positive values are observed in the central part, north eastern, and south eastern part of study area, suggesting increase of saline water intrusion with the concentrations of these ions, where shrimp farm area is very less (0.38 km²). The negative values are observed in the northern direction and few parts in southern and central parts of the study area with 1.19 km² of shrimp farming area which is apparently unaffected by aquaculture activities.

Factor 2 which account for approximately 13 % of total variance has a moderate loading of K, NO₃, and SO₄ indicating a very limited significance in the groundwater vulnerability for the study area. The spatial distribution map of factor 2 (Fig. 12) suggested negative scores and observed along north eastern and south eastern portion of the study area. The positive scores are obtained for the central and northwestern portion of the study area.

Factor 3 accounted for 10 % of the total variance within the study area and showed higher loading of pH. This suggested an increase in hydrogen ion concentration in the groundwater, which resulted in the increase of other ions in determining the chemical make-up of the groundwater within the study area (Giridharan et al. 2009). The spatial distribution map for factor 3 suggested positive scores at the downstream of north eastern, south western region, and central part of the study area (Fig. 13). Negative values are observed in south eastern side and few parts in central region within the study area.

Factor 4 accounted for 8 % of total variance and had moderate loadings of Mg, CO₃, and NO₃. The spatial distribution map of factor 4 (Fig. 14) showed positive value in northern side and in few parts of central and south region of the study area. The negative values of factor 4 are observed in the south western and some portions in central and north part of the study area.

Conclusion

In the present study, a total of 46 groundwater samples collected across the region were analysed for their physicochemical constituents. The groundwater geochemistry showed that the ion concentration of the region was Na>Ca>Mg>K=Cl>

HCO₃>CO₃>SO₄>NO₃>Br. The spatial distribution maps of chemical parameters in the region surrounding the shrimp farming areas were prepared. The results of EC, TDS, and Revelle coefficient suggested that groundwater of the region was not affected by the salinity due to the shrimp farm areas. The salinity of the region increased towards the eastern margin along the coastal region suggesting the significant intrusion of sea water into the aquifer system. Most of the groundwater in the study area was suitable for the agriculture activities. The results of factor analysis indicated that factor 1 signified the variation of Na, Cl, Br, Ca, Mg, TDS, and EC, where a high loading of these parameters was noticed. The positive correlation of these factor elements signified considerable salt water intrusion into the groundwater system, but away from the shrimp farming areas. A positive correlation of factor 2 variance constituting K, NO₃, and SO₄ was noticed mainly along the southern and central portion of the study area. This suggested a significant importance of the litho-conditions of the region. Factor 3 which constituted the variance of pH was found to be dominating along the central and south western portion of the study area. Factor 4 constituted the significance of Mg, CO₃, and NO₃ and was found to have positive significance along the northern region of the study area. The results suggested that the impact of shrimp farming area along the region was very feeble, and the groundwater conditions were not altered to a great extent by the aquaculture. The factor analysis and the AHP weightage criterion were significantly useful in the selection of statically important parameters for analysing the impact of the shrimp farms on the groundwater system.

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