models, 2014; https://cran.rproject.org/web/packages/SPACECAP/index.html (accessed on 24 June 2016).
20. Royle, J. A., Karanth, K. U., Gopalaswamy, A. M. and Kumar, N. S., Bayesian inference in camera trapping studies for a class of spatial capture-recapture models. *Ecology*, 2009, **90**, 3233–3244.
21. Karanth, K. U. and Nichols, J. D., Estimation of tiger densities in India using photographic captures and recaptures. *Ecology*, 1998, **8**, 2852–2862.
22. Gubbi, S., Nagashettihalli, H., Kolekar, A., Poornesha, H. C., Reddy, V., Mumtaz, J. and Madhusudan, M. D., From intent to action: a case study for the expansion of tiger conservation from southern India. *Glob. Ecol. Conserv.*, 2017, **9**, 11–20.
23. Joshi, A. R. *et al.*, Tracking changes and preventing loss in critical tiger habitat. *Sci. Adv.*, 2016, **2:2**, e1501675.

ACKNOWLEDGEMENTS. We thank G. V. Sugur, Vinay Luthra and Dilip Kumar Das in guiding the entire exercise is acknowledged. The support of the National Tiger Conservation Authority (NTCA), New Delhi has been extremely valuable not just in this monitoring exercise but also for the conservation of tigers in this landscape. We also thank all the staff of Biligiri Rangaswamy Temple Tiger Reserve for support. Funding for the camera trapping work was supported by the Karnataka Forest Department and National Tiger Conservation Authority. We also thank H. C. Poornesha for help in cartography work. R.B. and S.G. acknowledge the earlier support of Panthera, and current support of IUCN-KfW under the integrated Tiger Habitat Conservation Program (ITHCP). The authors declare no conflict of interest.

Received 2 November 2016; revised accepted 15 June 2017

doi: 10.18520/cs/v113/i09/1759-1763

Land-use/land-cover change dynamics and groundwater quality in and around shrimp farming area in coastal watershed, Cuddalore district, Tamil Nadu, India

P. Nila Rekha*, R. Gangadharan, P. Ravichandran, Shirley Dharshini, Wilmart Clarke, S. M. Pillai, A. Panigrahi and A. G. Ponniah

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

The present study was envisaged mainly to ascertain the influence of aquaculture on salinization of coastal groundwater resources in the Cuddalore district of Tamil Nadu located between 11°30′N–11°20′N and 79°38′E–79°48′E. Watershed-based multidisciplinary approach combining GIS and Remote Sensing, and hydro-geochemistry has been applied. The land-use study revealed that though aquaculture was initiated after 1991, the groundwater quality in some locations showed elevated total dissolved solids and electrical conductivity content during that time itself, supporting the fact that aquaculture has been initiated in *in situ* saline area. Land-use change dynamics showed no defined relationship between area of culture and the groundwater quality, indicating that there was no salinity build-up due to shrimp farming. Besides major chemical compositions, the hydro-geochemical analysis using Chadha's plot suggests that reverse ion exchange is dominant in the study area due to the natural geological condition and it controls the groundwater quality rather than sea water incursion to a large extent. Thus these analyses clearly bring out the fact that shrimp farming is not the main reason for the source of salinity in the study area.

Keywords: GIS and remote sensing, hydrogeology, groundwater, salinization, watershed, shrimp farming.

THE world aquaculture production continued to grow, reaching 97.2 million tonnes (live weight) during 2013 with an estimated value of US$ 157 billion[1] and is perceived as one of the avenues to meet the growing demand for seafood. In addition, aquaculture has great potential for alleviation of poverty and generation of wealth for the people living in coastal areas, especially in developing countries. At the same time, aquaculture development is challenging because it might bring out significant environmental issues which could impair coastal resources. Environmentalists elsewhere have pointed out the boom and bust cycle, disease problem, and socioeconomic impacts of shrimp farming[2,3]. The impacts of shrimp farming reported are economic benefits, utilization of marginal lands and water for economic benefits, the conversion of important coastal ecosystems like lakes, salt pans, mangroves and agricultural lands to aquaculture farms[4–6], salinization of drinking water resources adjacent to shrimp farms[7], nutrient loading of coastal water bodies and estuaries[8,9], multi-user conflicts and escape of aquaculture stocks, viz. biological pollution of wild population. Briggs and Smith[10] estimated the nitrogen and phosphorus from intensively developed shrimp ponds in Thailand as it was reported that these inputs were not converted to shrimp biomass as expected, rather there was a possibility that they were released into the surrounding environment[11,12]. It may be mentioned here that in many studies the range and severity of shrimp farming impacts have been either exaggerated or misrepresented, mainly owing to the high profitability/visibility of the aquaculture sector, failure to distinguish between actual and hypothetical hazards[13] and projection of piece meal studies which were location-specific.

Brackishwater aquaculture basically utilizes saline water either from sea or estuary or creek. The groundwater salinization in and around shrimp farming area is

*For correspondence. (e-mail: rekha@ciba.res)

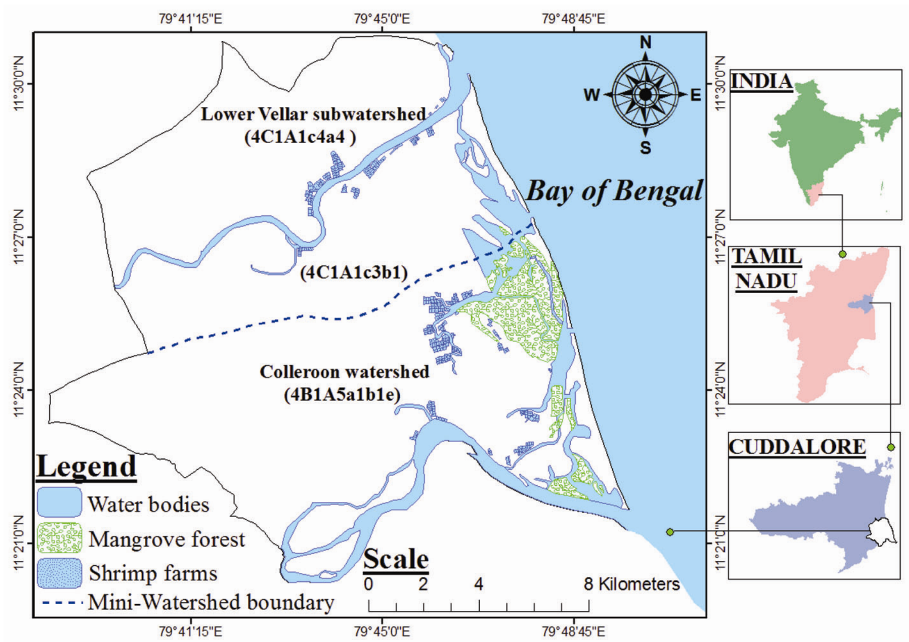

Figure 1. Coastal watershed, Cuddalore district, Tamil Nadu.

Table 1. Details of satellite data used in the study

Satellite sensor	Sensor product number	Date	Path and row
Landsat TM	ETP142R52_5T19910825	25-08-1991	142 and 052
Landsat ETM +	ELP142R052_7T20001028	28-10-2000	142 and 052
Landsat ETM	LE71420522012143PFS00	22-05-2012	142 and 052

one of the important parameters to be addressed for sustainable shrimp farming. The coastal groundwater system and the quality are vulnerable for wide fluctuations due to tidal influx from the seaside and upstream influx through river discharge. In addition, a large-scale and gradual change in climate and land use also influences groundwater quality[14]. With this background, watershed-based impact assessment was undertaken to ascertain the influence of aquaculture on salinization of coastal groundwater resources. A multidisciplinary approach combining Geographical Information System (GIS), remote sensing and hydro-geochemistry was adopted. Part of the results was published earlier[15] wherein the main factors affecting the groundwater quality in shrimp farming areas were evaluated through multivariate statistical methods. Another study[16] discussed the methodology for selection of representative sampling locations using GIS-based analytical hierarchical process. The present communication deals with the changes of land use/land cover and its influence on groundwater quality in shrimp farming areas.

In order to precisely assess the impact of shrimp farming, it is imperative to select an area where aqua farming is in operation and in the process of expansion. Such an area was chosen for the present study between 11°30′–11°20′N and 79°38′–79°48′E in Cuddalore district, Tamil Nadu. As it was proposed to assess the impacts on watershed basis, three adjacent coastal mini-watersheds covering the shrimp farming areas of Cuddalore district have been delineated using ArcGIS.10 (Figure 1). The total extent of the study area is about 213.438 sq. km. About 4 sq. km area is covered by shrimp farms which are scattered as six clusters. More details about the study area have been given in earlier publications[15,16].

The geographical information system coupled with remote sensing is a powerful tool for analysing spatially and visualizing different scenarios precisely. Among the different land uses in coastal watershed, brackish water aquaculture is also predominant and is an important livelihood means. The status of the groundwater quality before initiation of brackish water aquaculture in the study area and during the course of development of aquaculture at different time periods till date, was studied using remote sensing data and archived groundwater quality data available with the Central Ground Water Board (CGWB), Government of India, Tamil Nadu Water Supply and Drainage board (TWAD), and Public Works Department (PWD) of Government of Tamil Nadu for 1991 and 2000. In 2012, groundwater samples were collected at the same locations and analysis carried out for EC and TDS using standard procedures[17].

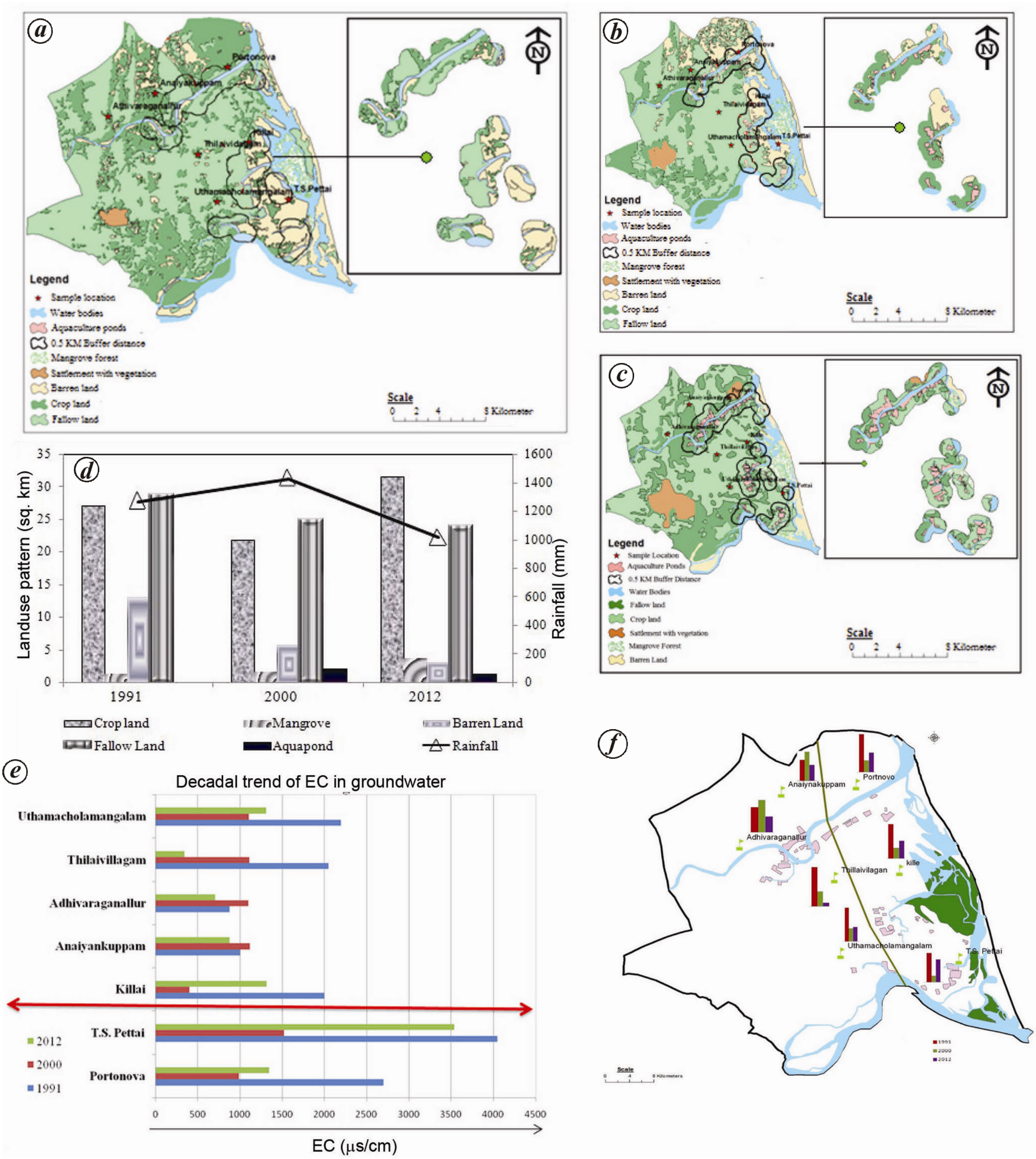

Figure 2. ***a***, Land-use pattern during 1991 (before initiation of aquaculture); ***b***, Land-use pattern during 2000, ***c***, Land-use pattern during 2012; ***d***, Land-use pattern with rainfall for 1991, 2000 and 2012; ***e***, Decadal trend of EC in groundwater; ***f***, Decadal trend of TDS (mg/l) in groundwater.

Four aspects of land-use change dynamics, viz. identifying the changes, nature, areal extent and spatial pattern of the change have been captured using satellite data in 1991, 2000 and 2012 (Table 1) and shown in Figure 2 *a*–*c* respectively. To establish the relationship between land-use pattern change and groundwater quality, both groundwater quality and land use analysis were examined for two criteria, viz. within ≤0.5 km buffer zone around the shrimp farming area and 5 km from the coast. Land use classes are typically mapped from digital remotely

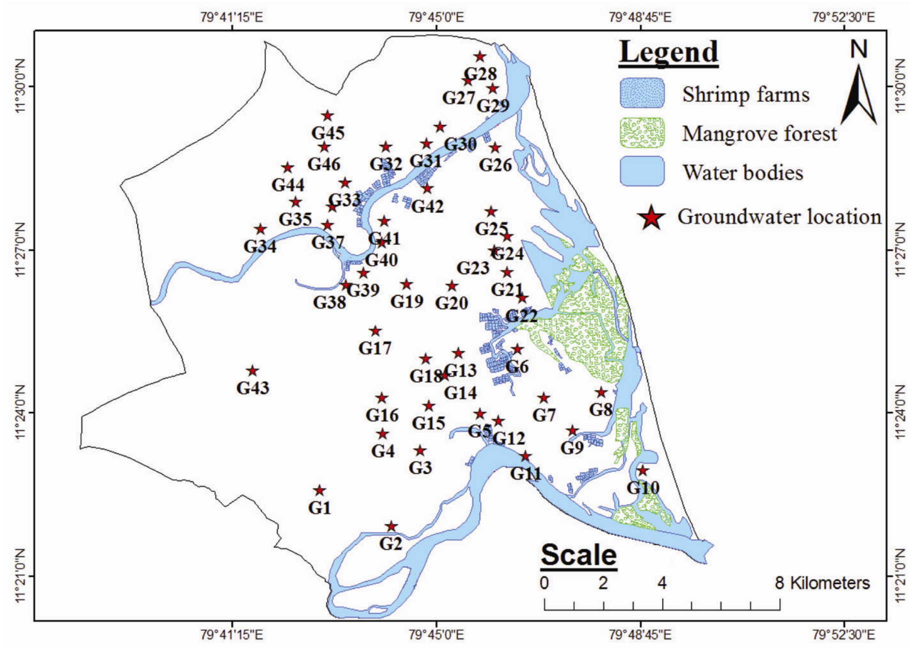

Figure 3. Groundwater sampling location map.

sensed data through the process of image classification[18]. It was hypothesized that the influence of shrimp farming on groundwater salinity could be felt when the groundwater TDS increases. Also as distance from the farm increases, salinity decreases. Satellite images were classified into seven classes, viz. water bodies, aquaculture ponds, settlement with vegetation, mangrove plantations, crop land, fallow land and barren land. A simple statistical analysis of the land-cover changes indicates that there was no aquaculture during 1991 and the groundwater quality analysis showed that among the seven wells, two wells at T. S. Pettai and Portonova were near aquaculture farms (located within 0.5 km from aquaculture farms). During 1991 itself, the TDS and EC values were high in these two wells. This led us to infer that the aquaculture was initiated in the study area where there was *in situ* salinity and the salinity was not built up in the study area following aquaculture (Figure 2 *a–f*). During 2000, it was observed that aquaculture was practised in 1% of area (2.1 sq. km) and this area increased by 1.6% to 4.0 sq. km by 2012. The spatial analysis clearly depicts that TDS and EC values are not high near shrimp farms, rather they are in patches near the sea shore (within 5 km from the sea coast) in the study area. Results (Figure 2 *e–f*) show that groundwater quality at Athivaraganallur and Anaiyankuppam, located about 0.5 km from the shrimp farm, had water with increased EC and TDS during 2000 compared to 2012. These show that there is no relation between area of aquaculture and groundwater quality. The geological condition coupled with precipitation due to monsoon influence the groundwater quality in the study area.

An increase in mangrove plantation has been recorded as visualized in Figure 2 *a–c*. It is observed that mangrove plantation which was about 1% during 1991 and 2000 increased to 4% by 2012. This happened at the expense of barren land. This may be due to efforts of re-plantation of mangroves by the forest officials under the eco-restoration plan. By contrast, the crop land which constituted about 16% during 1991 decreased to 8% in 2000 and thereafter increased to 20% during 2012. There appears to be no relation between the increase/decrease in shrimp farming with crop land or mangrove plantation. The crop land area varies based on the water resources available. The agriculture in the study area is rainfed and this is seen from the decrease/or increase in fallow land in relation to the rainfall received during the study period.

Hydrogeochemical study is a useful tool to identify and evaluate the main factors affecting groundwater quality. Groundwater samples were collected once in two months from 46 groundwater wells in this area (Figure 3) between October 2011 and June 2013 and analysed for pH, EC, TDS, cations and anions. The analytical precision for the measurements of cations and anions indicated by the ionic balance error was computed on the basis of ions expressed in mill equivalent per litre (meq/l). The values were observed to be within a standard error ±5% (ref. 19). The precise latitude and longitude of the sampling points were determined by e-Trex Vista HCxHigh sensitivity global positioning system (GPS). The descriptive statistics are given in Table 2. The pH ranged from 7.67 to 8.61, indicating alkaline nature of the groundwater in the area. The EC and TDS of the groundwater were in the range between 418–6792 μS/cm and 248–4396 mg/l

Table 2. Groundwater quality

Concentration of ions in the groundwater samples					WHO (1993 and 2004)		ISI (1983)	
Total study area								
Parameters	Minimum	Maximum	Average	Standard	Maximum accept limit (mg/l)	Maximum allowable limit (mg/l)	Highest desired limit (mg/l)	Maximum permissible limit (mg/l)
Ca (mg/l)	34	218	95	39	75	200	75	200
Mg (mg/l)	45	164	80	26	50	150	30	100
Na (mg/l)	19	821	225	183	–	200	–	–
K (mg/l)	1	68	21	17	45	–	–	–
Cl (mg/l)	119	1094	290	273	200	600	250	1000
NO_3 (mg/l)	2	49	10	10	45	–	–	–
SO_4 (mg/l)	4	84	34	25	200	400	–	–
HCO_3 (mg/l)	172	388	312	54	–	–	–	–
CO_3 (mg/l)	15	65	37	13	45	–	–	–
pH	7.67	8.61	8.04	0.21	6.5	8.5	6.5–8.5	6.5–9.5
EC (µs/cm)	418	6792	2305	1477	–	–	–	–
TDS (mg/l)	248	4396	1502	1001	500	1500	500	2000

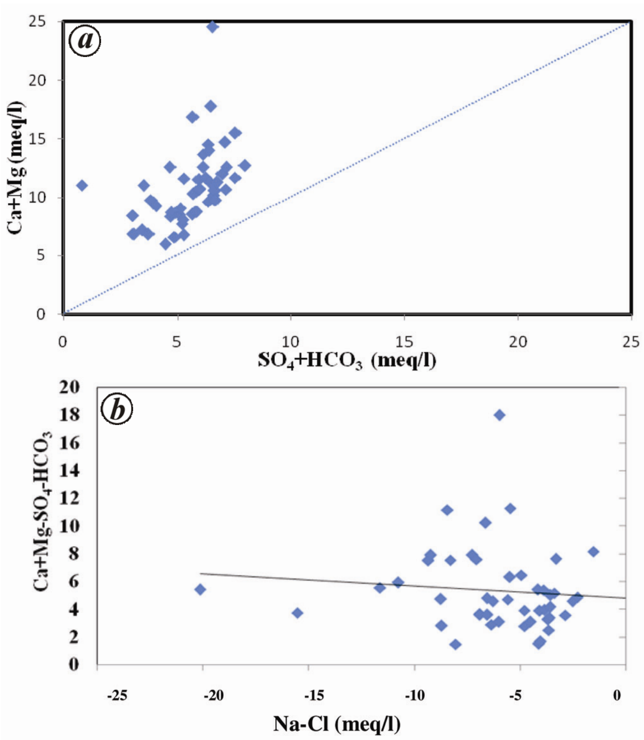

Figure 4. ***a***, Ca + Mg versus $HCO_3 + SO_4$. ***b***, Na–Cl versus Ca + Mg–HCO_3–SO_4.

respectively. The wide variation in EC and TDS observed in the study area indicates multiple sources influencing the groundwater quality.

Many a time information on chemical processes taking place in the groundwater system can be gauged by correlation of the concentration of major ions[20] in the groundwater using ionic ratios and indices. The scatter plot of Ca + Mg versus $HCO_3 + SO_4$ (Figure 4*a*), reveals the fact that calcium and magnesium are slightly in excess in the groundwater which could be the result of weathering of carbonates and sulphate minerals[21]. To be specific, this may be due to dissolution of calcite, dolomite and gypsum which are dominant reactions in the groundwater system in the study area[22] as the sampling locations mostly fall along the equiline ($Ca + Mg = HCO_3 + SO_4$). In addition to weathering, reverse ion exchange process also enhances the calcium and magnesium concentration in groundwater. This hypothesis is based on the fact that, if the Ca and Mg in the groundwater system in study area solely originated from carbonate and silicate weathering, these should be balanced only by alkalinity. However, most points are placed on the Ca + Mg side, which indicates excess calcium and magnesium derived from other process such as reverse ion exchange reactions. The plot of Na–Cl versus Ca + Mg–HCO_3–SO_4 (Figure 4*b*) also supports the hypothesized reverse ion exchange process, as the sampling points form a line with a slope of –0.0846. Another observation is that base ion exchange does not influence the ionic concentration significantly. If base ion exchange is the dominant process in the system, the sampling points should have formed a line with slope-1 which is not the case. This confirms that Ca, Mg and Na concentrations are inter-related through reverse ion exchange. To summarize, an excess of calcium and magnesium in the groundwater of sedimentary formations was observed due to the exchange of sodium in water by calcium and magnesium in clay material.

The ratio of $[Cl^-]/[HCO_3 + CO_3]$, which is referred to as the Revelle coefficient, was used to evaluate the salinity status in the groundwater[23,24]. Usually, chloride is the dominant ion in seawater and its concentration is much less in fresh groundwater. Similarly, bicarbonate is usually the most abundant ion in groundwater, but occurs in minor amounts in seawater[25]. If the ratio of $[Cl^-]/[HCO_3 + CO_3]$, is >2.0, then it indicates high possibility of salinity brought about by seawater intrusion. If it falls between 1.5 and 2.0, it is in the medium range and if it is

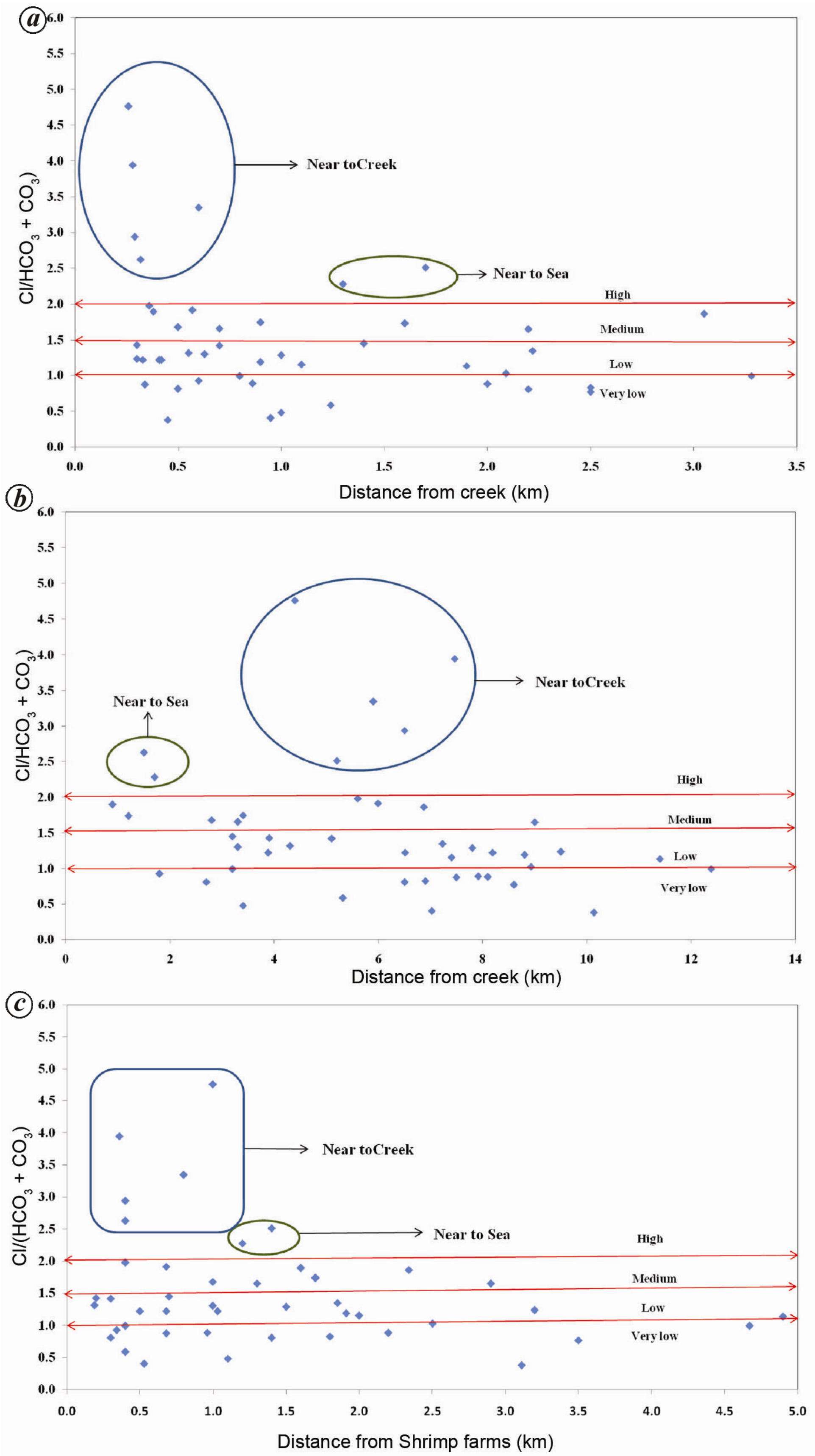

Figure 5. ***a***, $[Cl^-]/[HCO_3 + CO_3]$ versus distance from creek (km); ***b***, $[Cl^-]/[HCO_3 + CO_3]$ versus distance from sea (km); ***c***, $[Cl^-]/[HCO_3 + CO_3]$ versus distance from shrimp farms (km).

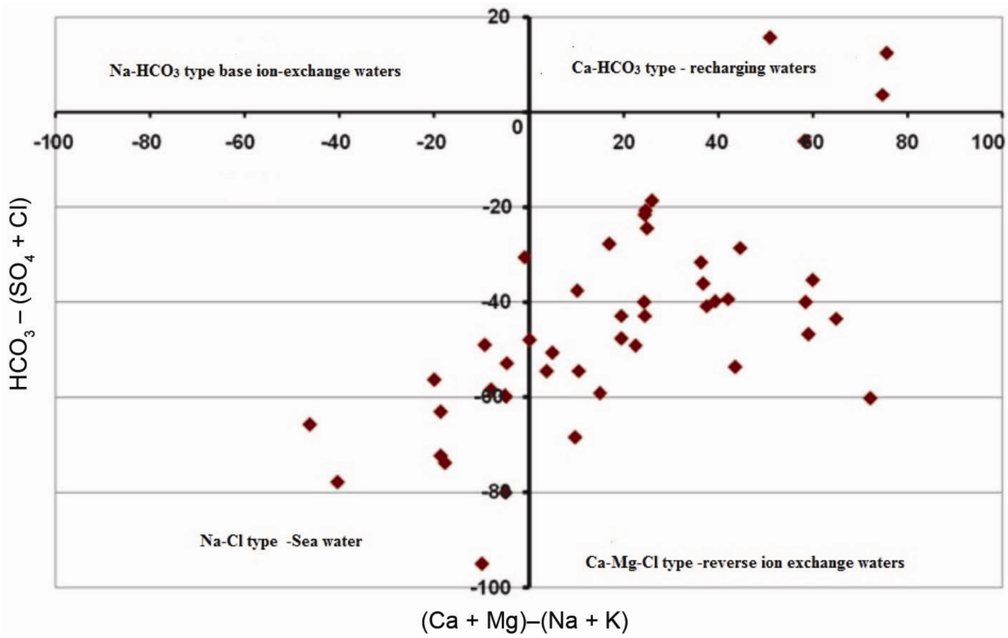

Figure 6. Chadha's classification.

between 1.5 and 1.0 it is low and if it is <1.0 it is very low. The plot of $[Cl^-]/[HCO_3 + CO_3]$versus distance from (shrimp farms, creek and sea) (Figure 5 *a–c*) shows that most of the groundwater data dominated by low to very low ratio lies near the shrimp farming area. If there is any elevated salinity, it is either near the creek or sea and not near the shrimp farm. This evidently suggests that shrimp farming is not the main reason for groundwater salinization.

To clearly bring out the hydro-geochemical processes for a coastal aquifer occurring in the study area, the diagram proposed by Chadha was adopted[26]. The groundwater quality data were converted to percentage reaction values (milliequivalent percentages) and expressed as the difference between the alkaline earths (Ca + Mg) and alkali metals (Na + K) for cations, and the difference between the weak acidic anions $(HCO_3 + CO_3)$ and strong acidic anions $(Cl + SO_4)$[27].

Chadha's plot (Figure 6) is characterized as follows:

Quadrant 1: $Ca–HCO_3$ type-recharging waters.
Quadrant 2: Ca–Mg–Cl type-reverse ion exchange waters.
Quadrant 3: Na–Cl type-Sea water.
Quadrant 4: $Na–HCO_3$ type base ion-exchange waters.

The groundwater quality of the study area was plotted and results are shown in Figure 6. It is observed that water from three sample wells, viz. G7, G33 and G34 falls in quadrant-1 (recharging water) indicating that calcium is the result of dissolved carbonate. G33, which is near the shrimp farm of the study area comes under this quadrant, which shows that groundwater quality is good. Therefore shrimp farming does not influence the groundwater quality.

About 65% of the samples (30 wells) fall in quadrant-2 which represents reverse ion exchange process. In groundwaters of this type, the Ca + Mg is in excess of Na + K due to reverse base exchange reactions of Ca + Mg in solution and subsequent adsorption of Na on to mineral surfaces. Quadrant-3 (Na–Cl type) waters represent the typical coastal aquifers wherein salinity is expected in the groundwater. Only 28% of the samples (13 wells), viz. G4, G5, G6, G11, G13, G17, G19, G20, G21, G27, G28, G39 and G41 were seen between recharging waters and Na–Cl type, indicating that fresh waters are becoming saline due to the coastal environment. Among these wells, only two wells G6 and G13 were near shrimp farms and other groundwater sample locations were either near the creek or coast. Quadrant-4 represents waters belonging to $Na–HCO_3$ type. No groundwater sample falls under this category. This elucidates that base ion exchange is not the preferred process for groundwaters of the study area.

All the analyses explain that changes in groundwater quality are in localized wells due to mineral weathering and not due to shrimp farming. The quality of groundwater in the study area can be attributed to many origins, such as marine contribution, the dissolution of secondary minerals within the sedimentary formations, inducing reverse ion exchange or most often, and a combination of some of these processes.

A multidisciplinary approach on watershed basis helped to prove that aquaculture is not the sole influencing factor of groundwater quality. The land use study revealed that though aquaculture was initiated after 1991, groundwater quality had elevated TDS even before aquaculture began, suggesting that aquaculture has been initiated in *in situ* saline area. The study also showed that there was no definite relationship between area of shrimp culture and the groundwater quality, indicating that there was no salinity build-up in the vicinity of shrimp farms. The hydrogeochemical analysis using Chadha's plot suggests that reverse ion exchange waters are dominant in the study area due to the natural geological conditions and this controls the groundwater quality, rather than sea water incursion. Thus the present study corroborates the previous conclusions where it was postulated that groundwater quality in the study area is mainly due to natural processes and that shrimp farming is not the influencing factor and the intensity of the problem of salinization of coastal groundwater is absolutely location-specific. Detailed scientific studies such as isotopes and geophysics are required to arrive at the real scenario at each location.

1. FAO, Food and Agriculture Organization of the United Nations. *Crop Prospects and Food Situation*, 2016.
2. Phillips, M. J., Lin, C. K. and Beveridge, Shrimp culture and environment; Lessons from the most rapidly expanding warm water aquaculture sector. In *Environment and Aquaculture in Developing Countries* (eds Pullin, R. S. V., Rosenthal, H. and Maclean J. L.), ICLARM Conference Proc., 1993, vol. 36, pp. 171–197.
3. Newport, J. K. and Jawahar, G. G. P., Brackisli water shrimp farming culture; impacton eco-environment and socioeconomic aspects of rural fisher folk. *Fishing Chimes*, 1995, **15**(5), 15–16.
4. Perez, O. M., Telfer, T. C. and Ross, L. G., On the calculation of wave climate for offshore cage culture sites election: a case study in Tenerife (Canary Islands). *Aquac. Eng*., 2003, **29**, 11–21.
5. Rosenberry, D. O., Watershed-scale research from many perspectives – the interdisciplinary research initiate at the Shingobee river Headwaters area. *US Geological Survey*, 1998, **4**, 044–98; http://www.brr.cr.usgs.gov/projects/IRI/fs-044-98.pdf
6. Primavera, J. H., Socio-economic impacts of shrimp culture in aquaculture research, South-east Asian fisheries development centre, Ilolio, 1997, vol. 28, pp. 815–827.
7. Paez-Osuna, F., Gracia, A., Flores-Verdugo, F., Lyle-Fritch, L. P., Alonso-Rodraguez, R., Roque, A. and Ruiz-Fernandez, A. C., Shrimp aquaculture development and the environment in the Gulf of California ecoregion. *Mar. Pollut. Bull.*, 2003, **46**, 806–815.
8. Lacerda, L. D., Vaisman, A. G., Maia, L. P., Silva, C. A. R. and Cunha, E. M. S., Relative importance of nitrogen and phosphorus emissions from shrimp farming and other anthropogenic sources for six estuaries along the NE Brazilian coast. *Aquaculture*, 2006, **253**, 433–446.
9. Paez-Osuna, F., The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. *Environ. Manage.*, 2001, **28**, 131–140.
10. Briggs and Fvnge-smith, S. J., A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquacul. Fish. Manage*., 1994, **25**, 789–811.
11. Jackson, C., Preston, N., Thompson, P. J. and Burford, M., Nitrogen budget and effluent nitrogen components at an intensive shrimp farm. *Aquaculture*, 2003, **218**, 397–411.
12. Páez-Osuna, F., Guerrero-Galván, S. R., Ruiz-Fernández, A. C., and Espinoza-Angulo, R., Fluxes and mass balances of nutrients in a semi-intensive shrimp farm in north-western Mexico. *Mar. Pollut. Bull.*, 1997, **34**, 290–297.
13. Jerald, J. A., Aquaculture pollution: a fallacy. *Fishing Chimes*, 1996, **16**(3), 19–20.
14. Panwar. S. and Chakrapani, G. J., Climate change and its influence on groundwater resources. *Curr. Sci.*, 2013, **105**, 37–46.
15. Rekha, P. N., Ravichandran, P., Gangadharan, R., Bhatt, J. H., Panigrahi, A., Pillai, S. M. and Jayanthi, M., Assessment of hydrogeochemical characteristics of groundwater in shrimp farming area in coastal Tamil Nadu. *Aquacult. Int*., 2013, **21**, 1137–1153.
16. Rekha, P. N., Gangadharan, R., Ravichandran, P., Mahalakshmi, P., Panigrahi, A. and Pillai, S. M., Assessment of impact of shrimp farming on coastal groundwater using Geographical Information System based Analytical Hierarchy Process. *Aquaculture*, 2015, **448**, 491–506.
17. APHA. *Standard Methods for the Examination of Water and Waste*, Public Health Associations, Washington, Am, 2005, 19th edn.
18. Campbell, J. B., *Introduction to Remote Sensing*, Taylor and Francis, London, Third edn, 2002.
19. Domenico, P. A. and Schwartz, W., *Physical and Chemical Hydrogeology*, Wiley, New York, 1998, 2nd edn, p. 506.
20. Elango, L. and Ramachandran, S., Major ion correlations in groundwater of a coastal aquifer. *J. Indian Water Reso. Soc*., 1991, **11**, 54–57.
21. Datta, P. S. and Tyagi, S. K., Major ion chemistry of groundwater in Delhi area: chemical weathering processes and groundwater flow regime. *J. Geol. Soc. India*, 1996, **47**, 179–188.
22. Rajmohan, N. and Elango, L., Modelling the movement of chloride and nitrogen in the unsaturated zone. In *Modelling in Hydrogeology* (Proc United Nations Educational, Scientific, and Cultural Organization – International Hydrological Program (UNESCO–IHP)) (eds Elango, L. and Jayakumar, R.), Allied, New Delhi, India, 2001, pp. 209–225.
23. Bowen, R., *Groundwater*, Elsevier Applied Science, London, 1986.
24. Revelle, R., Criteria for recognition of sea-water in ground-water [M]. *Trans. Amer. Geophys. Union* (part III). 1941, pp. 595–596.
25. Lenin Kalyana Sundaram, V., Dinesh, G., Ravikumar, G. and Govindarajalu, D., Vulnerability assessment of seawater intrusion and effect of artificial recharge in Pondicherry coastal region using GIS. *Indian J. Sci. Technol*., 2008, **1**(7), 1–7.
26. Vandenbohede, A., Courtens, C. and William de Breuck, L., Fresh–salt water distribution in the central Belgian coastal plain: an update. *Geol. Belg*., 2010, **11**(3), 163–172.
27. Karmegam, U., Chidambaram, S., Sasidhar, P., Manivannan, R., Manikandan, S. and Anandhan, P., Geochemical characterization of groundwaters of shallow coastal aquifer in and around Kalpakkam, South India. *Res. J. Environ. Earth Sci*., 2010, **2**(4), 170–177.

ACKNOWLEDGEMENT. The research grant to the first author by the Ministry of Water Resources, Government of India is gratefully acknowledged.

Received 8 December 2015; revised accepted 23 May 2017

doi: 10.18520/cs/v113/i09/1763-1770