SPATIAL AND TEMPORAL VARIATION IN GROUNDWATER CHARACTERISTICS OF THE COASTAL REGIONS OF TAMIL NADU

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Introduction

Coastal region is receiving more attention than before because of our multiple needs to meet the increasing demands for food, fuel wood, fodder, fibre, etc. of mounting demographic pressure all over world. This has created more pressure on coastal resources, which necessitates rational utilization of land and groundwater in coastal region. Groundwater is the major source of irrigation for coastal agriculture besides its domestic utility. The availability of groundwater depends mainly on rainfall and recharge from fresh water sources *viz.*, river and canal. The demand for fresh water is increasing drastically over the years and groundwater is being exploited beyond its renewable capability. This extensive exploitation lowers the groundwater level resulting in seawater intrusion and associated freshwater crisis in coastal region (Bear *et al.*, 1999).

Chemical composition of groundwater in coastal region differs broadly depending on diverse geo-hydrology, hydrometeorology, topography, drainage and other artificial conditions imposed (Kim *et al.*, 2005). The salinization processes in coastal area are very complex which is due to multitude of factors *viz.*, seawater intrusion, prawn culturing and pollution phenomena (Morell *et al.*, 1996). Groundwater quality in this intermediary tract is the balance among fresh water recharge, groundwater use and seawater intrusion. Maintaining groundwater quality is the most critical issue in coastal region and it necessitates understanding of seawater intrusion and salinization process for the wise management of groundwater. With this background, present work on groundwater characterization was carried out in the coastal region of Cuddalore district of Tamil Nadu, during 2006.

Material and Methods

Study area description

Study was conducted during 2006 in a part of coastal region of Cuddalore district comprising thirteen revenue villages with a coverage area of 8592.9 ha. The area lies between 11°28'3.60" and 11°38'27.45" N latitude and between 79°42'6.03" and 79°46'25.19" E longitude. The climate of the region is semi-arid with a mean annual rainfall of 1306 mm and mean annual air temperature of 29.1°C. The soil moisture and temperature regimes of the area are Ustic and Isohyperthermic, respectively. The coastal area is mainly underlain by alluvium in inlands, laterites in some pockets and sand along coastal region.

Groundwater sampling

The study area was divided into three transect zones based on the distance from the sea (Zone I - < 1.5 km; Zone II - 1.5 to 3 km and Zone III - > 3 km from the sea). Twenty-seven representative shallow wells were selected in the depth range of 20-30 feet for collecting water samples from shallow aquifers. This included seven from zone I, nine from zone II and eleven from zone III based on spatial variability. The samples were drawn as per standard procedures at tri-monthly interval from respective wells during the period of January to December 2006. The results are reported for summer and monsoon season to reduce the data complexity.

The pH and electrical conductivity were determined by adopting USSL Staff method (1954). Sodium and potassium were analysed by flame photometry (Stanford and English, 1949). Calcium and Magnesium were determined by versenate method (Diehl *et al.*, 1950). Anions *viz.*, carbonate, bicarbonate and chloride were determined by titration method (AOAC, 1950). Sulphate was determined by turbidity method as described by Tandon (1995).

Characterization of groundwater quality

Quality parameters of the groundwater *viz.*, Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), Potential Salinity (PS), Soluble Sodium Percentage (SSP), Residual Sodium Bicarbonate (RSBC), Magnesium Hazard (MH) and Permeability Index (PI) were computed using specific formulae as given below. In all calculations, concentrations were expressed in meq L^{-1}.

Residual Sodium Carbonate value (USSL Staff, 1954)

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

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Soluble Sodium Percentage value (USSL Staff, 1954)

$$SSP = \frac{Na^{+}}{CA^{2+} + Mg^{2+} + Na^{+}} x100$$

Sodium Adsorption Ratio (USSL Staff, 1954)

$$SAR = \frac{Na^{+}}{\sqrt{(CA^{2+} + Mg^{2+})/2}} x100$$

Potential Salinity (Doneen, 1975)

$$PS = Cl^{-} + \sqrt{SO_4^{2-}}$$

Permeability Index (Doneen, 1975)

$$Permeability index = \frac{(Na^{+} + HCO_3^{-})}{Ca^{2+} + Mg^{2+} + Na^{+}} x100$$

Residual Sodium Bicarbonate (Gupta, 1983)

$$RSBC = HCO_3^{-} - Ca^{2+}$$

Magnesium Hazard (USSL Staff, 1954)

$$MH = \frac{Mg^{2+}}{Ca^{2+}}$$

Results and Discussion

Characteristics of groundwater

The groundwater characteristics are presented in Table 1. Groundwater was alkaline in reaction irrespective of distance from seacoast and seasons. The degree of alkalinity decreased during monsoon season due to the fresh water dilution effect brought out by monsoon rain. The mean pH value for the whole study area was 7.81 and 7.68 for summer and monsoon season, respectively. The pH of groundwater in coastal region was dominantly controlled by seawater intrusion during summer season and rain water during monsoon season.

The EC of groundwater decreased both spatially and temporally. The mean EC value in zones I, II and III was 4.02, 2.05 and 1.79 dS m^{-1} during summer whereas in monsoon season it was 1.68, 1.12 and 1.29 dS m^{-1}, respectively. The higher EC (> 3 dS m^{-1}) in zone I was due to high concentration of chloride and sulphate salts of sodium and magnesium contributed by seawater (Gunnar *et al.,* 2007). With increasing distance from sea, Zone II and III recorded lesser EC value. Adequate fresh water recharge coupled with lesser extraction of groundwater produced sufficient hydrostatic pressure to prevent the seawater intrusion in these areas. Besides, variation in landform influences EC indirectly by influencing seawater intrusion (Ayers, 1977). The low EC value during monsoon season was because of dilution of soluble salts by rain water (Hanna and Altalabani, 1970). Higher soluble salt concentration in summer was due to the concentration of groundwater by massive evaporation and associated saltwater intrusion from sea.

Cation concentration in groundwater varied widely. Wells located in zone I recorded higher concentration of cations whereas wells located away from seacoast noticed lesser concentration. Overall mean concentration of Calcium, Magnesium, Sodium and Potassium were 3.23, 3.76, 4.08, 0.37 and 2.75, 2.97, 2.56, 0.31 meq L^{-1}, respectively for summer and monsoon season. Among cations, Sodium ion was more dominant followed by Magnesium, Calcium and Potassium in zone I, which is similar to seawater composition (Rajasekar *et al.,* 2007). In zone II, Magnesium and Sodium were more or less equal in proportion but calcium was moderately less. This showed partial mixing of seawater in this zone (Mahendran and Arunachalam, 2002). In case of wells in zone III, Calcium ion was more dominant than Magnesium, Sodium and Potassium except few wells, which indicates it is of fresh water origin. Higher concentration of cations was recorded during summer whereas monsoon season showed lowest concentration.

Carbonate was absent in all wells throughout the year. The concentration of bicarbonate was 2.56, 3.31, 3.98 and 2.42, 3.51, 4.12 meq L^{-1}, respectively for zone I, II and III during summer and monsoon season. High concentration of bicarbonate was observed during monsoon season and this was due to the dissolution of carbonate minerals by downward rainwater from soil. Bicarbonate concentration increased spatially with increasing distance from sea. Similar findings were reported for the groundwater in the coastal region of Ramanathapuram, (Tamil Nadu) by Rajasekar *et al.* (2007).

A decreasing trend of chloride concentration was observed with increasing distance from sea as well as progressing from summer to monsoon season. The mean values of chloride concentration in wells located in zone I, II and III were 8.51, 3.49, 3.03 and 4.01, 2.49, 2.66 meq L^{-1}, respectively for summer and monsoon season. The chloride ion concentration was very high along seacoast as a result of saline water mixing and to some extent by leaching from topsoil (Ramanathan *et al.,* 1998).

The sulphate ion concentration in groundwater was higher in summer followed by monsoon season. The mean sulphate ion concentration in zone I, II and III were 1.79, 1.34, 1.26 and 1.29, 1.14, 1.04 meq L^{-1} in summer and monsoon season, respectively. With respect to spatial variation, sulphate concentration increased in the close vicinity of sea due to sulphur contribution by seawater (Frapporti *et al.,* 2001).

Table 1
Characteristics of groundwater

Parameter	Zone I		Zone II		Zone III		Average	
	Summer	Monsoon	Summer	Monsoon	Summer	Monsoon	Summer	Monsoon
pH	7.77	7.62	7.91	7.75	7.77	7.6	7.81	7.68
EC (d S m^{-1})	4.02	1.68	2.05	1.12	1.79	1.29	2.45	1.33
Ca^{2+}(meq L^{-1})	3.46	2.40	3.18	2.74	3.12	2.97	3.23	2.75
Mg^{2+}(meq L^{-1})	4.69	3.30	4.18	3.08	2.84	2.66	3.76	2.97
Na^{+}(meq L^{-1})	7.82	4.09	3.80	2.69	1.92	1.49	4.08	2.56
K^{+}(meq L^{-1})	0.37	0.31	0.30	0.24	0.42	0.36	0.37	0.31
HCO_3^- (meq L^{-1})	2.56	2.42	3.31	3.51	3.98	4.12	3.39	3.48
Cl^- (meq L^{-1})	8.51	4.01	3.49	2.49	3.03	2.66	4.60	2.95
SO_4^{2-}(meq L^{-1})	1.79	1.29	1.34	1.14	1.26	1.04	1.42	1.14

Table 2
Quality characteristics of groundwater

Parameter	Zone I		Zone II		Zone III		Average	
	Summer	Monsoon	Summer	Monsoon	Summer	Monsoon	Summer	Monsoon
RSC (meq L^{-1})	-5.59	-3.28	-4.04	-2.31	-1.97	-1.51	-3.60	-2.24
RSBC (meq L^{-1})	-0.90	0.02	0.13	0.77	0.86	1.15	0.16	0.73
SSP	48.69	41.39	31.10	29.46	24.51	21.06	32.98	29.13
SAR	3.88	2.42	1.94	1.57	1.13	0.90	2.12	1.52
MH	1.36	1.39	1.36	1.17	0.98	0.94	1.20	1.14
PS (meq L^{-1})	9.83	5.14	4.62	3.54	4.15	3.68	5.78	4.01
PI	65.50	66.48	66.10	75.63	75.46	78.80	69.76	74.55

RSC: Residual Sodium Carbonate; RSBC: Residual Sodium Bicarbonate; SSP: Soluble Sodium Percentage; SAR: Sodium Adsorption Ratio;
MH: Magnesium Hazard; PS: Potential Salinity; PI: Permeability Index

Water quality parameters

Table 2 depicts the quality of ground water in this coastal region. All wells in the study area recorded RSC values much less than the critical limit of 1.25 meq L^{-1} in all seasons, which is acceptable for agricultural uses. The RSBC hazard value slightly increased with increasing distance from sea. In case of temporal variation, the monsoon season registered positive RSBC value compared to summer season. The mean RSBC value in zone I, II and III during summer and monsoon seasons were -0.90, 0.13, 0.86 and 0.02, 0.77, 1.15 meq L^{-1}, correspondingly. The carbonate and bicarbonate concentration was comparatively lesser than the Calcium and Magnesium concentration; hence all wells registered a negative RSC value. All wells within 1.5 km from the sea registered a negative value, which indicated the dominance of Calcium ion over bicarbonate ion along the coastal zone. RSBC value was found to be higher during post monsoon season due to the dissolution of carbonates with rain water.

Mean soluble sodium percentage was less than the critical limit (60 per cent) except in few wells in Zone I during summer. But it was nearer to critical limit in most of the cases. The SAR values in groundwater samples were less than 10 in all wells and the mean values were 3.88, 1.94, 1.13 and 2.42, 1.57, 0.90, respectively for zone I, II and III during summer and monsoon seasons. The SSP and SAR value decreased with increasing distance from sea as well as temporally from summer to monsoon season which is mainly controlled by seawater intrusion (Kumaraperumal, 2006) and rain water dilution (Rajasekar *et al.*, 2007).

Mean magnesium hazard value was more than 1.00 in all wells in zone I and II and more than 0.90 in zone III throughout the year. Continuous use of this water for irrigation causes nutrient imbalance in soil leading to loss of soil fertility. But mean value showed a decreasing trend with increasing spatial distance from sea as well as temporal progression from summer to monsoon season which is primarily because of lesser seawater intrusion in zone III and fresh water recharge during monsoon season.

The results on potential salinity indicated that potential salinity decreased with increasing spatial distance from sea. With respect to temporal variations, the mean potential salinity showed a decreasing trend from summer to monsoon season. The overall mean value of potential salinity was 5.78 and 4.01 for summer and monsoon season, respectively. High potential salininty in zone I was due to the contribution of chlorides and sulphates by seawater whereas in zone II and III, it was relatively lesser indicating partial seawater mixing.

Mean permeability index in zone I, II and III was 65.50, 66.10 and 75.46 during summer and 66.48, 75.63 and 78.80 during monsoon season. The permeability index increased with increasing distance from sea and from summer to monsoon season. The higher value of permeability index indicates the less permeability of water in soil (Doneen, 1975). The continuous use of this water for irrigation will degrade the soil physical properties.

Conclusion

Groundwater quality in coastal region is influenced by multitude of factors viz., rainfall, artificial recharge, soil, topography, domestic exploitation, seawater intrusion and other artificially imposed conditions. Among this, seawater intrusion determines the quality in whole of coastal lands. Saline water contamination occurs mostly during summer season during which hydrostatic groundwater pressure from inland is low. Extensive exploitation of groundwater aggravates this salt water intrusion. Present study infers that the groundwater in zone I is very poor due to seawater intrusion. In zone II and III, the groundwater quality was moderate indicating lesser intrusion of seawater. Even then these zones are more vulnerable to seawater intrusion if groundwater is utilized more. Hence, continuous use of saline water for irrigation would create soil salinity problems and nutrient imbalances. This will result in decreasing soil productivity and affect sustainability of production. Hence, sufficient care might be taken when utilizing this water for agricultural/agroforestry/forestry purposes. This necessitates the optimum use and wise management of groundwater in coastal region.

SUMMARY

This research work was aimed to study the spatial and temporal changes in groundwater quality of the coastal region of Cuddalore district, Tamil Nadu. The study was conducted during 2006 for which the coastal area was divided in to three zones based on 1.5 km spatial distance from sea. The groundwater was collected from 27 representative shallow wells for the whole year with three-month interval representing different seasons. The water samples collected were characterized for its chemical composition as well as electro-chemical properties. Based on the chemical composition, different quality parameters were arrived. The results revealed that 88 per cent of the wells recorded for slightly alkaline pH ranging from 7.6 to 7.9 with electrical conductivity varying from1.1 to 4.0 dS m^1. The sodium and magnesium hazard was higher in most of the wells. Seawater intrusion is the key factor, which decides the quality of groundwater in this coastal zone. Natural rainfall is the next most important factor which balances the negative effects of seawater intrusion. In total, the

groundwater quality of this coastal zone was poor during summer and optimum during monsoon and post monsoon seasons which necessitates that sufficient care may be taken when using this water for agricultural/agroforestry/forestry/other land use purposes.

Keywords: Ground water quality, coastal region, seawater intrusion, spatial variation, temporal variation.

तमिलनाडु के समुद्रतटवर्ती क्षेत्रों के भूमिजल की विशेषताओं में पाई जाती स्थलीय और समय जुड़ी विभिन्नता

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सारांश

इस गवेषणा कार्य का उद्देश्य जिला कड्डालूर, तमिलनाडु के सागरतटीय क्षेत्र के भूमिजल की गुणवत्ता में होते स्थलीय और समय जुड़े परिवर्तनों का अध्ययन करना था। यह अध्ययन 2006 में सम्पन्न किया गया जिसमें सागरतटीय क्षेत्रों को तीन प्रदेशों में बांट दिया गया जिन्हें समुद्र से 1.5 किमी स्थल दूरी के आधार पर निश्चित किया गया। तीन महीने का अन्तराल रखकर, जो मौसमों का सूचक था, पूरे वर्ष भर प्रतिनिधि उथले 27 कुओं से भूमिजल संग्रह किया गया। संग्रहीत जल नमूनों की रासायनिक गठन और विद्युत रासायनिक विशेषताएं मालूम की गई। रासायनिक गठन के आधार पर विभिन्न गुणवत्ता परिमाण ज्ञात किए गए। परिणामों से पता चला कि 88% कुओं का जल मामूली क्षारीय पी.एच वाला , 7.6 से 7.9 तक था जिसका विद्युत संवाहकता 1.1 से 4.0 dsm^{-1} तक थी। सोडियम और मैगनीशियम संकट अधिकांश कुओं में ज्यादा निकला। समुद्रजल का प्रवेश मुख्य कारक है जो इस सागरतटीय क्षेत्र के भूमिजल की गुणवत्ता निश्चित करती है। दूसरा सबसे महत्वपूर्ण कारक प्राकृतिक वर्षा है जो समुद्रजल प्रवेश के नकारात्मक प्रभावों को संतुलित करता है। कुल मिलाकर इस सागर तटीय क्षेत्र के भूमिजल की गुणवत्ता गर्मियों में घटिया और मानसून वाले मौसम में इष्टतम गुणों वाली रहती है जिससे यह आवश्यक हो जाता है कि इस जल को कृषि/कृषि वानिकी/वानिकी/अन्य भूमि उपयोगों में काम लगाते समय काफी सावधानी बरती जानी चाहिए।

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