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Spatial and Temporal Variation in Groundwater Quality and Impact of Sea Water in the Cauvery Delta, South India

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Abstract: The spatial and temporal groundwater quality of the Cauvery delta in Tamil Nadu was studied. Groundwater samples were collected from fifty locations during the post monsoon season (February 2014) and the pre monsoon season (June 2014). The collected samples were analyzed for physicochemical characteristics like pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, $S0_4^{2-}$, CO_3^{-} and HCO_3^{-}. Geographical Information System (GIS) was used for the preparation of maps showing spatial and temporal distribution of water quality parameters in the study area. The changes in the concentration of various water quality parameters were evident in spatial distribution maps. The study highlighted that 56% of samples in the post monsoon season and 46% of samples in the pre monsoon season are fit for drinking. The values of total hardness suggest that all samples in both the seasons fall in the category of very hard water. The results of the present study are expected to be of great use for the Cauvery delta. The delta is important from the points of view of agriculture and ecology.

Keywords: *Groundwater, water quality, spatial variation, Cauvery delta*

1. Introduction

Water is a vital asset needed for all living organisms on the earth. The fresh water is a primary need of human beings. Generally, groundwater is considered to be purer and safer than surface water. During the summer season, dependence on groundwater is more due to lack of surface water sources. Due to over exploitation and pollution, groundwater has become scarce. Groundwater is a major source of fresh water for different purposes like drinking, irrigation and industrial uses. The increasing demand of water for various needs results in misuse of groundwater. Groundwater quality is subject to deterioration due to various hydro geochemical processes and anthropogenic activities. The coastal areas witnessed fast growth of towns and cities in the recent past along with development of agricultural, industrial and tourism activities. The proximity of coastal aquifers to the sea, presence of saline soil and brine, agricultural activities as well as geological, geomorphological and hydrological factors cause salinity intrusion in to aquifers. Coastal cities are highly vulnerable to sea water intrusion [1, 2, 3].

The chemical alteration of recharging meteoric water of the area acquires unique groundwater chemistry [4, 5]. Anthropogenic activities and geological formations of an area influence the physical and chemical variations in the groundwater quality [6, 7, 8, 9].

The present study was carried out in the Nagapattinam and Karikal districts on the coastal belt of Cauvery delta. The study area includes one of the largest rice producing districts in Tamil Nadu. The coastal stretch has several salt pans and aqua culture farms. The Vedaranyam wetland ecosystem consisting of a combination of mangroves, salt marshes, lagoons, tidal channels and mudflats is in this delta; the Point Calimere, the only Ramsar wetland in Tamil Nadu, is under threat due to salt pans and aqua culture farms in and around it.

2. Materials and Methods

2.1. Description of the Study Area

Nagapattinam and Karikal are the coastal districts in Tamil Nadu and Puduchery respectively situated on the eastern Coromondal coast. The study area is bounded by Cuddalore district on the north, Bay of Bengal on the east, Palk Strait on the south and Thiruvarur district on the west. It lies between 10^0 15' and 10^0 24' N and 79^0 30' and 79^0 50' E longitude with a total area of 2,876 km^2 (Fig 1). The study area is a part of the Cauvery delta and the delta is known as the 'rice bowl' of Tamil Nadu. Irrigation channals and waterways of river Cauvery crisscross the study area; important irrigation channels of Cauvery in the area are Tirumalairajanar, Arasalar, Vennar, Kollidam and Vettar. The delta is having a gentle slope towards the Bay of Bengal on the eastern side, many channels of Cauvery river flow through the study area. The study area is mostly underlined by fluvial-marine sediments like the mixture of sand, silt and clay of Quaternary formation [10]. Sand, clay and gravel constitute Pliocene and Quaternary aquifers. On the eastern and south eastern part of the study area, the aquifer is clayey except in the coastal stretches where beach sand is found. In these formations, groundwater occurs as confined, unconfined and semi confined conditions. Groundwater from these formations is generally extracted by filter points, tube wells and

open wells. The aquifer depths are different in different locations; the shallow aquifer depth varies from 3 to 35 m and deep aquifer depth varies from 80 to 100m. Nagapattinam receives an average annual rainfall of 1372 mm with 76 percentage of rainfall in the north east monsoon season and the rest in other seasons [11]. Semi-arid climate is experienced in the area of study. The river flow to the deltaic region is controlled by a series of dams constructed across the Cauvery river [12]. The delta is important from the angles of agriculture and ecology.

Fig 1: *The study area with groundwater sampling stations*

2.2. Groundwater Sampling and Analysis

Fifty groundwater samples were collected from the open wells and hand pumps during February and June 2014 from the study area to determine the water quality. A GPS (GARMIN 76 CSx) was used to fix the sampling locations and import it to Arc Gis. While collecting samples, standard procedures were followed; one liter capacity polythene bottles were used for the collection of samples. The bottles were washed using diluted HNO_3 acid and distilled water in the laboratory prior to sample collection. The pH and EC of the collected groundwater samples were measured in-situ in the field using Hach HQ40d. The TDS was estimated from the EC; total hardness, Ca^{2+}, Mg^{2+}, CO_3, Cl^- and HCO_3^- were determined titrimetrically. ELCO Cl380 flame photometer was used to determine Na^+ and K^+ and SO_4^{2-} using turbidity method. The physico-chemical parameters for the pre monsoon and post monsoon seasons are given in Table 1 as a statistical summary. The details on the permissible limits of water quality parameters as per WHO are given in Table 2. In order to present the water quality parameters determined on a spatial platform, spatial distribution maps were prepared using Arc Gis software. IDW algorithm interpolates values between known measurements. It estimates weighted average values of surrounding sample locations. The weights are calculated by the inverse of the distance from an observation site to an estimate. If the sampling locations are close to each other, the local variation can be represented by IDW method.

Table 1 *Physico-chemical parameters for the pre monsoon and post monsoon seasons*

Water Quality Parameters	Post-monsoon			Pre-monsoon		
	Min	Max	Avg	Min	Max	Avg
pH	6.4	8	7.3	6.5	8.1	7.3
EC	289.8	10540	2307.1	399.6	12450	2469.1
TDS	185.4	6745.6	1476.6	255.74	7968	1580.2
TH	480	8080	1775.6	420	6120	1546
Ca^{2+}	48	896	302.2	24	1040	255.2
Mg^{2+}	62.4	1809.6	244.8	19.2	1209.6	217.9
Na^{1}	18.7	1425	267.3	29.1	1110	260.9
K^+	6.6	256.2	45.48	5	266.8	53.4
Cl^-	185.5	6745.6	1476.6	60.1	3764.2	524.2
SO_4^{2-}	16.1	956.4	152.8	14.8	476.7	75.8
CO_3^-	0	60	21.6	40	420	112
HCO_3^-	30	140	65	120	770	261

Table 2 *Permissible limits for drinking water as per WHO standards*

Water Quality Parameters	WHO		Post-monsoon		Pre-Monsoon	
	Most desirable limits	Max. allowable limits	No. of samples exceeding allowable limits	Percentage of samples exceeding allowable limits	No. of samples exceeding allowable limits	Percentage of samples exceeding allowable limits
pH	6.5-8.5	9.2	0	0	0	0
EC	-	1400	24	48	28	56
TDS	500	1500	16	32	18	56
TH	-	500	48	50	47	94
Ca^{2+}	75	200	32	64	6	12
Mg^{2+}	50	150	25	50	24	48
Na^+	-	200	23	46	24	48
K^+	-	12	35	70	39	78
Cl^-	200	600	9	18	15	30
SO_4^{2-}	200	400	5	10	6	12

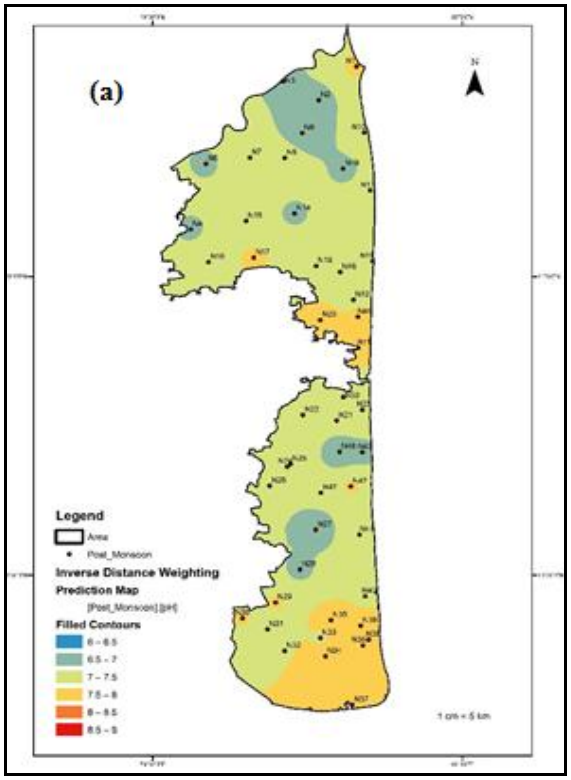
3. Results and Discussions

3.1. pH

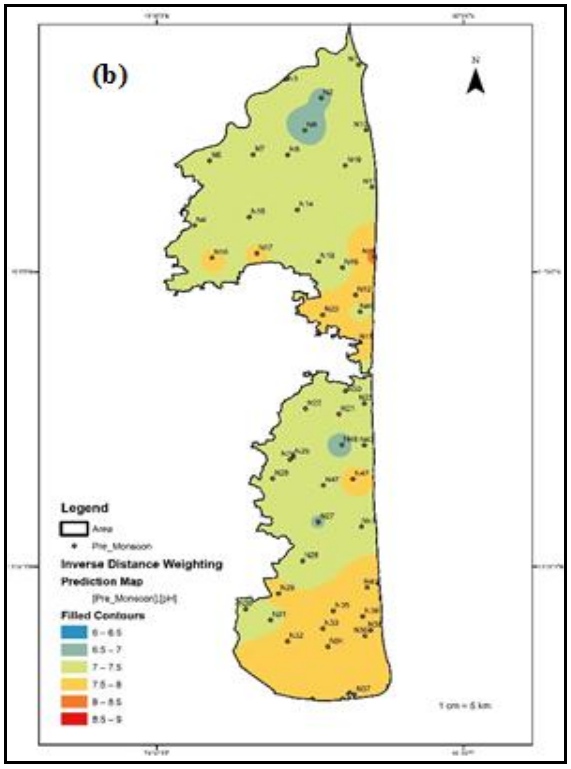
The pH is considered as the primary parameter to assess the quality of water since it decides the alkaline or acidic nature of water. Dissolved carbon dioxide, carbonate and hydroxide are primary causes of alkalinity in drinking water; pH value in the range of 6.5 and 8.5 is considered as desirable limit and 9.2 as maximum allowable limit by WHO [13]. In the post monsoon season, groundwater sample from Sirkazhi gives a pH value of 6.5 and from Thettakudi, a value of 8. In the pre monsoon season, the sample from Nirtharamangalam gives a pH value of 6.5 and from Tharagambadi, a value of 8.1. From the spatial distribution maps (Fig.2), central and southern parts show higher values of pH. The reason for high pH value in the central part is due to the chloride of sea water or marine clay. This area is highly populated and depends on groundwater for its needs; this may cause over extraction leading to salt water intrusion [14, 15, 16]. Carbonate and bicarbonate rocks are the main causes for alkalinity in groundwater, other minor contributors being borates, silicates and hydroxides.

3.2. Electrical Conductivity (EC)

Electrical conductivity of the study area varies from 290 to 10,540 µS/cm and from 400 to 12450 µS/cm in the post monsoon and pre monsoon seasons.



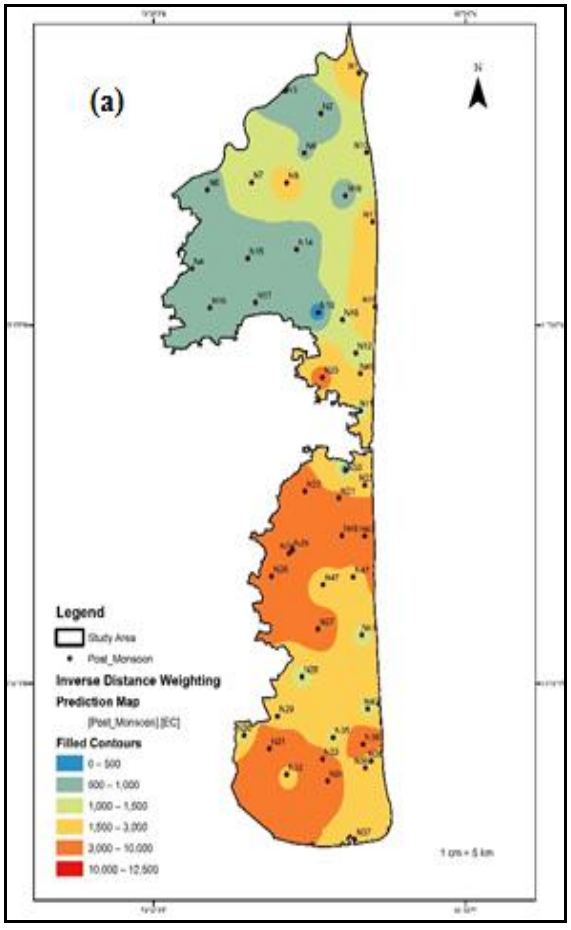
(a) Post monsoon



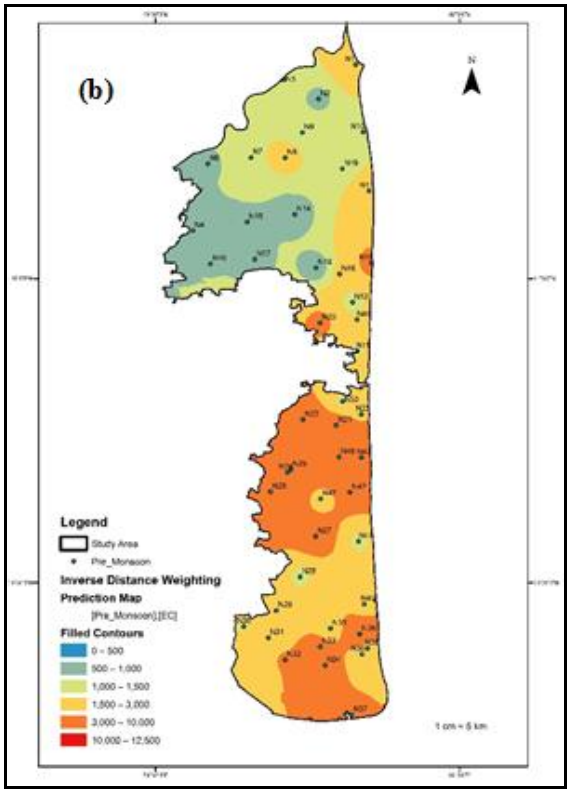
(b) Pre monsoon

***Fig. 2** Spatial variation of pH*

In both the seasons, Sankaran Pandal showed minimum concentration and maximum concentration was observed at Killugudi School well. The study area highlighted that 54 percentage of samples in the post monsoon season and 46 percentage of samples in the pre monsoon season were under the permissible limit (<1,500 µS/cm). Rest of the groundwater samples were either classified as not permissible or under hazardous category. Also 22 percentage of samples in the post monsoon and pre monsoon seasons fall in the range of 1,500 and 3,000 µS/cm which comes under the classification of not permissible; 24 percentage of samples in the post monsoon season and 32 percentage of samples in the pre monsoon season are found to be hazardous (> 3,000 µS/cm). A detailed classification of groundwater based on EC is given in Table 3. Drinking water with high electrical conductivity causes variation of blood pressure in children and water balance disturbance. High EC can also have negative effects on kidney patients and heart patients. The plants with high EC may prevent water absorption by roots due to elevated osmotic pressure created by salinity [17]. Figure 3 shows spatial distribution of EC in the study area. The EC concentrations are higher in coastal belts and southern part of the study area since sea water intrusion is a major cause for its high values in the coastal stretches.



(a) Post monsoon



(b) Pre monsoon

***Fig. 3** Spatial variation of EC*

Due to the presence of flow in the Kollidam channel of Cauvery, the salinity levels are low in the nearby wells. There can be a lateral recharge to sandy aquifers on the northern part of study area adjacent to the channel; low EC values are observed on the northern parts. Because of the peculiar geomorphology and also because the eastern and southern sides are covered by sea and also landforms are just above MSL, the southern streach is prone to saline water intrusion. The presence of aquaculture farms near the coast and also the backwater causes salinity in the channels of Cauvery delta.

***Table 3** Groundwater classification according to EC values*

Range of EC	Classification	Post-monsoon		Pre-Monsoon	
		No. of samples	Percentage of samples	No. of samples	Percentage of samples
< 1,500	Permissible	27	54	23	46
1,500-3,000	Not permissible	11	22	11	22
>3,000	Hazardous	12	24	16	32

3.3. Total Dissolved Solids

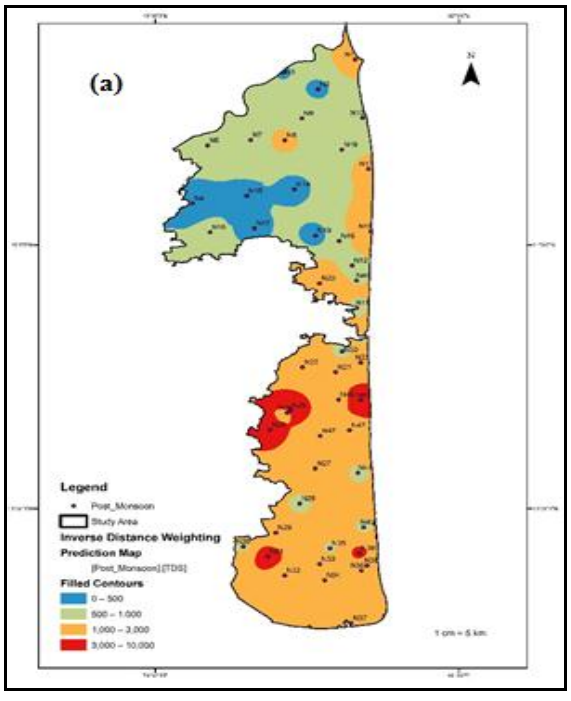
It is the measure of all the organic and inorganic content dissolved in weter. It represents the minerals present in the groundwater in the dissolved form. The TDS is generally calculated by multiplying EC value with a factor of 0.64. As per WHO standards, desirable limit of TDS is 500 mg/l and the maximum allowable limit is 1,500 mg/l.The TDS shows the same trend as the EC. The study area shows a range of TDS from 186 mg/l to 6745 mg/l in the post monsoon season and from 256 mg/l to 7968 mg/l in the pre monsoon season. In both the seasons and Killugudi School the maximum concentration. Groundwater classification based on TDS, recommended by Davis and De Viest, is given in Table 4. High TDS is due to longer residence time. Spatial distribution map of TDS shows high concentrations along the coastal belt, increasing from the central to southern part.

***Table 4** Groundwater classification based on TDS*

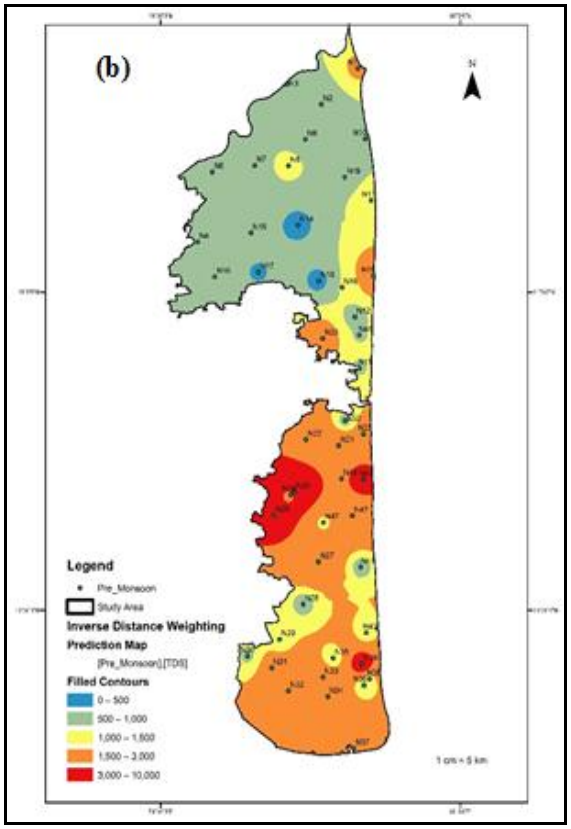
Range of TDS	Classification	Post-monsoon		Pre-Monsoon	
		No. of samples	Percentage of samples	No. of samples	Percentage of samples
< 500	Desirable for drinking	8	16	4	8
500-1,000	Permissible for drinking	20	40	20	40
1,000-3,000	Useful for irrigation	17	34	22	44
>3,000	Unfit for drinking	5	10	4	8

3.4. Calcium

The presence of calcium in groundwater is due to minerals of silicate group and shale, sandstone and carbonate rocks. Generally, calcium concentration is higher than magnesium. Desirable limit of calcium in groundwater is 75 mg/l and maximum permissible limit is 200 mg/l in drinking water as per WHO. In the post monsoon season, low concentration was observed at Sirkazhi (48 mg/l) and high concentration at Manakudi (896 mg/l). In the pre monsoon season, low concentration was observed at Vaitheswaran Kovil (24 mg/l) and high concentration at Ayakarapulam (1040 mg/l). Fig. 5 shows the spatial distribution of calcium with higher concentrations in the coastal belt and southern part. Ayakarapulam and Manakudi, closer to the backwaters, show higher concentration of calcium.

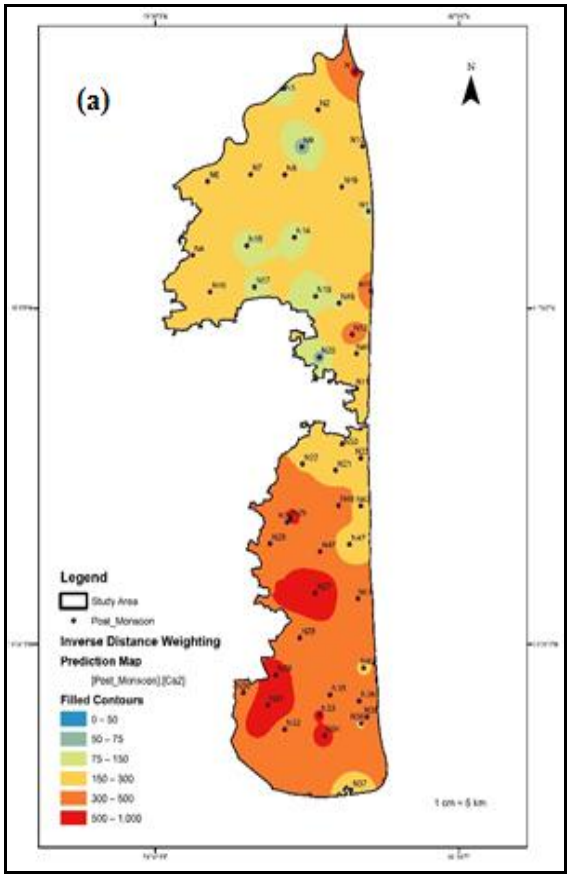


(a) Post monsoon

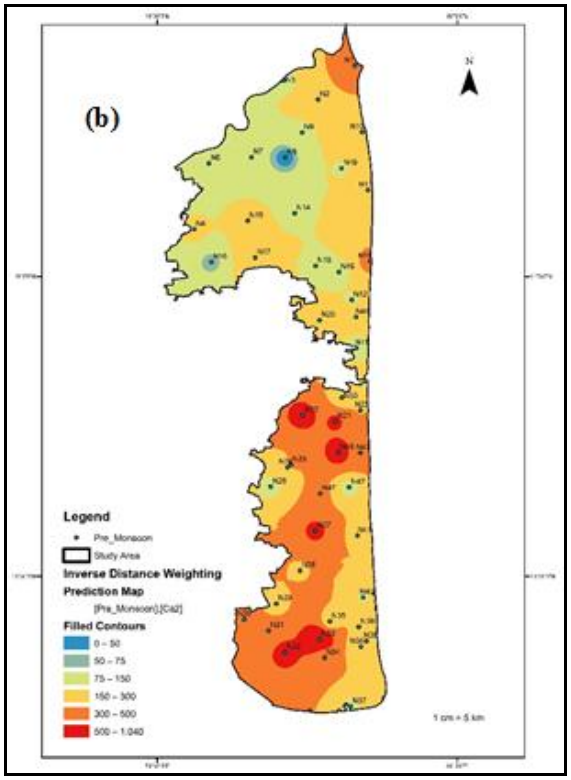


(b) Pre monsoon

Fig. 4 *Spatial variation of EC*



(a) Post monsoon



(b) Pre monsoon

Fig.5 *Spatial variation of Ca (mg/l)*

Table 5 *Groundwater classification according to TH values*

Range of TH	Classification	Post-monsoon		Pre-Monsoon	
		No. of samples	Percentage of samples	No. of samples	Percentage of samples
< 75	Soft	0	0	0	0
75-150	Moderately hard	0	0	0	0
150-300	Hard	0	0	0	0
>300	Very Hard	50	100	50	100

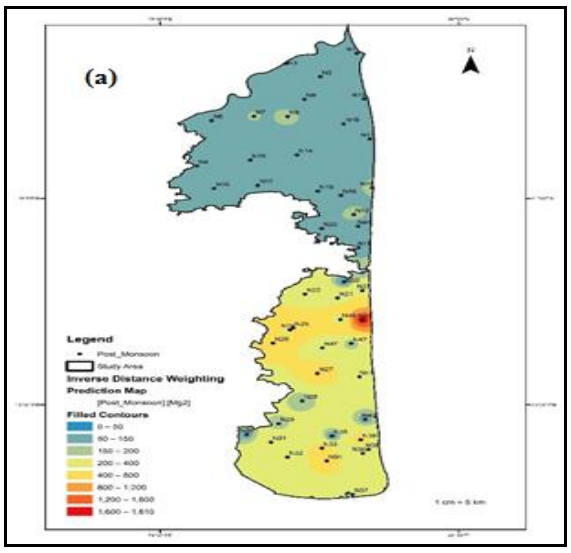
3.5. Magnesium

Dissolution of magnesium is a slow process and the groundwater samples from the area show low concentration of magnesium compared to calcium. Higher concentration of magnesium in drinking water may cause vomiting, depression, nerve problem, diarrhea and muscle slackening. Concentration of Mg in the samples ranged between 62.4 and 1809.6 mg/l in the post monsoon and between 19.2 and 1209.6 mg/l in the pre monsoon. In the post monsoon, low concentration was at Parvai and high concentration at Sankaran Pandal and in the pre monsoon season, low concentration at Thirunallar and high concentration at Killugudi School. Spatial distribution maps of magnesium are shown in Fig 6. The map shows higher concentrations on the south of Karikal district.

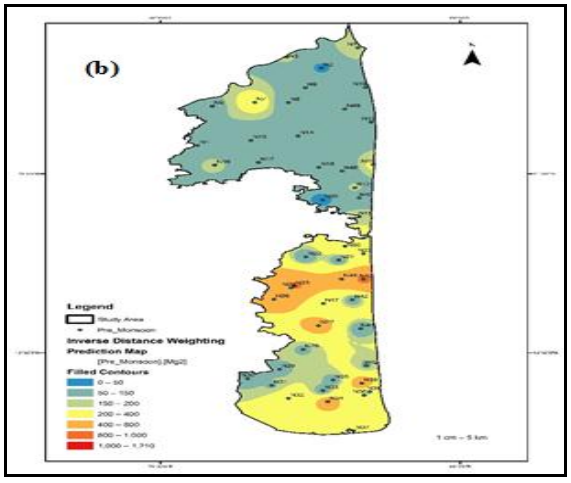
3.6. Total Hardness (TH)

Hardness of water is determined by the presence of multivalent cations like Ca_2^+ and Mg_2^+ in water samples. Hardness in groundwater is caused by

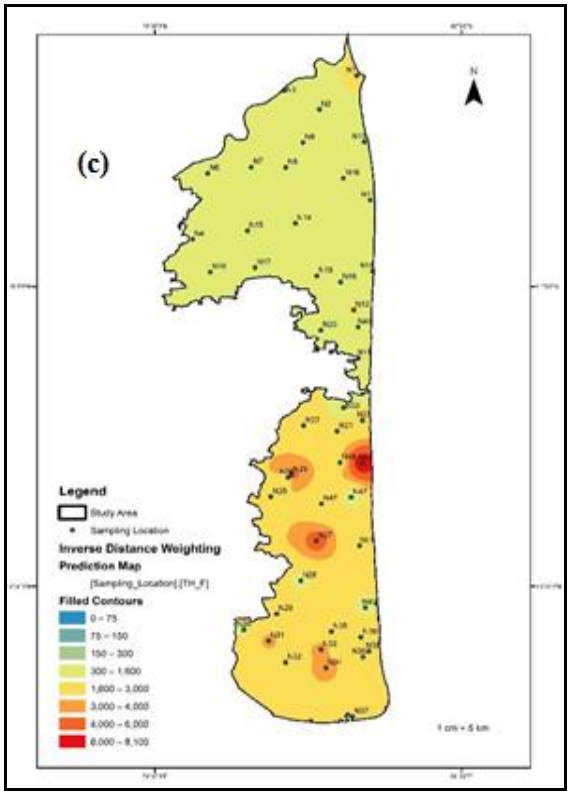
dissolved polyvalent metallic ions like magnesium and calcium. Hardness may be due to carbonates and non-carbonates. The WHO recommends permissible limit of hardness for drinking water as 150 mg/l. The range of total hardness varies from 480 mg/l at Sirkazhi to 8080 mg/l at Paravi in the post monsoon and from 420 mg/l at Vaitheswaran Kovil to 6120 mg/l at Killugudi School sample in the pre monsoon season. Hardness causes an alkaline taste to water, and soap and detergents do not produce foam when hard water is used. Total hardness may cause scales on boilers and pipes. Hardness can cause cardiovascular problems in human beings. A detailed classification of total hardness of groundwater samples is given in Table 5. The table suggests that all the samples belong to very hard category in both the seasons. Fig. 7 shows the spatial distribution of total hardness in the study area. Coastal areas near Nagapattinam town and Killugudi School near a channel have the highest hardness values because of salt water effect. In the post monsoon season highest concentration is at Paravai (8080 mg/l) and in the pre monsoon at Killugudi School (6120 mg/l).



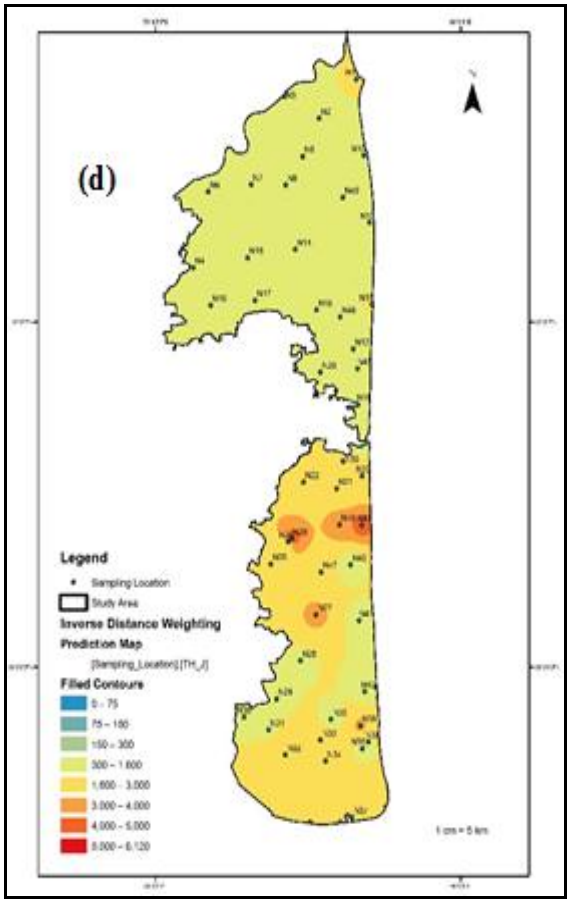
(a) Post monsoon



(b) Pre monsoon

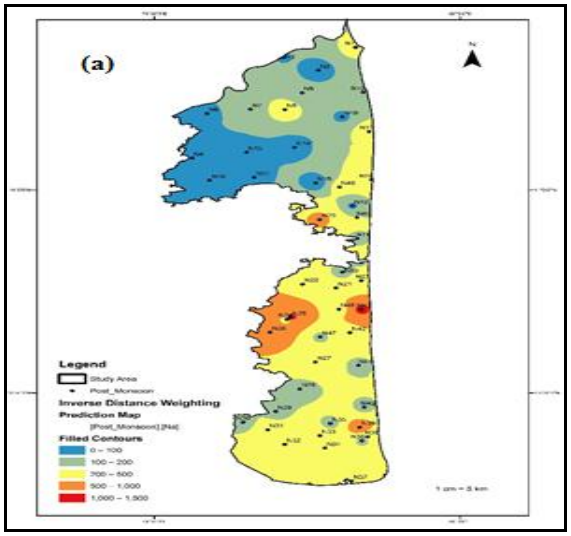


(c) Post monsoon

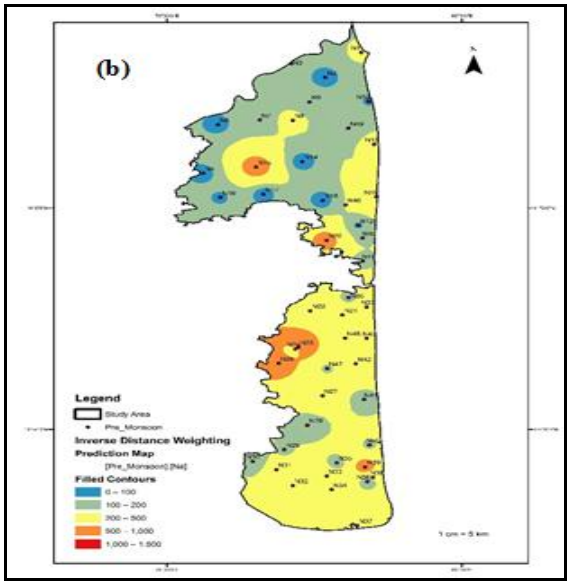


(d) Pre monsoon

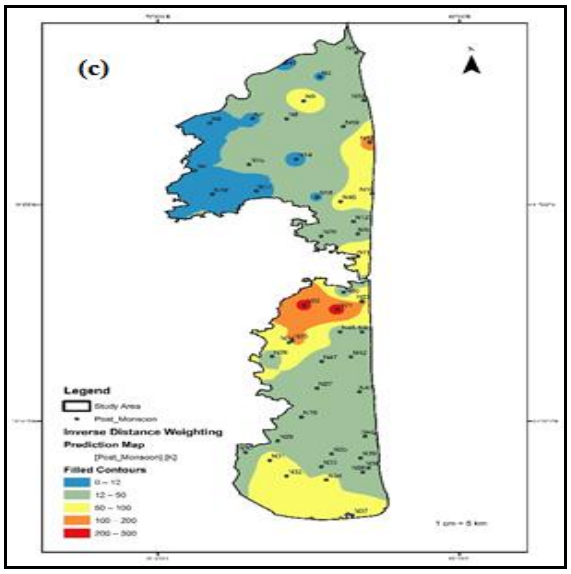
***Fig.6** Spatial variation of Mg (mg/l)*



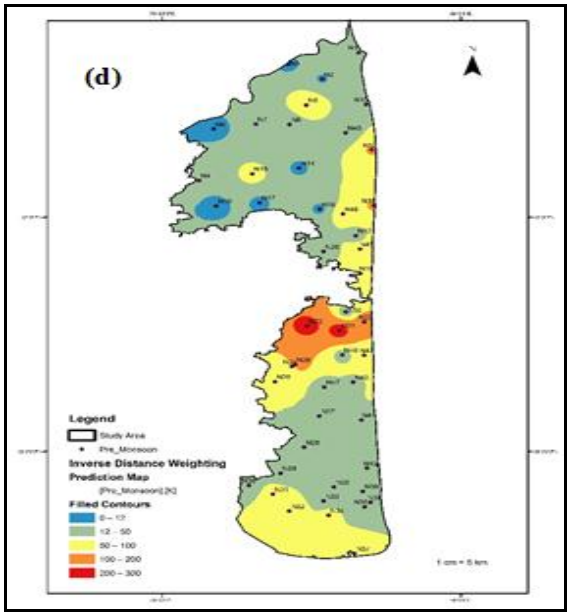
(a) Post monsoon



(b) Pre monsoon



(c) Post monsoon



(d) Pre monsoon

***Fig.7** Spatial variation of TH (mg/l)*

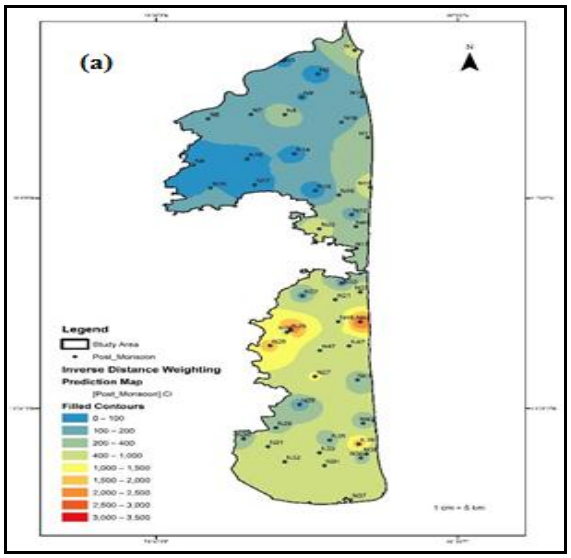
3.7. Sodium

Groundwater contains higher concentrations of salts and minerals than surface water sources. The presence of sodium ions is high due to its solubility. Higher concentrations of sodium and chloride result in saline taste to groundwater. As per WHO standards, maximum allowable limit of sodium is 200 mg/l. High intake of sodium may cause blood pressure and arteriosclerosis and fewer intakes may cause dehydration and general numbness. Sodium concentrations in the study area vary from 18.1 to 1425 mg/l (post monsoon) and 29 to 1110 in mg/l (pre monsoon). In both the seasons, Sankaran Pandal showed minimum concentration and Killugudi School the maximum concentration. Higher concentration of sodium causes toxic effect on crops; it disperses soil colloidal particles rendering the soil resistant to water penetration, it disperses soil colloidal particles rendering the soil resistant to water penetration, causing elevated osmotic pressure and difficulty in water absorption by plant roots. Plant growth and yield are affected by variation in salinity [18]. For irrigation water quality, the percentage of sodium in it is an important index:

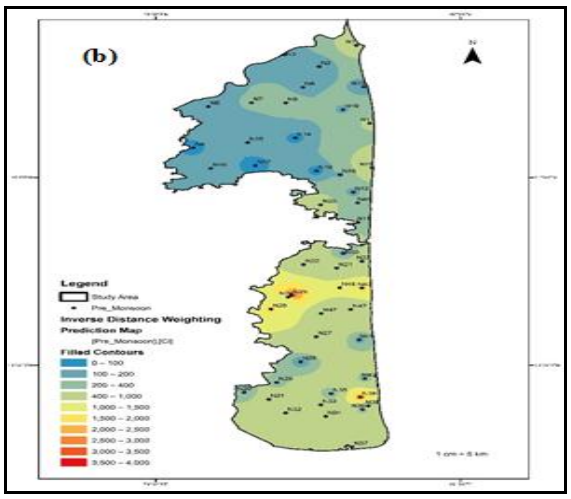
$$\frac{Na + K \times 100}{Na + Ca + K + Mg}$$

A detailed classification of percentage of sodium in groundwater samples is given in Table 6. In the post monsoon season, 26 percentage of samples fall in the category of excellent, 44 percentage in the category of good, 26 percentage in the permissible category; 2 percentage in doubtful and unsuitable categories. In the pre monsoon season, 8 percentage of samples fall under the excellent category, 50 percentage samples under the good, 30 percentage under the permissible,

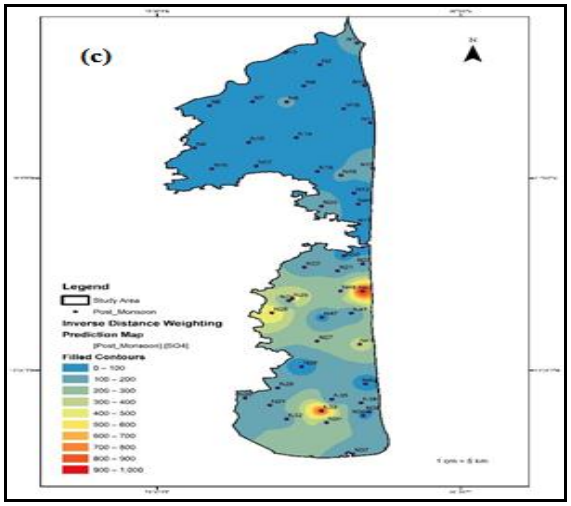
10 percentage under the doubtful and 2 percentage under the unsuitable. Central and southern parts of the study area have higher concentrations of salinity as seen from the spatial distribution map in Fig.8.



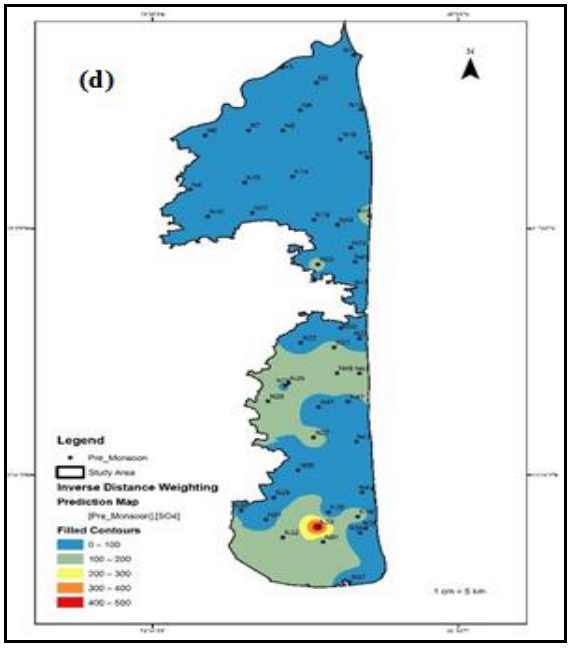
(a) Post monsoon



(b) Pre monsoon



(c) Post monsoon



(d) Pre monsoon

Fig.8 *Spatial variation of K (mg/l)*

Table 6 *Groundwater classification based on the percentage of sodium*

Na%	Classification	Post-monsoon		Pre-Monsoon	
		No. of samples	Percentage of samples	No. of samples	Percentage of samples
< 20	Excellent	13	26	4	8
20-40	Good	22	44	25	50
40-60	Permissible	13	26	15	30
60-80	Doubtful	1	2	5	10
>80	Unsuitable	1	2	1	2

3.8. Potassium

Origin of potassium is generally geogenic; weathering of important igneous and metamorphic rocks gives rise to the potassium content in the groundwater; samples from Manganellur and Komal show lower concentrations (6.6 mg/l) and from Sikkal shows higher concentration (256.2 mg/l) in the post monsoon season. Samples from Sanakaran Pandal show lower concentration (5 mg/l) and from Sikkal shows higher concentration (266 mg/l) in the pre monsoon season.

3.9. Chloride

It is a common inorganic anion present in groundwater mainly due to biogenic sources. Other sources of chloride in groundwater are from sewage, saline water intrusion, runoff and industrial effluents. High concentrations of chloride are observed in locations with high temperature and low rainfall. High concentration of chloride imparts salty taste to groundwater. In the post monsoon season, the lowest chloride concentration is observed at Sankaran Pandal with 20 mg/l and the highest concentration at Killugudi School with 3314 mg/l. In the pre monsoon season, the lowest concentration is observed at

Manganellur and Sankaran Pandal with 60 mg/l and higher concentrations at Killugudi School with 3764 mg/l. Manganellur and Sankaran Pandal sampling sites are located near to Uppanar channel.

3.10. Sulphate

Different geochemical processes, residence time and sources influence the concentration of sulphate. Important sources of sulphate in groundwater is dissolution or weathering of sulfur; the sources include evaporate minerals like anhydrite and gypsum. Hydro geochemical study shows that concentration of sulphate ranges from 16 mg/l to 956 mg/l (post monsoon) and 15 mg/l to 476 mg/l (pre monsoon). Manganellur shows lower concentrations and Parvai shows higher concentrations in the post monsoon season. Manganellur is located on the bank of Uppanar river and Paravai is located near Nagapattinam town, close to which there are backwaters and aqua culture farms. In the pre monsoon, lower concentrations are found in Pushpavanam and higher in Ayakarapulam.

4. Conclusions

In the present study, groundwater samples collected from Karikal district in Puducherry and parts of Nagapattinam district in Tamil Nadu in Cauvery delta were analyzed for understanding the spatial distribution of physical and chemical parameters in post monsoon and pre monsoon seasons. Groundwater quality marginally varies with the two predominant seasons of the region. The pH is observed to be less tending towards acidic in post monsoon season and more in pre monsoon season tending to alkalinity. EC values of samples suggest that in post monsoon 22 percentage of samples fall into not permissible category and 24 percentage of samples as hazardous. In pre monsoon season 22 percentage of samples has EC values categorized as not permissible and 32 percentage of samples fall in hazardous category. Sodium percentage is in the category of doubtful to unsuitable indicating groundwater is not suitable for irrigation in some areas. Principal occupation of people in the region is agriculture and to meet the water requirements, groundwater is exploited. Analysis for total hardness suggests that all the groundwater sources in the area yield very hard water. High values of electrical conductivity and also high concentrations of chloride and sodium in the coastal belts suggest the possibility of sea water intrusion in to coastal aquifers. The vulnerability increases with the presence of salt pan and aqua culture farms on the southern part of the study area. The presentation of data on a spatial framework using Arc Gis has been very useful in comparing the spatial distribution of groundwater quality parameters and the effect of surface water bodies, salt pans, aquaculture farms and urbanization on these parameters. Appropriate remedial measures has to adopted in this important delta to address the water quality issues.

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