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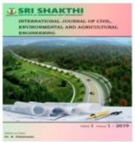

Irrigation Water Quality Assessment Using Water Quality Index and GIS Technique in Pondicherry Region, South India

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Abstract: The utility of groundwater, irrespective of its availability, is essential for mankind. The efficacy of the coastal aquifer's groundwater quality for agriculture purpose in the Pondicherry region was gauged by their hydrochemistry. 44 groundwater samples were collected during 4 different seasons namely, pre-monsoon (PRM), southwest monsoon (SWM), northeast monsoon (NEM) and post-monsoon (POM). The samples were measured for physico-chemical parameters like pH, EC, TDS, Na, K, Ca, Mg, Cl, HCO_3, PO_4, SO_4 and NO_3. The spatio temporal variations of EC indicates that the coastal groundwater were relatively saline except during PRM. The suitability of groundwater for irrigation is evaluated through various water quality parametrs such as Electrical Conductivity (EC), pH, Na%, sodium absorption ratio (SAR), residual sodium carbonate (RSC) and permeability index (PI). Na%, SAR, PI and EC values were spatially interporlated and integrated to determine the regions suitable for irrigation

purpose. The study infers that the groundwater of the study area is suitable for irrigation except few samples' locations along the western part, as they have attained an alarming stage and they are unsuitable for irrigation. Thus, proper management strategy for irrigation water source has to be developed and a preventive management practice to address this issue has to be implemented.

Keywords: Groundwater, Irrigation, Water Quality, Spatial Index, Overlay Analysis.

Introduction

There are many indexes adopted for determining the suitability of irrigation water, such as degree of acidity or alkalinity (pH), electrical conductivity (EC), residual sodium carbonate (RSC), sodium adsorption ratio (SAR) and permeability index (PI). [1-3]. Different methods, such as geochemical modeling, classification, statistical and geographic information systems (GIS) adopted to determine the assessment of groundwater quality for irrigation. Delbari et al (2014) [4] assessed the groundwater quality for irrigation prupose using GIS technique. Ahamed et al., (2013) and Gholami et al., (2013) [5,6] have analysed the effects of agriculture using irrigation efficiency parameters on groundwater quality. However, [4,7] have used multivariate statistical approaches to evaluate the irrigation water quality of a region.

There were a few local studies carried out by many researchers in the study area. Peth Perumal et al (2008) and Thilagavathi et al (2012) [8, 9] have studied the spatial and temporal variability of groundwater chemistry in multi-layered aquifers to assess the suitability for domestic utility by comparing the concentrations of selected parameters. The groundwater budgeting in the region was also studied using a novel method in GIS platform [10]. Agriculture is well diversified in the Pondicherry and almost all crops with different types of crop patterns are cultivated [11]. Hence, it is crucial to evaluate the irrigation water quality in this region. Thus, the main objective of this study is to evaluate the suitability of water quality for irrigation purpose.

Study Area

The study area is located in east coast of India, in Puducherry district, between latitudes of 11 ° 45 'and 12 °02' N and 79 ° 37 'and 79 °53' E longitudes (Figure 1). The Gingee and Ponnaiyar Rivers are two major rivers in this region. Coastal plains (younger and older), alluvial plains and uplands are the main physiographic units [12, 13].

Sedimentary deposits are the major lithounits of Cretaceous to Recent age in the study area, The physiography of the area shows more or less flat land with an average elevation of about 15 amsl. Nearly 85.94 percent of the study area is occupied by agricultural land (Figure 2). The primary crop grown here is paddy. High-yielding varieties account for about 98 percent of the paddy growing area. Sugarcane ranks second in cultivation. Millets, pulses, oil seeds, cotton, vegetables, and tapioca are also grown in addition to paddy and sugarcane. The most water-consuming crops grown are paddy and sugarcane. Depending on the climatic condition, water demand for irrigation paddy ranges from 542mm/year to 1.02 mm/year. The water requirement for sugarcane is 1800 mm/year [14]. Fertilizers such as Urea, Ammonium Sulphate, Diammonium Phosphate, Super Phosphate, Potash Muriate and various grades of Nitrate Phosphate and Potash complex are widely used for growing the crop production in this region [15].

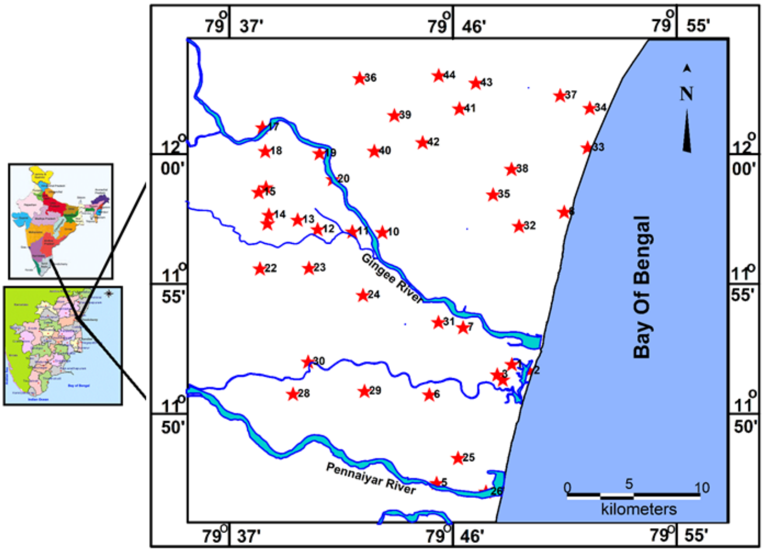

Figure 1. Location map of the study area

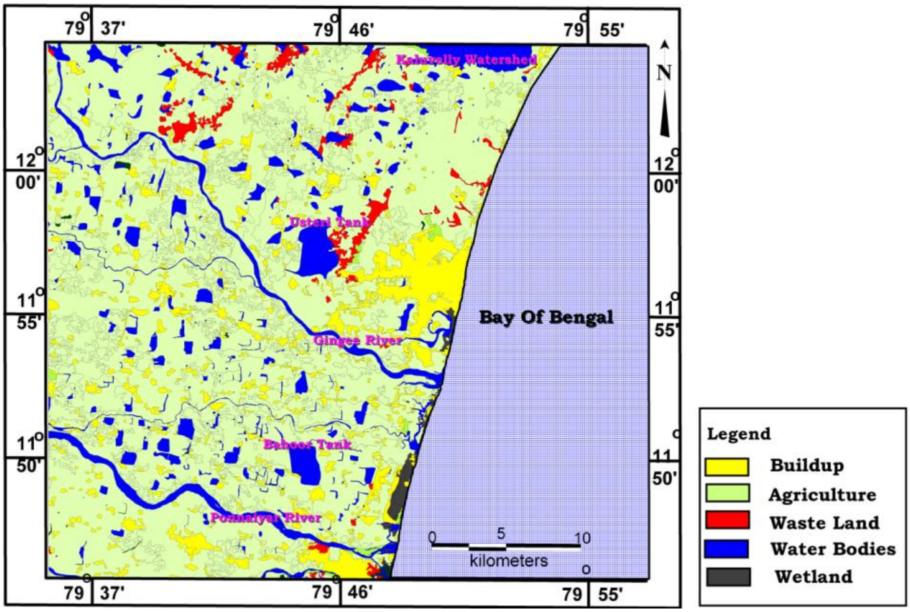

Figure 2. Landuse map of the study area

Table 1: Summary of analytical results and irrigational water quality index of local groundwater.

		Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	NO_3 (mg/l)	PO_4 (mg/l)	F (mg/l)	SIO_2 (mg/l)	PH	EC (µS/cm)	SAR (meq/L)	NA% (meq/L)	RSC (meq/L)	PI (meq/L)	NPK
PRM	Max	112.00	62.40	517.20	47.20	797.63	475.80	28.40	21.80	2.60	0.69	202.00	7.84	2596.00	19.19	89.43	4.61	98.46	3.38
	Min	12.00	0.00	7.10	0.10	35.45	73.20	0.00	0.00	0.02	0.13	2.00	6.60	221.70	0.30	9.18	-5.17	37.23	-1.56
	Avg	55.64	24.12	151.79	6.34	299.00	235.45	7.76	8.44	0.31	0.28	67.41	7.29	1077.33	4.44	50.69	-0.61	71.17	0.03
SWM	Max	132.00	88.80	287.00	61.00	567.20	488.00	20.00	11.80	66	1.14	160.00	7.70	2899.00	6.42	65.33	1.22	80.45	3.05
	Min	28.00	0.00	8.70	2.00	35.45	61.00	0.08	0.00	0.05	0.00	6.00	6.00	189.90	0.32	10.58	-6.13	28.96	-1.76
	Avg	62.32	29.29	72.35	15.26	193.68	249.30	5.43	3.48	8.73	0.25	84.44	6.98	1160.73	1.89	36.08	-1.40	58.72	0.06
NEM	Max	212.00	81.90	312.00	86.00	779.90	1037.00	20.00	90.80	1.50	1.90	130.00	8.50	2513.00	6.74	64.73	5.79	90.45	3.02
	Min	20.00	12.00	26.00	0.00	35.45	97.60	0.50	0.00	0.01	0.12	20.00	6.20	173.90	0.67	15.50	-10.91	27.56	-1.55
	Avg	92.68	38.95	90.23	19.91	211.79	433.93	8.38	17.85	0.14	0.33	86.18	7.17	1117.02	2.11	36.58	-0.99	57.86	-0.04
POM	Max	147.00	91.20	314.00	70.00	833.08	732.00	180.00	41.60	2.70	3.42	106.00	8.15	2352.00	6.33	70.76	2.89	91.42	2.80
	Min	27.00	1.60	20.00	1.00	70.90	61.00	1.00	0.00	0.10	0.00	10.00	6.28	168.40	0.59	17.04	-6.69	43.67	-1.40
	Avg	71.25	37.40	118.05	24.30	248.23	346.26	70.60	9.90	0.30	0.48	70.55	7.38	1116.52	2.91	45.49	0.97	64.52	0.02

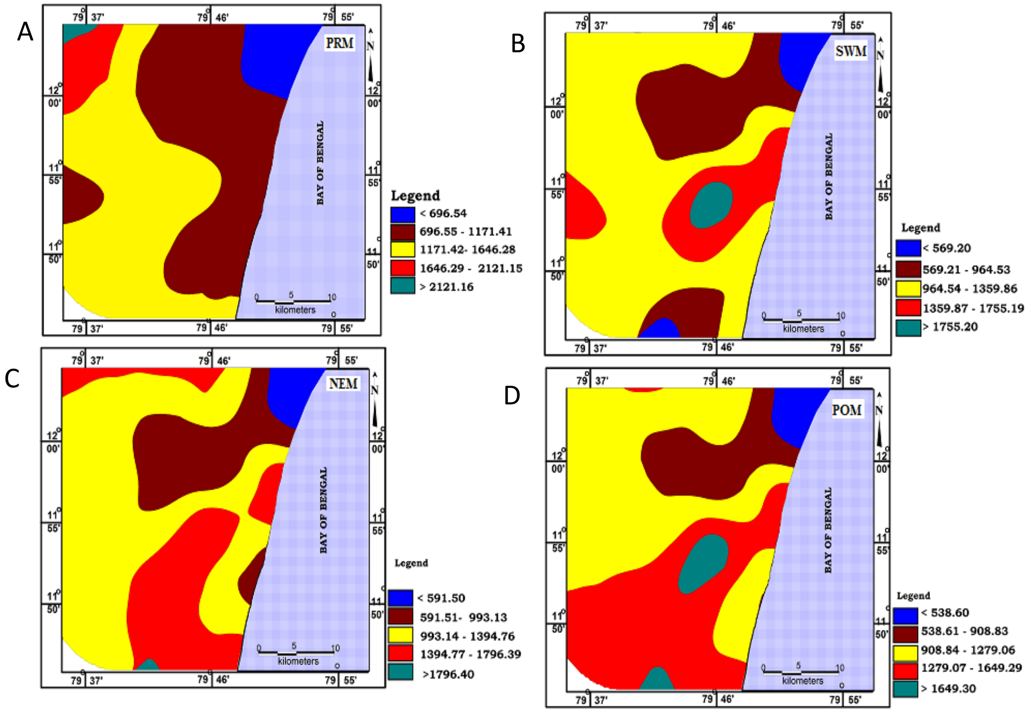

Figure 3. Spatial distribution of EC in the local groundwater for four different seasons A) PRM, B) SWM, C) NEM, D)POM

Methodology

A total of 176 groundwater samples were collected, 44 in each season (Pre-Monsoon, South West Monsoon, North East Monsoon and Post Monsoon), from shallow borewells in the

Pondicherry region (Figure 1). The standard protocolswere adopted to collect the samples [16] and the collected samples were analysed for various physico-chemical parameters. Major cations such as Ca and Mg; anions like Cl and HCO_3were analyzed through titrimetric method, flame photometer for Na and K (Elico CL378), and spectrophotometer for SO_4 and H_4SiO_4 (HACH, DR 5000 UV-Vis Laboratory Spectrophotometer). EC and pH was analysed using ion sensitive electrodes (Thermo) in the field. CHIDAM program [17] was used to classify the water for Sodium Absorption Ratio (SAR), Sodium Percentage (Na Percent), Permeability Index (PI), Residual Sodium Carbonate (RSC). AquaChem 4.0 software was used to identify the hydrochemical facies through Piper diagram. Statistical analysis (Factor analysis and Factor score) was performed for the groundwater samples to identify the key factors controls the groundwater geochemistry, and their spatial distribution [18].

The spatial analysis of various physico-chemical parameters and indices were performed using MapInfo software. In order to interpolate the data spatially and to estimate values between measurements, an Inverse Distance Weighted (IDW) algorithm was used. The IDW method calculates a value for each grid node by analysing surrounding data points that lie within a user-defined search radius [19]. All of the data points are used in the interpolation process and the node value is calculated by averaging the weighted sum of all the points [20].

Result and Discussion

Maximum, minimum and average values of physiochemical parameters in groundwater samples are represented in Table 1. pH and EC, both plays an important role in evaluating the suitability of groundwater for irrigation purpose. The spatial variation in both the parameters, with respect to four different seasons in the study area has discussed in detail in the following sections:

Hydrogen Ion Activity (pH)

pH is one of the most important parameters for evaluating water's suitability for agriculture. The pH in the study area ranges between 6 and 8.5. Highest pH is observed in NEM, whereas lowest in SWM (Table 1) and it ranges between 6.5 to 8.4, acceptable for irrigation. If the pH exceeds beyond the limit of nutritional imbalances occurs or toxic ions can be triggered by irrigation water [2].

Electrical Conductivity

The most important parameter in evaluating the irrigation water quality is electrical conductivity (EC), and it also an indicator of salinity hazard to crops [21]. The EC ranges between 221µS/cm to 2596 µS/cm during PRM (Figure 3A,B,C,D) The eastern, northeastern and northwestern part of the study area shows lower EC. However, there is a sharp increase of EC along the southeastern part, due to the influence of coastal salinity influence in groundwater. Higher EC is observed along the central and western parts of the study area (Figure 3A), which is related to leaching of salts from underlying geological formation (Figure 3B). The spatial distribution of EC during SWM ranges between 189µS/cm -2899 µS/cm. Higher EC during SWM may be associated with leaching or dissolution of the aquifer content or saline water mixing [22, 23]. The NEM EC ranges between 173 µS/cm and 2513 µS/cm during NEM (Figure 3C). The higher EC is noted along centre and eastern part during NEM, which may be due to the effect of backwaters in the shallow well [15]. During POM, EC ranges between 168µS/cm to 2352 µS/cm (Figure 3D). The higher EC is observed in the southern part of the study area during POM. In general, lower EC is observed in the Northeastern region of the study area irrespective of seasons.

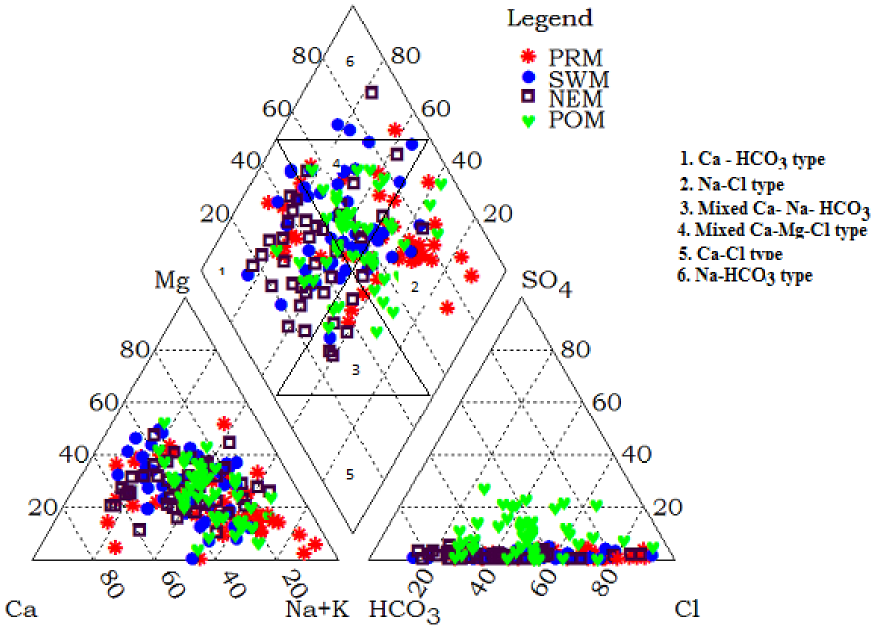

Figure 4. Piper diagram showing the relative cation and anion composition of groundwater samples.

Hydrochemical Facies

Most of PRM samples fall with in the 1, 2, 3 and 4 fields (Figure 4). Field 2 indicate process of adsorption or elimination of ions from the aquifer and reflecting discharge. Migration of samples from the mixed Ca-Mg-Cl to Na-Cl facies is noted, which can be related to seawater influence and long residence time in aquifer matrix [24]. In SWM, the sample clusters in fields 1 and 4 (Figure 4), reflecting the influence of recharge [9].

The NEM sample clusters in field 1 shows dominance of alkaline and strong acid (Figure 4). A few samples fall in field 4 of mixed Ca-Mg-Cl, and Ca-Na-HCO_3 type. Lesser representation of sample is noticed in field 2 reflecting influence of saline water. POM samples are well represented in mixed zone of Ca-Na-HCO_3 and Ca-Mg-Cl type (Figure 4). Cluster of samples also represented in Na-Cl type reflecting influence of saline water.

Evaluation of irrigation water quality

Total Dissolved Solids (TDS), salinity and indices such as sodium adsorption ratio (SAR), Sodium Percentage (Na percent), Residual Sodium Carbonate (RSC) and Permeability Index (PI) are selected in this study to evaluate the suitability of water quality for irrigation.

SAR indicate the degree to which irrigation water enters into soil and cation exchange reactions. The parameters are determined by using the formula:

$SAR = Na^{+}/\sqrt{(Ca^{2+}+Mg^{2+})/2}$. (Concentrations are in meq/L) (1)

The SAR value beyond 26 indicates the unsuitability of water for irrigation purpose [25]. The SAR value of the present study ranges between 0.29 to 19.2. However, season wise, the value ranges between 0.3 and 19.2, 0.32 and 6.42, 0.67 and6.74, 059 and6.33 for PRM, SWM, NEM and POM respectively. Highest value of SAR is noted in PRM. The SAR in groundwater samples range between good to excellent (Table 2). Thus, these samples are appropriate for irrigation purposes regardless of season. Except for a few, all sampling sites are suitable for irrigation purposes for the present study.

The suitability of the agricultural is also intented by the sodium percentage (Na%) of the samples [26,27]. Clay particles that dislocate the ions Mg^{2+} and Ca^{2+} and the Na exchange mechanism in soil for Ca^{2+} and Mg^{2+} in water appear to absorb Na^{+} ions, thus decreasing permeability and eventually resulting in soil with poor internal drainage. Therefore, during wet conditions, air and water movement is reduced, such soils are typically hard when dry [28,29]. Thus Na% is considered as an important parameter in evaluation of irrigation water quality which can be determined by using the following formula:

$Na\% = (Na+K) / (Ca+Mg+Na+K) * 100$. (Concentrations are in meq/L) (2)

The Na% for the local groundwater ranges between 9.17 and 89.43, However, season wise the value varies between 9.18 and 89.4,10.6 and 65.3,15.5 and 64.7 and 17 and 70.8 during PRM, SWM, NEM and POM respectively. The maximum value is noted during PRM. The sodium in the water will displace the soil's calcium and magnesium. This would result in a decline in the soil's ability to form stable aggregates and a loss of soil structure. The bivariate plot between SAR and Na% shows that most of samples of four different seasons are within outstanding to permissible category suggesting, the suitability of water for irrigation (Figure 5). except for a few samples of PRM.

Residual Sodium Carbonate (RSC) is an index used to assess the risk of bicarbonate in groundwater. RSC is calculated by using the formula:

$RSC = (HCO_3 + CO_3) - (Ca + Mg)$ (Concentrations are in meq/L) (3)

Table 2. The physio-chemical ranges for irrigation usage, the basis of spatial distribution and overlay analysis

Category		Range	Spatial index value	PRM (%)	SWM (%)	NEM (%)	POM (%)
Na% Wilcox (1955)	Excellent	0-20	1	11.4	20.5	18.2	2.3
	Good	20-40	2	18.2	36.4	43.2	43.2
	Permissible	40-60	3	34.1	36.4	36.4	31.8
	Doubtful	60-80	4	29.5	6.8	2.3	22.7
	Unsuitable	>80	5	6.8	0.0	0.0	0.0
S.A.R. Richards (1954)	Excellent	0-10	1.25	93.6	100.0	100.0	100.0
	Good	10 - 18	2.50	3.2	0.0	0.0	0.0
	Permissible	18-26	3.75	3.2	0.0	0.0	0.0
	Unsuitable	>26	5.00	0.0	0.0	0.0	0.0
Permibility Index	Excellent	< 18	1.25	0.0	0.0	0.0	0.0
	Good	18- 70	2.50	40.9	79.5	72.7	70.5
	Permissible	70 - 120	3.75	59.1	20.5	27.3	29.5
	Unsuitable	>120	5.00	0.0	0.0	0.0	0.0
NPK	Excellent	<0	1.67	52.3	47.7	63.6	54.5
	Permissible	0-0.5	3.33	25.0	29.5	20.5	27.3
	Unsuitable	0.5-1	5.00	22.7	22.7	15.9	18.2
EC Wilcox (1955)	Excellent	<250	1	2.3	6.8	6.8	4.5
	Good	250-750	2	29.5	20.5	22.7	25.0
	Permissible	750-2250	3	61.4	68.2	63.6	68.2
	Doubtful	2250-5000	4	6.8	4.5	6.8	2.3
	Unsuitable	>5000	5	0.0	0.0	0.0	0.0

Water with high bicarbonate concentrations, have a propensity towards calcium and magnesium to precipitate out as carbonates [30]. The RSC ranges between -1.82 and 5.78 in the present study. Month wise RSC varies between -5.1 and 4.61, -6.1 and 1.22, -10.9 and 5.7, -6.6 and 2.8 during PRM, SWM, NEM and POM respectively The maximum RSC is noted in NEM samples. The bivariate plot of SAR and RSC indicates that, most of samples are within excellent category suggesting its suitability fr irrigation. A few representations of NEM and POM samples noted in fair to poor category (Figure 6). The samples showing negative RSC Figure 6) indicates that, calcium and magnesium are not fully precipitated [31].

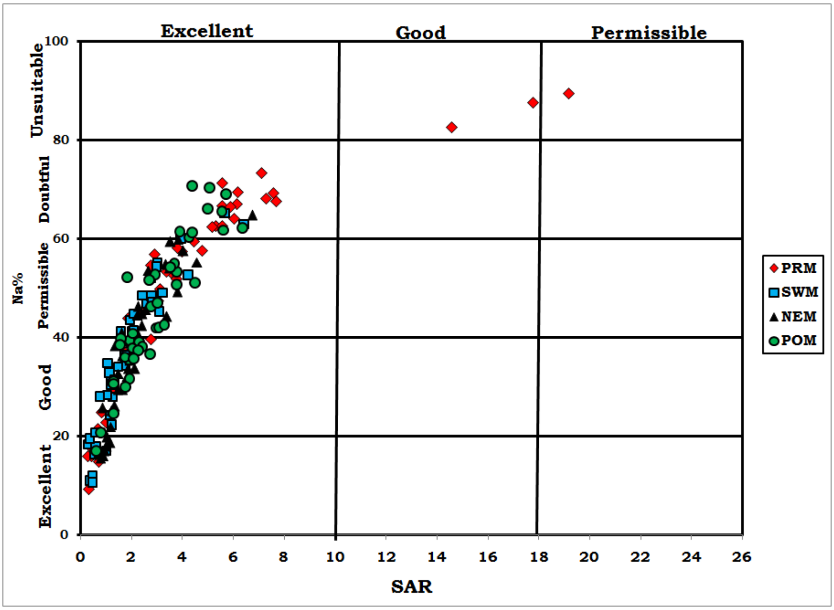

Figure 5. Relationship between SAR and Na% of local groundwater.

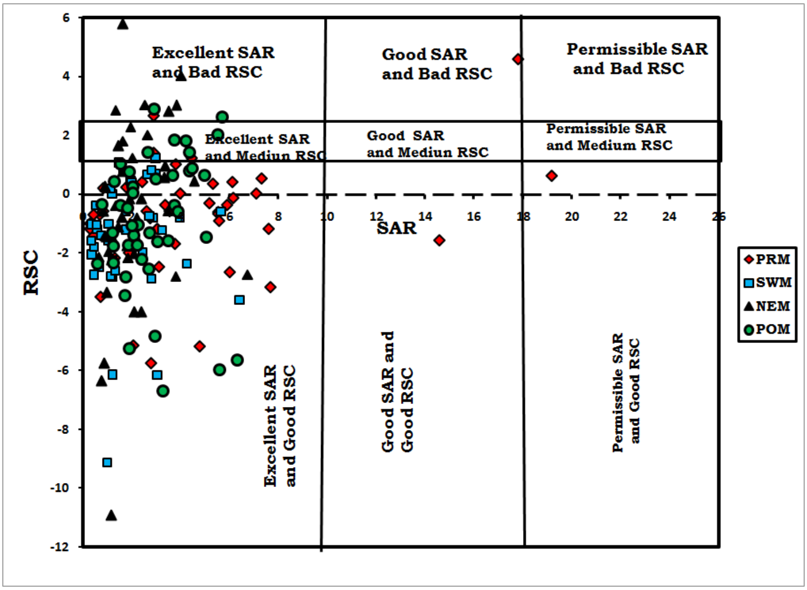

Figure 6. Relationship between SAR and RSC of the groundwater samples

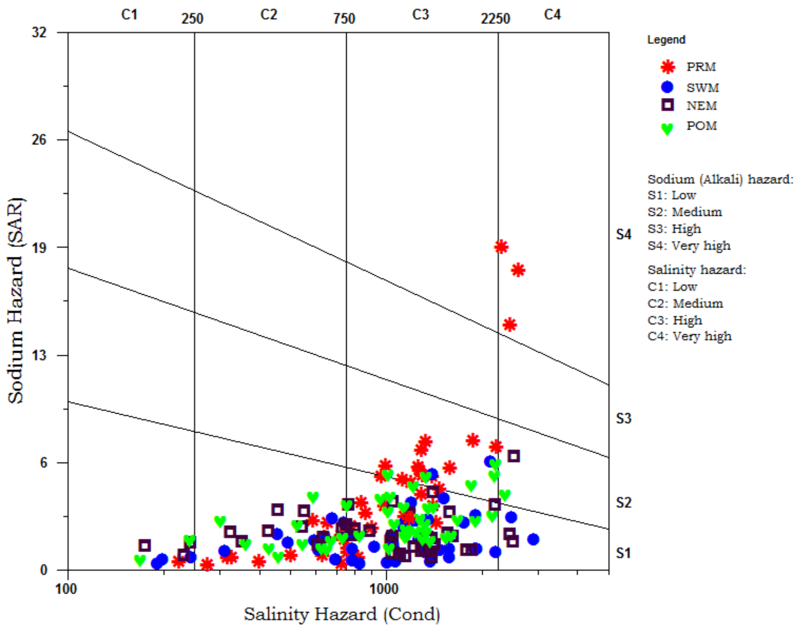

Figure 7. Rating of groundwater samples in relation to salinity hazard and sodium hazard (USSL 1954)

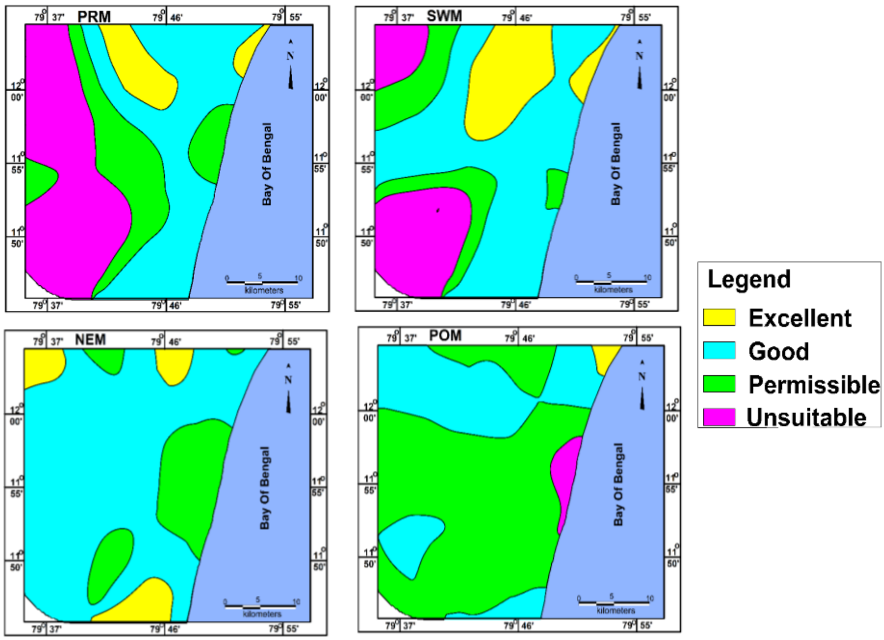

Figure 8. Index map of water quality classification for irrigation a) PRM b) SWM c) NEM d) POM

The long-term use of irrigation water impacts the permeability of soils. A criterion for determining the suitability of water for irrigation based on the permeability index (PI) (Concentrations are in meq/L) was defined by [32] and can be calculated as follows.

$$PI= [\{Na+ (\sqrt{HCO_3})\}/ (Ca+ Mg+ Na)] * 100 \text{ (Concentrations are in meq/L)} \quad (4)$$

The PI ranges between 27.5 and 98.5 in the groundwater. Season wise the value ranges between 37.2 and 98.4,28.9 and 58.7,27.5 and 90.4, 43.6 and 91.4 during PRM, SWM, NEM and POM respectively. Maximum PI value is noted in the samples collected during PRM. The PI value of most of the samples are within the permissible range and thus, are suitable for irrigation.

The EC and SAR value are considered as significant factors and the groundwater was classified into low, medium, high and very high hazard categories for irrigation (Figure 7). The groundwater of four seasons PRM, POM, SWM and NEM in the study area falls in low hazard zone. However, there are a few representations of samples from all four seasons in medium hazard zone. Three samples of PRM fall in very high hazard zone and the corresponding locations are Keezhkumaramangalam, Sompet, Kakilapet. Thus, groundwater of these locations is not suitable for irrigation. However, the samples which fall within low and medium category, groundwater of these locations can be opted for irrigation with more caution, depending on the crop cultivated.

The spatial index

In order to describe the physiochemical parameters, the spatial index was graded as excellent, permissible, good, and unsuitable on the basis of EC, Na% S.A.R., PI, NPK values of groundwater (Table 2). Classification is accomplished based on [3, 26, 33] classification. Spatial maps are plotted for the above 5 parameters individually for four different seasons like PRM, POM, SWM and NEM (Table 2). The spatial maps were compiled in the GIS platform to identify the regions of suitable irrigation water quality. The irrigation water quality is classified into four categories like excellent, good, permissible and unsuitable based upon the value provided in Table 2. The final index map shows that the western part is unsuitable for irrigation irrespective of seasons (Figure 8). Major portion of the study area falls within good and permissible category. However, the northeastern and central part of the study site is within the excellent category. Thus, it is inferred that, the groundwater of the study area is suitable for irrigation except the western region

Conclusion

To evaluate suitability groundwater for irrigation use, 176 groundwater samples were collected from existing wells and were analyzed for major cations and anions. It is observed that, EC is high in southeastern part of study area. The groundwater types of study reflect Ca-HCO_3, Na-Cl, Ca-Na-HCO_3, Ca-Mg-Cl, Na-HCO_3water types. The water type has undergone significant rock-water interaction during PRM. The water type changed from Ca-Mg-Cl to Na-Cl reflecting influence of saline water during PRM. The computed SAR Na%, RSC, EC, NPK and PI value shows that, groundwater samples are suitable for irrigation purposes, except few samples of PRM season. Though these samples fall in the moderate to good category in other selected parameters they have to be used in caution and it depends on the crop type cultivated. Spatial variation of various water quality parameters were produced using IDW interpolation technique in GIS. Final spatial index map was prepared by overlay analysis, assigning relative weight and quality rating scale for each parameter for four different season. It shows that, groundwater samples have excellent and good water quality, for irrigation purpose except a few locations in the western part of the study area. These locations along western part needs management to use for irrigation purpose. Assessment of spatial variation of groundwater quality led to a better understanding of groundwater quality in the Pondicherry region and helps for planning of new groundwater schemes.

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