Original Research Article

Groundwater Quality Assessment of shallow coastal aquifer in Guntur district of Andhra Pradesh

ABSTRACT

A survey was undertaken during the year 2021 to assess the quality of irrigated groundwater in coastal mandals of Guntur district, Andhra Pradesh. A total of 29 representative samples were collected along with GPS locations. The water samples were analyzed for various chemical properties *viz.*, pH, EC, Ca^{+2}, Mg^{+2}, Na^{+} , K^{+}; CO_3^{-2}, HCO_3^{-}, Cl^{-} and SO_4^{-2}. The pH, EC, SAR and RSC in groundwater ranged from 6.9-8.2, 0.6-9.2 (dSm^{-1}), 1.75-17.59 ($(mmol\ l^{-1})^{1/2}$), -35-7.8 ($me\ l^{-1}$). The concentration of cations *viz.*, Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} varied from 0.4-21.8, 1.2-20, 2.22-47.7 and 0.02-0.87 me l^{-1} with mean values of 8.51, 8.10, 19.30 and 0.23 me l^{-1} respectively. Concentration of anions viz., CO_3^{-2}, HCO_3^{-}, Cl^{-} and SO_4^{-2} varied from 0-0.8, 2.6-16.6, 2.0-52.0 and 0.4-21.8 me l^{-1} with an average values of 0.27, 7.19, 18.70 and 2.70 me l^{-1} respectively. The relative abundance of ions for most of the water samples were $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$ for cations and $Cl^{-} > HCO_3^{-} > SO_4^{-2} > CO_3^{-}$ for anions. According to CSSRI classification of irrigation water, 41.38, 17.24, 24.13, 13.80, 0.0, 0.0 and 3.45 per cent samples were good, marginally saline, Saline, High SAR Saline, marginally alkaline, alkali and highly alkali, respectively. Spatial variability maps of pH, EC, SAR, RSC and groundwater quality of the study area were developed.

Key Words: Coastal Ground Water Quality, EC, RSC, SAR, Sea water intrusion, Spatial Variability , Guntur district

Introduction

Human existence is mainly depend on availability of qualitative water either through surface or subsurface. Demand for ground water has increased tremendously in recent years due to the industrialization, urbanization, population increase, and intense agricultural activities.The countries with largest extent of areas equipped for irrigation with ground water in absolute terms are India (39 m ha), China (19 m ha) and USA (17 m ha) (Siebert *et al.* 2010).

Good quality groundwater in coastal areas of Guntur district exist in shallow aquifer. Groundwater in shallow aquifers can be replenished more frequently and rapidly relative to deep coastal aquifers. The marginal and poor quality waters constitute a greater part of phreatic groundwater resources in arid and semiarid regions (Gupta *et al*., 2019) as potential evapo-transpiration exceeds the rainfall and basin level natural drainage remains either absent or insufficient. It is the balance of groundwater with sea water is a critical factor for groundwater quality in coastal regions beside geological reasons. Quality rating of any water depends upon its intended use. In case of agriculture, water is categorized as good, if its long-term use sustains crop productivity without any adverse impact on soil resource or produce quality. Quality of irrigation water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated areas and it depends on primarily on the total amount of salt present and proportion of sodium to other cations and certain other parameters (Singh *et al.*, 2019). In view of this scenario, it is necessary to understand spatial distribution of groundwater quality for irrigation is essential to capture available groundwater resources for intensifying crop production of the region. Hence, a study was conducted to assess the groundwater quality of coastal aquifer in Krishna Western Delta command area of Guntur district of Andhra Pradesh.

Material and Methods

The study area lies in between 15.85777 and 16.2579 of Northern latitudes and 80.4727 and 80.8310 Eastern longitudes occupies north eastern part of Guntur district in Andhra Pradesh (**Fig 1**). with geographical area of 3776 km^2 . The study area is bordered by Krishna river on northern side and Bay of Bengal on eastern side. The annual rainfall is 889.1 mm through South-West and North-East monsoons. The maximum temperature varied 35 to 46^{o}C during summer and the minimum temperature of 23 to 25 ^{0}C during winter.

The soils of the study area are covered with river borne alluvium and coastal sands in the area bordering to the coast. The thickness of alluvium varies from few meters to over 100m. The deltaic alluvium found in paleo/buried channels up to 30 m depth with thick graveliferous sand. Groundwater is being developed in the flood plain areas along river course mostly through filter-points and shallow tube wells. In deltaic alluvium groundwater is brackish in nature. Quality of water in paleo –channels, buried channels is potable and brackish to saline at shallow depths in the area bordering the coast. The study area comes under command area in Krishna Western delta adjacent to Bay of Bengal having coastal line of 100 km on the right of bank of Krishna river (CGW,2019).

Twenty nine (29) representative ground water samples were collected from bore wells along with GPS coordinates (**Fig. 1**). Sampling was carried out using preconditioned clean high density polythene bottles, which were rinsed three times with sample water prior to sample collection. The pumps were run for 5-6 minutes prior to collection of water samples. Samples were collected in polyethylene bottles and immediately after collection of water samples toluene was added to avoid microbiological deterioration. Standard procedures were (**Table 1**) followed to analyze the quality of water. pH in water samples was determined by potentiometrically using pH meter (Jackson 1973). Electrical conductivity was determined by using Conductivity Bridge (Willard *et al.* 1974). Chlorides (Mohr's method), carbonates and bicarbonates (double indicator method) and calcium and magnesium (versenate method) were determined by adopting the procedures given by Richards (1954) .Similarly the sodium and potassium in ground water samples were determined by using flame photometer (Richards 1954). The Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were as calculated by using the formulas given by Richards (1954) such as $SAR = Na/((Ca^{2+}+Mg^{2+})/2)^{0.5}$ ………… (1)

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

The Na^{+}, Ca^{2+} and $Mg2^{+}$ are in m e L^{-1}. RSC, CO_3^{2-} , HCO_3^{-} , Ca^{2+} and Mg^{2+} are in meq L^{-1}. Soluble Sodium Percentage(SSP), Permeability Index(PI), Total Hardness(TH), Kelly's Ratio(KR), Corrosivity Ratio(CR), Mg hazard, Cl^{-}/HCO_3^{-} ratio and potential salinity were computed for determining the quality of groundwater.

The ground water samples were classified under different classes as per the limits of EC, SAR and RSC given by Gupta *et al.* (1994) and groundwater quality for irrigation is classified based on various parameters. Correlation coefficient of water properties were obtained as per the standard methodology given by Panse and Sukhatme (1961).

Results and Discussion

Groundwater quality determination

The concentration and composition of dissolved constituents in groundwater determine its quality for irrigation use. The ground water samples were analyzed for various chemical parameters like pH, EC, Cations (Ca^{+2}, Mg^{+2}, Na^{+} and K^{+}) and anions (CO_3^{-2}, HCO_3^{-}, Cl^{-} and SO_4^{-2}) subsequently SAR, RSC, Soluble Sodium Percentage(SSP), Permeability Index(PI), Total Hardness(TH), Kelly's Ratio(KR), Corrosivity Ratio(CR), Mg hazard, Cl^{-}/HCO_3^{-} ratio and potential salinity were calculated for these samples. The analytical data of ground water samples of the study area collected during 2021 are presented in the **Table 2.**

The pH of ground water is important parameter for determining its reaction. The pH of water samples varied from 6.9 to 8.2 **(Table 2)** with "a mean of 7.38" . The low pH may be due to presence of sandy soils in certain pockets and dominance of chloride ions in groundwater. Higher pH of ground water may be due to dominance of Na^{+}, Ca^{+2}, Mg^{+2} and CO_3^{-} and HCO_3^{-} ions. The spatial variability of pH of groundwater in the study area is depicted in **Fig.2.** Indicates that the highest pH(>7.6) in groundwater was in parts of Bapatla, Karlapalem and Nizampatnam mandals. Significant positive correlation was observed between pH and CO_3^{-2} (r=0.377*) and RSC (0.367*) of groundwater. The similar results were also reported by Subbaiah *et al*.(2020) in groundwater of Chittoor district and Naidu *et al*.(2020) in Nellore district

Water salinity determined in terms of EC. The EC values in water samples of the study area ranged from 0.6 to 9.2 dS m^{-1} with a mean of 0.27 dS m^{-1} (**Table 2**). Electrical conductivity is customarily used for indicating the total concentration of the ionized constituents of natural water. Electrical conductivity is related to the conduction of electricity and is correlated to the saturation of water with regard to the dissolved solids (Sachin *et al.*,2021). The spatial variability of EC of Ground water is depicted in **Fig. 3.** The electrical conductivity values (**Table 3**) were grouped into different classes with an interval of two units upto 10 dSm^{-1}. Out of 29 samples collected 37.93 per cent samples had <2 dSm^{-1} followed by 27.59 per cent in range of 2-4 dSm^{-1} followed by 6.89 per cent in 4-6 dSm^{-1}, 24.14 per cent in 6-8 dSm^{-1} range and 3.44 per cent in 8-10 dSm^{-1} range. The variation in EC may be due to variation in hydro-geological conditions, distribution alluvial material and the anthropogenic activities in the region. The correlation matrix of the groundwater samples exhibits highly significant positive correlation between EC and Ca^{+2} + Mg^{+2}, Na^{+}, Cl^{-}, SO_4^{-2} and HCO_3^{-} , SAR and CR. Highly significant negative correlation (-0.76**) with RSC of water indicates the Na^{+}-Cl^{+} type of water , similar results were also reported by Naidu *et al*.(2020) with Nellore district.

The concentration of cations viz., calcium, magnesium, sodium and potassium in water samples varied from 0.4-21.8, 1.2-20, 2.22-47.7 and 0.02-0.87 me l^{-1} with mean values of 8.51, 8.10, 19.30 and 0.23 me l^{-1} respectively. The cationic concentration followed the order sodium, calcium, magnesium and potassium. The presence of sodium in groundwater primarily resulted from the chemical decomposition of feldspars and the presence also predicts the sodicity danger of the water (Subbaiah *et al*., 2020). The presence of calcium in groundwater might be attributed to calcium rich minerals such as amphiboles, pyroxenes and feldspars (Naidu *et al*., 2020) and the Mg^{+2} in groundwater might be due to olivine minerals in the surrounding rocks and soils. The low levels of potassium in groundwater samples may be ascribed to its tendency to be fixed by 2:1 type clay minerals and to participate in the formation of secondary minerals due to evaporation (Jalali, 2010).

The concentration of anions viz., carbonate, bicarbonates, chloride and sulphate varied from 0-0.8, 2.6-16.6, 2.0-52.0 and 0.4-21.8 me l^{-1} with an average values of 0.27, 7.19, 18.70 and 2.70 me l^{-1} respectively. The relative abundance of ions for most of the water samples are

$Cl^- > HCO_3^- > SO_4^{-2} > CO_3^-$ .The chloride **(Table 4)** and bicarbonate ions are dominant among all the anions then followed by sulphates and carbonates. The chloride content in the groundwater may be due to natural process like weathering, dissolution of salt deposits and irrigation drainage return flow (Kumar *et al*., 2009). Loizidou and Kapetanios (1993) proposed that the excess of chloride in the groundwater is by and large taken as an index of groundwater contamination. The higher concentration of bicarbonate ions in groundwater can be ascribed to carbonate weathering as well as from the dissolution of CO_2 in the aquifers from the possible mechanisms (Houatmia *et al*., 2016). The sulphate ions in groundwater might be due to the presence of sulphide –bearing minerals and gypsum in aquifer materials, application of sulphate rich fertilizers and industrial wastes (Sridharan and Nathan, 2017). Moreover application of soil amendments like gypsum is expected to be responsible for higher SO_4^{-2} content in the groundwater (Pal *et al*., 2018).

Sodium Adsorption Ratio(SAR):

The SAR of groundwater ranged from 1.75- 17.59 $(m\ mol\ l^{-1})^{1/2}$ with a mean of 6.56 $(m\ mol\ l^{-1})^{1/2}$. The lowest SAR of 1.75 $(m\ mol\ l^{-1})^{1/2}$ in water samples was observed in Sammetavaripalem village and highest value of SAR was found as 17.59 $(m\ mol\ l^{-1})^{1/2}$ in village Perali of Bapatla mandal. The spatial variability of SAR of groundwater is depicted in **Fig.4** It was observed that with increase in SAR of irrigation water, the SAR of soil solution increases which ultimately increases the exchangeable sodium of the soil (Bhat *et al*., 2018). FAO (1994) reported that irrigation water having SAR value between 0-10, i.e., low sodium water poses almost no risk of exchangeable sodium, medium sodium water having SAR 10-18 can show considerable hazard, while on the contrary, high and very-high sodium water with SAR 18-26 and greater than 26, respectively, are regarded as unfavorable as they can lead to detrimental levels of exchangeable sodium in soils. According to this classification 82.75 and 17.25 per cent samples (**Table 5**) belonged to excellent, moderate Na hazard respectively.

Residual Sodium Carbonate (RSC):

Residual sodium carbonate is an important parameter that has extraordinary influence on the suitability of irrigation water (Pal *et al*., 2018). The residual sodium carbonate (RSC) of groundwater varied from -35-7.8 meq L^{-1} with a mean of -9.15 meq L^{-1} . The spatial distribution of residual sodium carbonate was depicted in **Fig.5**. Based on RSC water can be categorized into three categories such as safe (<2.5 meq L^{-1}), moderately suitable (2.5-4.0 meq L^{-1}) and unsuitable (>4 meq L^{-1}). In the present study, it was found that 26 samples **(Table 6)** were of safe category, 2 samples were moderately suitable and 1 sample unsuitable for irrigation purposes.

Ionic correlation studies:

The dominance of major ions was in the order of $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$ for cations and $Cl^{-} > HCO_3^{-} > SO_4^{-2} > CO_3^{-}$ for anions. Therefore, the chemical composition of the groundwater was characterized by Na^{+}-Cl^{-} water type. Highly significant positive correlation (**Table 7**.) was observed between major cations, Na^{+} - Ca^{+2} (r = 0.689**) and Na^{+} - Mg^{+2} (r = 0.828**) . Highly significant positive correlation was observed between Na^{+} - Cl^{-} (r = 0.921**), Na^{+} - HCO_3^{-} (r = 0.706**), SAR(0.866**), Kelly's ratio(0.458**) and positive correlation with Corrosivity ratio(0.367*). The positive correlation indicated that dissolution of sodium from respectivee ion containing minerals. The correlation between between Mg^{+2} and Cl^{-} (r = 0.936**) and between Ca^{+2} and Cl^{-} (r = 0.864**) indicates that they most likely derive from the same source of water (Pal *et al.*, 2018) which might be sea water (Sherene *et al.*,2020). Highly significant positive correlation observed between corrosivity ratio and EC (0.502**), Ca^{+2} (0.585**), Mg^{+2} (0.631**), Cl^{-} (0.575**) and SO_4^{-2} (0.859**) and significant positive correlation with Na^{+} (0.367*). This indicates that salinity of water due to preasence of Cl^{-} and SO_4^{-2} salts of Ca^{+2}, Mg^{+2} and Na^{+} are major cause for corrosivity of irrigation pipes. Possitive correlation was observed between permeability index and pH(0.441*), K^{+}(0.513**) CO_3^{-2}(0.472**) and HCO_3^{-} (0.389*) and negative correlation with Ca^{+2}(-0.633**) and Mg^{+2}(-0.479**)

Ground water quality classification for irrigation purpose

The groundwater was classified into 5 classes for irrigation purpose (Minhas and Gupta, 1992) and details are presented in **Table 8.** The 41.38% samples were of good quality, 17.24% were of marginally saline, 24.13% of saline, 13.8% high SAR saline and 3.45% of highly alkali. (Fig. 6).

Gibbs plot:

The chemical composition of water and ascertained close relationship that exists between aquifer lithology and water compositional chemistry were proposed by Gibbs (1970) through Gibbs diagram. It has three fields namely precipitation dominanace, evaporation dominance and rock dominance. Gibbs diagrams were constructed by ploting ratios of (1) dominant cations [(Na^+)/(Na^+ + Ca^{+2})] and TDS (2) dominant anions (Cl^-/Cl^- + HCO_3^-) an TDS(Fig.7).

The distribution of samples on the Gibbs plot showed that majority of them fall in the rock to evaporation dominance zone. It suggested that the process of evaporation in case of groundwater might have taken place when water level should have reached very much close to surface (Todd, 1980). This might have increased the ion concentration in the groundwater. Sometimes it might happen due to several other anthropogenic activities. Few samples falls in the rock dominant region and surrounding rock minerals plays key role in concentration of major cations and anions. This suggests that the ionic composition of groundwater might be controlled by chemical weathering of minerals in weathered and fractured zone of soil.

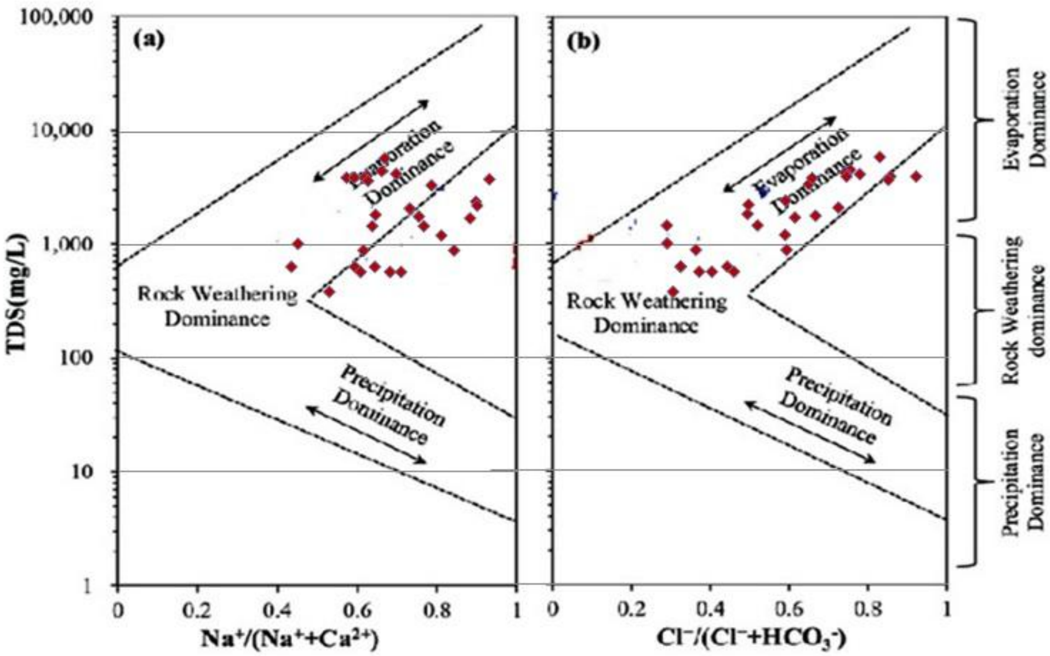

Fig 7. Gibbs ratio analysis for groundwater samples

Cl^-/HCO_3^- ratio:

The salinization amount in the ground water can be classified using the Cl^-/HCO_3^- ratio (Revelle 1941). The Cl^-/HCO_3^- ratio was computed for the groundwater samples of the study area and given in Table 9. No groundwater samples in the study area having ratio of Cl^-/HCO_3^- less than 0.5. 89.7 percent groundwater sample in the study area had slight to moderate salinity. Only 10.3 % groundwater samples had under severe salinity. However, high values of Cl^-/HCO_3^- ratio at some locations might be attributed to anthropogenic activities such as seepage from domestic sewage or uncontrolled agricultural practices rather than seawater intrusion.

Sodium(%):

Sodium concentration in groundwater is a very important parameter in determining the irrigation quality. The formula used for calculating the sodium percentage was

$$Na\% = (Na^{+} + K^{+})/(Ca^{+2} + Mg^{+2} + K^{+} + Na^{+})\ x100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where all ionic concentrations are in meq/L.

The determined value of sodium percentage lies between 43.42 and 92.99 (Table 10). The maximum allowable limit of sodium percentage in groundwater is 60% . The percentage sodium and electrical conductance are correlated by Wilcox as shown in Fig.9. Sodium concentration of irrigation water became high, sodium ions tends to replace the Mg^{+2} and Ca^{+2} ions due to absorption by clay particles. This process in soil reduces the permeability and decreases the internal drainage of the soil. Hence and water and air circulation is restricted during wet conditions and such soils become hard in dry conditions(Subbramani *et al*. 2005). Higher concentrations of sodium and chlorine in groundwater are controlled by rock water interaction most likely by feldspar weathering. The low sodium in some of the samples is due to the ion exchange with calcium and magnesium in clays, which is common in saline groundwater (Cartwright et al.2004).

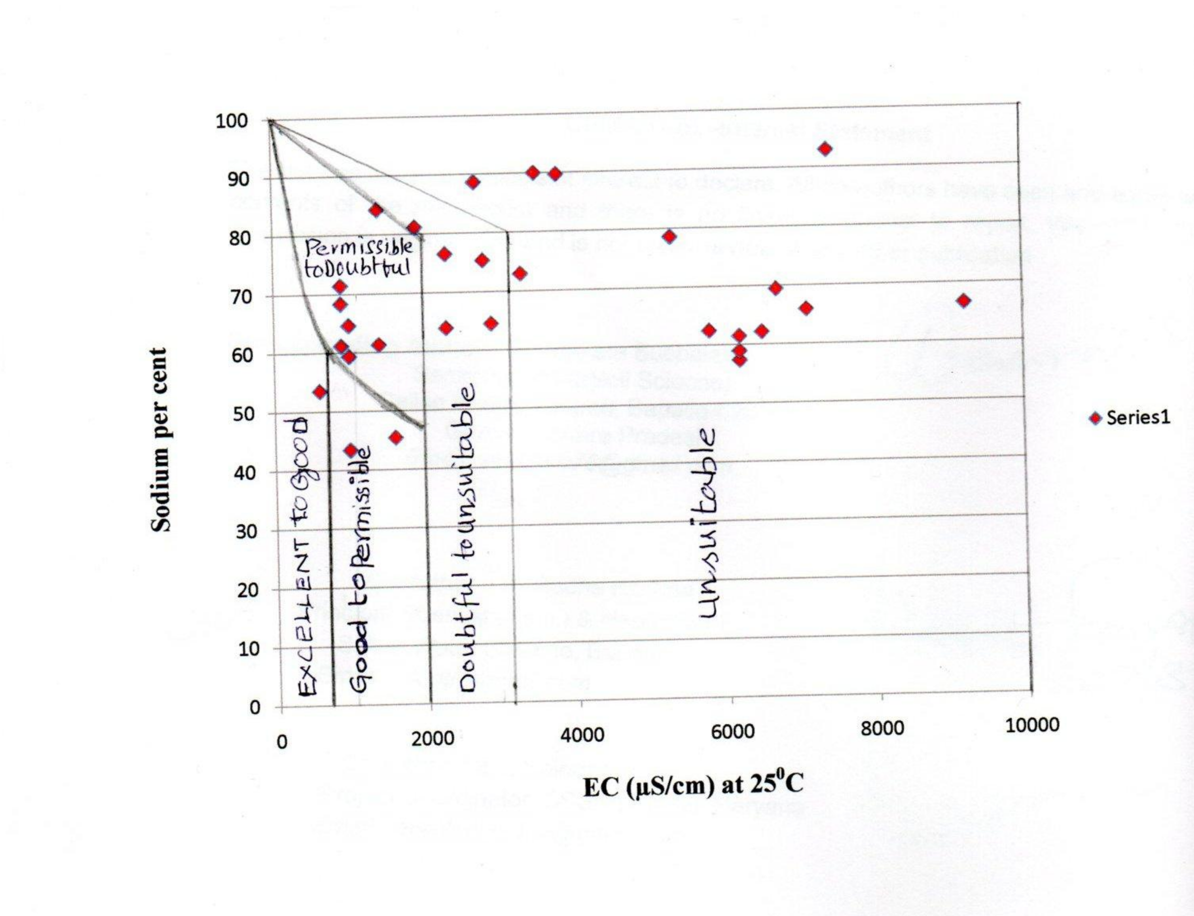

Fig.8 Suitability of groundwater for irrigation Wilcox diagram

Chloroalkaline indices:

Chloroalkaline indices 1 and 2 are used to understand the chemical reactions in which ion exchange takes place (Swarna Latha and Nageswara Rao, 2012). Ions in groundwater exchange with the ions of its aquifer environment during the periods of residence and movement. They are calculated as follows:

$$CAI1 = \{ Cl^- - (Na^+ + K^+)\}/Cl^- \qquad \text{……………………………..(4)}$$

$CAI2 = \{ Cl^{-} - (Na^{+} + K^{+})\}/(SO_4^{-2} + HCO_3^{-} + CO_3^{-2})$ ……………………………..(5)

Where the concentration of ions are in meq/L

Both the above indices are negative if there is an exchange between calcium or magnesium in the groundwater with sodium and potassium in the aquifer material and both these indices will be positive if there is a reverse ion exchange (Scholler, 1977). The obtained results point out that most of the samples (20 samples) in the study area display negative, this indicates exchange between calcium or magnesium in the groundwater with sodium and potassium in the aquifer material is leading process in the groundwater.

Kelley's ratio:

Kelley's ratio was used to classify the irrigation water quality (Kelley 1940), which is the level of Na^{+} measured against calcium and magnesium. The formula for calculating the Kelley's is as follows

$$KR = \frac{Na^{+}}{(Ca^{+2} + Mg^{+2})} \quad \text{…………………………..(6)}$$

Where the concentration of ions are in mg/L

Kelley's ratio for all the groundwater samples are calculated and it lies between 0.65 to 5.38 mg/L (Table 11). Kelley's ratio value less than one is suitable for irrigation(4 samples) and more than one is unsuitable (25 samples).

Magnesium ratio (MR):

In groundwater Mg^{+2} and Ca^{+2} maintain equilibrium. But, they do not behave equally in soil. Higher Mg^{+2} concentration damages soil structure, when water contains more Na^{+} and salinity. The presence of Mg^{+2} in higher concentrations also indicates the mixing of sea water and it deteriotes soil quality by rendering alkaline and also affects crop yields. This effect on crop yields is expressed in terms of magnesium ratio(Szaboles and Darab 1964), which is computed as follows, where all ions are expressed in meq/L.

$$MR = \frac{Mg^{+2}}{(Ca^{+2}+Mg^{+2})} \times 100 \qquad \ldots\ldots\ldots\ldots(7)$$

If MR is more than 50 in groundwater, the water quality is harmful for irrigation to crops due to its adverse effect on soil and crop yields. The present ground water is with MR range of 22.22-81.25 with a mean of 51.54. In the study area 55.17 per cent samples are safe (<50 MR) and 44.83 per cent samples are unsafe (>50 MR) for irrigation (Table 12).

Corrosivity ratio :

corrosivity ratio (CR), which is expressed as the ratio of alkaline earth metals to saline salts in groundwater (Ryner 1944; Raman 1985). Corrosivity is calculated from the formula

$$CR = \frac{(Cl^{-}/35.5) + 2(SO_4^{-2}/96)}{2[(CO_3^{-2} + HCO_3^{-})/100]} \qquad \ldots\ldots\ldots\ldots(8)$$

Where the concentrations of ions is in mg/L

Losses in hydraulic capacity of pipes are an effect of corrosion. About 79.31% of samples have the corrosivity ratio >1 which cannot be transported through metal pipes(Table 13). In such cases, the non corrosive [(polyvinyl chloride (PVC)] pipes can be a better choice for the water transportations (Aravindan *et al*. 2004).

Permeability index

Longterm use of irrigation contains Na^{+}, Ca^{+2}, Mg^{+2} and HCO_3^{-} ions greatly influence the soil permeability . Doneen 1964 expressed the degree of soil permeability in terms of permeability index(PI).

$$PI = \frac{(Na^{+} + \sqrt{HCO_3^{-}})}{(Ca^{+2} + Mg^{+2} + Na^{+})} \times 100 \qquad \text{.......(9)}$$

The suitability of groundwater for irrigation is classified based PI index into three classes(Table 14). They are (a) Class I, (b) Class II and (c) Class III, which have 100, 75 and 25% maximum permeabilities, respectively. The class I is suitable, class II is marginally suitale and class III is unsuitable. Based on permeability index, the groundwater in the study area is classified as suitable(17.24%) and marginally suitable (82.76%).

Conclusions:

The ground water quality varied from place to place. The dominance of major ion was in the order of $Na^+ > Ca^{+2} > Mg^{+2} > K^+$ for cations and $Cl^- > HCO_3^- > SO_4^{-2} > CO_3^-$ for anions, which indicated the quality of groundwater used for irrigation is Na^+-Cl^- type. Groundwater belonged to rock to evaporation dominance category. It indicated that process of evaporation from groundwater might have happened when groundwater might have remained very much close to surface. Good water (41.38%) and marginally saline water (17.24%) of the study area can be used effectively for crop production. However, adoption of proper management practices is needed in case of poor quality ground water. The spatial maps of different parameters, prepared using GIS could be valuable for policy makers for initiating groundwater quality monitoring of the area as well as for suggesting management plans. Assessment and mapping of quality of irrigated groundwater may help the farmers in selection of suitable crops and other agronomic management practices for intensifying the crop production to get getting profitable yields without affecting the soil health.

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Table 1. Methods used for estimation of different hydrochemical parameters of groundwater

Parameters	**Method used**
pH	Glass electrode (Richards,1954)
EC(Electrical conductivity)	Conductivity Bridge method (Richards,1954)
Na^+ (Sodium)	Flame Photometric method (Osborn and Johns, 1951)
K^+ (Potassium)	Flame Photometric method (Osborn and Johns, 1951)
Ca^{+2}(Calcium)	EDTA titration method (Richards, 1954)
Mg^{+2}(Magnesium)	EDTA titration method (Richards, 1954)
CO_3^{-2}(Carbonate)	Acid titration method (Richards,1954)
HCO_3^- (Bicarbonate)	Acid titration method (Richards,1954)
Cl^- (Chloride)	Mohr's titration method (Richards,1954)

SO_4^{-2} (Sulphate)	Turbidity method using $CaCl_2$ (Chesnin and Yien, 1950)

Table 2 . Range and average of different water quality parameters

S.NO.	Parameter	Range	Mean	Standard deviation	Standard error
1	pH	6.9-8.2	7.38	0.35	0.06
2	EC(dSm^{-1})	0.6-9.2	3.54	2.51	0.46
3	CO_3^{2-} (me L^{-1})	0-0.8	0.27	0.23	0.02
4	HCO_3^- (me L^{-1})	2.6-16.6	7.19	3.70	0.68
5	Cl^-(me L^{-1})	2-52	18.70	15.77	2.92
6	SO_4^{2-}(me L^{-1})	0.4-21.8	2.70	4.25	0.79
7	Ca^{2+}(me L^{-1})	1.2-24	8.51	7.32	1.36
8	Mg^{2+}(me L^{-1})	1.2-20	8.10	5.61	1.04
9	Na^+(me L^{-1})	2.22-47.7	19.30	14.08	2.61
10	K^+(me L^{-1})	0.02-0.87	0.23	0.23	0.04
11	RSC(me L^{-1})	-35-7.8	-9.15	12.28	2.28
12	SAR	1.75-17.59	6.56	3.94	0.73
13	Permeability index(PI)	44.62-87.08	63.28	11.61	2.15
14	Potential salinity	3.1-52.30	18.90	15.38	2.90
15	Total hardness	159-2186	824	627	116
16	Kelly's ratio	0.65-5.38	1.85	1.22	0.22
17	Sodium percentage	43.42-92.99	68.68	12.75	2.36
18	Total dissolved solids	384-5888	2237	1568	291
19	Corrosivity ratio	0.56-17.64	2.68	3.24	0.60
20	Mg ratio	22.22-81.25	51.54	13.86	2.57

Note: EC= Electrical conductivity; SAR= Sodium adsorption ratio; RSC= Residual sodium carbonate

Table 3: Ground water samples based on EC (dSm^{-1})

S.No.	EC(dSm^{-1})	No.of samples	Per cent of samples
1	0-2	11	37.93
2	2-4	8	27.59
3	4-6	2	6.897
4	6-8	7	24.14
5	8-10	1	3.448

Table 4: Classification based on Chloride content ($me\ L^{-1}$)

Chloride concentration ($me\ L^{-1}$)	Water quality	No.of samples	Per cent of samples
<4	Excellent water	8	27.586
4-7	Moderately good water	3	10.345
7-12	Slightly unsuitable	3	10.345
>12	Not suitable for irrigation	15	51.724

purpose

Table 5: Classification of ground water samples based on SAR

S.No.	SAR	No. of samples	Per cent of samples
1	<10	24	82.75
2	10-18	5	17.25
3	18-26	0	0
4	>26	0	0

Table 6 : Classification of ground water samples based on RSC (mel^{-1})

S.No.	RSC (mel^{-1})		No. of samples	Per cent of samples
	Class	Value		
1	None	<2.5	26	89.7
2	Slight to moderate	2.5-4	2	6.9
3	Severe	>4	1	3.4

Table 7. Correlation matrix among the chemical constituents of the groundwater

	pH	*EC*	*ca*	*Mg*	*Na*	*K*	*CO3-2*	*HCO3-*	*Cl-*	*SO4-2*	*RSC*	*SAR*	*PI*	*KR*	*CR*
pH	1														
EC	-0.272	1.000													
ca	-0.472	0.836**	1.000												
Mg	-0.280	0.936**	0.903**	1.000											
Na	-0.221	0.961**	0.689**	0.828**	1.000										
K	0.348	0.164	-0.191	0.023	0.319	1.000									
CO3-2	0.377*	-0.047	-0.334	-0.160	0.066	0.700**	1.000								
HCO3-	-0.174	0.551**	0.203	0.340	0.706**	0.464*	0.441*	1.000							
Cl-	-0.260	0.982**	0.864**	0.936**	0.921**	0.132	-0.085	0.475**	1.000						
SO4-2	-0.017	0.116	0.209	0.225	0.030	-0.192	-0.188	-0.288	0.197	1.000					
RSC	0.367*	-0.761**	-0.955**	-0.896**	-0.575**	0.260	0.429*	0.036	-0.801**	-0.319	1.000				
SAR	-0.015	0.708**	0.265	0.479**	0.866**	0.594**	0.359	0.835**	0.652**	-0.045	-0.117	1.000			
PI	0.441*	-0.234	-0.633**	-0.479**	0.002	0.513**	0.472*	0.389*	-0.282	-0.201	0.725**	0.437*	1.000		
KR	0.284	0.227	-0.282	-0.025	0.458**	0.717**	0.568**	0.692**	0.172	-0.120	0.402*	0.834**	0.792	1.000	
CR	-0.084	0.502**	0.585**	0.631**	0.367*	-0.157	-0.250	-0.172	0.575**	0.859**	-0.695**	0.124	-0.438	-0.159	1.000

*Significant at 0.05 probability level

**Significant at 0.01 probability level

Table 8. Classification of Ground Water and their Management (Minhas and Gupta, 1992)

Rating	Class	EC (dSm^{-1})	SAR	RSC (me L^{-}	number of samples	Per cent Samples
A.Good	A	<2	<10	<2.5	12	41.38
B. Saline						
Marginally saline	B1	2-4	<10	<2.5	5	17.24
Saline	B2	>4	<10	<2.5	7	24.13
High SAR Saline	B3	>4	>10	<2.5	4	13.80
C. Alkali Water						
Marginally alkaline	C1	<4	<10	2.5-4.0	0	0.0
Alkali	C2	<4	<10	>4.0	0	0.0
Highly alkaline	C3	variable	>10	>4.0	1	3.45

Table 9. Classification based on Cl^{-}/HCO_3^{-} ratio values (Revelle 1941)

Cl^{-}/HCO_3^{-} ratio	Claasification	Total samples	percentage
<0.5	not affected	0	0
0.5-6.6	slight to	26	89.7
>6.6	Severely affected	3	10.3

Table 10. Classification of groundwater based on %Na values (Wilcox 1955)

%Na (after Wilcox 1955)	Classification	Total no.of samples	percentage
<20	Excellent	0	0.00
20-40	Good	0	0.00
40-60	Permissible	6	20.69
60-80	Doubtful	17	58.62
>80	Unsuitable	6	20.69

Table 11. Classification of groundwater for irrigation based on Kelly's ratio(Kelly 1940)

KR	Suitability	Sample numbers	Per cent
<1.0	Good	4	13.8
>1.0	Not good	25	86.2

Table 12.Classification of groundwater based on MR for irrigation (Sazaboles and Darab 1964)

MR	Suitability	Sample numbers	Per cent
<50	Suitable	16	55.17
>50	Unsuitable	13	44.83

Table 13.Classification of groundwater based on CR for irrigation (Ryner 1944; Raman 1985)

CR	Suitability	Sample numbers	Per cent
<1	Suitable	6	20.69
>1	Unsuitable	23	79.31

Table 14.Classification of groundwater based on permeability index for irrigation (Doneen 1964)

Classification of PI	Permeability	Suitability	Sample numbers	Per cent
I	75-100	Suitable	5	17.24
II	25-75	Marginal	24	82.76
III	<25	Unsuitable	0	0.0

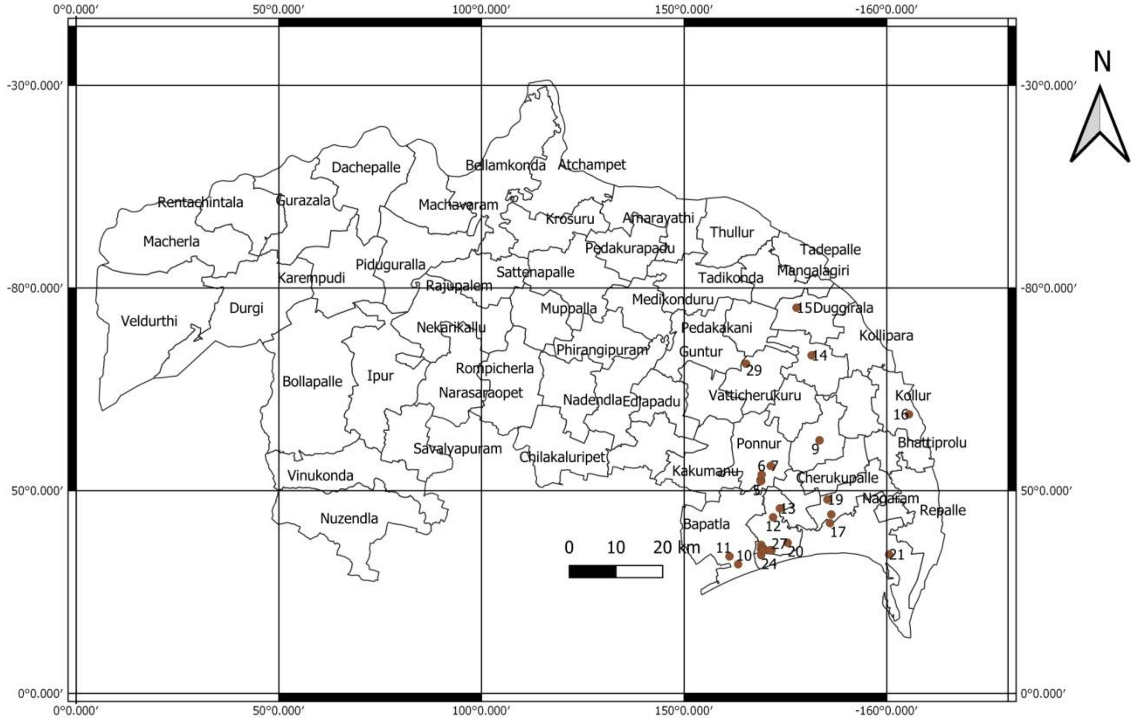

Fig.1 Groundwater sampling sites

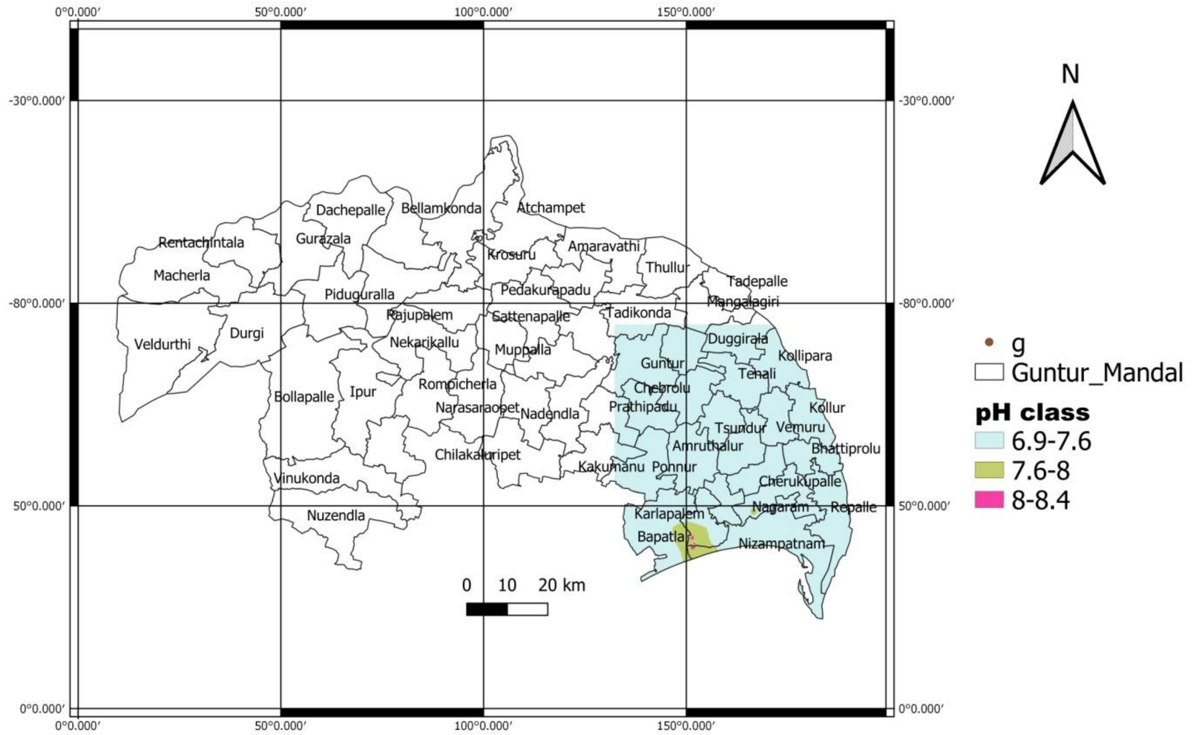

Fig.2 Spatial distribution of pH in groundwater

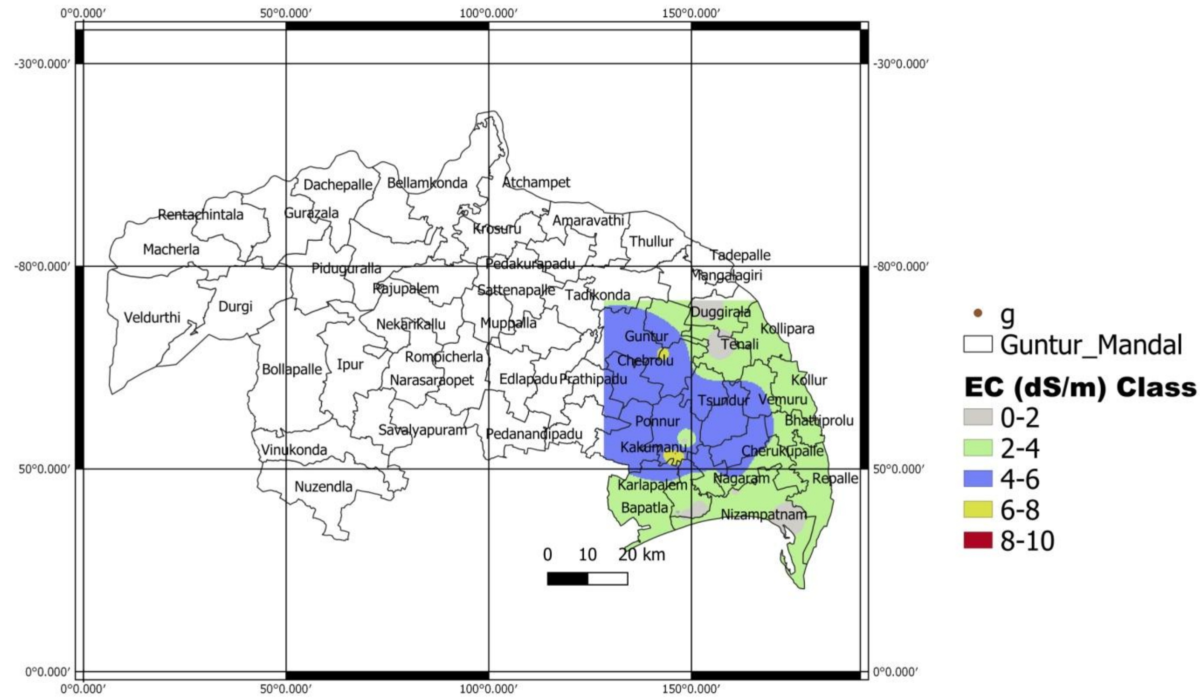

Fig.3 Spatial distribution of EC(dS/m) of Groundwater

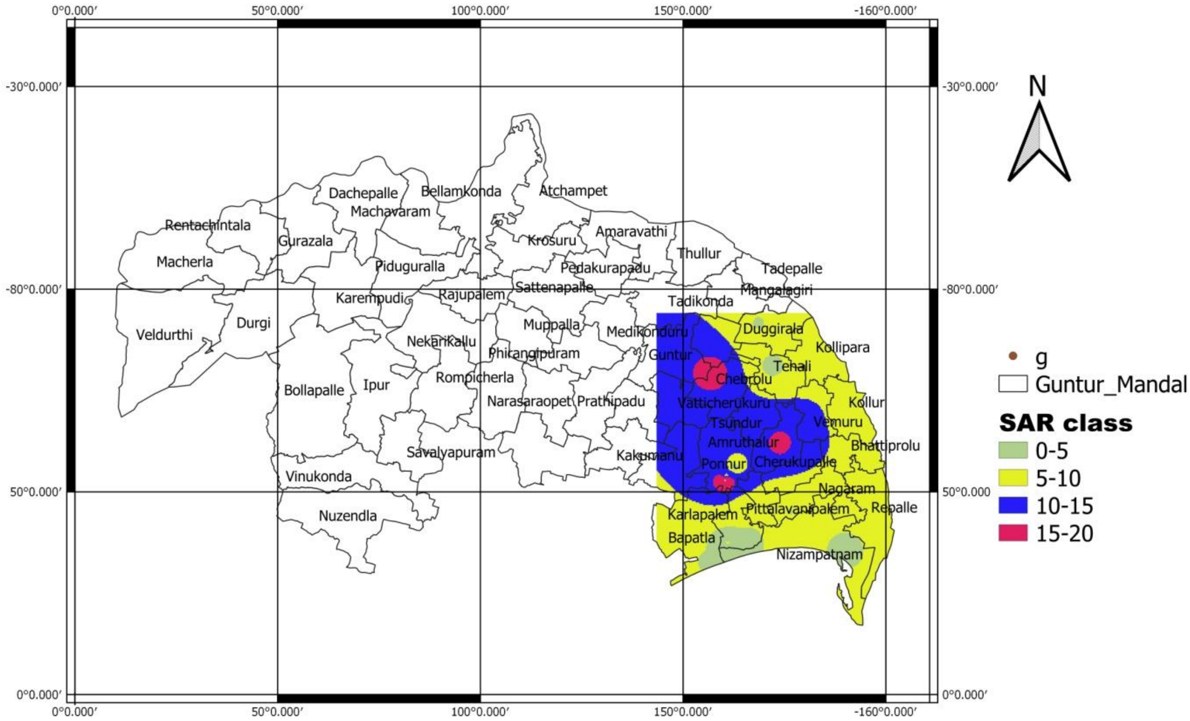

Fig 4. Spatial distribution of SAR in groundwater

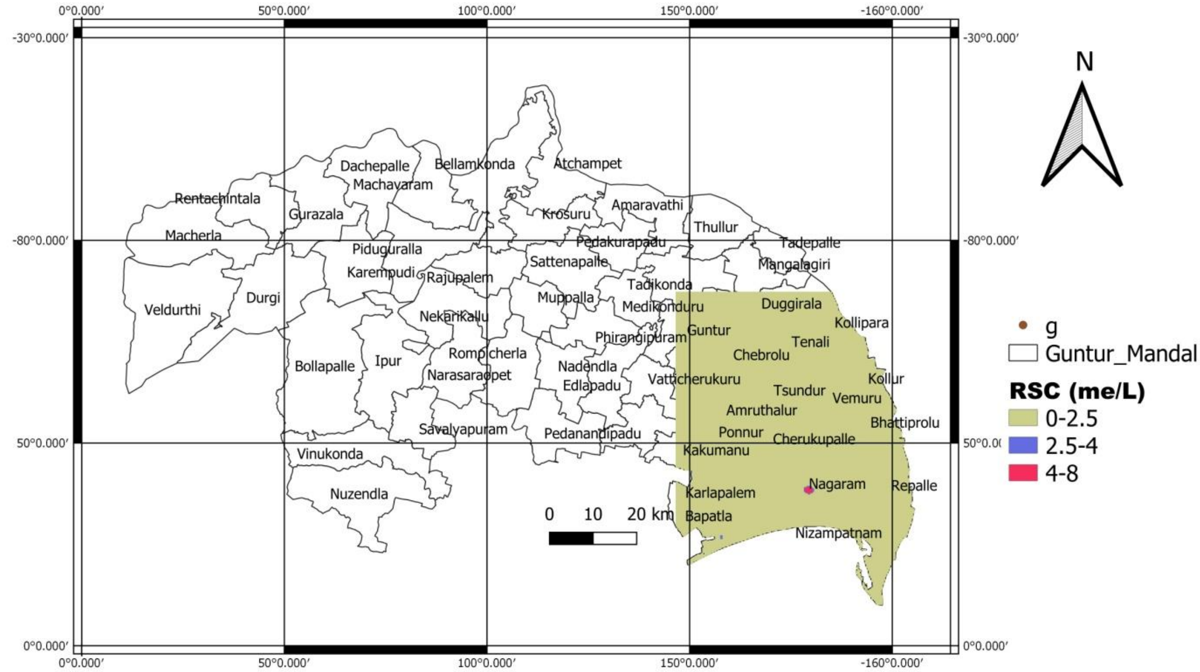

Fig 5. Spatial distribution of RSC (me/L) in groundwater

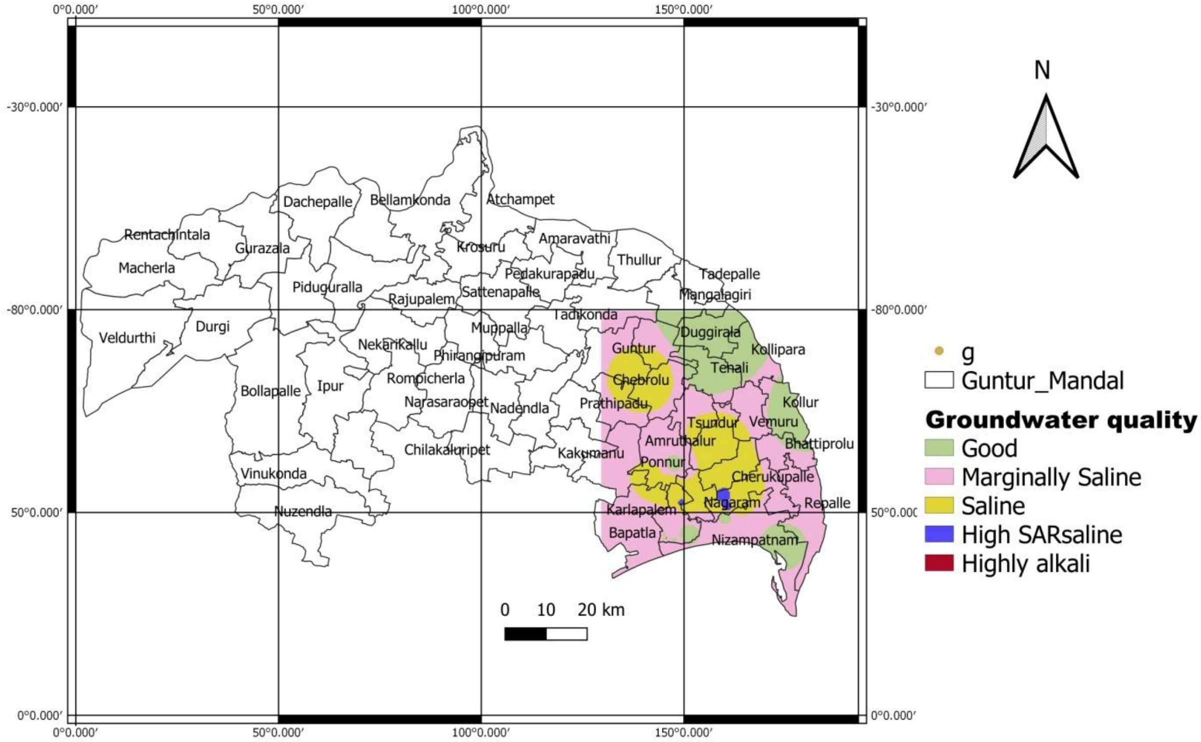

Fig 6. Spatial distribution of groundwater quality