Original Research Article

Assessment and Mapping of Groundwater Quality for Irrigation in and Around Areas of Paper Board Industry

ABSTRACT

A survey was undertaken during the year 2020 to assess the quality of groundwater for irrigation in Mondipatti region of Tiruchirapalli district of Tamil Nadu. A totally 18 samples were collected from bench mark wells of (W1-W18) in and around the paper board industry and GPS locations of sampling points were recorded. The water samples were analyzed for various chemical properties *viz.,* pH, EC, Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}; CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-}. The pH, EC, SAR and RSC in groundwater ranged from 7.6-8.4, 0.68-5.12 (dS m^{-1}), 0.69-12.9 and -8.1 to 5.3 (meq L^{-1}), respectively. The concentration of cations *viz.,* Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} varied from 1.7 to 10.8, 0.7 to 14.3, 0.009 to 0.931 and 2.8 to 39.2 meq L^{-1} with average of 5.4, 4.51, 0.190 and 9.24 meq L^{-1}, respectively. The concentration of anions *viz.,* carbonate, bicarbonates, chloride and sulphate varied from nil to 3.2, 3.2 to 9.6, 2.8 to 39.2 and 0.25 to 4.52 meq L^{-1} with average values of 0.64, 6.72, 11.88 and 1.31 meq 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 water quality classification, 44.5, 44.5, 5.5 and 5.5 per cent of good, marginally saline, High SAR saline and Alkaline, respectively. Spatial variability maps of pH, EC, SAR and RSC of groundwater used for irrigation in and surrounding areas of paper board industry were also generated.

Keywords: Anions, Cations, Residual Sodium Carbonate (RSC), Sodium Absorption Ratio (SAR) and Mapping of groundwater quality

1. INTRODUCTION

Water has become a precious commodity as a result of over-exploitation and pollution caused by a variety of factors. One-fifth of the water consumed by humans comes from groundwater resources. Since surface water sources are gradually depleted in many important agricultural areas, groundwater is the ultimate source of fresh water. In absolute terms the countries with largest extent of areas equipped for irrigation with ground water are India (39 m ha), China (19 m ha) and USA (17 m ha) [1}. In modern times, water has critical importance in the economic growth of all contemporary societies [2]. Underground water is the most important source for irrigation in India, thus deserving significant awareness about its use in agriculture and other sectors. Quality of irrigation water is an important consideration in any appraisal of salinity or alkali conditions in irrigated areas and it depends on primarily on the total amount of salt present and proportion of sodium to other cations along with various certain other parameters [3]. Over exploitation and contamination with various chemical and biological sources has greater impact on groundwater resources [4&5] In arid and semiarid regions of the world, mapping of groundwater quality for irrigation is essential to meet the ever-increasing demand for water. The qualities of water that impact its suitability for specific uses such as irrigation and drinking are referred to as water quality. Total groundwater withdrawals are estimated to be in the range of 600-1100 km^3 yr^{-1}, accounting for one fifth to one third of worldwide freshwater withdrawals (Singh *et al*., 2006; Bhat *et al*., 2016). The viability of groundwater for various applications is largely determined by its quality, hence groundwater evaluation is an important [6&7].

The assessment of ground water quality gains importance in recent times due to contamination of ground water by geo-hydrological pollution, weathering of minerals, urbanization and point source pollution and also because of over exploitation due to increase in urbanization, industrialization and interference of agricultural activities [8].

The data on quality of water is important for planning and remediating contamination for the agriculture and humans purpose. The continuous monitoring of groundwater resources, thus, plays a major role in sustainable management of water resources. The irrigation quality of water is expressed by the type and amount of dissolved salt [9]. Groundwater is precious only when its quality is suitable for a variety of purposes. Water for irrigation should satisfy the needs of soil and the crop as the liquid phase in soil water for plant growth and crop production [10]. Groundwater quality is affected by water-soil-rock interactions and the sources of numerous pollutants, in addition to excessive groundwater removal, which can alter the natural quality of groundwater. As a result, groundwater quality must be improved through safety management methods. Groundwater is essential for society's long-term growth; therefore, assessing groundwater quality in every region of the country is a must for improved oversight [11]. The current study was conducted to analyze the groundwater for assessment of quality for irrigation in and around areas of the paper board industry in the Mondipatti region of Tiruchirapalli district, Tamil Nadu, where the effluent water is being applied for irrigation through drip to the agroforestry system.

2. MATERIAL AND METHODS

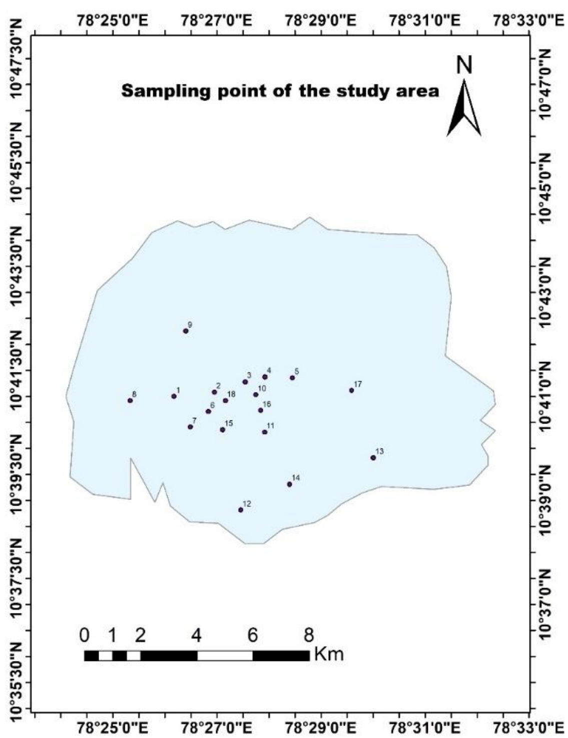
Tamil Nadu Newsprint and Paper Limited (TNPL) - Unit II located at Mondipatti Village, Manaparai Taluk, Trichy district, The site is situated at the intersection of latitude 10º 41' N and longitude 78º 26" E. A study was undertaken during December 2020 on the ground water survey and characterization of TNPL Unit II Mondipatti and its surrounding villages in Tiruchirappalli district. Totally eighteen ground water samples were collected from open wells and tube wells. The position of sampling points was recorded by GPS at each location were presented in Table. 1 and Fig.1.

Table 1. Location details of benchmark wells in and surrounding areas of paper board industry

S. No.	Location of bench mark wells	GPS Position	
		Latitude	Longitude
W1	Research & Developement block	10.683384°	78.436203°
W2	East Gate Block	10.684726°	78.449211°
W3	Block 2	10.688043°	78.459015°
W4	Block 3	10.689652°	78.465392°
W5	Block 5	10.689282°	78.474222°
W6	Mondipatti	10.678474°	78.447244°
W7	Sengudi	10.673555°	78.441494°
W8	Chinnareddiyarpatti	10.681974°	78.422204°
W9	Paadiripatti	10.704304°	78.440026°
W10	Vadakuserpatti	10.683886°	78.462467°
W11	Therkuserpatti	10.671895°	78.465262°

W12	Mutthapaudayapatti	10.646944°	78.457588°
W13	Samuthiram	10.663734°	78.500104°
W14	Maravanur	10.655227°	78.473265°
W15	Chokkampatti	10.672708°	78.451804°
W16	Kallikadu	10.678877°	78.463981°
W17	Karichampatti	10.685277°	78.493178°
W18	Poongodipatti	10.682027°	78.452697°

Fig 1. Groundwater sampling point of benchmark wells of in and surrounding areas paper board industry



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. Before analysis of groundwater the instruments were caliberated in accordance with the manufacturer's recommendations. The chemical analysis was followed based on standard methods are given in Table 2.

Table 2. Methods used for estimation of different hydro-chemical parameters of groundwater

Parameters	**Method used**
pH	Glass electrode [12]
EC (Electrical conductivity)	Conductivity Bridge method [12]
Na^+ (Sodium)	Flame Photometric method [13]

K^+ (Potassium)	Flame Photometric method [13]
Ca^{2+} (Calcium)	EDTA titration method [12]
Mg^{2+} (Magnesium)	EDTA titration method [12]
CO_3^{2-} (Carbonate)	Acid titration method [12]
HCO_3^- (Bicarbonate)	Acid titration method [12]
Cl^- (Chloride)	Mohr's titration method [12]
SO_4^{2-} (Sulphate)	Turbidity method using $CaCl_2$ [13]

pH in water samples was determined by potentiometrically using pH meter [14]. Electrical conductivity was determined by using Conductivity Bridge [15]. Chloride by titrating against standard silver nitate solution, carbonates and bicarbonates (double indicator method) and calcium and magnesium (Versenate method) were determined by standard protocol given by Richards (1954) [12]. Similarly, the sodium and potassium in ground water samples were measured by using flame photometer [12]. ArcGIS 10.3 version software were used to create thematic maps of the in and around areas of TNPL Unit II, Mondipatti, Tiruchirapalli district related to groundwater quality. Water quality indices SAR [12] and RSC [16] were calculated by using following equation.

a.) $SAR = Na/ \sqrt{(Ca^{2+}+Mg^{2+})/2}$ ……………… (1)

b.) $RSC\ (meq\ L^{-1}) = CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$………………. (2)

Suitability assessment of ground waters for irrigation

Based on EC, SAR and RSC, water samples were classified into different categories as per the classification of All India Coordinated Research Project (AICRP) on Management of Salt affected Soils and Use of Saline Water in Agriculture as given by Gupta *et al*. (1994) (Table 5.)

3. RESULTS AND DISCUSSION

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 and RSC were calculated for these samples. The analytical data of ground water samples collected from different location in and surrounding villages of TNPL Unit II, Mondipatti region of Tiruchirapalli district, Tamil Nadu during 2020 are presented Table 3.

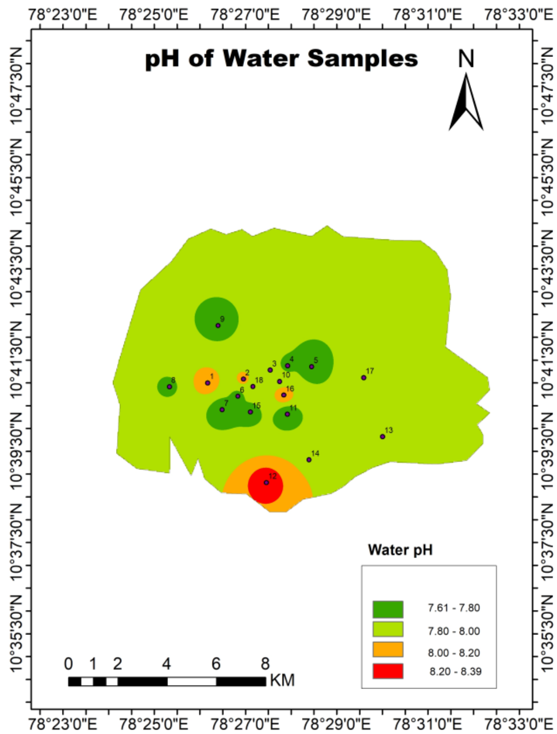
The pH of ground water is important parameter for determining its reaction in determining its acidity, neutrality or alkalinity. The pH values of groundwater samples were found to be ranged from 7.61 to 8.40 with a mean of 7.90 (Table 3) indicated that water is neutral to near alkaline in nature. The lowest pH were recorded in W11 (Therkuserpatti village) and the highest pH were recorded in W9 (Muthapaudayanpatti village). The variations in pH are relatively less and findings shows that the alkaline pH of the groundwater samples due to bicarbonate and not due to carbonate alkalinity [17]. The higher pH of groundwater may be due to dominance of Na^+, Ca^{2+}, Mg^{2+} CO_3^{2-} and HCO_3^- ions [18] as carbonate and bicarbonate are hydroxyl generating ions [19]. The low pH may be due to presence of forest areas in certain pockets. The spatial variability of pH of groundwater in and around areas of paper board industry is shown in Figure. 2

Table 3. Range and average of different water quality parameters in and around areas paper board industry

Particulars	Range	Mean
pH	7.61-8.4	7.90
EC (dS m^{-1})	0.68-5.12	2.07
TDS (mg L^{-1})	440-3300	1328

Calcium (meq L^{-1})	1.7-10.8	5.39
Magnesium (meq L^{-1})	0.7-14.3	4.51
Carbonate (meq L^{-1})	0-3.2	0.64
Bicarbonate (meq L^{-1})	3.2-9.6	6.72
Sodium (meq L^{-1})	1.84-39.35	9.24
Chloride (meq L^{-1})	2.8-39.2	11.88
Potassium (meq L^{-1})	0.009-0.931	0.190
Sulphate (meq L^{-1})	0.25-4.52	1.31
RSC (meq L^{-1})	0-5.3	0.32
SAR (mmol L^{-1})	0.69-12.9	4.03

Fig 2. Spatial variability of pH of groundwater in and surrounding areas of paper board industry



Electrical conductivity

The electrical conductivity of natural water is commonly used to indicate the total concentration of ionised components. Electrical conductivity is associated to the saturation of water in terms of dissolved particles and is related to the conduction of electricity through water [19]. The Electrical Conductivity in the study area ranged from 0.68 to 5.12 dS m^{-1} with a mean of 2.07 dS m^{-1}. The lowest EC of 0.68 dSm^{-1} was observed in W2 (East gate block) and the highest value of 5.12 dS m^{-1} was recorded in W13 (Samudiram) followed by Therukuserpatti (4.05 dS m^{-1}). Santhosh kumar *et al*., (2019) [20] studied the assessment of groundwater quality in mondipatti village and its surrounding area, Tiruchirapalli district, Tamil Nadu, India and reported that electrical conductivity varied from 0.56 to 3.54 dS m^{-1} with a mean value of 1.61 dS m^{-1}. When comparing both the findings, from 2015 to 2020 the EC value has gradually increased in a few benchmark sites of TNPL Unit II and its surrounding areas. The electrical conductivity classes were grouped into different classes with an interval of two units up to 2-4 dS m^{-1}. Out of 18 samples collected 50.0 per cent samples had EC < 2 dS m^{-1} followed by 44.44 per cent in 2-4 dS m^{-1} , 5.55 per cent in 4-6 dS m^{-1} (Table 5). There were fewer groundwater quality samples with higher electrical conductivity. Variation in electrical conductivity affects the variation in total soluble salt concentration and ultimately results in salinity of the groundwater samples. The correlation matrix of the groundwater samples exhibits excellent positive correlation between EC and calcium, magnesium, sodium, potassium, chloride and sulphate (Table 4.)

Table 4. Correlation matrix among the chemical constituents of the groundwater

	pH	EC (dSm^{-1})	TDS (mg L^{-1})	CO_3^{2-} (meq L^{-1})	HCO_3^- (meq L^{-1})	Ca^{2+} (meq L^{-1})	Mg^{2+} (meq L^{-1})	Na^{2+} (meq L^{-1})	K^+ (meq L^{-1})	Cl^- (meq L^{-1})	SO_4^{-} (meq L^{-1})	RSC (meq L^{-1})	SAR
pH	1												
EC (dSm^{-1})	-0.29	1											
TDS (mg L^{-1})	-0.29	1.00**	1.0										
CO_3^{2-} (meq L^{-1})	0.50**	-0.27	-0.28	1									
HCO_3^- (meq L^{-1})	-0.09	0.73**	0.74**	-0.35	1								
Ca^{2+} (meq L^{-1})	-0.56	0.31**	0.31**	-0.52	0.18**	1							
Mg^{2+} (meq L^{-1})	-0.18	0.88**	0.87**	-0.09	0.60**	-0.01	1						
Na^{2+} (meq L^{-1})	0.17**	0.72**	0.72**	0.05*	0.60**	0.01*	0.74**	1					
K^+ (meq L^{-1})	-0.10	0.69**	0.69**	-0.02	0.41**	-0.19	0.89**	0.70**	1				
Cl^- (meq L^{-1})	-0.25	0.97**	0.97**	-0.21	0.66**	0.17**	0.91**	0.69**	0.78*	1			
SO_4^- (meq L^{-1})	-0.20	0.37**	0.36**	-0.35	0.33**	0.77**	0.01*	0.36**	-0.17	0.18**	1		
RSC (meq L^{-1})	0.61**	-0.68	-0.68	0.49**	0.23**	-0.67	-0.61	-0.35	-0.49	-0.65	-0.42	1	
SAR	0.37**	0.58**	0.58**	0.14*	0.59**	-0.12	0.56**	0.94**	0.53**	0.54**	0.35*	-0.08	1

*Significant at $p \leq 0.05$ probability level; **Significant at $p \leq 0.01$ probability level

Table 5. Suitability assessment of ground waters for irrigation

Water quality	Sub class	EC (dSm^{-1})	SAR (mmol L^{-1})$^{1/2}$	RSC (meq L^{-1})	No. of samples	Frequency (%)
A. Good	A	<2	<10	<2.5	8	44.5
B. Saline						
i. Marginally saline	B1	2-4	<10	<2.5	8	44.5
ii. Saline	B2	>4	<10	<2.5	-	-
iii. High SAR saline	B3	>4	>10	<2.5	1	5.5
C. Alkali water						
i. Marginally alkaline	C1	<4	<10	2.5-4.0	-	-
ii. Alkaline	C2	<4	<10	>4.0	1	5.5
iii. High alkaline	C3	Variable	>10	>4.0	-	-

The concentration of cations *viz*., calcium, magnesium, potassium and sodium in water samples varied from 1.7 to 10.8, 0.7 to 14.3, 0.009 to 0.931 and 1.84 to 39.35 meq L^{-1} with average of 5.4, 4.51, 0.190 and 9.24 meq L^{-1}. (Table 3.) The cationic concentration followed the order of sodium > calcium > magnesium > potassium. The presence of sodium in groundwater primarily results from the chemical decomposition of feldspars [21] and the presence also predicts the sodicity hazard of the water [3]. The presence of Ca^{2+} in groundwater might be attributed due to calcium-rich minerals such as amphiboles, pyroxenes and feldspars and the Mg^{2+} in groundwater might by the presence of olivine mineral and the ion exchange of minerals in the surrounding rocks and soils [22]. The low levels of potassium in groundwater samples may be ascribed to its tendency to be fixed by clay minerals and to participate in the formation of secondary minerals [23].

The concentration of anions *viz.,* carbonate, bicarbonates, chloride and sulphate varied from nil to 3.2, 3.2 to 9.6, 2.8 to 39.2 and 0.25 to 4.52 meq L^{-1} with average values of 0.64, 6.72, 11.88 and 1.31 meq L^{-1}, respectively (Table 3.). The anionic concentration followed the order of chloride > bicarbonate > sulphate > carbonate. Natural processes such as weathering, salt dissolving, and irrigation drainage return flow may be responsible for the increasing chloride level in the groundwater [21]. Furthermore, the source of chloride could be non-lithogical (Poor salinity conditions, irrigation-return-flows, chemical fertilisers *etc*.,).The reasons for carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations in groundwater can be ascribed to carbonate weathering as well as from the dissolution of carbonic acid in the aquifers [24]. The presence of sulphide-bearing minerals and gypsum in aquifer materials, as well as the use of sulphate-rich fertilisers and industrial wastes, could all contribute to sulphate ions in groundwater [25]. Furthermore, greater SO_4^{2-} content in groundwater is expected as a result of the use of soil amendments such as gypsum [19].

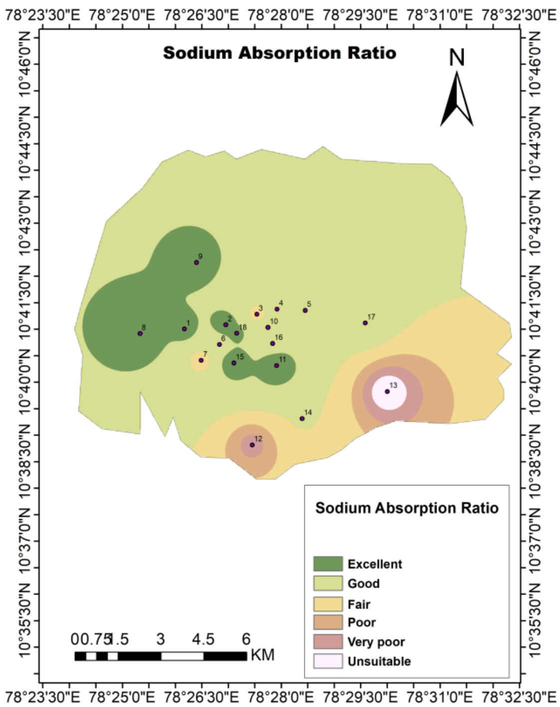
The relative abundance of ions for most of the water samples were $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ for cations and $Cl^- > HCO_3^- > SO_4^{2-} > CO_3^-$ for anions, respectively. As a result, the Na-Cl water type was used to characterize the chemical makeup of the groundwater. The ratio of Na^+/Cl^- in majority of the samples is more than 1, indicating that sodium was also liberated during silicate weathering. However, if sodium concentration in groundwater is caused by halite breakdown, the Na^+/Cl^- ratio should be around 1 [26&21]. The presence of high levels of Na^+ and Cl^- in water samples could indicate the presence of dissolving chloride salts [23]. The comparative concentration of major cations and anions in the regional groundwater of Minab plain, Iran were Sodium > Magnesium > Calcium > Potassium and Chloride > Bicarbonates > Sulpahte > Carbonates, respectively [27].

Highly significant positive correlation (Table 5) was observed between major cations, Na^+ and Mg^{2+} (r = 0.74**). Highly significant positive correlation was observed between Na^+ and HCO_3^- (r = 0.60**) and Na^+ and SO_4^{2-} (r = 0.36**). The positive correlation indicates the dissolution of sodium from its respective ion containing minerals. Highly significant positive correlation between Ca^{2+} and HCO_3^- (r = 0.18**) which indicates that the calcite may be a source in the presence Ca^{2+}. The correlation between SO_4^{-2} and Ca^{2+} (r = 0.77**) implies that a part of the SO_4^{-2} and Ca^{2+} may also be derived by the weathering of Calcium sulphate mineral [22]. The correlation between Mg^{2+} and HCO_3^- (r = 0.60**) between Cl^- and Na^+ (r = 0.69**) indicates that they most likely derive from the same source of water.

Sodium Absorption Ratio (SAR)

The most useful parameter for determining the suitability of groundwater for irrigation purposes is the sodium adsorption ratio. The SAR values varied from 0.69 to 12.90 with mean value of 4.03. The maximum value was observed in W13 (Samudiram) followed by W12 (Muthapaudayanpatti) and W7 (Sengudi). The minimum SAR value was received in W11 (Therkuserpatti). Santhosh kumar *et al*., (2019) [20] studied the assessment of groundwater quality in mondipatti village and its surrounding area, Tiruchirapalli district, Tamil Nadu, India and concluded that SAR value ranged from 1.06 to 11.1 with mean value of 4.56. In both the findings, there is no significant variation observed in the SAR value from 2015 to 2020. The spatial variability of SAR of groundwater in and around areas of paper board industry shown in Figure 3. Isaac *et al*. (2009) [28] ascertained that, the SAR of soil solution is increased with the increase in SAR of irrigation water which eventually increases the exchangeable sodium of the soil. Singh *et al*., (2018) [29] reported that sodium adsorption ratio varied from 3.69-28.59 with mean value 10.34 in groundwater samples of Kaithal block, Haryana. Ayers and Wiscot (1976) [30] 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 >26, respectively are regards as unfavorable as they can lead to detrimental levels of exchangeable sodium in soil. According to above criteria groundwater does not contribute any sodicity hazard.

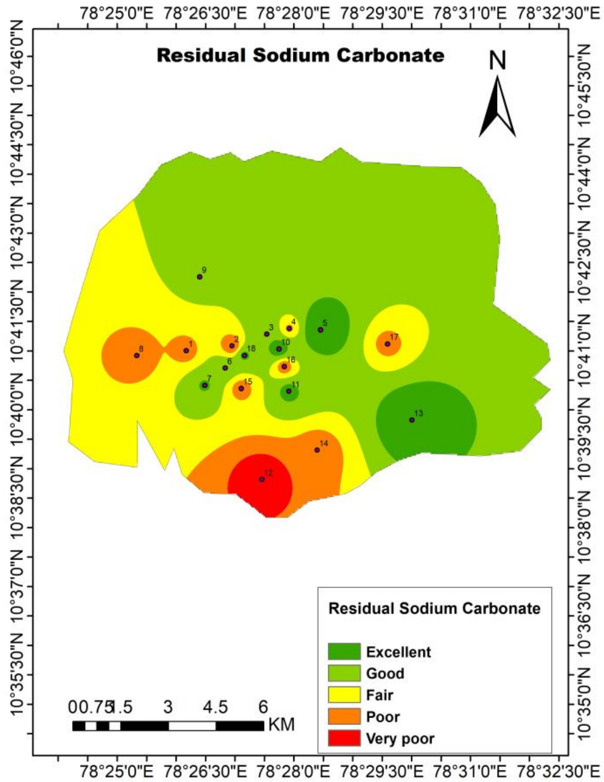
Fig 3. Spatial distribution of SAR of groundwater in and surrounding areas of paper board industry



Residual Sodium Carbonate (RSC)

Residual sodium carbonate is an important parameter that has extraordinary influence on the suitability of irrigation water. RSC is usually used to evaluate the deleterious effect of carbonate and bicarbonate to determine the quality of water. The residual sodium carbonate was recorded in the range of nil to 5.3 meq L^{-1} with the mean value of 0.32 meq L^{-1}. Naseem *et al*. (2010) [31] reported that pH, EC and SAR of the irrigation water are significantly influenced by RSC. Based on RSC, water can be categorized into three categories such as safe (2.5 meq L^{-1}), marginally suitable (1.25-2.5 meq L^{-1}) and unsuitable (>2.5 meq L^{-1}). In present study it was found that 17 samples were found to be under safe category.

Fig 4. Spatial distribution of RSC of groundwater in and surrounding areas of paper board industry



Suitability assessment of ground waters for irrigation

Screening of groundwater samples for their suitability to irrigation done on the basis of EC, SAR and RSC values as suggested by Central Soil Salinity Research Institute, Karnal is given in Table 5. The results indicate that, majority of the samples coming under good (44.5) followed by marginally saline (44.5%), high SAR saline (5.5 %) and alkaline (5.5%). High SAR saline of the ground water sample might be due to presence of sodium and chloride ions and alkalinity of the ground water samples might be due to the presence of bicarbonates.

4. CONCLUSION

The ground water quality of in and around areas of TNPL Unit II, mondipatti villages 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, respectively. Thus, the irrigated groundwater quality is Na-Cl type. The results indicate that, majority of the samples coming under good (44.5) followed by marginally saline (44.5%), high SAR saline (5.5 %) and alkaline (5.5%). The spatial distribution maps generated for various parameters using GIS techniques could be valuable for policy makers for initiating groundwater quality monitoring in the area. Assessment and mapping of quality of groundwater may help the farmers in choice of crops and other agronomic management practices for getting profitable yields without affecting the soil health. Therefore, continuous monitoring of groundwater is imperative to avoid major environmental threat.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authorss.

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