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Groundwater Quality Assessment for Chittoor District of Andhra Pradesh for Irrigation Purpose and Management Options

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Abstract

A survey was undertaken during the year 2019 to assess the quality of groundwater for irrigation in Chittoor district of Andhra Pradesh. A total of 358 samples were collected 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 5.5-8.8, 0.2-13.5 (dS m^{-1}), 0.26-20.4 $(mmol\ l^{-1})^{1/2}$, and 9.4-37.6 (me L^{-1}), respectively. The concentration of cations *viz.,* Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} varied from 0.8-26.4, 0-15.6, 0.25-91.31 and 0.001-2.64 me L^{-1} with mean values of 5.13, 3.64, 6.58 and 0.11 me L^{-1}, respectively. Concentration of anions viz., CO_3^{-2}, HCO_3^{-}, Cl^{-} and SO_4^{-2} varied from 0-5.6, 0.2-14.6, 0.8-85.2 and 0-45 me L^{-1} with average values of 0.84, 6.46, 5.84 and 2.03 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 $HCO_3^{-} > Cl^{-} > SO_4^{-2} > CO_3^{-}$ for anions. In total the irrigation water samples were 65.64, 25.69, 0.27, 6.7, 1.11 and 0.55 per cent of good, marginally saline, high SAR saline, marginally alkaline, alkali and highly alkali, respectively. Spatial variability maps of EC, SAR, RSC of ground water used for irrigation in the district and groundwater quality map were also generated. Yields of major crops grown with poor- quality groundwater (saline/ alkali) were assessed. Yield losses (7.7 to 53.3%) under seven different crops due to poor-quality irrigation were estimated by comparing those yields with good-quality ground water areas. Soil and crop management practices were suggested to overcome the crop yield losses in poor-quality soil and water environment in the district.

Key words: Ground water quality, RSC, SAR, Spatial variability, Yield losses, Management options

Introduction

Water has become a scarce commodity due to its over exploitation as well as its pollution due to different reasons. Globally, one fifth of the water used is obtained from the ground water resources. For many important agricultural areas ground water is the ultimate source of fresh water as surface water sources have been depleted .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). The use of ground water for irrigation is significant and provides farmers with a reliable source of water that can be used in a flexible manner. Total ground water withdrawals are essential to be in the range of 6000-1100 km^3 year $^{-1}$ or between 1/5th and 1/3rd of the global fresh water withdrawals (Shah *et al.*, 2017).

Generally, the rates of ground water recharge in semiarid and arid regions are low such that in the absence of alternative resources of water, ground water withdrawals can exceed aquifer recharge and can result in depletion. 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 and certain other parameters (Singh *et al.*, 2019). 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 (Ackah *et al.,* 2011). In the areas where availability of surface water is limited throughout the year, farmers are compelled to use poor-quality ground water for agricultural purposes. Groundwater development of Andhra Pradesh is 44.15% of which 58.92% is only for Chittoor district. Both are lesser than national average of 63%. The Chittoor district is using 90.8 per cent of exploited groundwater for irrigation of crops (CGWB, 2017). Farmers also report ground water quality issues in certain pockets. In view of this scenario, it is necessary to understand the groundwater quality of Chittoor district for irrigation purpose and its effect on soil quality. Such assessment might be helpful to understand the effect of irrigation water quality on crop productivity and to suggest the soil and crop management practices for better crop yields by reducing adverse effects of saline/ alkali water irrigation. Therefore, the present study was undertaken.

Material and Methods

The Chittoor district lies in between 12°37′ and 14°18′ of Northern latitudes and 78° 03′ and 79°55′ Eastern longitudes (Fig 1). Chittoor has a total geographical area of 15,152 km^2 and bordered by the SPSR Nellore to the east, North Arcot and Dharmapuri districts of Tamil Nadu to the south and in the north by YSR Kadapa and Anantapuram districts. The annual rainfall of the district was found ranging from 719 to 908 mm through South-West and North-East monsoons. The maximum temperature varied 36 to 46°C during summer and the minimum temperature of 23 to 24°C during winter. About 40 percent of the total geographical area is covered by hills and forests. Another 15 percent of the area has been put to non-agricultural uses. Hence, about 45 per cent of the total geographical area is available for planning of development of ground water resources.

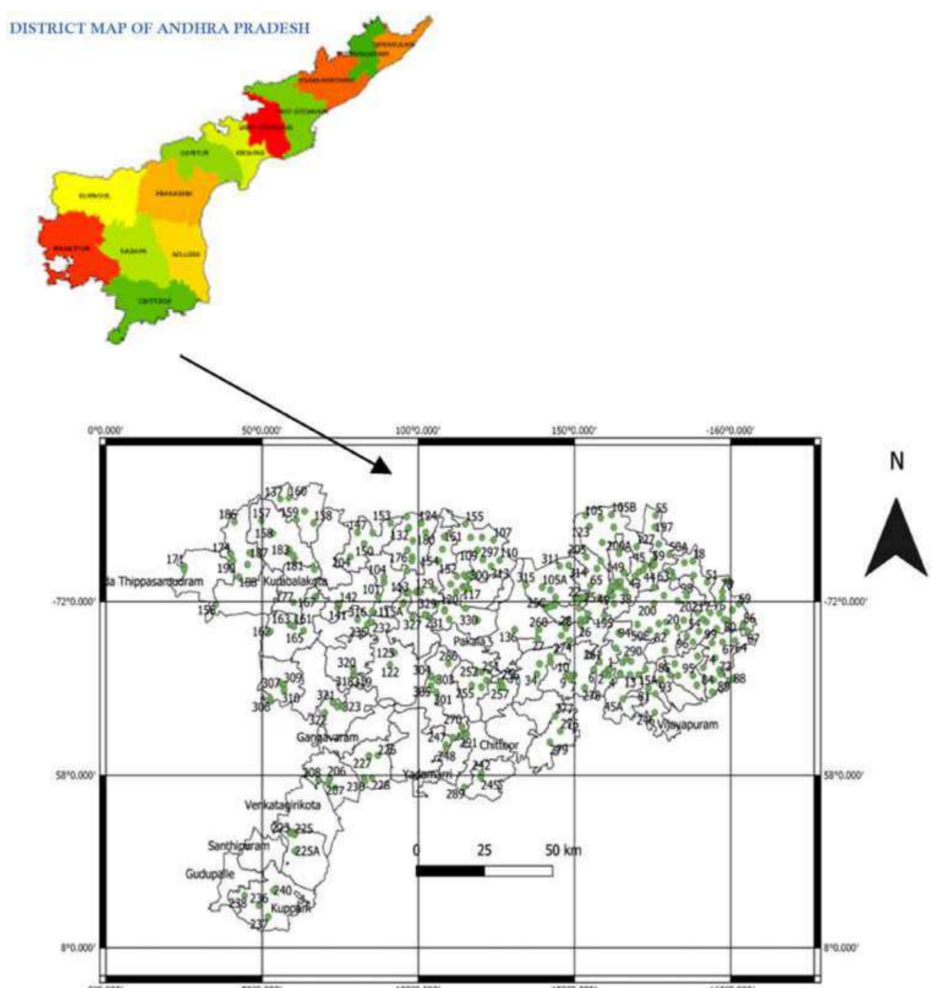

Fig. 1 Groundwater sampling sites of Chittoor District

Table 1. Methods used for estimation of different hydro-chemical 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)

The Ground water resources have been assessed watershed wise and are apportioned to mandals by (CGWB, 2017). The Total Annual Ground Water Recharge of the State of Andhra Pradesh has been estimated as 21.22 bcm and Annual extractable resource is 20.15 bcm. The Current Annual Ground Water extraction for all uses is 8.90 bcm and Stage of Ground Water extraction is 44.15%. Out of 670 mandals, 45 have been categorized, as 'Over-exploited', 24 as 'Critical', 60 as 'Semi-Critical', 501 as 'Safe' and 40 are 'Saline mandals. Chittoor district of Andhra Pradesh was one among all the districts in Andhra Pradesh using ground water as major source for irrigation. Chittoor district has of 1,65000 tube wells and filter points and 38000 dug wells covering nearly 90.8 percent irrigated area of the district. Total groundwater recharge for district is 187340.94 ha m. Total utilizable groundwater is 177973.88 ha m and present irrigation use is 95256.50 ha m. Groundwater development for district, considering all uses, is 58.92 percent which is higher than the state groundwater development (CGWB, 2017).

Three hundred and fifty eight (358) ground water samples were collected from different sources like bore wells, open wells and hand pumps by selecting 5-6 villages at random in each Mandal and in each village one sample was collected by noting their GPS coordinates (Fig. 1) in all the Mandals of Chittoor district. Sampling was carried out using preconditioned clean high-density polythene bottles, which were rinsed three times with sample water prior to sample collection. The dug wells waters were lifted to the ground surface by rope and bucket while tube well waters were pumped to the surface by using hand pump. 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 $= Na/ ((Ca^{2+}+Mg^{2+})/2)^{0.5}$ and RSC $= (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$. The Na^{+}, Ca^{2+} and Mg^{2+} are in m mol L^{-1} for calculation of SAR and CO_3^{2-}, $H CO_3^{-}$, Ca^{2+} and Mg^{2+} are in me L^{-1} for RSC calculations.

The ground water samples were classified under different classes as per the limits of EC, SAR and RSC given by Gupta *et al.* (1994). Correlation coefficient of water properties were obtained as per the standard methodology given by Panse and Sukhatme (1961). Soil samples were also collected and analyzed for soil salinity and sodicity. The data pertaining to crop yields were noted by conducting survey and crop cutting experiments to study the effect of prolonged use of poor-quality groundwater for irrigation on crop yields. Further, estimated the effect of poor-quality irrigation water on crop yield by comparing the yields of poor-quality ground water areas with good-quality irrigation water areas. The percent deviations in crop yields were used to work out yield losses due to prolonged use of poor- quality ground water for irrigation purpose.

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 and RSC were calculated for these samples. The analytical data of ground water samples collected from various Mandals of Chittoor district in Andhra Pradesh during 2019 are presented (Table 2) in me L^{-1}.

The pH of ground water is important parameter for determining its reaction in determining its acidity, neutrality or alkalinity. The pH of water samples varied from 5.5 to 8.8 with a mean of 7.35. Higher pH of ground water may be due to dominance of Na^{+}, Ca^{+2}, Mg^{+2} and CO_3^{-2} and HCO_3^{-} ions. The low pH may be due to presence of forest areas in certain pockets. The spatial variability of pH of groundwater in Chittoor is depicted in Fig.2. Water salinity determined in terms of EC.

The EC values in water samples of various mandals of Chittoor district was ranged from 0.2 to 13.5 dS m^{-1} with a mean of 1.73 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

Table 2. Range and average of different water quality parameters in Chittoor district

Parameter	Range	Mean
pH	5.5-8.8	7.35
EC (dS m^{-1})	0.2-13.5	1.73
CO_3^{2-} (me L^{-1})	0-5.6	0.84
HCO_3^{-} (me L^{-1})	0.2-14.6	6.46
Cl^{-} (me L^{-1})	0.8-85.2	5.84
SO_4^{2-} (me L^{-1})	0-45	2.03
Ca^{2+} (me L^{-1})	0.8-26.4	5.13
Mg^{2+} (me L^{-1})	0-15.6	3.64
Na^{+} (me L^{-1})	0.25-91.31	6.58
K^{+} (me L^{-1})	0.001-2.64	0.11
RSC (me L^{-1})	-37.6-9.4	-1.46
SAR	0.26-20.14	3.08

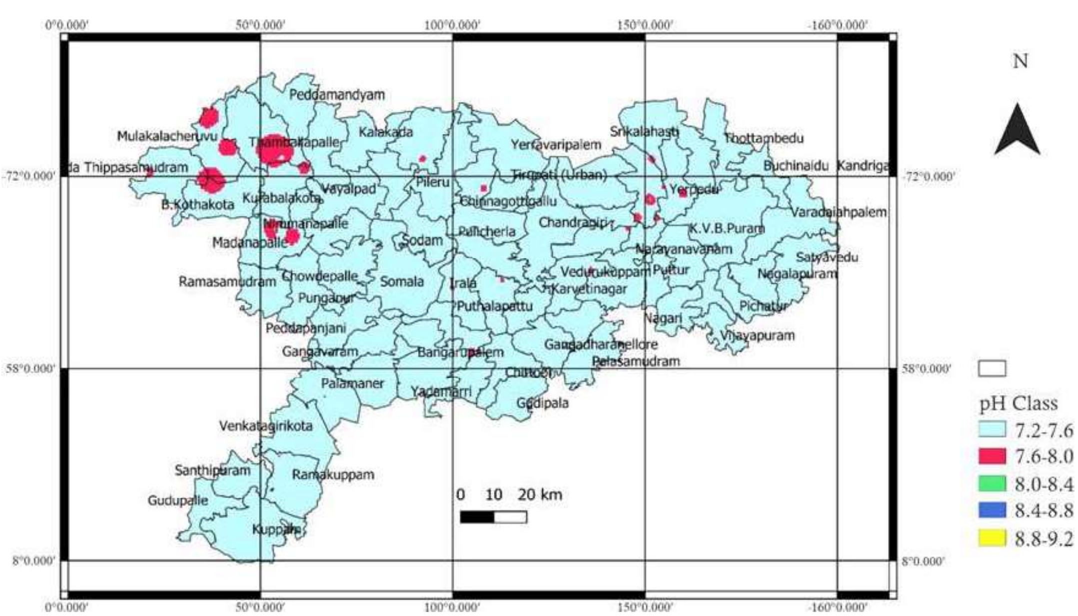

Fig. 2 Spatial variability of pH of ground water of Chittoor District

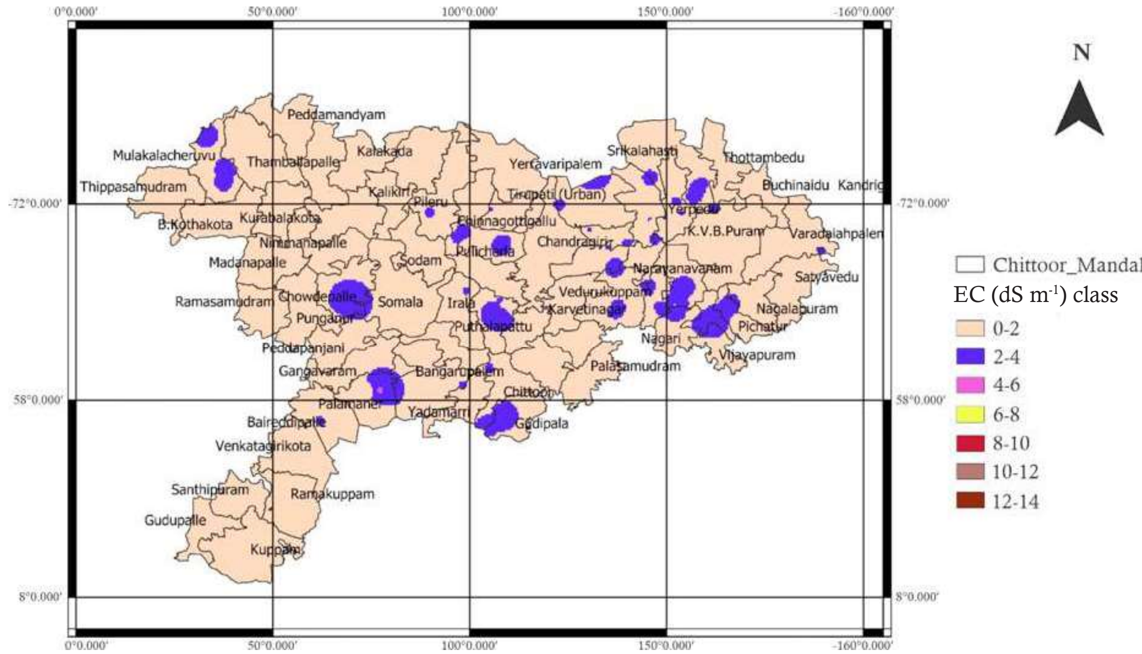

Fig. 3 Spatial distribution of EC (dS m^{-1}) of ground water of Chittoor District

electricity and is correlated to the saturation of water with regard to the dissolved solids (Pal *et al.*, 2018). The spatial variability of EC of ground water in Chittoor district is depicted in Fig. 3. The electrical conductivity classes (Table 3) were grouped into different classes with an interval of two units up to 14 dS m^{-1}.

Out of 358 samples collected 71.78 per cent samples had <2 dS m^{-1} followed by 27.65 per cent in range of 2-4 dS m^{-1} followed by 0.27 per cent in 4-6 dS m^{-1} and 0.27 per cent in 12-14 dS m^{-1} range. There is no sample recorded the EC ranges of 6-8, 8-10 and 10-12 dS m^{-1}. The groundwater samples having higher electrical conductivity were less in number. The variation in EC may be due to variation in hydro-geological conditions and the

Table 3. Ground water samples based on EC (dS m^{-1})

S.No.	EC (dS m^{-1})	No.of samples	Per cent of samples
1	0-2	257	71.78
2	2-4	99	27.65
3	4-6	1	0.27
4	6-8	0	0.0
5	8-10	0	0.0
6	10-12	0	0.0
7	12-14	1	0.27

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^{+}, K^{+}, Cl^{-}, SO_4^{-2} and HCO_3^{-}. The concentration of cations viz., calcium, magnesium, sodium and potassium in water samples varied from 0.8-26.4, 0-15.6, 0.25-91.31 and 0.001-2.64 me L^{-1} with mean values of 5.13, 3.64, 6.58 and 0.11 me L^{-1} respectively. The cationic concentration followed the order sodium, calcium, magnesium and potassium. The presence of sodium in groundwater primarily results from the chemical decomposition of feldspars (Kumar *et al.*, 2009) and the presence also predicts the sodicity danger of the water (Singh *et al.*, 2018a). The presence of calcium in groundwater might be attributed to calcium rich minerals such as amphiboles, pyroxenes and feldspars (Jalali, 2010) 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 clay minerals and to participate in the formation of secondary minerals (Jalali, 2005).

The concentration of anions viz., carbonate, bicarbonates, chloride and sulphate varied from 0-5.6, 0.2-14.6, 0.8-85.2 and 0-45 me L^{-1} with average values of 0.84, 6.46, 5.84 and 2.03 me

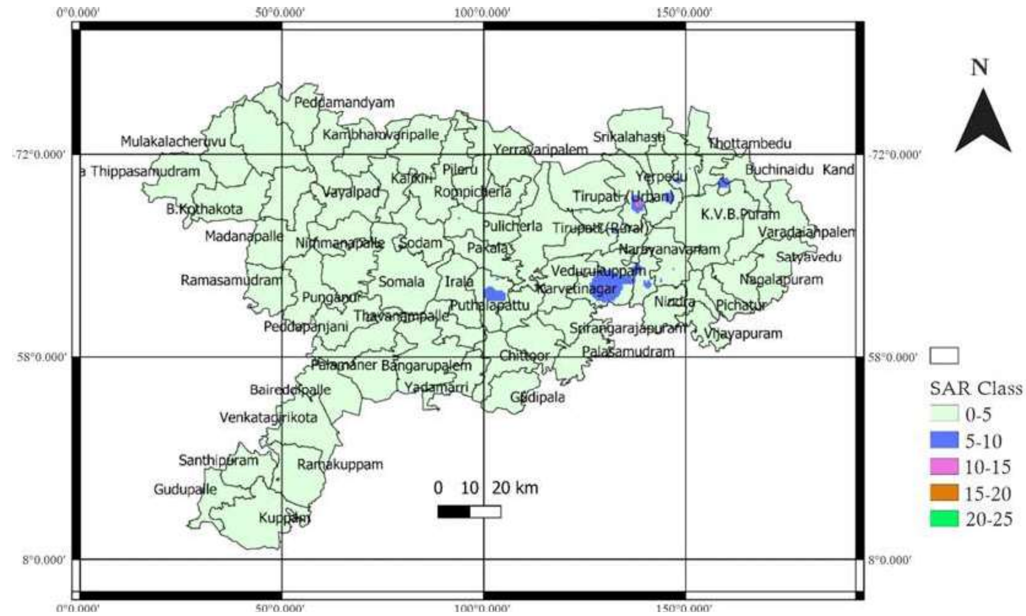

Fig. 4 Spatial variability of SAR of ground water of Chittoor District

L^{-1}, respectively. The relative abundance of ions for most of the water samples are $HCO_3^- > Cl^- > SO_4^{-2} > CO_3^{-2}$. The bicarbonate and chloride ions are dominant among all the anions then followed by sulphates and carbonates. The higher concentration of bicarbonate ions in groundwater can be ascribed to carbonate weathering as well as from the dissolution of carbonic acid in the aquifers from the possible mechanisms (Houatmia *et al.*, 2016). 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 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).

The SAR of groundwater of Chittoor district ranged from 0.26- 20.14 (m mol $l^{-1})^{1/2}$ with a mean of 3.08 (m mol $l^{-1})^{1/2}$. The lowest SAR of 0.26 (m mol $l^{-1})^{1/2}$ in water samples was observed in village Erramreddigaripalli of Pulicherla Mandal and the maximum value of SAR was found as 20.14 (m mol $l^{-1})^{1/2}$ in village P.V. Kandriga village of K.V.B Puram. The spatial variability of SAR of groundwater in Chittoor district 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 (Isaac *et al.*, 2009; Bhat *et al.*, 2018). Singh *et al.* (2018b) reported that sodium adsorption ratio varied from 3.69-28.59 (m mol $l^{-1})^{1/2}$ with mean value of 10.34 (m mol $l^{-1})^{1/2}$ in groundwater samples of Kaithal block, Haryana. Ayers and Westcot (1976) 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 98.6, 1.11 and 0.27 per cent samples (Table 4) belonged to excellent, good and doubtful, respectively.

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

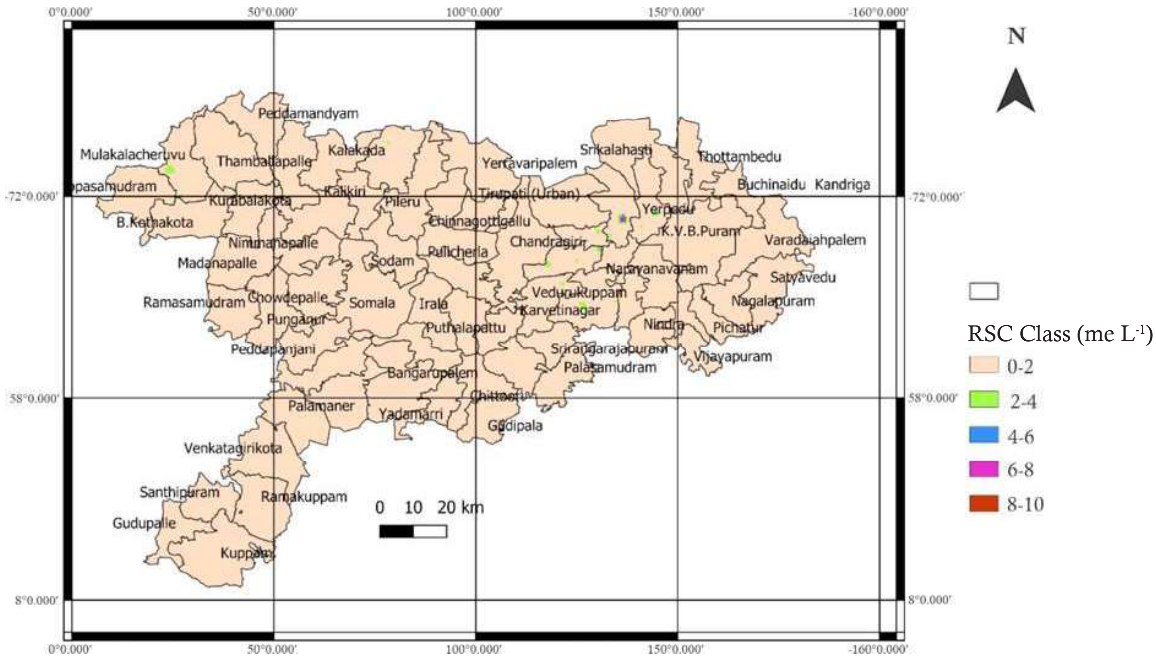

Fig. 5 Spatial variability of RSC (me L^{-1}) of ground water of Chittoor District

Table 4. Classification of ground water samples based on SAR

SAR	No. of samples	Per cent of samples
<10	353	98.6
10-18	4	1.4
18-26	1	0.27
>26	0.0	0.0

Table 5. Classification of ground water samples based on RSC (me L^{-1})

RSC (me L^{-1})		No. of	Per cent of
Class	Value	samples	samples
None	<2.5	328	91.6
Slight to moderate	2.5-4	22	6.14
Severe	>4	8	2.23

in Chittoor district varied from -37.6-9.4 me L^{-1} with a mean of -1.46 me L^{-1}. The highest RSC of 9.4 me L^{-1} in water samples was observed in Guruvaraju palli village of Renigunta mandal. Lowest was recorded with P.V. Kandriga village of KVB puram mandal. The spatial distribution of residual sodium carbonate was depicted in Fig. 5. The pH, EC and SAR of the irrigation water were significantly influenced by RSC. Based on RSC water can be categorized into three categories such as safe (<2.5 me L^{-1}), moderately suitable (2.5-4.0 me L^{-1}) and unsuitable (>4 me L^{-1}). In the present study, it was found that 328 samples (Table 5) were of safe category, 22 samples were moderately suitable and 8 samples were unsuitable for irrigation purposes.

The dominance of major ions was in the order of $Na^{+} > Ca^{+2} > Mg^{+2} > K^{+}$ for cations and $HCO_3^{-} > Cl^{-} > SO_4^{-2} > CO_3^{-2}$ for anions. Therefore, the chemical composition of the groundwater was characterized by $NaHCO_3$ water type. Highly significant positive correlation (Table 6) was observed between major cations, Na^{+} and Ca^{+2} (r = 0.58**), Na^{+} and Mg^{+2} (r = 0.52**) and Na^{+} and K^{+} (r = 0.22**). Highly significant positive correlation was observed between Na^{+} and Cl^{-} (r = 0.83**), Na^{+} and HCO_3^{-} (r = 0.40**) and Na^{+} and SO_4^{-2} (r = 0.79**). The positive correlation indicates the dissolution of sodium from respective ion containing minerals. Highly significant positive correlation between Ca^{+2} and HCO_3^{-} (r = 0.27**) which indicates that calcite may be the source of Ca^{+2}. The correlation between SO_4^{-2} and Mg^{+2} (r = 0.42**) implies that a part of the SO_4^{-2} and Mg^{+2} may also be derived by the weathering of magnesium sulphate mineral (Jalali, 2010). The correlation between Mg^{+2} and HCO_3^{-} (r = 0.44**) between Mg^{+2} and Cl^{-} (r =

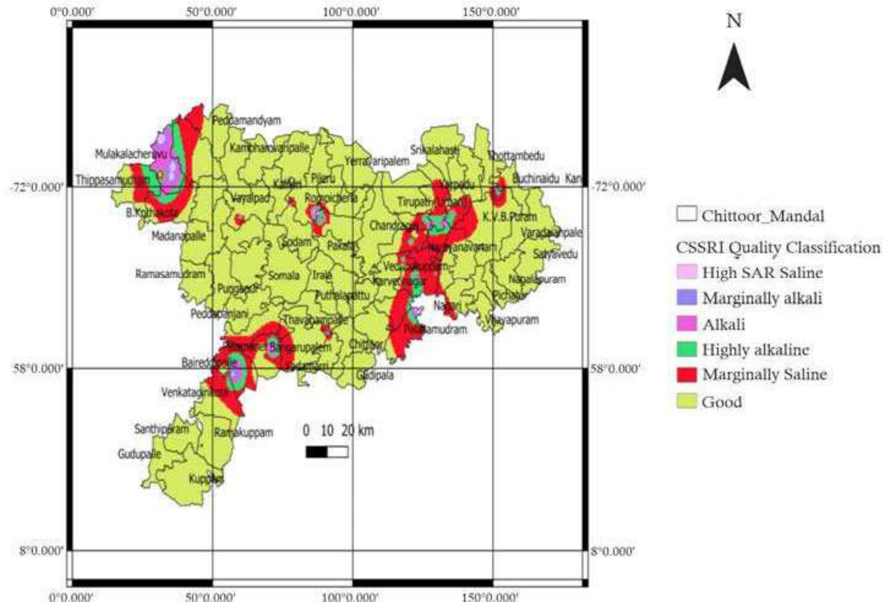

Fig. 6 Spatial distribution of groundwater quality (CSSRI Classification) in Chittoor District

Table 6. Correlation matrix among the chemical constituents of the groundwater

	pH	EC	Cl-	CO_3^{-2}	HCO_3^-	Ca^{+2}	Mg^{+2}	K^+	Na^+	SO_4^{-2}	SAR	RSC
pH	1											
EC	0.10*	1										
Cl-	-0.01	0.94**	1									
CO_3^{-2}	0.30**	0.08	-0.01	1								
HCO_3^-	0.24**	0.43**	0.21**	-0.06	1							
Ca^{+2}	-0.06	0.80**	0.81**	-0.01	0.27**	1						
Mg^{+2}	0.11*	0.73**	0.68**	0.16*	0.44**	0.59**	1					
K^+	-0.03	0.24**	0.22**	-0.03	0.17**	0.17**	0.11*	1				
Na^+	0.11*	0.91**	0.83**	0.07	0.40**	0.58**	0.52**	0.22**	1			
SO_4^{-2}	0.00	0.79**	0.74**	-0.01	0.08	0.62**	0.42**	0.18**	0.79**	1		
SAR	0.25**	0.68**	0.56**	0.12*	0.49**	0.29**	0.29**	0.20**	0.86**	0.50**	1	
RSC	0.18**	-0.65**	-0.77**	0.10*	0.16**	-0.81**	-0.65**	-0.07	-0.41**	-0.59**	-0.03	1

*Significant at p≤0.05 probability level; **Significant at p≤ 0.01 probability

0.68**) and between Ca^{+2} and Cl^- (r = 0.81**) indicates that they most likely derive from the same source of water (Pal *et al*., 2018).

Ground water quality classification for irrigation purpose

The groundwater of Chittoor district was classified into 7 classes for irrigation purpose (Minhas and Gupta, 1992) and details are presented in Table 7. The 65.64% samples were of good quality, 25.69% were of marginally saline, 0.27% of high SAR saline, 6.7% of marginally alkali, 1.11% of alkali and 0.55% of highly alkali. There were no samples under saline category (Fig. 6).

Soil salinity and alkalinity and crop yields in relation to prolonged use of groundwater

Salt-affected soils are distributed in an area on 19628 hectares which accounts 1.31 per cent geographical area of the district (Fig. 7). The soils of Narayanavanam, Yerpedu, Srikalahasti, Renigunta, KVB Puram, BN Kandriga, Varadayyapalem, Pitchatur, Nidnra, B Kothakota Peddatippasamudram, Mulakalacheruvu,

Table 7. Classification of ground water and their management (Minhas and Gupta, 1992)

Rating and Class	Sub-class	EC (dS m^{-1})	SAR	RSC (me L^{-1})	number of samples	Per cent samples
A.Good	A	<2	<10	<2.5	235	65.64
B. Saline						
Marginally saline	B1	2-4	<10	<2.5	92	25.69
Saline	B2	>4	<10	<2.5	0.0	0.0
High SAR saline	B3	>4	>10	<2.5	1	0.27
C. Alkali water						
Marginally alkaline	C1	<4	<10	2.5-4.0	24	6.7
Alkali	C2	<4	<10	>4.0	4	1.11
Highly alkaline	C3	variable	>10	>4.0	2	0.55

Salt-affected soil map of Chittoor district

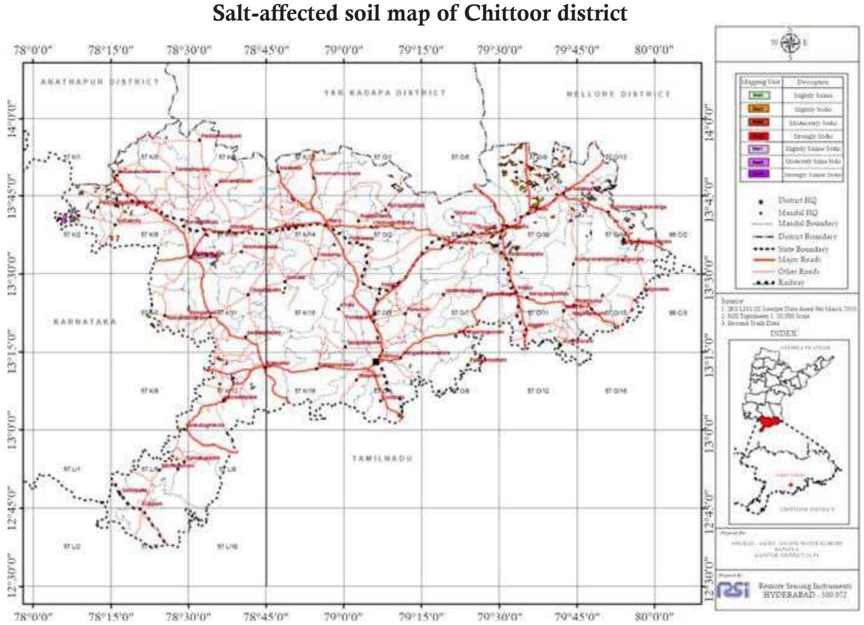

Fig. 7 Spatial distribution of saline and alkaline soils in Chittoor district as irrigated with poor-quality ground water

Tirupati rural, Pulicherla, Baireddi palle, Gudipala, Yadamarri, Puthalapattu, Palasamudram, S.R. Puram, Bangarupalem, Thavanampally, Somala, Chowdepalli and Punganur Mandals are classified into Slightly saline, Slightly sodic, Moderately sodic, strongly sodic, slightly saline sodic, moderately saline sodic and strongly saline sodic (Table 8). The pH, Electrical conductivity, RSC and SAR of irrigated groundwaters of these Mandals are presented in Table 9. The cropping pattern (Table 10) and varietal performance (Table 11) were observed in these Mandals. The crop yields in the areas with good ground water quality were compared with the actual crop yields of marginally saline, High SAR saline, marginally alkaline, alkali and highly alkaline waters. The groundnut recorded 4.0 Mg ha^{-1} yield with good quality groundwater, lesser crop yields were recorded with marginally saline (25%), High SAR saline (32.5%), marginally alkali

Table 8. Salt-affected soils of Chittoor District

Type of salt-affected soils	Area (ha)	Per cent
Sodic –slight	9521	0.63
Sodic –moderate	8367	0.56
Sodic –severe	1494	0.1
Saline sodic-Slight	118	0.01
Saline sodic-moderate	82	0.01
Saline sodic-severe	46	0.00
Total	19628	1.31

Source: APSAC (2018)

Table 9. Quality of irrigation water in saline and alkali soil dominated Mandals of Chittoor District

Name of the Mandal	pH		EC (dS m^{-1})		RSC (me L^{-1})		SAR	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Narayanavanam	7.28	6.9-7.5	2.07	1.3-3.5	-5.8	-11.2 to -1.2	2.64	0.76-6.27
Yerpedu	7.46	7.2-8.0	2	1.3-3.0	-4.2	-15.6 to 5.8	3.47	1-9.69
Srikalahasti	7.38	7.3-7.6	2.25	1.8-2.9	-2.27	-4.8 to 1.2	4.55	2.45-7.0
Renigunta	7.39	6.9-8.2	1.51	0.4-2.4	1.12	-1 to 0.6	3.6	0.64-3.96
KVB Puram	7.36	7.0-8.0	4.26	1.9-13.5	-6.08	-37.6 to 2.0	8.37	2.79-20.14
B.N. Kandriga	7.33	7.0-7.5	1.50	1.1-2.6	-0.93	-9.4 to 5.4	4.31	0.85-8.51
Varadayapalem	7.36	7.3-7.5	1.8	1.3-2.0	-2.88	-5.4 to 0.8	2.89	2.3-4.66
Pichatur	7.42	7.1-7.5	2.24	1.4-2.7	-3.84	-4.6 to -2	3.36	1.66-4.73
Nindra	7.32	7.2-7.5	3.36	2.5-3.8	-9.84	-11.8 to -5.8	4.43	3.52-4.84
B.Kothakota	7.54	7.3-7.5	1.78	1.3-2.3	-2.52	-5.2 to 0.8	3.39	3.07-3.89
Peddathippasamudram	7.56	7.5-7.7	1.54	0.9-1.9	1.76	-0.6 to 3.4	3.36	1.77-4.37
MulakalaChruvu	7.64	7.2-8.0	2.06	1.6-2.4	-2.36	-4.0 to 2.4	4.17	3.07-4.91
Tirupati Rural	7.6	7.4-7.7	2.05	1.4-2.4	-0.17	-1.6 to 3.8	3.82	2.83-4.72
Pulciherla	7.76	7.2-8.8	1.28	0.5-2.0	2.52	0.2 to 3.6	2.48	0.27-4.63
Byreddipalli	7.4	7.0-7.9	1.7	1.1-1.2	-3.44	-9.0 to 0.6	1.56	1.0-2.28
Gudipala	7.54	7.4-7.7	2.26	2.1-2.4	-1.24	-2.0 to 0.0	3.72	3.1-4.05
Yadamarri	7.44	7.2-8.0	2.02	1.3-2.4	0.6	-3.0 to 4.2	4.5	2.74-6.47
Puthalapattu	7.32	7.0-7.8	2.26	1.1-3.2	-0.64	-3.0 to 0.8	4.80	1.51-7.33
Palasamudram	7.5	7.3-7.7	1.82	1.1-2.8	1.68	0.2 to 2.8	3.89	1.7-6.53
S.R. Puram	7.4	7.2-7.9	2.28	2.1-2.6	-0.04	-1.6 to 1.4	4.55	2.78-5.46
Bangarupalem	7.38	7.3-7.5	1.92	1.2-3.1	0.24	-6.8 to 3.8	4.01	1.77-4.98
Thavanampalli	7.44	7.3-7.5	2.16	2.1-2.2	-1.6	-2 to -0.4	4.84	4.59-5.06
Somala	7.36	7.3-7.4	2.14	0.3-3.7	-3.88	-7.4 to 0.2	3.29	1.15-5.14
Chowdepalli	7.46	7.2-7.6	2.42	1.4-3.6	-6.8	-12.8 to -0.4	2.66	0.72-4.76
Punganur	7.42	7.3-7.5	2.24	1.3-3.9	-2.76	-10.4 to 1.4	4.27	3.0-7.24

Table 10. Cropping pattern of Chittoor district

Major farming situation	Cropping pattern	Change in crop/ Cropping system
Rainfed-sahllow red soil	Groundnut + Redgram (7:1 or 11:1) inter crop	No change
Irrigated lands Wells/ bore wells	Rice-rice Rice-groundnut Rice-vegetables Rice-tomato Sugarcane	Rice –Groundnut Groundnut- Blackgram Maize-Tomato
Problematic soils	Rice	Salt tolerant varieties NLR145 (130 days), NLR 33641 (150 days)

Note: Change in cropping pattern takes place under deficit rainfall conditions.

(37.5%) and alkali (45.0%) groundwater. Rice recorded 6.5 Mg ha^{-1} grain yield, with good ground water area and relatively lesser crop yields were recorded with marginally saline (7.7%), High SAR saline (15.4%), marginally alkali (20.0%), alkali (23.0%) and highly alkaline (23.0%) groundwater. Sugarcane recorded 98 Mg ha^{-1} cane yield with good quality water, relatively lesser crop yields were recorded with marginally saline (18.4%), High SAR saline (26.5%), marginally alkali (32.7%) and alkali (38.8%) groundwater. Tomato recorded 60 Mg ha^{-1} fruit yield with good quality groundwater, lesser crop yields were recorded with marginally saline (33.3%), High SAR saline (40.0%), marginally alkali (43.3%) and alkali (46.7%) groundwater. Black gram recorded

Table 11. Performance of major crops under good and poor-quality irrigated groundwater conditions

Major Crops	Popular varieties	Yield with good quality water (Mg ha^{-1})	Rain fed (Mg ha^{-1})	Irrigated yield (Mg ha^{-1})					Per cent deviation from good quality water					
				Marginally saline	High SAR saline	Marginally alakli	Alkali	Highly alkaline	Rain fed	Irrigated				
										Marginally saline	High SAR saline	Marginally alakli	Alkali	Highly alkaline
Groundnut	Dharani, Narayani	4.0	1.2	3.0	2.7	2.5	2.2	NR	70.0	25.0	32.5	37.5	45.0	NR
Rice	ADT 37,39 BPT 5204	6.5	NR	6.0	5.5	5.2	5.0	5.0	NR	7.7	15.4	20.0	23.0	23.0
Sugarcane	86 v 96	98	NR	80	72	66	60	NR	NR	18.4	26.5	32.7	38.8	NR
Tomato	Hybrids	60	NR	40	36	34	32	NR	NR	33.3	40.0	43.3	46.7	NR
Blackgram	TBG 104	2.5	1.0	1.5	1.2	1.2	NR	NR	60.0	40.0	52.0	52.0	NR	NR
Brinjal	hybrids	60	NR	40	34	30	28	NR	NR	33.3	43.3	50.0	53.3	NR
Maize	Hybrids	7.0	3.5	60	50	48	40	NR	50.0	14.2	28.6	31.4	42.8	NR

NR=not reported

2.5 Mg ha^{-1} with good quality water, lesser crop yields were recorded with marginally saline (40%), High SAR saline (52.0%) and marginally alkali (52.0%) groundwater. Brinjal recorded 60 Mg ha^{-1}with good quality water, lesser crop yields were recorded with marginally saline (33.3%), High SAR saline (43.3%), marginally alkali (50.0%) and alkali (53.3%) groundwater. Maize recorded 7.0 Mg ha^{-1} with good quality water, lesser crop yields were recorded with marginally saline (14.2%), High SAR saline (28.6%), marginally alkali (31.4%) and alkali (42.8%) groundwater. The reduction in yields of various crops might be due to the degradation in soil quality due to continuous use of poor-quality groundwater years together (Fig. 7). Hence, it is suggested to adopt the practices which can mitigate or overcome existing poor-quality conditions of soil and waters. Among them the varietal strategy is very important, selection of salt tolerant crop varieties (Table 12) along with good soil and agronomic management practices enhance the soil quality and productivity of crops.

Soil and crop management strategies

In case of saline groundwater rain water conservation for leaching of salts accumulated through saline water irrigation is important technology and farmers are need to be educated about these aspects. The ICAR –CSSRI guide lines related to saline and alkali water use are provided in Table 13 and 14. Use of harvested rain water through sprinklers at critical growth stages of crops can promote crop growth and yield (Singh *et al.*, 2018a). Foliar application of nutrient mixtures may help the crop under nutrient stress conditions (Meena *et al.*, 2018).

In case of alkali ground waters soil application of chemical amendments like gypsum or distillery spent wash (DSW) or phospho-gypsum is proposed. Otherwise alkali groundwater may be treated with gypsum or DSW in gypsum bed before irrigation. Green manuring with Dhaincha (*Sesbania aculeata*) @ 6.25 Mg ha^{-1} or crop residue incorporation can help in reducing sodicity / alkalinity stress (Kaledhonkar *et al.*, 2020). Green manuring improves soil physical conditions and also saves about 60-70 kg ha^{-1} of nitrogen in the following rice crop. During first few years after

Table 12. Salt tolerant varieties of major crops in Chittoor District and suggested agronomic practices

Crop	Tolerant varieties	Agronomic management practices
Groundnut	Kadiri-3, Kadiri-6	Use of better available water at germination and peg penetration stage, application gypsum and sprinkler irrigation
Rice	NLR 145, NLR 33358, MTU 4870, MTU 7029 and MCM 101	Application gypsum, Dhaincha as green manure crop
Sugarcane	CO 453, CO1341, CO1111 and CO 62329	Application gypsum, paired row planting, Drip irrigation
Tomato	Hybrids	Drip irrigation, application of gypsum
Black gram	TBG 104, GBG-1, LBG 787	Use of better available water at germination and peg penetration stage, application gypsum and sprinkler irrigation
Brinjal	Hybrids	Use of better available water, drip irrigation, application of gypsum
Maize	30 V 92, Sandhya and DHM 117	Use of better available water, drip irrigation, application of gypsum

Table13. Guidelines for use of saline water RSC (<2.5 me L^{-1})

Soil texture(% clay)	Crop tolerance	Upper limits of ECiw (dS m^{-1}) in different rainfall regions		
		350 mm	350-550 mm	550-750 mm
Fine (> 30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately fine(20-30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately coarse(10-20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (< 10)	S	- -	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

Table 14. Guidelines for alkali groundwaters with RSC > 2.5 me L^{-1} and ECiw < 4.0 dS m^{-1}

Soil texture (% clay)	Upper limits of SAR (m mol L^{-1})$^{1/2}$	RSC (me L^{-1})	Remarks
Fine (>30)	10	2.5-3.5	Limits pertain to kharif fallow – rabi crop rotation when annual rainfall is 350 –550 mm
Moderately fine(20-30)	10	3.5-5.0	When water has Na < 75%, Ca+Mg >25% or rainfall>550mm, the upper limit of RSC becomes safe
Moderately coarse (10-20)	15	5.0-7.5	For double cropping, RSC neutralization with gypsum is essential based on quantity of water used during rabi season. Grow low water requiring crops during kharif.
Coarse (<10)	20	7.5-10.0	

reclamation, crops are to be fertilized with about 25 percent more nitrogen compared to recommended dose for normal soil. Split application of nitrogen through urea should be given. In rice basal dose of urea should be applied under pre-submerged conditions to reduce ammonia volatilization losses and to enhance nitrogen use efficiency. Alkaline soils suffer from Zn and Fe deficiency because of inherently poor supply of these nutrients due to their low solubility (Meena *et al.*, 2019). Zinc sulphate @ 35 kg ha^{-1} should be applied particularly to the kharif crop

(Meena *et al.*, 2018). Phosphorus, potassium and other limiting nutrients may also be applied on the basis of soil test values. Some alkali waters might be rich in nutrients like nitrogen, potassium and sulphur. Such waters should be analyzed and the fertilizer doses of concerned nutrients may be reduced accordingly as per their composition in such water.

In case of growing of sugarcane, maize and other vegetable crops with saline and alkali waters, use of drip irrigation was found quite useful as desired quantity of irrigation water was at frequent intervals. Performance of drip irrigation method on vegetable crops (drumstick, cabbage, cauliflower) under saline environment was studied during 2017 and 2018. Average yield of vegetables increased under drip irrigation with best available water (BAW) but at par yields were obtained with irrigation water having 4 to 8 dSm^{-1} depending on salt tolerance of crops (Kaledhonkar *et al.*, 2019; AICRP on SAS & USW, 2018). Above discussion suggested that it is possible to use saline and alkali ground water with scientific soil, crop and irrigation management practices.

Conclusions

The ground water quality in Chittoor District varied from place to place. The dominance of major ion was in the order of $Na^+ > Ca^{+2} > Mg^{+2} > K^+$ and $HCO_3^- > Cl^- > SO_4^{-2} > CO_3^{-2}$ for cations and anions, respectively, which indicates that the irrigated groundwater quality is $NaHCO_3$ type. Among the salt-affected soils sodic soils are dominant which occupy 19628 ha cultivable area (1.31% of total area). The main reasons for the development of these sodic soils of various classes are due to the prolonged use of poor-quality groundwater dominated by Na^+ and HCO_3^- ions. Less than 2/3rd of the ground water samples was found good in quality for irrigation. However, where the water is of poor-quality, proper management is to be taken to use the water for irrigation. 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 irrigated groundwater may help the farmers in choice of crops and other agronomic management practices for getting profitable yields without affecting the soil health. Ground water in the study area should be used judiciously by adopting water saving techniques like sprinkler and drip irrigation system.

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References

Ackah M, Agyemang O, Anim AK, Osci J, Bentil N, Kpattah L, Gyamfi ET and Hanson JEK (2011) Assessment of ground water quality for drinking and irrigation ; the case study of Teiman –Oyarifa community , Ga East municipality, Ghana. *Proceedings of the International Academy of Ecology and Environmental Sciences* **1:** 186-194.

AICRP on SAS & USW (2018) Biennial report (2017-18) ICAR-AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, Bapatla pp: 112-116.

Al-Tabbal JA and Al-Zboon KK (2012) Suitability assessment of groundwater for irrigation and drinking purpose in the Northern Region of Jordan. *Journal of Environmental Science and Technology* **5(5):** 274-290.

Ayers RS and Westcot DW (1976) Water quality for the irrigation. Irrigation drainage paper 29. Rome: FAO, United Nations.

Bhat MA, Wani SA, Singh VJ, Sahoo J, Tomar D and Sanswal R (2018) An overview of the assessment of groundwater quality for irrigation. *Journal of Agricultural Science and Food Research* **9(1):** 1-9.

CGWB (2017) National Compilation on *Dynamic Ground Water Resources of Indi*a. Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation. Govt. of India. 298pp.

Chesnin L and Yien CH (1950) Turbidimetric determination of available sulphates. *Proceedings of Soil Science Society of America* **14:** 149-151.

Gupta RK, Singh NT and Sethi Madhurima (1994) *Ground Water Quality for Irrigation in India .Technical Bulletin* No.90, CSSRI, Karnal pp.23.

Houatmia F, Azouzi R, Charef A and Bedir M (2016) Assessment of groundwater quality for irrigation and drinking purposes and identification of hydro-geochemical mechanisms evolution in Northeastern, Tunisia. *Environmental Earth Sciences* **75:** 746.

Isaac RK, Khura TK and Wurmbrand JR (2009) Surface and subsurface water quality appraisal for irrigation. *Environmental Monitoring and Assessment* **159:** 465-473.

Jackson, M.L, (1973) *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd. New Delhi. 134-182.

Jalali M (2005) Nitrates leaching from agricultural land in Hamadan, western Iran. *Agriculture Ecosystems and Environment* **110:** 210-218.

Jalali M (2010) Groundwater geochemistry in the Alisadr, Hamadan, western Iran. *Environmental Monitoring and Assessment* **166:** 359-369.

Kaledhonkar MJ, Meena BL and Sharma PC (2019) Reclamation and nutrient management for salt-affected soils. *Indian Journal of Fertilisers*, **15 (5):** 566-575.

Kaledhonkar MJ, Singh AK, Singh Ranjeet and BL Meena (2020) Management of saline water irrigation in water stress arid regions. technological advances in enhancing productivity of salt affected soils. In: Masilamani *et al*. (eds)*Technological Advances in Enhancing Productivity of Salt Affected Soils* .Today & Tomorrow's Printers and Publishers, New Delhi, pp 69-82.

Kumar SK, Rammohan V, Sahayam JD and Jeevanandam M (2009) Assessment of groundwater quality and hydro-geochemistry of Manimuktha River basin, Tamil Nadu, India. *Environmental Monitoring and Assessment* **159:** 341-351

Loizidou M and Kapetanios EG (1993) Effect of leachate from landfills on underground quality. *Science of the Total Environment* **128:** 69-81.

Meena BL, Datta SP, Rattan RK, Singh S, Kumar A, Kaledhonkar MJ, Meena RL (2019) A new soil testing programme for the evaluation of intensity and quantity factors of iron. *National Academy Science Letters* **42(3):** 191-193.

Meena BL, Kumar P, Kumar A, Meena RL, Kaledhonkar MJ and Sharma PC (2018). Zinc and iron nutrition to increase the productivity of pearl millet-mustard cropping system in salt affected soils. *International Journal of Current Microbiology and Applied Sciences* **7(8):** 3201-3211.

Minhas PS and Gupta RK (1992) *Quality of Irrigation Water – Assessment and Management*. ICAR, New Delhi. pp123.

Osborn GH and Johns H (1951) The rapid determination of sodium and potassium in rocks and minerals by flame photometry. *Analyst* **76:** 410-415.

Pal SK, Rajpaul, Ramprakash, Mohammad Amin Bhat and Yadav SS (2018) Assessment of groundwater quality for irrigation use in Firozpur-Jhirka Block in Mewat district of Haryana, North India. *Journal of Soil Salinity and Water Quality* **10(2):** 157-167.

Panse VG and Sukhatme PV (1985) *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi.

Richards LA (1954) *Diagnosis and improvement of Saline and Alkali Soils*. Agricultural Hand Book No.60, USDA, Washington DC, 160.

Shah T, Burke J and Villholth K (2017) Ground water - a global assessment of scale and significance*, In* Molden, D. and Earthscan (ed) *Water For Food*, *Water For Life*, Landon, U.K. and IWMI, Colombo, Srilanka, pp 395-423

Sieber S, Burke J, Faures M, Freken K, Hoogeveen J, Doll P and Portmann FT (2010) Ground water use for irrigation –A global inventory .*Journal of Hydrolopgy and Earth System Science* **14:** 1863-1880

Singh Ranjeet, Singh AK, Yadav SR, Singh SP, Godara AS, Kaledhonkar MJ and Meena BL (2019) Effect of saline water and fertility levels on pearl millet-psyllium crop sequence under drip irrigation in arid region of Rajasthan. *Journal of Soil Salinity and Water Quality* **11(1):** 56-62.

Singh RB, Kaledhonkar MJ, Chaudhari SK, Shishodia PK. and Meena BL (2018a) Effect of saline and alkaline water on mustard yield under sprinkler irrigation. *Journal of Soil Salinity and Water Quality* **10(2):** 246-253.

Singh VK, Ram-Prakash, Bhat MA, Gagan-Deep and Kumar S (2018b) Evaluation of groundwater quality for irrigation in Kaithal block (Kaithal District) Haryana. *International Journal of Chemical Studies* **6(2):** 667-672.

Sridharan M and Nathan DS (2017) Groundwater quality assessment for domestic and agriculture purposes in Puducherry region. *Applied Water Science* **7:** 4037-4053.

Willard HH, Meritt LL and Dean JA (1974*) Instrument Methods of Analysis*.5th edition, D Van Nastrand Company, New York.

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