Quality assessment of groundwater of Kadapa district, Andhra Pradesh, India for irrigation purpose and management options

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Water samples collected from various locations in Kadapa district, Andhra Pradesh (AP), India were analysed for quality parameters, namely reaction (pH), salinity, Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}; CO_3^{-2}, HCO_3^{-}, Cl^{-} and SO_4^{-2}. The pH fell in the range 6.5–8.1, electrical conductivity (EC) from 0.4 to 11.1 (dS m^{-1}), sodium adsorption ratio (SAR) from 0.4 to 41.2 (mmol $l^{-1})^{1/2}$ and residual sodium carbonate (RSC) from –52.4 to 16.2 (meq l^{-1}). The presence of positively charged ions, namely calcium, magnesium, sodium and potassium varied from 0.4 to 46.0, 1.2 to 16.4, 0.76 to 60.1 and 0.002 to 11.78 meq l^{-1} respectively. The concentration of bicarbonates, chlorides and sulphates varied from 0 to 2.0, 1.0 to 17.6, 0.4 to 76.0 and 0.3 to 14.8 me l^{-1} respectively. The dominance of ions for majority of the samples was $Na^{+} > Ca^{2+} > Mg^{+2} > K^{+}$ for positively charged ions and $HCO_3^{-} > Cl^{-} > SO_4^{-2} > CO_3^{-}$ for negatively charged ions. According to classification of irrigation water by the Central Soil Salinity Research Institute, Karnal, Haryana, India, 53.18% water samples is good, 21.88% marginally saline, 0.3% saline, 4.56% high SAR saline, 6.69% marginally alkaline, 7.90% alkaline and 5.47% highly alkaline. Spatial variability of pH, EC, SAR, RSC and groundwater quality in Kadapa district, AP was demonstrated using GIS maps.

Keywords: Groundwater quality, ionic correlation, salinity, sodium absorption ratio, spatial variability.

IRRIGATION water quality is an important factor and depends chiefly on the total amount of salt present as well as sodium, other positive ions and certain other parameters[1]. In areas with limited availability of surface water throughout the year, the farmers are forced to use low-quality groundwater for agricultural purposes. Soil quality is influenced by the use of low-quality groundwater and consequently plant growth by reducing the osmotic action in plant cells[2].

The present study was conducted in Kadapa district, Andhra Pradesh (AP), India. Average elevation of this district is 138 m amsl. Farmers in the district have reported groundwater quality issues in certain pockets. However, these are not due to sea-water intrusion. In view of this situation, it is essential to understand the spatial distribution of groundwater quality in Kadapa district, AP, in order to determine its suitability for irrigation purposes. Such an assessment is helpful to understand the influence of irrigation water quality on crop productivity and to suggest agronomic practices for better crop yields by reducing the adverse effects of saline/alkaline water irrigation.

Material and methods

Kadapa district, AP (13°43′–15°14′N lat. and 77°55′–79°29′E long.) has a total geographical area of 15,359 sq. km (Figure 1 *a*). It is bordered by the Sri Potti Sriramulu, Nellore district to the east, Anantapuram district to the west, Chittoor district to the south, and Kurnool and Prakasam districts to the north. The yearly rainfall of the district ranges from 502 to 927 mm due to the southwest and northeast monsoons. The temperature in the summer months varies from 34°C to 40°C and in winter from 25°C to 35°C.

Kadapa district, AP, has 64,313 tube wells and filter points, and 18,046 dug wells serving nearly 86% of the irrigated area. The total groundwater recharge in the district is 1162 MCM. The total utilizable groundwater is 798 MCM and the present withdrawal is at 738 MCM. The stage of groundwater development is 69% as per the Central Groundwater Board Report[3].

The sedimentary rocks of the Kadapa and Kurnool Groups include mostly shales (a typical shale is composed of clay minerals (58%), quartz (28%), feldspar (6%), carbonate minerals (5%), iron oxide (2%), quartzite, limestone and dolomite (Figure 1 *b*). Mineral resources like barites, limestone, black granite, chrysotile asbestos and clay are dominant in various parts of Kadapa district, AP. Black soils with 2 : 1-type clay minerals are distributed in 231,400 ha area and occupy 49% of the geographical area. Red soils with kaolinite and bentonite clay minerals are distributed in 198,343 ha (42%). Sandy and salt affected soils are distributed in 42,503 ha (9%; Figure 1 *c*)[3].

Groundwater samples (329) were collected from borewells and open wells. About 5–6 samples along with GPS

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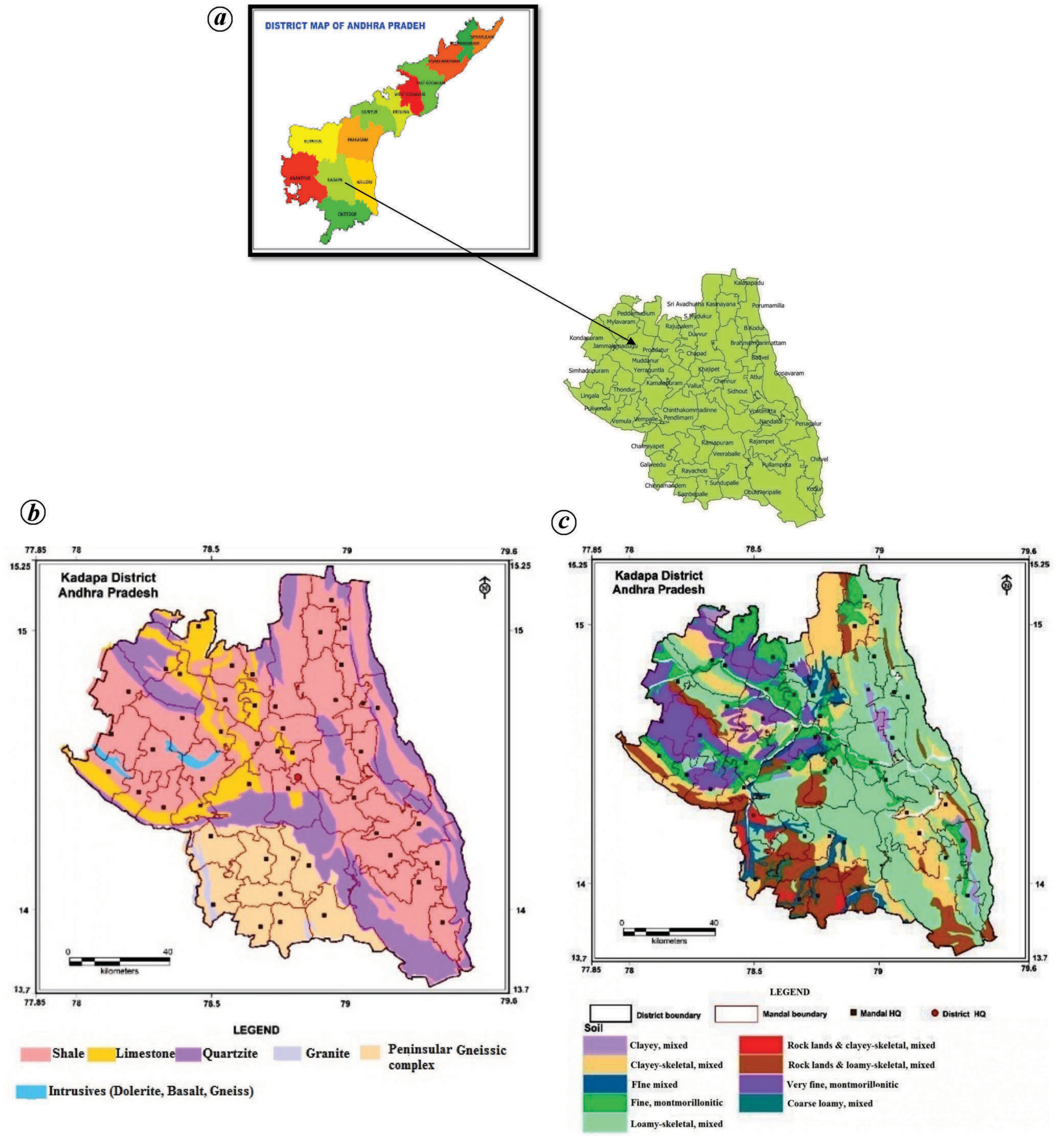

Figure 1. ***a***, Location map of Kadapa district, Andhra Pradesh (AP), India[21]. ***b***, Geology map of Kadapa district, AP[3]. ***c***, Soil map of Kadapa district AP[3].

coordinates were collected from every mandal of Kadapa district, AP (Figure 2). Pre-conditioned, new, highly thick polyethylene bottles were used for sample collection. The sample water was used to rinse the bottles three times prior to sample collection. Rope and bucket were used to lift the samples from the dug wells, whereas water from tube wells was pumped to the surface using hand pump or submersible pump. The pump was run for 5–6 min prior to sample collection of water. Immediately after collection of water samples in polyethylene bottles, toluene was added to avoid microbiological deterioration. Standard procedures were followed to analyse these water samples. pH was determined by potentiometry using a pH meter[4]; conductivity bridge was used to measure electrical conductivity

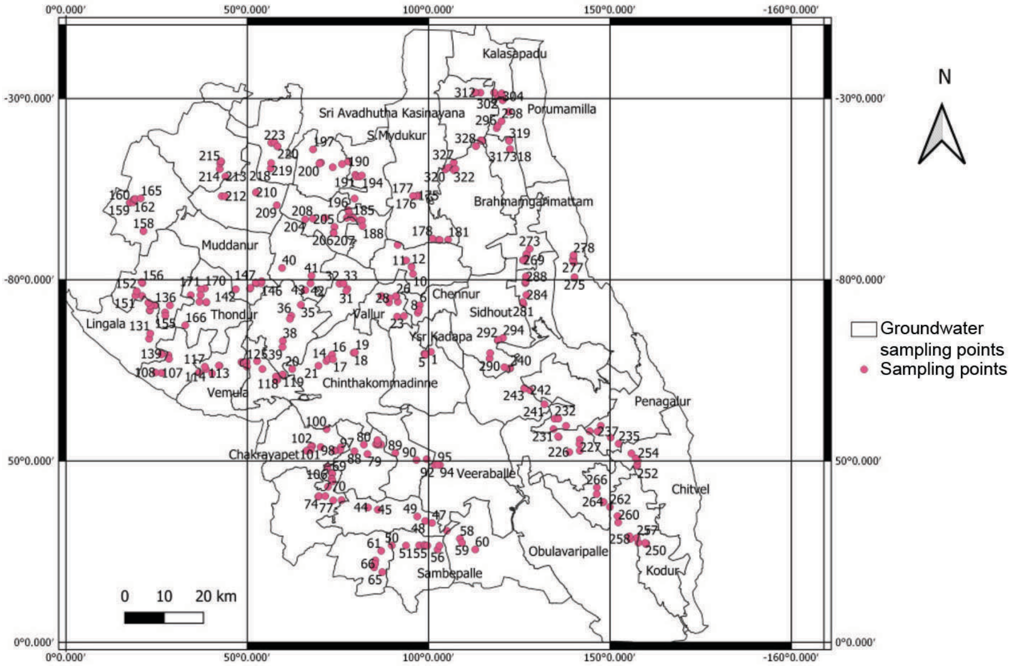

Figure 2. Groundwater sampling sites in Kadapa district, AP.

Table 1. Range and average of groundwater quality parameters in Kadapa district, Andhra Pradesh (AP), India

Parameters	Range	Mean	Standard deviation
pH	6.5–8.1	7.43	0.26
Electrical conductivity (EC; dS m^{-1})	0.4–11.1	1.98	1.35
CO_3^{2-} (meq l^{-1})	0.0–2.0	0.1	0.24
HCO_3^- (meq l^{-1})	1.0–17.6	7.96	2.34
Cl^- (meq l^{-1})	0.4–76.0	7.88	9.06
SO_4^{2-} (meq l^{-1})	0.3–14.8	3.24	2.97
Ca^{2+} (meq l^{-1})	0.4–46.0	4.75	4.06
Mg^{2+} (meq l^{-1})	1.2–16.4	4.67	3.11
Na^+ (meq l^{-1})	0.76–60.1	10.4	9.54
K^+ (meq l^{-1})	0.002–11.78	0.35	0.97
Residual sodium carbonate (RSC; meq l^{-1})	–52.4–16.2	0.0	6.49
Sodium adsorption ratio (SAR) (mmol $l^{-1})^{1/2}$	0.4–41.2	5.10	4.71

(EC) of water[5]; chloride was determined by Mohr's method; carbonates and bicarbonates by double indicator method, and calcium and magnesium by the Versenate method adopting the standard procedures[6]. Similarly, sodium and potassium were estimated using the flame photometer[7]. Residual sodium carbonate (RSC) and sodium adsorption ratio (SAR) were determined using the equations given by Richards[6]: $RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ and $SAR = Na/((Ca^{2+} + Mg^{2+})/2)^{1/2}$. Na^+, Ca^{2+}, Mg^{2+} RSC, CO_3^{2-}, HCO_3^-, Ca^{2+} and Mg^{2+} were expressed in milliequivalents per litre.

Based on EC, SAR, and RSC, groundwater can be grouped into seven classes[7]. Descriptive statistics and correlation coefficients of various water properties were obtained according to the standard methodology[8].

Results and discussion

Groundwater quality determination

The concentration of dissolved components in groundwater determines its quality for use in irrigation. The samples were assessed 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, residual sodium carbonate (RSC) and sodium adsorption ratio (SAR) were computed from the analyses. Table 1 shows the analytical data of groundwater samples collected during 2020 from various mandals of the Kadapa district, AP.

The pH of water samples varied from 6.5 to 8.1 with a mean of 7.43. The usual pH range is 6.5–8.4 in irrigation

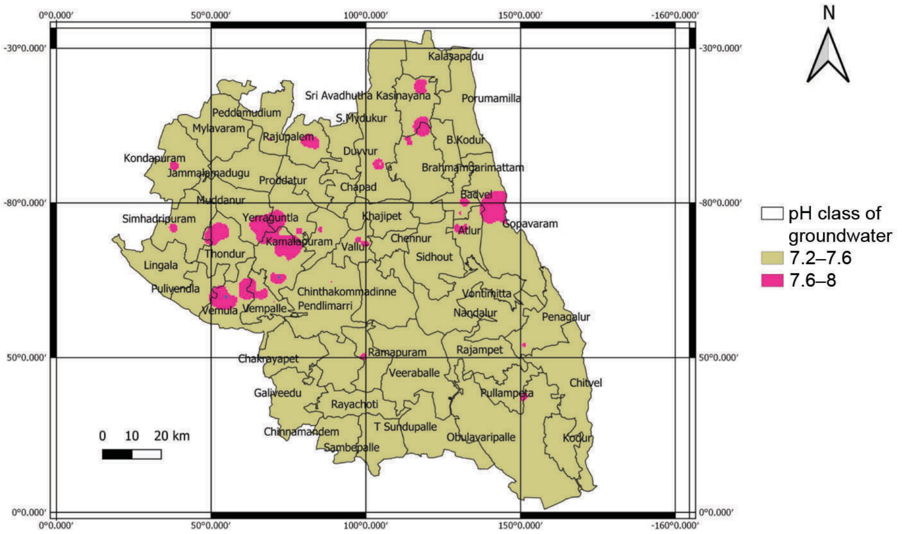

Figure 3. Spatial distribution of pH in groundwater of Kadapa district, AP.

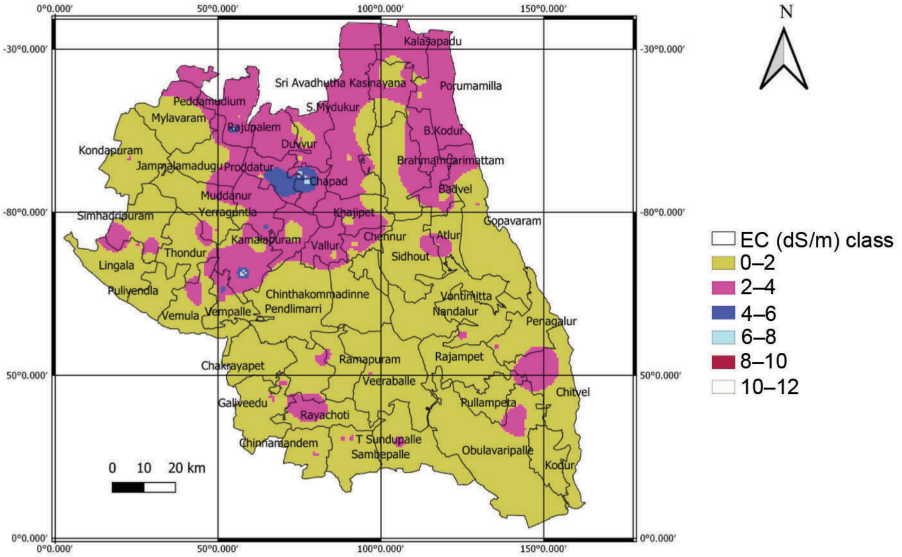

Figure 4. Spatial distribution of electrical conductivity (dS/m) class in groundwater of Kadapa district, AP.

water and the crops grow well within this range[9]. The acidic pH range may be because of the presence of forested areas in certain pockets. Higher pH in the alkaline range may be due to high amounts of Na^+, Ca^{+2}, Mg^{+2}, CO_3^- and HCO_3^- ions. The spatial variability of pH in the groundwater of Kadapa district, AP, indicated that the highest pH values (>7.6) were observed in parts of Kasinayana, B. Koduru, S. Mydukuru, Badvel, Gopavaram, Atloor, Brahmamgarimatam, Valluru, Rajupalem, Duvvur, Kamalapuram, Yerraguntla, V. N. Palli, Vemula, Vempalli, Thondur, Simhadripuram, Kodapuram, Penagaluru, Pullampeta and Ramapuram mandals (Figure 3). Positive correlation was noted between pH and CO_3^{-2} as well as RSC and SAR.

Table 2. Groundwater class based on EC (dS m^{-1}) of the samples in Kadapa district, AP

EC class	No. of samples	Percentage of samples
0–2	222	67.48
2–4	87	26.44
4–6	14	4.26
6–8	3	0.91
8–10	2	0.61
10–12	1	0.30

Water salinity was determined in terms of EC. The EC values were in the range 0.4–11.1 dS m^{-1} with a mean 1.98 dS m^{-1} (Table 2). EC is regularly used to represent the total ionized constituents in natural water. Thus, it is

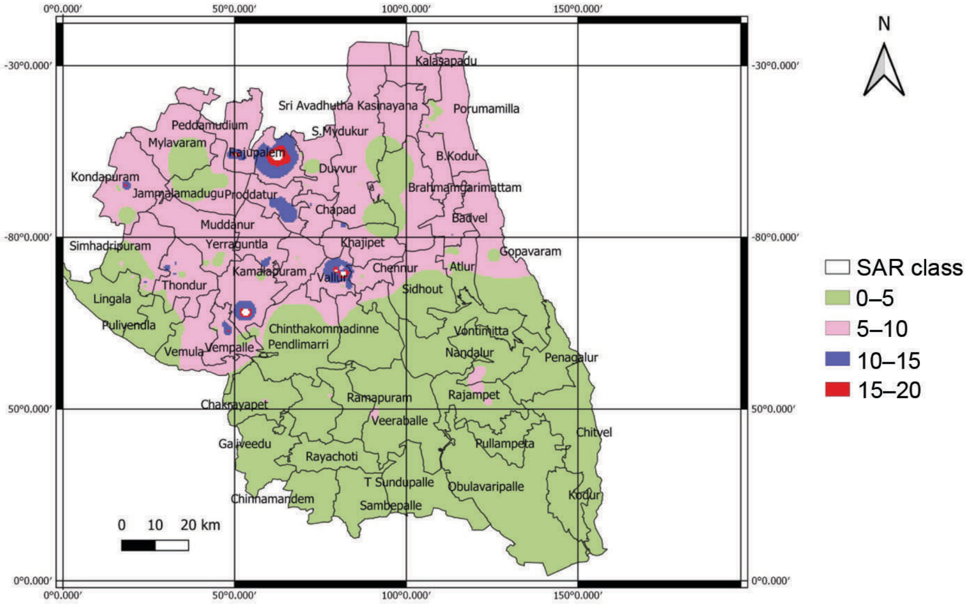

Figure 5. Spatial distribution of sodium adsorption ratio (mmol $l^{-1})^{1/2}$ class in groundwater of Kadapa district, AP.

Table 3. SAR (mmol $l^{-1})^{1/2}$ class of groundwater in Kadapa district

SAR class	No. of samples	Percentage of samples
<10	295	89.67
10–18	27	8.21
18–26	4	1.22
>26	3	0.91

correlated to the total dissolved solids[10]. Figure 4 depicts the spatial variability of EC in the groundwater of Kadapa district, AP. The EC classes were grouped up to 12 dS m^{-1} (Table 2). Out of 329 samples collected, 67.48% had EC < 2 dS m^{-1}, 26.44% had EC in the range 2–4 dS m^{-1}, 4.26% in the range 4–6 dS m^{-1}, 0.91% in the range 6–8 dS m^{-1}, 0.61% in the range 8–10 dS m^{-1} range and 0.30% in the range 10–12 dS m^{-1}. The samples with higher EC were only a few in number. Highest EC (11.1 dS m^{-1}) was observed at Annavaram village of Chapadu mandal (sample no. 184).This is due to the presence of clayey soils with montmorillonitic and loamy, skeletal and mixed soils of the region which may result in poor drainage of the soil and enhanced salt content in groundwater. Lowest EC (0.4 dS m^{-1}) was observed at Mallipalli of Galiveedu mandal (sample no. 68). Presence of coarse loamy and mixed soils with good natural drainage might be diluting the groundwater. The variation in EC may be due to diverse hydrometeorology, topography, lithology, drainage, geohydrology, depth of weathering, surface-water irrigation and overexploitation of groundwater[3]. The correlation of compositional parameters of the groundwater samples showed that EC is significant and positively correlated with Ca^{2+}, Mg^{2+}, Na^+, Cl^- and SO_4^{-2}. Significant negative correlation was observed with RSC (r = –0.66**) of groundwater.

The composition of cations, viz. calcium, magnesium, sodium and potassium in the water samples ranged from 0.4 to 46.0, 1.2 to 16.4, 0.76 to 60.1 and 0.002 to 11.78 meq l^{-1} with an average of 4.75, 4.67, 10.4 and 0.35 meq l^{-1} respectively. The cations followed the order sodium, calcium, magnesium and potassium. The occurrence of sodium in groundwater primarily resulted from the chemical decay of feldspar (albite)[11] and its presence also predicts the sodicity of groundwater which is harmful to soil health[12]. The occurrence of calcium in groundwater might be due to calcium mineral-rich rocks such as limestone, dolomite and Mg^{2+} in the groundwater and dolomite in the surrounding rocks and soils[3]. Low levels of potassium in groundwater samples may be ascribed to its affinity to be fixed by clay minerals and participate in the formation of secondary minerals[13].

The concentration of carbonate, bicarbonate, chloride and sulphate ions varied from 0 to 2.0, 1.0 to 17.6, 0.4 to 76.0 and 0.3 to 14.8 meq l^{-1} with an average of 0.1, 7.96, 7.88 and 3.24 meq l^{-1} respectively. The abundance of negative ions was in the order $HCO_3^- > Cl^- > SO_4^- > CO_3^-$. Presence of bicarbonates in higher concentration can be attributed to carbonate weathering[13], along with disintegration of minerals containing carbonic acid like dolomite and shale in the aquifers from the possible mechanisms[14]. The chloride content in groundwater may be because of natural processes like weathering, dissolution of salt deposits and irrigation drainage return flow[11]. Presence of excess chlorides indicates groundwater contamination[15]. The sulphate ions in groundwater might be due to the sulphide-containing minerals, viz. barite and gypsum in aquifer materials, application of sulphate-rich fertilizers and industrial waste[16]. Application of soil amendments like gypsum

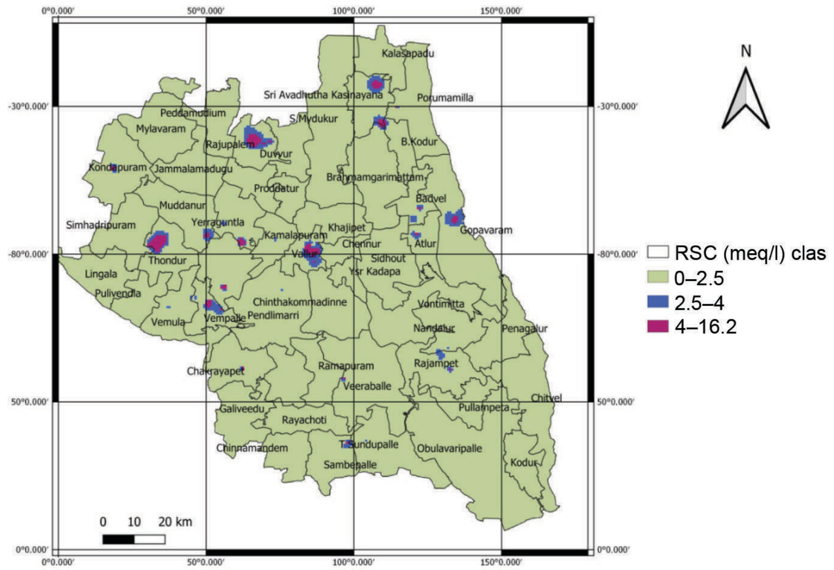

Figure 6. Spatial distribution of residual sodium carbonate (meq l^{-1}) class in groundwater of Kadapa district, AP.

Table 4. RSC (meq l^{-1}) class of groundwater in Kadapa district, AP

RSC class	Value	No. of samples	Percentage of samples
None	<2.5	260	79.03
Slight to moderate	2.5–4	25	7.60
Severe	>4	44	13.37

could be responsible for higher SO_4^{-2} content in groundwater[10].

Sodium adsorption ratio

The SAR of groundwater in Kadapa district, AP, was in the range 0.4–41.2 (m mol $l^{-1})^{1/2}$, with a mean of 5.10 (m mol $l^{-1})^{1/2}$. The lowest SAR of 0.4 (m mol $l^{-1})^{1/2}$ was observed in Anantarajupeta village of R. Kodur mandal and maximum value of 41.2 (m mol $l^{-1})^{1/2}$ in Vengalayapalle village of Rajupalem mandal. The spatial variability of SAR in groundwater in Kadapa district, AP indicated higher values (>10) in parts of Rajupalem, Peddamodium, Proddatur, Thondur, Chapadu, Khajipeta, Valluru, Yerraguntla, V. N. Palli, Vempalli, and Kondapuram mandals (Figure 5). The high SAR of groundwater might be because of shale and sodium feldspar minerals exposed to rapid weathering and release of higher amounts of sodium. It may also be due to dominance of very fine montmorillonitic clay in the soils, which restricts drainage contributing to high SAR of groundwater. It has been reported that with an increase in the SAR of irrigation water, SAR of the soil solution also increases, which eventually results in an increase in exchangeable sodium in the soil[17,18]. Low sodium irrigation water with SAR between 0 and 10, poses no risk of exchangeable sodium. Medium sodium abundance water having SAR between 10 and 18 shows significant hazard, whereas high and very high sodium water with SAR between 18 and 26 and SAR > 26 is regarded as unfavourable for irrigation, as it can lead to harmful levels of exchangeable sodium in the soils[19]. According to this classification, 89.67%, 8.21% and 2.13% water samples respectively belong to the excellent, good and unfavourable category (Table 3).

Residual sodium carbonate

RSC is a property of water which has an important role in the irrigation water quality[15]. The groundwater RSC in Kadapa district, AP varied from –52.4 to 16.2 meq l^{-1}. The highest RSC of 16.2 meq l^{-1} was observed in Vengalayapalle of Rajupalem mandal, which indicates dominance of sodium along with bicarbonate. Lowest RSC of –52.4 meq l^{-1} was recorded in Annavaram village of Chapadu mandal. This indicates the dominance of sodium with chlorides and sulphates. The spatial variation of RSC indicated the highest value (>2.5 mel^{-1}) in groundwater in parts of Kasinayana, B. Kodur, Badvel, Goapavaram, Atlur, Rajampeta, Vallluru, Yerraguntla, V. N. Palle, Muddanur, Vempalle, Rajupalem, Thondur, Veeraballi, Sambepalli and Chakrayapetamandals (Figure 6). This may be due to dominant and rapid weathering of shale, which contributed the highest amount of bicarbonates along with sodium in the groundwater[3]. The pH, EC and SAR of irrigation water were notably influenced by RSC. Based on RSC, water can be categorized into three classes: safe (<2.5 meq l^{-1}), moderately suitable (2.5–4.0 meq l^{-1}) and unsuitable (>4 meq l^{-1}). In this study, 79.03% water samples belonged to the safe category, 7.6% to moderately suitable category and 13.37% to unsuitable category (Table 4).

Table 5. Correlation matrix of groundwater in Kadapa district, AP

	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^-	Cl^-	SO_4^{-2}	RSC	SAR
pH	1											
EC	–0.21	1.00										
Ca^{2+}	–0.46	0.77**	1.00									
Mg^{2+}	–0.28	0.64**	0.54	1.00								
Na^{+}	0.01	0.90**	0.48	0.38	1.00							
K^{+}	–0.21	0.40	0.35	0.13*	0.26	1.00						
CO_3^{-2}	0.31	0.01	–0.16	–0.02	0.14	–0.10	1.00					
HCO_3^-	0.12	0.35	–0.01	0.27	0.43	0.13	0.21	1.00				
Cl^-	–0.24	0.96**	0.77**	0.63**	0.85**	0.31	–0.05	0.21	1.00			
SO_4^{-2}	–0.17	0.74**	0.60**	0.48	0.71**	0.26	0.08	0.13	0.66**	1.00		
RSC	0.48	–0.66**	–0.89**	–0.72**	–0.33	–0.24	0.23	0.24	–0.71**	–0.56	1.00	
SAR	0.31	0.53	0.04	–0.02	0.80**	0.10	0.26	0.51	0.43	0.46	0.18	1.00

**Significant at >0.6.

Table 6. Classification of groundwater and its management[7]

Rating	Class	EC (dSm^{-1})	SAR	RSC (meq l^{-1})	Number of samples	Percentage samples
(I) Good	A	<2	<10	<2.5	175	53.19
(II) Saline						
(i) Marginally saline	B1	2–4	<10	<2.5	72	21.88
(ii) Saline	B2	>4	<10	<2.5	1.0	0.30
(iii) High SAR saline	B3	>4	>10	<2.5	15	4.56
(III) Alkaline water						
(i) Marginally alkaline	C1	<4	<10	2.5–4.0	22	6.69
(ii) Alkaline	C2	<4	<10	>4.0	26	7.90
(iii) Highly alkaline	C3	Variable	>10	>4.0	18	5.47

Ionic correlation studies

Abundance of major ions was in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ for positive ions, and $HCO_3^- > Cl^- > SO_4^{-2} > CO_3^-$ for negatively charged ions. Therefore, the chemical concentration of groundwater corresponded to the Na^+–HCO_3^- type. Higher HCO_3^- ions could be due to rapid weathering of carbonate minerals, viz. dolomite, calcite and clay minerals of shale which has source for the development of soils (Figure 1 *b*)[3]. Positive correlation at 1% level of significance was observed among the major positive ions Na^+–Ca^{2+}, Na^+–Mg^{2+} and Na^+–K^+ (Table 5). Significant positive correlation at 1% level of significance was observed with Na^+–Cl^- ($r = 0.85$**) and Na^+–SO_4^{-2} ($r = 0.71$**). The positive correlation indicates dissolution of sodium from albite mineral. The relationship between SO_4^{-2} and Mg^{2+} implies that a part of SO_4^{-2} and Mg^{2+} may be due to weathering of Mg^{2+} and SO_4^{-2} containing minerals, viz. baryte, dolomite, pyrite and shale in the study area[20]. The correlation between Mg^{2+} and Cl^- ($r = 0.63$**) and Ca^{2+} and Cl^- ($r = 0.77$**) indicates that they are derived from the same source, viz. dolomite[12]. Major rock types in Kadapa district, AP, as mentioned earlier, are quartzite, shale, limestone, phyllite, granite, garnodiorite, granite gneiss and laterite. These rocks have abundant quanitites of minerals such as asbestos, barite, calcite, dolomite, limestone, shale, etc. Weathering of these minerals in the soil would have contributed to ionic concentrations observed in the groundwater[3]. The same was also observed in the groundwater of Chittoor and Nellore districts in AP[12,13].

Classification of irrigation water

The groundwater of Kadapa district, AP, for irrigation purposes was classified into seven classes (Table 6)[7]. About 53.19% of the samples represent good quality groundwater, 21.88% marginally saline, 0.3% saline, 4.56% high SAR saline, 6.69% marginally alkaline, 7.9% alkaline and 5.47% highly alkaline (Figure 7).

Conclusion

The groundwater class in Kadapa district, AP, varied from place to place. Abundance of major positively charged ions was in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and negatively charged ions in the order $HCO_3^- > Cl^- > SO_4^{-2} > CO_3^-$. Therefore, groundwater used for irrigation was Na^+–HCO_3^--type. Among the problem soils of Kadapa district, AP, sodic soils were dominant; they occupied 19,628 ha of cultivable area (1.31% of total area). The major reason for the development of these sodic soils of various classes is the prolonged use of poor-quality groundwater rich in Na^+ and HCO_3^- ions. Less than two-thirds of the groundwater samples analysed in the study area were of good quality for

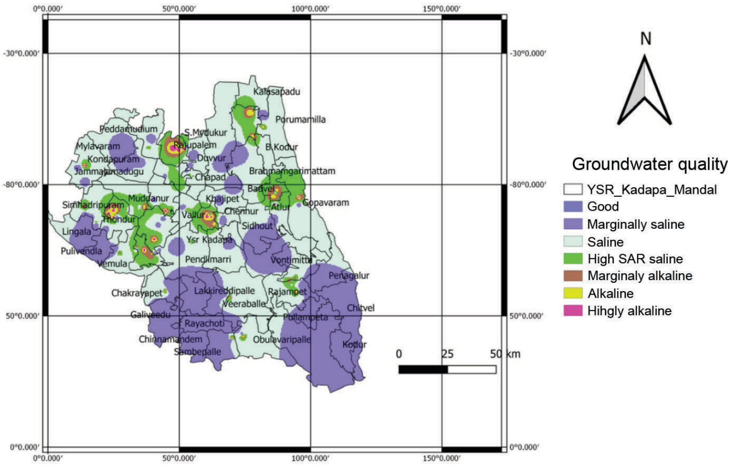

Figure 7. Spatial distribution of groundwater of Kadapa district, AP.

irrigation. Proper management practices are needed in areas having poor-quality groundwater. Spatial maps of different parameters prepared with GIS could be valuable to policy makers for initiating groundwater quality monitoring, as well as for suggesting suitable management plans. Assessment and mapping of the quality of irrigation groundwater may help the farmers in selecting suitable crops and other agronomic management practices for obtaining profitable yields without affecting soil health.

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