International Journal of Plant & Soil Science

Volume 36, Issue 3, Page 306-314, 2024; Article no.IJPSS.112862
ISSN: 2320-7035

Assessment of Spatial Variability in Groundwater Quality of Kurnool Region for Irrigation Purpose and Management Options

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2024/v36i34428

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/112862

Original Research Article

Received: 03/12/2023
Accepted: 08/02/2024
Published: 15/02/2024

ABSTRACT

Assessment of Spatial variability in Groundwater quality of Kurnool region for irrigation purpose and management options was conducted by collecting groundwater samples using GPS locations at various farming situations in different mandals of Kurnool district. The irrigation water quality indices were assessed to classify the ground water for its suitability based on ionic 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, RSC, Kellys ratio, Saturated sodium per centage and Permeability index in groundwater ranged from 6.5-8.4, 0.4-15.6

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(dSm^{-1}), 0.44-28.77 (mmol l^{-1})$^{1/2}$, -66.8-15.4 (me l^{-1}), 0.15-24.61, 11.04-94.89 and 17.22-111. The concentration of cations *viz.,* Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} varied from 0.8-24.4, 0.4-34.8, 0.5-108 and 0.003-27.6 me l^{-1} with mean values of 6.71, 6.19, 12.24 and 0.59 me l^{-1} respectively. Concentration of anions viz.,CO_3^{-2}, HCO_3^{-}, $Cl^{-}$and SO_4^{-2}varied from 0-1.2, 0.4-18.2, 0.8-77.2 and 0.001-8.39 me l^{-1} with an average values of 0.04, 6.59, 8.78 and 1.78 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. Based on physico-chemical properties the groundwater is classified into good, marginally saline, saline, high SAR saline, marginally alkali, alkali, high SAR alkali for irrigation. Thematic maps representing spatial variability in groundwater quality in respect to pH, EC, SAR, RSC and irrigation water class were prepared by inverse distance weightage interpolation method using geographical information system. This will give the information of the irrigation water quality for management options in crop production.

Keywords: Kurnool; ground water quality; spatial variability; kurnool district; irrigation.

1. INTRODUCTION

"Ground water is most important natural resource for agriculture in arid and semiarid regions like Kurnool district. 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 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" [1]. "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 this results poor agricultural performance of crops over a period of time due to accumulation of salts at root zone environment" [1]. In this context a study was conducted in Kurnool district for assessing the quality of groundwater for irrigation purpose and management options in crop production. Subbaiah et al. [2] also reported that assessment of spatial variability in groundwater of Anantapur district are useful for practicing good agronomic management practices in the areas of poor quality groundwater for irrigation. It is evident that reclamation of groundwater techniques can be effectively used by knowing the quality of groundwater and its spatial distribution in any district. The farmers were suggested and incentives were planned accordingly to overcome the problem of salinity in agriculture by various agronomic management practices [3].

2. MATERIALS AND METHODS

The study area falls under Deccan plateau hot arid eco-region in Kurnool district, Andhra Pradesh. The Kurnool district lies in between 15^{o} 8' 35.037" and 15^{o}57' 34.284" of Northern latitudes and 76^{o} 58' 31.383" and 78^{o} 16' 45.383" Eastern longitudes occupies southern part of Andhra Pradesh (Fig 1). Kurnool has a total geographical area of 7977 km^2 The district is bordered by Mahaboobnagar district of Telangana in North, on the east by Nandyal, West by Karnataka and Anantapur on South. The annual rainfall of the district is 665 mm through South-West and North-East monsoons. The temperature varies from place to place. "Kurnool district of Andhra Pradesh was one among all the districts in Andhra Pradesh using ground water as major source for irrigation. Kurnool district has of 86,379 tube wells and filter points and 26,400 dug wells covering nearly 46.5 percent irrigated area of the district. Total groundwater recharge for district is 120856 ha m. Total utilizable groundwater is 70873 ha m and present irrigation use is 41185 ha m. Groundwater development for district, considering all uses, is 34 percent" [4].

Two hundred and eight (208) ground water samples were collected from different sources like bore wells, open wells and hand pumps. Around 5 to 6 samples along with GPS coordinates were randomly collected from each mandal of Kurnool district (Fig. 2) in all the mandals of Kurnool 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 5-6minutes priorto 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 followed to analyze the quality of water. pH in water samples was determined by potentiometrically using pH meter" [5]. "Electrical conductivity was determined by using Conductivity Bridge" [6]. "Chlorides (Mohr'smethod), carbonates and bicarbonates (double indicator method) and calcium and magnesium (versenate method) were determined by adopting the procedures given by Richards [7].Similarly the sodium and potassium in ground water samples were determined by using flame photometer" [7].Sodium Adsorption Ratio (SAR), RSC were calculated by using the formulas given by Richards [7] such as SAR = Na/ $((Ca^{2+}+Mg^{2+})/2)^{0.5}$ and RSC = $(CO_3^{2-} + H\ CO_3^{-}) - (Ca^{2+} + Mg^{2+})$. The Na^+, Ca^{2+} and $Mg2^+$ are in m e L^{-1}. RSC, CO_3^{2-} , $H\ CO_3^{-}$, Ca^{2+} and Mg^{2+} are in meq L^{-1}.

2.1 Kelley's Ratio

Kelley's ratio was used to classify the irrigation water quality [8], which is the level of Na^+ measured against calcium and magnesium. The formula for calculating the Kelley's is as follows

$$\mathrm{KR} = \frac{\mathrm{Na}^+}{(\mathrm{Ca}^{+2} + \mathrm{Mg}^{+2})}$$

Where the concentration of ions are in mg/L

2.2 Soluble Sodium Percentage (SSP)

Sodium concentration in groundwater is a very important parameter in determining the irrigation quality. The formula used for calculating the sodium percentage [9].

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

Where all ionic concentrations are in meq/L.

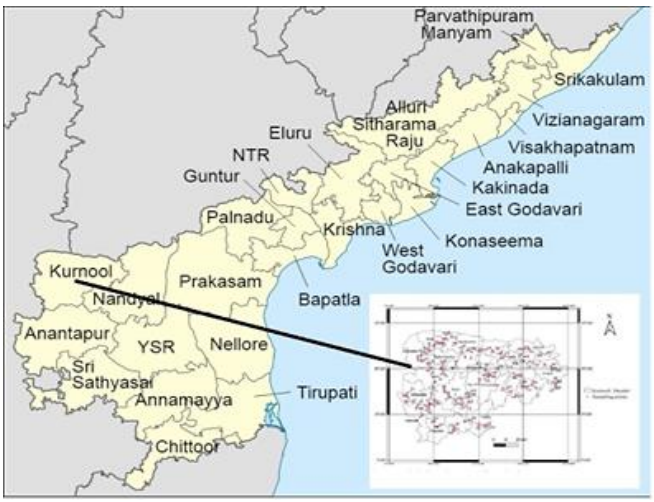

Fig 1. Location map of the study area

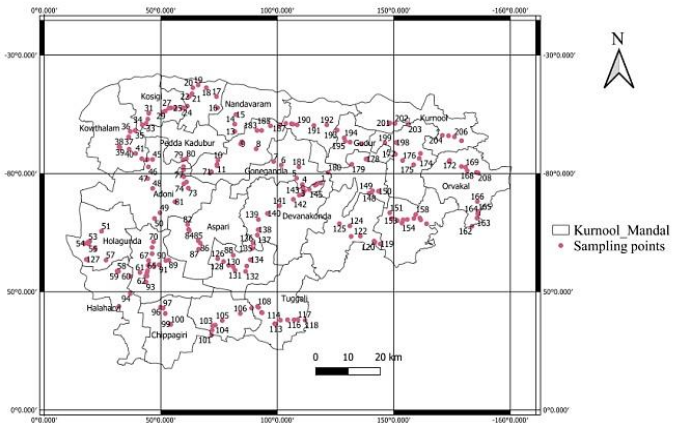

Fig 2. Groundwater sampling points in Kurnool district

2.3 Permeability Index

Long-term use of irrigation contains Na^+, Ca^{+2}, Mg^{+2} and HCO_3^- ions greatly influence the soil permeability. Doneen [10] expressed the degree of soil permeability in terms of permeability index (PI).

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

Where all ionic concentrations are in meq/L.

2.4 Statistical Analysis and Mapping

Research data were analyzed in SPSS 20.0 using Pearson correlation coefficient matrix to know significant variations between the physicochemical properties. Descriptive statistics were calculated using Microsoft Excel (Microsoft, WA, USA) spread sheet. Spatial distribution of groundwater quality was depicted in figures using Q-GIS 3.16.10.

3. RESULTS AND DISCUSSION

3.1 Groundwater Quality Determination

The Kurnool district's groundwater quality varies according on the geological environment, climate, soil type, and drainage conditions. The quality of groundwater for irrigation purposes is determined by the nature of its dissolved elements. The analytical data of ground water samples collected from various mandals of Kurnool district in Andhra Pradesh during 2022 are presented in meq L^{-1} and given in the Table 1.

3.2 Spatial Variability in Water Reaction (Ph)

The groundwater reaction namely acidity, neutrality or alkalinity is determined by its pH.The pH of water samples of Kurnool district varied from 6.5to 8.4 (Table1) with a mean of 7.23. Gupta et al. [11] reported that crops do well with the irrigation water pH 6.5-8.4. The neutral to alkaline pH of groundwater is because of archaean crystalline rocks in the district [4]. The low pH may be due to presence of forest areas in certain pockets.The spatial variability of pH of groundwater in Kurnool is depicted in Fig. 3. Indicates that the highest pH(>7.6) in groundwater was in parts of Devanakonda, Prattikonda, Gudur and Kurnool mandals of Kurnool district.

3.3 Spatial Variability inEC

The electrical conductivity of groundwater of Kurnool district ranged from 0.4 to 15.6 dSm^{-1} with a mean of 2.28 dSm^{-1}(Table1). Based on electrical conductivity groundwater is grouped into different classes (Table 2.) *viz.,* Groundwater with<2 dSm^{-1}(66.35%), 2-4 dSm^{-1}(18.27%), 4-6 dSm^{-1} (9.13%), 6-8 dSm^{-1} (2.88%), 8-10 dSm^{-1} (0.96%) and >10 dSm^{-1} (2.40 %). Highest EC (15.6 dSm^{-1}) was reported with Mugathi village of Yemmiganur mandal and lowest EC (0.4 dS m^{-1}) was reported with Maddikera village of Maddikera mandal (Fig 4). The variation in EC may be due to variation in geological conditions, soil type, drainage, climate of the district [12].

3.4 Spatial Variability in SAR

The SAR of groundwater of Kurnool district ranged from 0.44-28.78(m mol $l^{-1})^{1/2}$ with a mean of 4.67. The lowest SAR of 0.44 (m mol $l^{-1})^{1/2}$ in water samples was observed in Chippagiri village and mandaland the maximum value of SAR was found as 28.78 (m mol $l^{-1})^{1/2}$ in Gudur mandal. The spatial variability of SAR of groundwater in Kurnool district is depicted in Fig. 5 indicated that highest SAR(>10) in groundwater was observed in parts of Gudur and Yemmiganur mandals. Based on SAR values of groundwater (Table 3) most (90.38%) of the samples are having<10 (m mol $l^{-1})^{1/2}$in Kurnool district.

3.5 Spatial Variability in RSC

“Residual sodium carbonate is an important parameter that has extraordinary influence on the suitability of irrigation water” [13]. The residual sodium carbonate (RSC) of groundwater in Kurnool district varied from –49.2 to 13.4 meq L^{-1} with a mean of -6.26meq L^{-1} . The highest RSC of 13.4 meq L^{-1} in water samples was observed in parts of Gudurmandal. The spatial distribution of residual sodium carbonate was depicted in Fig. 6 indicates that highest RSC(>2.5 me/L)in groundwater was observed with parts of Gudurmandal of Kurnool district.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 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 192 samples (Table 4)

were of safe category, 5samples were moderately suitable and 11 samples were unsuitable for irrigation purposes.

3.6 Grouping of Groundwater Quality for Irrigation

The groundwater of Kurnool district was classified into 7 classes for irrigation purpose [14] and details are presented in Table 5. The 62.02% samples were of good quality, 16.83% were of marginally saline, 6.73% of saline, 6.73% high SAR saline, 2.88% of marginally alkali, 1.92% of alkali and 2.88 % of highly alkali. (Fig. 7).

Grouping of groundwater based on saturated sodium percentage: The saturated sodium percentage values of groundwater of Kurnool district varied from 11.04-94.89. Based on saturated sodium percentage values (Table 6), the groundwater of Kurnool district 20.19 per cent samples are not suitable for irrigation.

Grouping of groundwater based on kelley's ratio: The Kelly's ratio of groundwater samples varied from 0.15-24.61. Based on Kelley's ratio 52.40 samples are safe for irrigation (Table 7).

Grouping of groundwater based on permeability index: The permeability index of groundwater of Kurnool district varied from 17.22 to 111 with mean values 55.05. Based on the permeability index (Table 8) 2.88 percent groundwater samples are unsuitable for irrigation

3.7 Spatial Variability in Ionic Concentration

The concentration of cations *viz.,* Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} varied from 0.8-24.4, 0.4-34.8, 0.5-108 and 0.003-27.6 me l^{-1} with mean values of 6.71, 6.19, 12.24 and 0.59 me l^{-1} respectively. The relative abundance of cations for most of the water samples are Na^{+}> Ca^{+2}> Mg^{+2}> K^{+}. The Concentration of anions viz.,CO_3^{-2}, HCO_3^{-}, $Cl^{-}$and SO_4^{-2}varied from 0-1.2, 0.4-18.2, 0.8-77.2 and 0.001-8.39 me l^{-1} with an average values of 0.04, 6.59, 8.78 and 1.78 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 chlorideand bicarbonate anions are dominant among all the anions then followed by sulphates and carbonates(Table 9). The ionic composition of groundwater is mainly influenced by soil type and rock forming minerals of the geological location

Table 1. Descriptive statistics for water quality parameters in kurnool district

S.NO.	Parameter	Range	Mean	Standard deviation	Standard error
1	pH	6.5-8.4	7.23	0.32	0.02
2	EC(dSm^{-1})	0.4-15.6	2.28	2.29	0.15
3	CO_3^{2-} (me L^{-1})	0.0-1.2	0.04	0.17	0.01
4	HCO_3^{-} (me L^{-1})	0.4-18.2	6.59	2.80	0.19
5	Cl^{-}(me L^{-1})	0.8-77.2	8.78	10.40	0.14
6	SO_4^{2-}(me L^{-1})	0.001-8.39	1.78	2.10	0.14
7	Ca^{2+}(me L^{-1})	0.8-24.4	6.71	4.51	0.31
8	Mg^{2+}(me L^{-1})	0.4-34.8	6.19	5.21	0.36
9	Na^{+}(me L^{-1})	0.5-108	12.24	15.99	1.10
10	K^{+}(me L^{-1})	0.003-27.6	0.59	2.41	0.16
11	RSC(me L^{-1})	-49.2 to13.4	-6.26	8.89	0.61
12	SAR	0.44-28.77	4.67	4.74	0.32
13	KR	0.15-24.61	1.51	2.13	0.14
14	SSP	11.04-94.89	42.84	18.76	1.30
15	PI	17.22-111	55.05	18.21	1.26

Table 2. Grouping of groundwater based on EC (dSm^{-1})

S.No.	EC(dSm^{-1})	No.of samples	Per cent of samples
1	0-2	138	66.35
2	2-4	38	18.27
3	4-6	19	9.13
4	6-8	6	2.88
5	8-10	2	0.96
6	>10	5	2.40

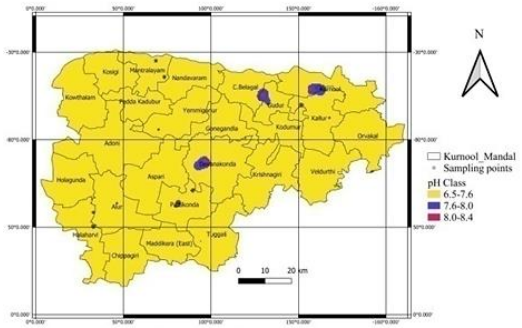

Fig 3. Spatial variability in pH of groundwater

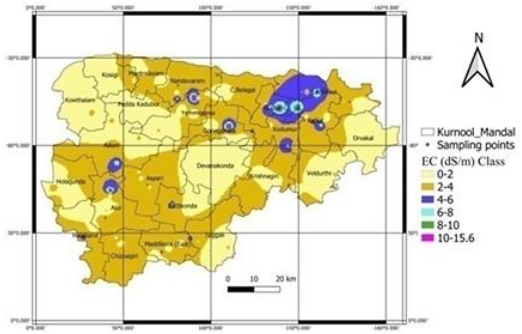

Fig 4. Spatial variability in EC (dS/m) of groundwater

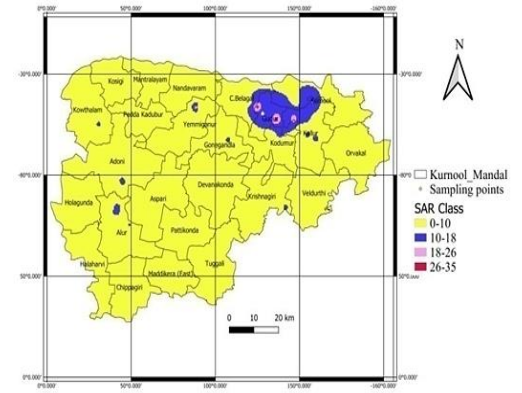

Fig 5. Spatial variability in SAR of groundwater

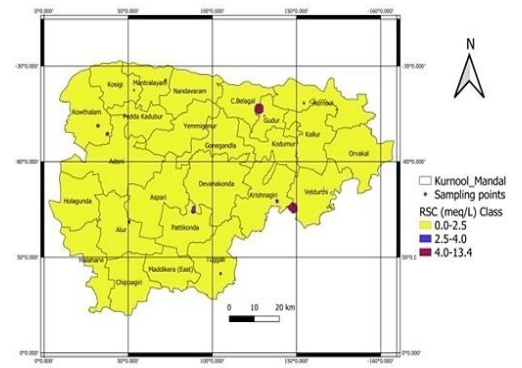

Fig 6. Spatial variability in RSC (meq/L) of groundwater

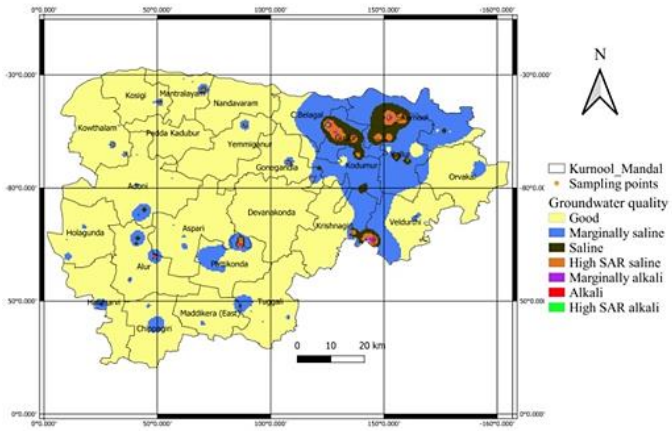

Fig 7. Spatial variability in groundwater quality

Table3. Grouping of groundwater based on SAR

S.No.	SAR	No. of samples	Per cent of samples
1	<10	188	90.38
2	10-18	14	6.73
3	18-26	4	1.92
4	>26	2	0.96

Table 4. Grouping of groundwater based on RSC (mel^{-1})

S.No.	RSC (mel^{-1})		No. of samples	Per cent of samples
	Class	Value		
1	None	<2.5	192	92.31
2	Slight to moderate	2.5-4	5	2.40
3	Severe	>4	11	5.29

Table 5. Grouping of groundwater of Kurnool district for irrigation [14]

Rating	Class	EC (dSm^{-1})	SAR	RSC (me L^{-1})	number of samples	Per cent Samples
A.Good	A	<2	<10	<2.5	129	62.02
B. Saline						
Marginally saline	B1	2-4	<10	<2.5	35	16.83
Saline	B2	>4	<10	<2.5	14	6.73
High SAR Saline	B3	>4	>10	<2.5	14	6.73
C. Alkali Water						
Marginally alkali	C1	<4	<10	2.5-4.0	6	2.88
Alkali	C2	<4	<10	>4.0	4	1.92
High SAR alkali	C3	variable	>10	>4.0	6	2.88

Table 6. Grouping of groundwater based on %Na values [9]

%Na (after Wilcox 1955)	Classification	Total no.of samples	percentage
<20	Excellent	23	11.06
20-40	Good	77	37.02
40-60	Permissible	66	31.73
60-80	Doubtful	37	17.79
>80	Unsuitable	5	2.40

Table 7. Grouping of groundwater based on Kelly's ratio [8]

Kelly's Ratio	Suitability	Sample	
		numbers	Per cent
<1.0	Good	109	52.40
>1.0	Not good	99	47.60

Table 8. Grouping of groundwater based on permeability index (PI) for irrigation (Doneen,1964)

Classification of PI	Permeability	Suitability	Sample	
			number	Per cent
I	>75	Suitable	35	16.83
II	25-75	Marginal	167	80.29
III	<25	Unsuitable	6	2.88

Table 9. Dominace of ions in groundwater of kurnool district

S.No.	Name of the mandal	Type of rocks and minerals	Soil type	Groundwater type
1	Kurnool	Lime stone	black (loam)	Na-Cl-HCO_3
2	Kallur	Limestone	black (loam)	Na-HCO_3
3	Orvakal	Silica sand, Lime stone	red, black (loam)	Na-Ca-HCO_3
4	Gudur	Lime stone	black (loam)	Na-Cl
5	C Belagal	Lime stone	black (loam)	Na-Cl
6	Kodumur	quartz	red, black (loam)	Na-Cl
7	Veldurthi	Steatite, Ochres	black, (loam) red	Na-HCO_3
8	Krishnagiri	Granite	red	Na-HCO_3
9	Gonegandla	Granite	red soil	Ca-Na-Cl
10	Yemmiganur	Granite	red soil	Na-Ca-Cl-HCO_3
11	nandavaram	Granite	black, red	Na-Cl
12	Mantralayam	Granite	loam, red	Na-Ca-HCO_3-Cl
13	Halaharvi	Granite	black, red	Na-HCO_3
14	Kosigi	Granite	red soil, balck	Na-Ca-Cl-HCO_3
15	Kauthalam	Granite	red soil, black	Ca-Na-HCO_3
16	Adoni	Granites	blck, red	Na-Ca-Cl-HCO_3
17	Alur	Quartz	black, red	Na-Ca-Cl-HCO_3
18	Holagunda	Granite	black, red	Ca-Na-HCO_3
20	Peddakadubur	Granite	red	Ca-HCO_3
21	Aspari	Granite	black, red	Na-Cl
22	Chippagiri	Quartz	black soil	Ca-Cl-HCO_3
23	Maddikera	Quartz	red soil, black (loam)	Na-Cl-HCO_3
24	Tuggali	Granite	red soil	Na-HCO_3
25	Pattikonda	gneissic terrain, Granite	red, black(loam)	Na-Ca-Cl-HCO_3
26	Devanakonda	gneissic terrain, quartz	red, black(loam)	Ca-Na-HCO_3

4. CONCLUSIONS

The groundwater quality in Kurnool district differed 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 irrigated groundwater is Na^{+}- Ca^{+2}-Cl^{-}-HCO_3^{-} type. Policymakers may find the spatial maps of various parameters created with GIS useful in starting monitoring programs for groundwater quality in the region and in recommending management plans to farmers for the selection of appropriate crops and other agronomic

management techniques that will yield profitable yields without negatively impacting the health of the soil.

ACKNOWLEDGEMENTS

Authors thank the Indian Council of Agricultural Research and ICAR- Central Soil Salinity Research Institute, Karnal for providing financial and technical support respectively,for conducting this research under AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture at BapatlaCentre in Andhra Pradesh.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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