Indian Journal of Ecology (2022) 49(6): 2229-2235
DOI: https://doi.org/10.55362/IJE/2022/3814

Manuscript Number: 3814
NAAS Rating: 5.79

Groundwater Quality Assessment for Sri Sathyasai Puttaparthy Region of Andhra Pradesh using Geographical Information System

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Abstract: The study area falls under scarce rainfall zone of Andhra Pradesh, groundwater is the major source of irrigation, two hundred and thirty one (231) groundwater samples were collected and were analyzed for water reaction, conductivity, ionic composition. The suitability was correlated based on the EC, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI), Kelly's ratio (KR), soluble sodium percentage, irrigation water quality index (IWQI) . Inverse distance weightage interpolation method used in geographical information system to develop spatial variability maps of pH, EC, SAR, RSC and groundwater irrigation quality. The analysis of groundwater showed the pH of groundwater falls in the range of 6.8-8.4, EC 0.1-4.2 dSm^{-1}, RSC -19.4 to 8.0, SAR 0.45-8.59, KR 0.20-3.69, PI 20.32-105.63 and SSP 12.6-71.78. The irrigation water quality index (IWQI) falls in the range 14.9-192.34. As per the AICRP criteria 64.50% reported good, 20.78% marginally saline, 0.43% saline, 6.93% marginally alkaline, 7.36% alkali in quality for irrigation.

Keywords: Groundwater quality, Spatial variability, SAR, RSC, IWQI, GIS

Irrigation water quality has major role in agriculture production and soil sustainability**.** Sri Sathyasai Puttaparthy region comes under scarce rainfall zone of Andhra Pradesh and predominantly dominated by shallow red soils using ground water as major source for irrigation. In arid and semiarid areas marginal and poor quality waters constitute a greater part of phreatic groundwater resources (Gupta et al 2019). The soil health is majorly affected by the use of poor quality groundwater over a period of time. The evapo-transpiration exceeds the rainfall and basin level natural drainage remains either absent or insufficient, it is necessary to assess groundwater quality of arid and semi-arid region for irrigation. The groundwater quality for irrigation also depends upon the mineral constituents present in the water and is essential to maintain higher productivity. It is a prerequisite to assess the groundwater for sustainable agricultural development and crop production (Vinothkanna et al 2020). It also helps in planning and implementation of groundwater management strategies for better crop production. Therefore, a database on groundwater quality and spatial variability maps of groundwater quality of Sri Sathyasai Puttaparthy region can help the farmers and policy makers for implementation and adoption of efficient crop production practices for profitable returns. Keeping this in view a study was conducted to assess the groundwater quality for irrigation in Sri Sathyasai Puttaparthy region of Andhra Pradesh.

MATERIAL AND METHODS

Study area: The Sri Sathyasai Puttaparthy region lies in between 13.68' and 14.65' of Northern latitudes and 76.88' and 78.47' Eastern longitudes occupies southern part of Andhra Pradesh (Fig. 1). The annual rainfall of the district is 535 mm through South-West and North-East monsoons. The maximum temperature varied 35°C to 46°C during summer and the minimum temperature of 23°C to 25°C during winter.

Analysis of groundwater: Two hundred and thirty one (231) ground water samples were collected from different sources like bore wells and open wells with GPS coordinates (Fig. 2). Sampling was carried out using preconditioned clean high density polythene bottles. The pumps were run for 5-6 minutes prior to collection of water samples, 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 (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 sulphates by turbidimetric method, sodium and potassium in ground water samples were determined by using flame photometer (Richards 1954). Sodium Adsorption Ratio (SAR), RSC were calculated by using the formulas given by Richards (1954) such as SAR = Na/ $(Ca^{2+}+Mg^{2+})/2)^{0.5}$ and RSC = $(CO_3^{2-}$ + 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}. The RSC, SAR, KR, SSP, PI was computed for assessing irrigation water quality index (IWQI).

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

$$Na\% = (Na^+ + K^+)/(Ca^{+2} + Mg^{+2} + K^+ + Na^+) \times 100$$

Where all ionic concentrations are in meq/L.

Kelley's ratio: Kelley's ratio was used to classify the irrigation water quality (Kelley 1963), which is the level of Na^+ measured against calcium and magnesium. The formula for calculating the Kelley's is as follows

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

Where the concentration of ions are in mg/L

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

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

Where all ionic concentrations are in meq/L.

Statistical analysis and mapping: Range, mean, standard deviation and standard error, correlation coefficient of water properties were computed. Spatial distribution of groundwater quality was depicted in figures using inverse distance weightage interpolation method of Q-GIS 3.16.10.

RESULTS AND DISCUSSION

Water reaction (pH): The pH of ground water varied from 6.8 to 8.4 (Table 1) with a mean of 7.37, variation in pH of groundwater in the study area are very small, the low pH may be due to presence of forest areas in certain pockets. Higher pH of ground water may be due to dominance of Na^+, Ca^{+2}, Mg^{+2} and CO_3^- and HCO_3^- ions (Bhat et al 2018). The spatial variability in pH of groundwater is depicted in Figure 3**.** Gupta et al (2019) reported that pH of groundwater should be 6.5-8.4 for better performance of crops, all the samples of ground water of the study area is within this limit can be used for sustainable crop production.

Electrical Conductivity (EC): The conductivity values of groundwater samples ranged from 0.1 to 4.2 dS m^{-1} with a mean of 1.51 dS m^{-1} (Table 1). Electrical conductivity is customarily used for indicating the total concentration of the

Table 1. Descriptive statistics of quality parameters in groundwater

Parameter	Range	Mean	Standard deviation
pH	6.8-8.4	7.37	0.26
EC (dSm^{-1})	0.1-4.2	1.51	0.69
CO_3^{2-} (me L^{-1})	0.0-1.0	0.19	0.26
HCO_3^- (me L^{-1})	1.6-13.8	7.07	1.97
Cl^-(me L^{-1})	0.8-21.6	5.00	4.20
SO_4^{2-} (me L^{-1})	0.27-10.55	2.39	1.86
Ca^{2+} (me L^{-1})	0.8-18.4	4.32	2.39
Mg^{2+} (me L^{-1})	0.8-12.0	3.72	2.21
Na^+ (me L^{-1})	0.7-17.2	5.08	2.80
K^+ (me L^{-1})	0.001-3.02	0.12	0.26
RSC (me L^{-1})	-19.4-8.0	-0.78	4.24
SAR	0.45-8.59	2.61	1.36
KR	0.20-3.69	1.00	0.65
PI	20.32-105.63	60.98	14.77
SSP	12.6-71.78	38.84	12.58
IWQI	14.9-192.34	102.67	31.22

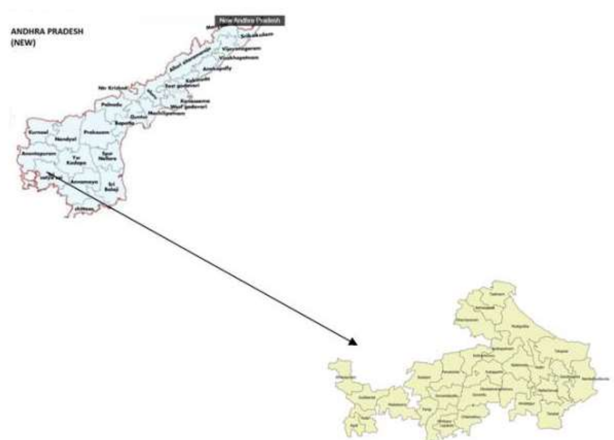

Fig. 1. Location map of Puttaparthy

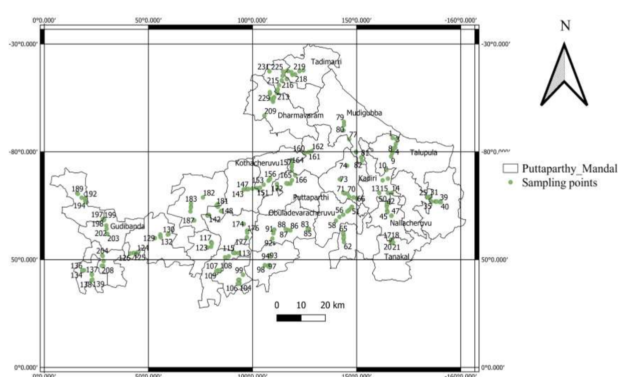

Fig. 2. Ground sampling points

ionized constituents of natural water. The spatial variability of EC in groundwater is depicted in Figure 4. The EC of groundwater indicated that 80.52 % samples are good, 19.05% samples are marginally saline and only 0.43% samples are highly saline (Table 2). The variation in EC may be due to variation in hydro-geological conditions and the anthropogenic activities in the region. Kumar and Balamurugan (2019) reported similar results with Omalur taluk of Tamilnadu.

Sodium adsorption ratio (SAR): The SAR of groundwater in the study area is safe for irrigation (Fig. 5). Presence of calcium and magnesium minimizes the sodicity danger of groundwater for irrigation (Naidu et al 2020).

Residual sodium carbonate (RSC): The residual sodium carbonate (RSC) of groundwater varied from -19.4-8.0 meq L^{-1} with a mean of -0.78 meq L^{-1}. The spatial distribution of residual sodium carbonate was depicted in. The RSC was higher in groundwater of few places due to its high Na^+ and HCO_3^- ion activity than calcium and magnesium ions (Fig. 6). Based on RSC (Table 3) 83.12% samples have no sodium hazard, 8.66% samples are with moderate hazard, 8.23% samples with severe hazard. Majority of the samples are with low sodium hazard indicated that dissolved calcium and magnesium contents are higher than carbonate and bicarbonate contents in groundwater (Kumar and Kumar 2021).

Table 2. Ground water quality based on electrical conductivity (dSm^{-1})

EC (dSm^{-1})	No. of samples	Per cent of samples
0-2	186	80.52
2-4	44	19.05
4-5	1	0.43

Table 3. Classification of ground water based on RSC (mel^{-1})

Residual Sodium Carbonate (mel^{-1})		No. of samples	Per cent of samples
Class	Value		
None	<2.5	192	83.12
Slight to moderate	2.5-4.0	20	8.66
Severe	>4.0	19	8.23

AICRP classification of groundwater for irrigation: The groundwater was classified into 6 classes for irrigation purpose (Minhas and Gupta 1992). The 64.50% samples were of good quality, 20.78% were of marginally saline, 0.43% of saline, 6.93% of marginally alkali and 7.36% of alkali (Table 4, Fig. 7). Similar results were also reported by Subbaiah et al (2020) with Chittoor district of Andhra Pradesh

Kelley's ratio (KR) for irrigation: Kelley's ratio for all the groundwater samples is calculated. Kelley's ratio value (Table 5) less than one is suitable for irrigation (63.20%) and more than one is unsuitable (36.80% samples). Though sodium is dominant ion in groundwater, presence dissolved calcium and magnesium minimized its effect on irrigation water quality in more number of samples

Permeability Index (PI): Based on permeability index irrigation water classified into Suitable (17.32%), marginally suitable (82.25%) and un suitable (0.43%) for irrigation (Table 6). Long-term use of irrigation water contains high salts may affect the permeability index of soils

Soluble sodium per cent (SSP): Soluble sodium per cent values (Wilcox 1955) classification of groundwater resulted 4.33% excellent, 53.68% good, 34.63% permissible, 7.36% samples doubtful. Overall majority of the samples are with less sodium hazard

Irrigation water quality index (IWQI): Irrigation water quality index resulted 2.16% samples are excellent, 50.22% samples are good, and 47.62 percent samples poor in quality for irrigation

Correlation coefficients: The groundwater quality mainly depends upon its ionic composition, presence of one ion may have correlation with other and together influence the quality of groundwater. Correlation coefficients of different ion are given in Table 9. The EC of groundwater has significant

Table 4. Classification of ground water and their management (Minhas and Gupta 1992)

Rating	EC (dSm^{-1})	SAR	RSC (me L^{-1})	Number of samples	Per cent Samples
A.Good	<2	<10	<2.5	149	64.50
B. Saline					
Marginally saline	2-4	<10	<2.5	48	20.78
Saline	>4	<10	<2.5	1	0.43
High SAR Saline	>4	>10	<2.5	0.0	0.0
C. Alkali Water					
Marginally alkaline	<4	<10	2.5-4.0	16	6.93
Alkali	<4	<10	>4.0	17	7.36
Highly alkaline	Variable	>10	>4.0	0.0	0.0

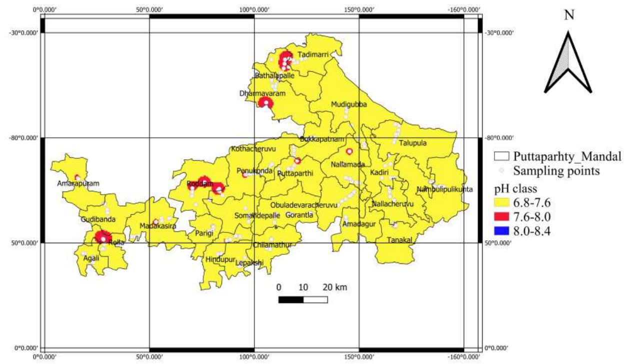

Fig. 3. Spatial distribution of pH in groundwater

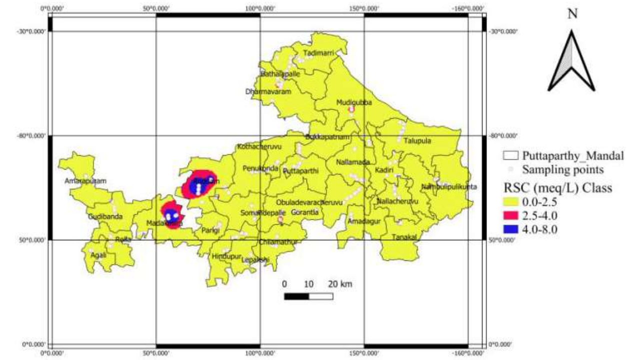

Fig. 6. Spatial variability in RSC (dS/m) of groundwater

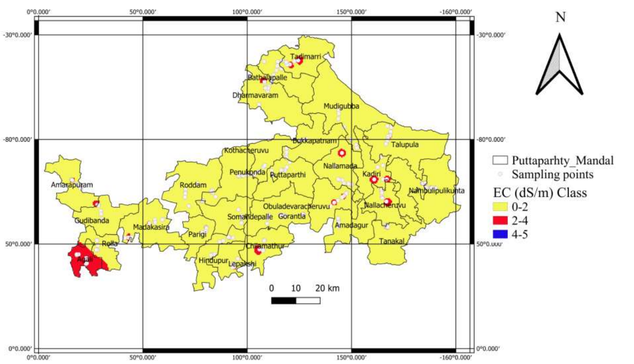

Fig. 4. Spatial variability in EC (dS/m) of groundwater

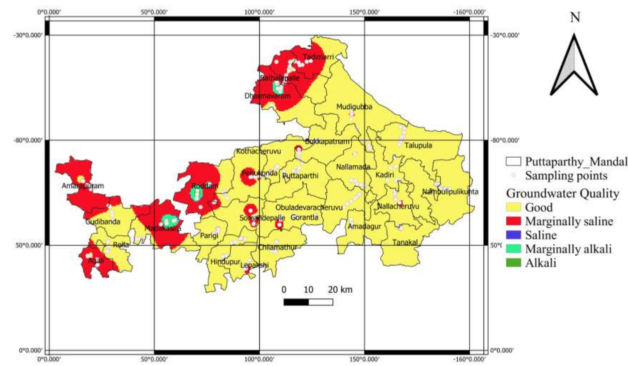

Fig. 7. Spatial variability in groundwater quality

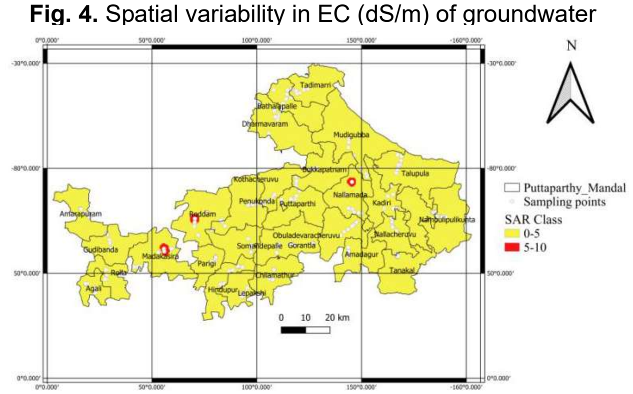

Fig. 5. Spatial variability in SAR (dS/m) of groundwater

Table 5. Classification of groundwater for irrigation based on Kelly's ratio (Kelly 1963)

Kelly's ratio	Suitability	Sample	
		Numbers	Per cent
<1.0	Good	146	63.20
>1.0	Not good	85	36.80

Table 6. Classification of groundwater based on permeability index (PI) for irrigation (Doneen 1964)

Classification of PI	Permeability	Suitability	Sample	
			Numbers	Per cent
I	>75	Suitable	40	17.32
II	25-75	Marginal	190	82.25
III	<25	Unsuitable	1	0.43

Table 7. Grouping of groundwater based on % Na values (Wilcox 1955)

% Na (After Wilcox 1955)	Classification	Total no. of samples	Percentage
<20	Excellent	10	4.33
20-40	Good	124	53.68
40-60	Permissible	80	34.63
60-80	Doubtful	17	7.36
>80	Unsuitable	0.0	0.0

Table 8. Grouping of groundwater based on IWQI for irrigation

Water value range	Water quality	No. of samples	Per cent samples	Sustainable state
<50	Excellent	5	2.16	Sustainable
51-100	Good	116	50.22	Sustainable
101-200	Poor	110	47.62	Slightly unsustainable
201-300	Very poor	0.0	0.0	Unsustainable
>301	Very bad	0.0	0.0	Highly unsustainable

Table 9. Correlation matrix among the chemical constituents of the groundwater

	pH	EC	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-}	Cl^{-}	SO_4^{-2}	RSC	SAR	SSP	PI	KR	IWQI
pH	1															
EC	-0.219	1.000														
Ca^{+2}	-0.455	0.717**	1.000													
Mg^{+2}	-0.153	0.810**	0.621	1.000												
Na^{+}	-0.050	0.799**	0.277	0.494	1.000											
K^{+}	-0.089	0.387	0.139	0.208	0.345	1.000										
CO_3^{-2}	0.280	0.172	-0.094	0.128	0.312	0.021	1.000									
HCO_3^{-}	-0.189	0.470	0.107	0.265	0.671**	0.314	0.149	1.000								
Cl^{-}	-0.175	0.952**	0.712**	0.824**	0.705**	0.342	0.173	0.288	1.000							
SO_4^{-2}	-0.260	0.602**	0.567	0.619**	0.454	0.151	0.030	0.186	0.537	1.000						
RSC	0.267	-0.597	-0.845**	-0.741**	-0.081	-0.039	0.119	0.277	-0.687**	-0.554	1.000					
SAR	0.126	0.461	-0.110	0.101	0.871**	0.278	0.362	0.678**	0.349	0.160	0.348	1.000				
SSP	0.233	0.145	-0.391	-0.203	0.637**	0.225	0.331	0.552	0.054	-0.100	0.605**	0.910**	1.000			
PI	0.310	-0.361	-0.699**	-0.597	0.173	-0.035	0.197	0.306	-0.415	-0.431	0.861**	0.588	0.834**	1.000		
KR	0.286	0.118	-0.391	-0.178	0.599	0.162	0.351	0.544	0.022	-0.095	0.589	0.907**	0.945**	0.803**	1.000	
IWQI	0.288	-0.171	-0.616**	-0.464	0.378	0.084	0.266	0.446	-0.252	-0.314	0.815**	0.755**	0.940**	0.969**	0.902**	1

Note: SAR= Sodium Adsoprtion Ratio; KR = Kelly's Ratio; CR= Corrosivity Ratio; PI= Permeability Index
IWQI= irrigation water quality index; ** Significant at r>0.6

Table 10. Quality of irrigation water in various mandals of Puttaparthy region

Name of the Mandal	pH		EC (dSm^{-1})		RSC (me L^{-1})		SAR		Groundwater type
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	
Amarapuram	7.52	7.2-8.1	1.83	1.1-2.8	-0.95	-4.6 to 4.4	2.85	1.96-3.94	Na^{+}-HCO_3^{-}
Parigi	7.37	7.1-7.5	1.3	0.6-2.2	2.2	0.4-6.4	3.12	1.08-4.67	Na^{+}-HCO_3^{-}
Roddam	7.58	7.1-8	1.24	0.7-2.1	3.62	-2.6 to 8.0	3.88	2.08-6.32	Na^{+}-HCO_3
Lepakshi	7.43	7.1-7.8	1.71	0.8-3	-0.2	-4.4 to 4.4	2.92	1.5-4.15	Na^{+}-HCO_3^{-}
Penukonda	7.54	7.3-7.9	1.8	1.1-2.6	0.875	-5.4 to 8.0	3.52	1.1-6.0	Na^{+}-HCO_3^{-}
Gornatla	7.26	6.9-7.6	1.09	0.5-1.7	0.96	-2.4 to 4.4	2.26	0.8-4.09	Na^{+}-Ca^{+2}-HCO_3^{-}
Bukkapatnam	7.26	7.1-7.5	1.01	0.6-1.5	1.42	-0.4 to 3.0	1.82	1.03-2.59	Na^{+}-HCO_3^{-}
Kadiri	7.18	7-7.3	1.66	0.9-2.8	-2.56	-19.4 to 1.8	2.75	1.0-6.5	Ca^{+2}-Na^{+}-HCO_3^{-}
Nallacheruvu	7.22	6.9-7.6	1.8	0.7-4.2	-1.44	-17.0 to 4.2	2.88	1.59-4.0	Na^{+}-HCO_3^{-}
Dharmavaram	7.4	7.1-8.1	1.92	1.1-3.6	-0.11	-14.2 to 5.6	3.96	1.47-5.89	Na^{+}-HCO_3^{-}
Mudigubba	7.24	7-7.6	1.15	0.8-1.7	0.73	-2.2 to 4.2	2.52	0.85-4.17	Na^{+}-HCO_3^{-}
Talapula	7.19	6.9-7.6	1.44	0.5-2.8	-2.8	-12.6 to 1.8	1.98	0.75-3.27	Ca^{+2}- Na^{+}-HCO_3^{-}
Gandlapenta	7.29	7.1-7.6	1.61	0.9-3.1	-1.75	-7.8 to 1.0	2.38	1.0-4.93	Na^{+}-Ca^{+2}-HCO_3^{-}
Tanakal	7.31	6.9-7.5	1.57	0.9-3.1	-3.04	-10.2 to 0.8	1.95	1.30-3.10	Ca^{+2}-HCO_3^{-}
O.D.Cheruvu	7.28	7.2-7.5	1.93	0.9-3.3	-4.0	-9.2 to 0.6	2.93	1.20-5.04	Na^{+}-HCO_3^{-}
Amadgur	7.27	6.8-7.7	1.17	0.7-1.6	-1.02	-5.4 to1.2	2.16	1.08-3.04	Ca^{+2}-HCO_3^{-}
Hindupur	7.4	7.1-7.9	1.23	0.4-2	0.34	-3.6to4.4	2.26	1.34-3.32	Na^{+}-HCO_3^{-}
Chilamthur	7.12	6.9-7.3	1.88	1.0-3.4	-5	16to-0.2	1.88	1.20-2.72	Ca^{+2}-HCO_3^{-}
Madakasira	7.4	7.0-7.7	1.86	1.5-2.5	1.0	-7 to 6.8	4.23	1.9-6.3	Na^{+}-HCO_3^{-}
N.P. Kunta	7.3	7.1-7.7	1.12	0.6-1.5	-0.8	-5.6 to 3.4	1.89	1.11-4.22	Ca^{+2}-HCO_3^{-}
Gudibanda	7.34	7.0-7.5	1.64	0.5-2.7	-2.68	-8.2 to 0.8	1.96	1.1-2.34	Ca^{+2}-HCO_3^{-}
Rolla	7.6	7.0-8.4	1.35	1.0-1.8	0.46	-2.4 to 3.0	2.72	1.7-4.0	Na^{+}-HCO_3^{-}
Agali	7.34	7.0-7.5	2.45	1.3-3.4	-5.7	-14 to 7.8	3.09	1.97-6.03	Na^{+}-HCO_3^{-}
Bathalapalli	7.6	7.1-8.0	1.32	0.6-1.9	-2.37	-6.2 to 3.0	1.85	0.45-4.53	Na^{+}-Ca^{+2}-HCO_3^{-}
Tadimarri	7.53	7.2-7.7	1.66	0.8-3.3	-1.05	-3.2 to 2.2	2.5	0.8-5.36	Na^{+}-Ca^{+2}-HCO_3^{-}
Kothacheruvu	7.43	6.9-7.8	1.22	0.7-2.1	0.08	-6 to 3.0	2.08	1.05-3.73	Na^{+}-HCO_3^{-}
Puttaparthy	7.5	6.9-8.1	1.48	0.7-2.7	-2.42	-9.2 to 1.0	1.70	0.87-2.64	Ca^{+2}-HCO_3^{-}
Nallamada	7.36	7.1-7.8	1.34	0.7-2.7	-0.42	-4.4 to 1.8	2.53	1.04-8.59	Ca^{+2}-HCO_3^{-}
Somandepalli	7.4	7.2-7.5	1.46	0.8-3.1	0.53	-7.4 to 3.2	2.50	1.41-3.99	Na^{+}-HCO_3^{-}

positive correlation with Na^+, Ca^{+2}, Mg^{+2}, Cl^- and SO_4^{-2} Ca^{+2} positively correlated with Cl and negatively correlated with RSC , PI and IWQI . Mg^{+2} is positively correlated with Cl^- and SO_4^{-2} and negatively correlated with RSC indicates presence calcium and magnesium minimized the sodium and bicarbonate hazard of groundwater (Pal et al 2018). Na^+ positively correlated with HCO_3^- Cl^-, SAR , SSP. HCO_3^- is positively correlated with SAR (0.678**) indicates sodium hazard of groundwater in few places of the study area, IWQI is positively correlated with RSC , SAR , and KR . KR is positively correlated with SAR, SSP and PI where *r* value is approaches to unity (r>0.6). The presence of minerals which contain sodium, calcium, magnesium, bicarbonates, chlorides and sulphates in the study area may be the reason for their higher amounts in groundwater.

Mandal wise groundwater quality: The mandal wise groundwater quality is given in Table 10, indicated that the presence of high RSC resulted dominance of Na^+ - HCO_3^- type of groundwater in parts of the mandals *viz.,* Amarapuram, Parigi, Roddam, Lepakshi, Penukonda, Gorantla, Nallacheruvu, Dharmavaram, Mudigubba, O.D. cheruvu, Hindupur, Madakasira, Rolla, Agali, Kothacheruvu, Somandepalli. This might due to dominance of sodium and bicarbonate containing minerals might have impact on groundwater quality. Dominance of Na^+-Ca^{+2}-HCO_3^- ions in groundwater was observed in mandals (with RSC <4) *viz.,* Bukkapatnam, Gandlapenta, Bathalapalli, Tadimarri. Ca^{+2}-Na^+-HCO_3^- ions were observed in Kadiri, Talapula. Ca^{+2}-HCO_3^- type groundwater observed in Tanakal, Amadgur, Chilamathur, N.P. Kunta, Gudibanda, Puttaparthy, Nallamada. The variation in groundwater type may be due to variation hydrogeological conditions of the study area (Shalini and Bhardwaj 2017).

CONCLUSION

The ground water quality in Srisathyasai Puttaparthy region varied from place to place. The dominance of major ion was in the order of Na^+ > Ca^{+2} > Mg^{+2} > K^+ for cations and HCO_3^- > Cl^- > SO_4^{-2} > CO_3^- for anions, which indicated the quality of groundwater used for irrigation is Na^+-HCO_3^- type, presence of calcium and magnesium in sufficient quantities minimized the sodium hazard of groundwater in majority of the samples, very few samples which have excess sodium and bicarbonate ions resulted high sodicity due to residual sodium carbonate. More than 50 per cent of groundwater quality of the region is good for irrigation can be used for sustainable crop production without affecting soil health, poor quality water is around 40 percent, use of this water limits the crop production. However, adoption of proper management practices are needed in case of poor quality ground water. The spatial maps of different parameters, prepared using GIS could be valuable for policy makers for initiating groundwater quality monitoring of the area as well as for suggesting management plans. Assessment and mapping of quality of irrigated groundwater may help the farmers in selection of suitable crops and other agronomic management practices for getting profitable yields without affecting the soil health.

ACKNOWLEDGMENT

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 Bapatla Centre in Andhra Pradesh.

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Received 11 August, 2022; Accepted 26 November, 2022