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ORIGINAL ARTICLE

Groundwater quality suitable zones identification: application of GIS, Chittoor area, Andhra Pradesh, India

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Abstract Due to uneven spatial and temporal distribution of rainfall and lack of sufficient water management technologies, the development activities of the society are totally depending on groundwater resources. In addition to the prevailing drought-prone conditions, the improperly treated and unplanned release of effluents of industry, municipal and domestic into the nearby streams and ponds and the majority usage of groundwater for irrigation are increasing the ionic concentration of the groundwater and making it more saline. The analytical results of the collected groundwater samples show that the groundwater is alkaline, and sodium and bicarbonate are the dominant cation and anion, respectively. Gibbs variation diagram shows that the control of the chemistry of groundwater in the study area is the weathering of granitic gneisses and also the leaching of evaporated and crystallized ions from the topsoil of the irrigated areas and improperly treated industrial effluent ponds. GIS, a potential tool for facilitating the generation and use of thematic information, has been applied and analyzed for identification of groundwater quality suitable zones for domestic and irrigation purposes. 30.06% of the area is with suitable, 67.45% of the area is with moderately suitable and 2.45% of the area is with unsuitable quality of groundwater for domestic purpose. 46% of the area is with suitable, 53.36% of the area is with moderately suitable and 0.64% of the area is with unsuitable quality of groundwater for irrigation purpose.

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Keywords Groundwater quality · GIS · Domestic purposes · Irrigation purposes

Introduction

Due to the frequent failures and uneven spatial and temporal distribution of rainfall in addition to the lack of sufficient surface water management technologies, the rapid developmental activities of the society are totally depending on groundwater resource. This situation is not only making more demand for groundwater but also polluting the available water resources due to improper releasing of the effluents into the natural system. This is the cause for the acute pressure of suitable quality of water for various needs of the society.

The study area ‘‘Chittoor’’ lies between North Latitude 13°10′00″–13°15′00″ and East Longitude 79°04′00″–79°09′00″ with an area of 83.7 km^2 (Fig. 1). It falls in drought-prone and economically backward Rayalaseema region of Andhra Pradesh, India. An ephemeral river ‘‘Niva’’ passes through the study area. The drainage pattern is dendritic to sub-dendritic. The surface flow in the river course presents only a few days after the heavy rains. ‘‘Chittoor’’ is a district headquarters of Chittoor district, Andhra Pradesh, and also it is the only urbanized town nearby the surrounding rural villages. The industrial (sugar factory, distillery, dairy and other industries), municipal and domestic effluents and wastes are released into the nearby ponds and stream courses without proper treatment.

Geologically the study area is underlined by Archaean age rocks of unclassified granitic gneisses. All these prevailing natural and anthropogenic conditions

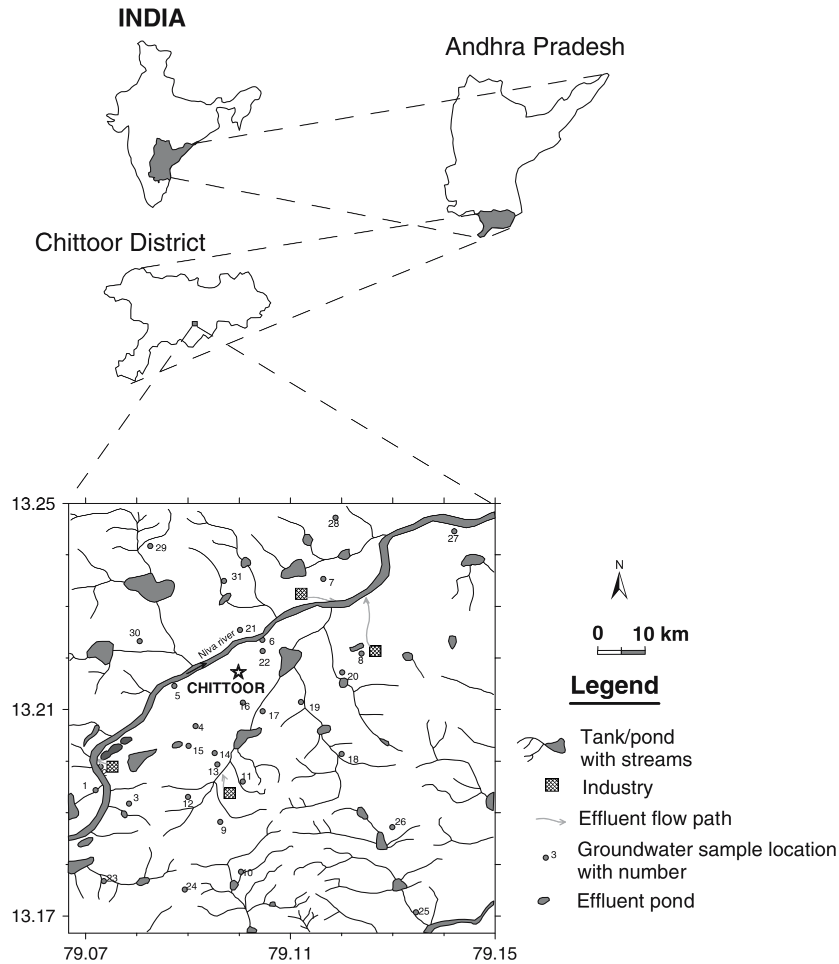

Fig. 1 Location map of Chittoor Area, Chittoor district, Andhra Pradesh, India

are in turn reflected in its groundwater quality conditions. The chemical composition of water is an important factor to be considered before it is used for domestic or irrigation purpose (Suresh et al. 1991). The present study has been conducted to assess and evaluate the groundwater quality conditions and to delineate the suitable groundwater quality zones for domestic and irrigation purposes, using the application of GIS technology.

Data used and methodology

Survey of India (SOI) topographic map (No. 57 O/4 of scale 1:50,000) was used for preparation of the base map. Detailed geological and hydrogeological studies were conducted. Well inventory and water table levels data were collected during the fieldwork Thirty-one groundwater samples were collected from dug, dug-cum-bore and borewells in the study area during December 1996 and its locations are shown in Fig. 1. The samples were analyzed using standard analytical methods (American Public Health Association et al. 1985; Brown et al. 1973) for major ions (i.e., Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, EC, total dissolved solids (TDS), pH). In order to study the quality of water, the obtained chemical data was evaluated in terms of its suitability for domestic and irrigation purposes. The results of the chemical analyses are shown in Table 1.

Using Integrated Land and Water Information System (ILWIS), groundwater quality maps of TDS, total hardness (TH), incrustation problem, magnesium concentration, electrical conductivity (EC), residual sodium carbonate (RSC), sodium adsorption ratio (SAR) and percent sodium (%Na) were prepared and classified for spatial analysis. The classification of each thematic map and their spatial distributions were given in Tables 2 and 5. Each class in every thematic map was assigned a weight. Highest weight was assigned to the class that is most favorable for that purpose and the lowest weight was assigned to the class that is least favorable/unfavorable class as per World Health Organization (WHO), Indian Standards Institute (ISI),

Table 1 Chemical composition of groundwater of the Chittoor area, Chittoor district, Andhra Pradesh

Sample no.	pH	EC (μS L^{-1})	Na^+ (mg L^{-1})	K^+ (mg L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	CO_3^- (mg L^{-1})	HCO_3^- (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{3-} (mg L^{-1})	TDS (mg L^{-1})	%Na (meq L^{-1})	SAR	RSC (meq L^{-1})	TH (mg L^{-1})	Alkalinity (mg L^{-1})
1	7.6	1,665	187	105	58	37	0	670	136	88	939	64.59	4.72	5.054	297	549
2	7.7	2,000	380	5	16	11	0	670	220	63	1,023	90.85	18.05	9.311	84	549
3	8.4	1,930	137	78	146	46	20	416	328	113	1,071	41.82	2.53	0	554	358
4	8.3	2,220	320	18	120	23	19	404	476	75	1,248	64.6	7.01	0	394	347
5	7.7	1,810	248	24	110	23	0	576	290	55	1,032	60.71	5.62	2.066	369	472
6	7.8	2,180	320	36	94	402	0	670	227	262	1,669	64.99	6.96	2.993	400	549
7	7.5	13,500	1,558	105	594	263	0	1,360	2,180	2,522	7,888	57.89	13.39	0	2565	1,115
8	7.2	2,520	144	8	254	74	0	473	45	779	1,535	25.63	2.05	0	938	388
9	7.6	1,670	128	9	146	37	0	472	186	150	887	35.91	2.45	0	517	387
10	7.6	820	66	5	54	36	0	400	37	50	444	34.71	1.71	0.906	284	328
11	7.9	3,070	296	153	172	72	0	267	899	75	1,797	53.65	4.78	0	725	219
12	7.4	1,200	155	3	66	20	0	530	90	25	618	58.01	4.3	3.755	248	434
13	7.9	2,480	387	9	102	68	0	718	433	75	1,425	66.8	8.17	3.293	535	588
14	7.8	3,650	370	21	300	60	0	667	815	125	2,017	45.53	5.1	0	996	547
15	8.2	3,750	476	15	246	59	45	492	855	213	2,150	55.33	7.1	0	856	441
16	7.4	4,840	523	15	442	38	0	980	953	258	2,709	47.88	6.41	0	1270	804
17	7.4	820	64	49	46	21	0	393	50	10	432	50.11	1.96	2.424	201	322
18	7.8	178	251	5	66	56	0	936	93	50	979	58.32	5.49	7.289	396	759
19	8.4	1,780	212	8	76	53	32	580	215	50	930	53.65	4.57	2.429	408	503
20	7.5	700	64	6	34	36	0	371	55	13	389	38.69	1.82	1.428	233	304
21	7.6	4,340	576	8	312	45	0	933	823	289	2,510	56.74	8.07	0	964	978
22	7.8	4,350	709	39	162	61	0	1,006	783	306	2,552	70.84	12.05	3.392	656	845
23	7.5	470	35	5	68	8	0	170	70	32	301	29	1.07	0	201	139
24	7.6	600	36	5	68	8	0	186	70	32	310	29.66	1.1	0	201	153
25	7.5	800	42	5	80	25	0	260	125	12	416	24.43	1.05	0	303	213
26	7.2	700	56	8	76	57	0	220	99	24	427.8	38.23	1.67	0	424	180
27	8.3	650	40	6	34	26	21	115	81	25	289.35	32.93	1.26	0	192	112
28	7.7	1,100	70	10	70	53	0	280	192	55	587.2	29.6	1.54	0	393	230
29	7.3	1,005	98	11	52	28	0	240	148	42	496.6	48.13	2.72	0	245	197
30	7.9	510	62	10	10	21	0	221	31	25	267.29	56.93	2.56	1.396	111	181
31	7.8	1,050	120	12	80	18	0	261	220	26	603.89	50.3	3.16	0	219	213

EC electrical conductivity, *TH* total hardness, *%Na* percent sodium, *SAR* sodium absorption ratio

Table 2 Criteria for the classification of thematic maps of groundwater quality for domestic and their spatial distribution

Class	Criteria	Percentage of the area	Area in km^2
Incrustation (bicarbonate and sulfate) ($mg\ L^{-1}$)			
No incrustation	If HCO_3 < 400 and SO_4 < 100	31.08	26.014
Soft incrustation	If HCO_3 > 400	62.56	52.363
Hard incrustation	If SO_4 > 100	6.36	5.323
Magnesium ($mg\ L^{-1}$)			
Suitable	If SO_4 > 250 and Mg < 30 (or) SO_4 < 250 and Mg < 150	74.86	62.658
Unsuitable		25.14	21.042
Total dissolved solids ($mg\ L^{-1}$)			
Very low	<250	0	0
Low	250–500	16.07	13.451
Moderate	500–750	18.02	15.166
High	750–1,000	14.92	12.488
Very high	>1,000	50.89	42.595
Total hardness ($mg\ L^{-1}$)			
Soft water	<75	0	0
Moderately hard water	75–150	0.02	0.017
Hard water	150–300	15.31	12.814
Very hard water	>300	84.67	70.869

Table 3 Classification of each theme of groundwater quality for domestic purpose and the assigned weights, Chittoor area, Andhra Pradesh, India

Class	Weight
Incrustation	
No incrustation	4
Soft incrustation	2
Hard incrustation	1
Magnesium	
Suitable	4
Unsuitable	1
Total dissolved solids	
Very low	5
Low	4
Moderate	3
High	2
Very high	1
Total hardness	
Soft water	4
Moderately hard water	3
Hard water	2
Very hard water	1

Raghunath (1983) and other standards. For example, Sawyer and McCarty (1967) classified the TH into four classes as follows: soft water (<75 $mg\ L^{-1}$), moderately hard water (75–150 $mg\ L^{-1}$), hard water (150–300 $mg\ L^{-1}$) and very hard water (>300 $mg\ L^{-1}$). As the

Table 4 Classification of groundwater quality for domestic purpose in Chittoor area, Andhra Pradesh, India (after overlaying and integrating all the themes of domestic purpose)

Class	Percentage of the area	Area in km^2	Added weights
Suitable	30.06	24.160	>12
Moderately suitable	67.45	56.456	<12
Unsuitable	2.49	2.084	<4

Table 5 Criteria for the classification of thematic maps of groundwater quality for irrigation purpose and their spatial distribution

Class	Criteria	Percentage of the area	Area in km^2
Electrical conductivity ($\mu S\ L^{-1}$)			
Excellent	<250	0	0
Good	250–750	8.26	6.914
Medium	750–2,250	61.45	51.434
Doubtful	2,250–4,000	23.34	19.535
Unsuitable	>4,000	6.95	5.817
Sodium absorption ratio			
Excellent	<10	99.22	83.047
Good	10–18	0.78	0.653
Doubtful	18–26	0	0
Unsuitable	>26	0	0
Percent sodium ($meq\ L^{-1}$)			
Excellent	<20	0	0
Good	20–40	35.19	29.454
Moderate	40–60	59.55	49.844
Doubtful	60–80	5.22	4.369
Unsuitable	>80	0.04	0.033
Residual sodium carbonate ($meq\ L^{-1}$)			
Excellent	<1.25	59.07	49.441
Moderate	1.25–2.5	31.10	26.031
High	>2.5	9.83	8.228

hardness increases the water is unsuitable to drinking purpose, so the highest weight (i.e., 4) is assigned to soft water class (<75 $mg\ L^{-1}$) and lowest weight (i.e., 1) is assigned to very hard water (>300 $mg\ L^{-1}$). In the same way, each class in every thematic map was assigned a weight as given in Tables 3 and 6.

Using GIS package of ILWIS, overlaying and integration analyses was done by adding the weights of the classified themes of incrustation problem, magnesium, TDS and TH and prepared a map of groundwater quality suitable domestic purpose. The output layer/map was classified into various classes as suitable, moderate and unsuitable for domestic purposes based on the added weights got from integrated analysis (Table 4). In the same way the groundwater quality suitable for irrigation purpose was also done by overlaying and integration analyses of adding the weights of

Table 6 Classification of each theme of groundwater quality for irrigation purpose and the assigned weights, Chittoor area, Andhra Pradesh, India

Class	Weight
Electrical conductivity	
Excellent	5
Good	4
Medium	3
Doubtful	2
Unsuitable	1
Sodium absorption ratio	
Excellent	4
Good	3
Doubtful	2
Unsuitable	1
Percent sodium	
Excellent	5
Good	4
Moderate	3
Doubtful	2
Unsuitable	1
Residual sodium carbonate	
Excellent	4
Moderate	2
High	1

the classified themes of EC, SAR, %Na and RSC. The out put layer/map was classified as suitable, moderate and unsuitable for irrigation purpose (Table 7). Finally, the thematic maps of groundwater quality suitable for domestic and groundwater quality suitable for irrigation purposes were overlaid and integrated for identification and delineation of groundwater quality suitable zones for domestic and irrigation purposes (Table 8). The processing flow chart of GIS application is shown in Fig. 2.

Table 7 Classification of groundwater quality for irrigation purpose in Chittoor area, Andhra Pradesh, India (after overlaying and integrating all the themes of irrigation purpose)

Class	Percentage of the area	Area in km^2	Added weights
Suitable	46.00	38.502	>10
Moderately suitable	53.36	44.662	<10
Unsuitable	0.64	0.536	<4

Results and discussion

Geologically, the study area is underlain by unnamed granitic gneisses of Archaean age. Recent alluvium consisting of gravel, sand (coarse to fine), silt and clay are present along stream course. Granites generally outcrop as hillocks, and rarely outcrop in sheet forms. Dolerite rocks intrude the granitic gneisses as dikes. Dike lengths range from a few meters, to a few kilometers, with widths ranging from a few meters to tens of meters. Dominant trend of the dikes is toward the NEE–SWW.

Groundwater occurs under unconfined condition in shallow weathered zone and semi-confined condition in joints, fissures and fractures extending beyond weathered zones. The maximum weathered zone thickness, i.e., 18 m below ground level (bgl), is in NE and south-central portions of the study area. The depth to water table ranges from 0.75 to 18 m bgl. Groundwater present at shallow depth in SE portion and at deeper levels in SW and central portions of the study area at some places.

The data obtained by chemical analysis were evaluated in terms of its suitability for domestic and irrigation purposes. The analytical results (Table 1) show the alkaline nature of groundwater as pH ranges from 7.2 to 8.3 with a mean of 7.7. Among the cations, the order of abundance (meq L^{-1}) is Na > Ca > Mg > K. The concentration of Na^+, Ca^{2+}, Mg^{2+} and K^+ ions ranged from 35 to 1,558, 10–594, 8–402 and 3–158 mg L^{-1} with a mean of 262.26, 134, 57.58 and 25.68 mg L^{-1}, respectively.

Among anions, the order of abundance is HCO_3^-, Cl^-, SO_4^{2-} and CO_3^{2-} ranged from 115 to 1,360, 31–2,180, 10–2,522 and 0.0–45 mg L^{-1} with a mean of 514, 362.10, 190.94 and 4.42 mg L^{-1}, respectively. The total hardness

Table 8 Classification of groundwater suitable for domestic and irrigational purposes in Chittoor area, Andhra Pradesh, India (after overlaying, integrating the maps of groundwater quality suitable map for domestic and groundwater quality suitable map for irrigation purposes)

Class	Percentage of the area	Area in km^2
Suitable for domestic and irrigation	27.14	22.716
Suitable for domestic and moderately suitable for irrigation	2.92	2.444
Moderately suitable for domestic and suitable for irrigation	16.37	13.702
Moderately suitable for domestic and irrigation	50.44	42.218
Moderately suitable for domestic and unsuitable for irrigation	0.64	0.536
Unsuitable for domestic and suitable for irrigation	2.49	2.084

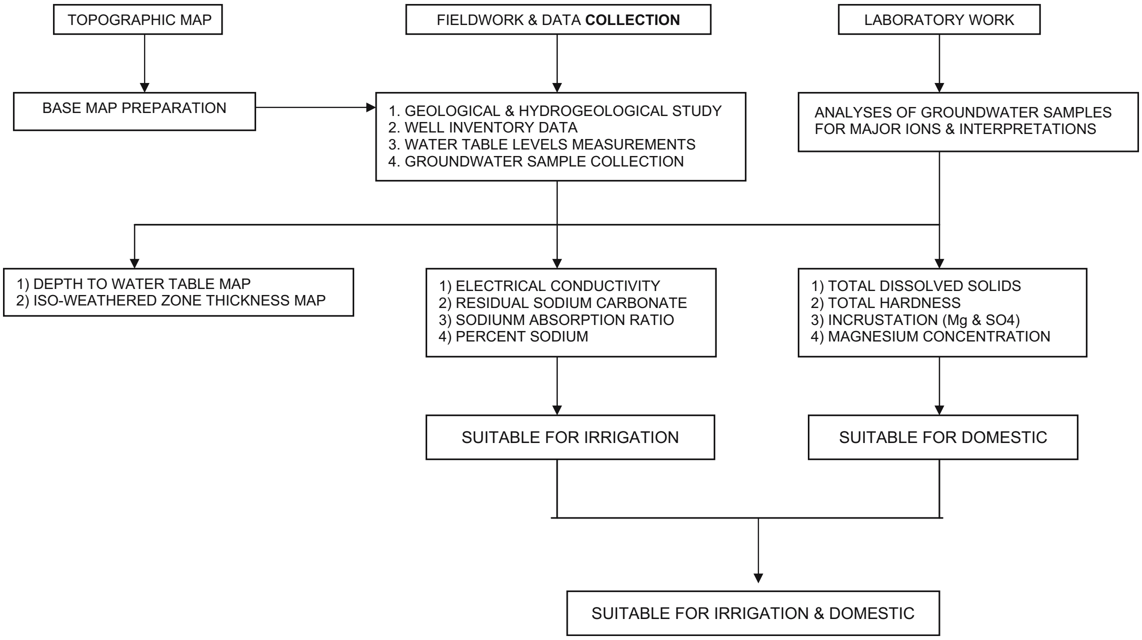

Fig. 2 Schematic diagram showing the flow chart used in the study

of groundwater varies between 84 and 2,565 mg L^{-1} with mean 521.9 mg L^{-1} indicating moderately hard to very hard type. The observed high concentration of chloride in groundwater in sample no. 7 (which is located near the sugar factory effluents discharging site) is an indication of pollution origin.

Gibbs (1970) variation diagram (Fig. 3) has been used to broadly assess the functional sources of dissolved ions by plotting the samples, according the variation in the ratio of Na^+: ($Na^+ + Ca^{2+}$) as a function of TDS. It is observed that the water chemistry of Chittoor area occupies the field categorized as rock dominance and also evaporation–crystallization dominance indicating that the major mechanism controlling the water chemistry of Chittoor area is weathering of rocks of granitic gneisses and also the leaching of evaporated and crystallized ions from the top soils of the irrigation areas and improperly treated industrial effluent ponds. This is expected, as evaporation greatly increases the concentrations of ions formed by chemical weathering, leading to higher salinity (TDS) in soils and as well as the groundwater due to the percolation of water. As the anthropogenic activities also influence the role of evaporation, leading to an increase in Na^+ and Cl^- and thus TDS (Hem 1992; Karanth 1991; Subba Rao 1998), the samples fall in an environment that tends toward a semi-arid/arid climate. Such an environmental condition is also responsible for movement

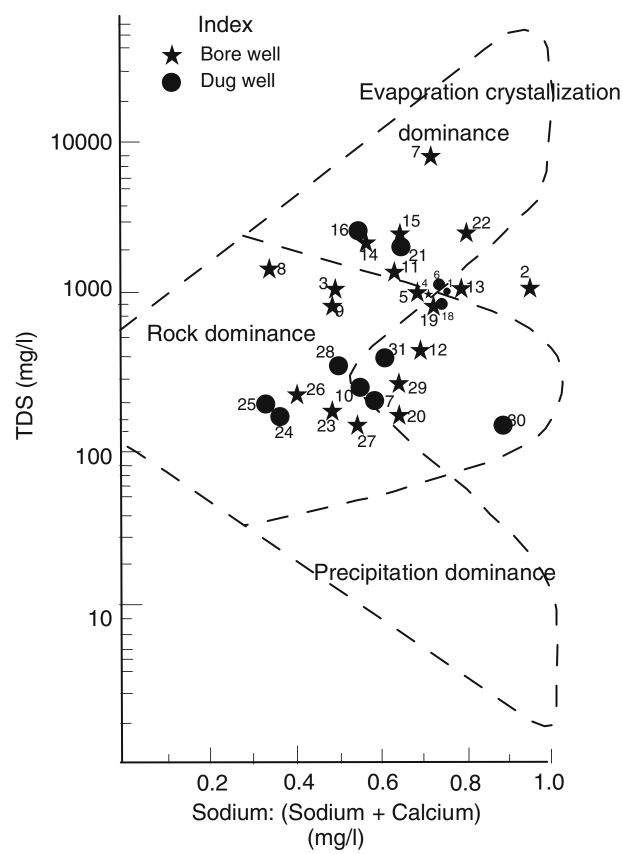

Fig. 3 Plot of Sodium: (Sodium + Calcium) versus TDS (after Gibbs 1970)

of the chemistry of groundwater toward the zone of evaporation and crystallization dominance. In the study area, releasing of improperly treated industrial effluents and municipal wastes into the nearby ponds and streams, the top soils of the ponds and streams are getting increased concentrated ions due to the evaporation dominant climatic of semi-arid/arid conditions. In addition to this, the usage already saline groundwater to the irrigation purpose also increases the concentration of ions in the topsoils of the study area. So in turn, while the rainfall occur, the dissolved ions with water percolates and reaching the groundwater that increases the ionic concentration of the groundwater in the study area.

The GIS is applied to study the spatial distribution of various ion concentration and for identification of suitable zones of groundwater quality for domestic and irrigation purpose as per the WHO and ISI standard methods.

Suitable zones of groundwater quality for domestic purpose

Magnesium ion concentration, incrustation problem, TH and TDS were considered as the criteria for classification of groundwater (Table 2) for domestic purpose.

According to WHO (1984) standards, magnesium ion should be below 30 mg L^{-1} when sulfate is more than 250 mg L^{-1}, and if magnesium is more than 150 mg L^{-1} then sulfate should be below 250 mg L^{-1}; otherwise, the water is not suitable for drinking purpose. The presence of higher magnesium concentration in drinking water would cause a laxative effect. Based on magnesium and sulfate concentration, groundwater is classified (Table 2) that 25.14% of the area is not suitable for drinking purpose.

According to Raghunath (1983), if the HCO_3^- is more than 400 mg L^{-1} then soft incrustation will form and, if SO_4 is more than 100 mg L^{-1} then hard incrustation will form. In some locations in the study area, borewell suction pipes and water-supplying lines are facing incrustation problems. Based on this criterion, the study area has been classified as soft incrustation, hard incrustation and no incrustation areas. 6.36% of the study area (Table 2) is with hard incrustation problem and 62.56% of the area with soft incrustation problem.

Hardness of water affects its reaction with soap and causes scale and incrustation accumulation in containers and conduits where the water is heated or transported. According to Sawyer and McCarty (1967), 84.67% of the study area has very hard water (>300 mg L^{-1} of TH). 15.31% of the area has (150–300 mg L^{-1} of TH) hard water. Only 0.02% of the area (Table 3) has moderately hard water (<150 mg L^{-1} of TH) (Table 2). 70.87 km^2 of the area is with very hard water except in boundaries of NW, SW and NE portions that are hard to moderately hard water.

In the study area, the TDS in groundwater ranges between 267 and 7,888 mg L^{-1} with a mean of 1,288 mg L^{-1}. The higher TDS in groundwater may be due to longer residence time of solution in the subsurface environment, leading to higher ionic concentration. While using for domestic purpose, the water should be soft with less dissolved solids. Based on total dissolved solids (Robinov et al.1958; Davis and Dewiest 1967), nearly 50.89% of the study area (Table 2) has very high concentration of total dissolved solids (i.e., 1,000 mg L^{-1} of TDS).

Each class in every thematic map was assigned a weight (Table 3). All the thematic maps of magnesium, incrustation problem, TH and TDS were overlaid and integrated by adding the weights. The map of groundwater quality suitable for domestic purpose was prepared and classified as suitable, moderately suitable and unsuitable (Table 4). Suitable quality of groundwater for domestic purpose is available in the SE, S, SW, NW and NE portions (i.e., 30.06%) of the study area (Fig. 4). In general, entire central portion (i.e., 67.45%) of the study area is moderately suitable, where Chittoor town is present. The unsuitable quality of groundwater (i.e., 2.49%) is at the northeastern portion as a (NW–SE) strip, spreading nearly 2.084 km^2 of the area, where the sugar factory effluents and industrial estate effluents are released into the streams through which consequently the groundwater system is getting polluted.

Suitable zones of groundwater quality for irrigation purpose

The mineral constituents in groundwater govern its suitability for the purpose of irrigation. In particular, salts can be highly deleterious because they can damage the growth of plants physically, by restricting the taking up of water by modification of osmotic processes, and chemically, by the effects of toxic substances upon metabolic processes. Features that generally need to be considered for evaluation of the suitable quality of groundwater for irrigation are the EC, percent sodium, RSC and SAR (Todd 1960; Richards 1954; Eaton 1950).

Electrical conductivity and sodium concentration are very important in classifying irrigation water. A high salt concentration in water leads to formation of saline soil and a high sodium concentration leads to development of alkaline soil. Electrical conductivity, which is a measurement of the ionic strength of solution, varies between 128 and 13,500 μS cm^{-1} at 25°C with a mean of 2,205 μS cm^{-1} at 25°C in the study area. Based on EC values, good quality of water is only available in 8.26% of the area (Table 5). Medium quality of groundwater is in 61.45% of the area, doubtful quality is in 23.34% of the area and unsuitable quality is in 6.95% of the area.

The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of SAR. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is adsorbed by the soils. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. The calculated value of SAR in the study area ranges from 1.05 to 18.05 in groundwater. Based on sodium adsorption ratio, the entire area (i.e., 99.22% of the area) is with excellent water and remaining (i.e., 0.78% of the area) is with good water (Table 5).

The percent sodium (%Na) in groundwater ranges from 24.43 to 90.85 meq L^{-1} in groundwater. As per the ISI (1983) standards, maximum %Na of 60% is recommended for irrigation water. In the study area, groundwater samples (sample nos. 1, 2, 3, 4, 5, 13, 22) show higher values of %Na than the prescribed for irrigation purpose. Based on percent sodium (Todd 1960), good quality of water is available in 35.19% of the area (Table 5); moderate quality of water is in 59.55% of the area and doubtful quality of water in 5.22% of the area.

A high value of RSC in water leads to an increase in the adsorption of sodium on soil (Eaton 1950). Groundwater (sample nos. 1, 2, 18) having RSC values greater than 5 meq L^{-1} have been considered harmful to the growth of plants, while waters (sample nos. 6, 12, 13, 22) with RSC values above 2.5 meq L^{-1} is not considered suitable for irrigation purpose. Based on RSC classification, nearly 59.07% of the study area (Table 5) is with excellent quality of water, 31.1% of the area is moderately suitable and, 9.83% of the area is with high RSC.

Each class in every thematic map of irrigation purpose was assigned a weight (Table 6). All the thematic maps of EC, SAR, percent sodium and RSC were overlaid and integrated by adding the weights. The map of groundwater quality suitable for irrigation purpose (Fig. 5) was prepared and classified as: suitable, moderately suitable and unsuitable. Suitable quality of groundwater for irrigation purpose is available in NE, NW, SE, S and SW portions (i.e., 46%) of the study area. Moderately suitable zones are in western, central and north portions (i.e., 53.36%) (Table 7) of the study area. Unsuitable zones are concentrated at some locations in western and central portions (i.e., 0.64% of the study area).

Suitable zones of groundwater quality for domestic and irrigation purpose

To find out the zones which are suitable for both domestic and irrigation purposes, the two maps of

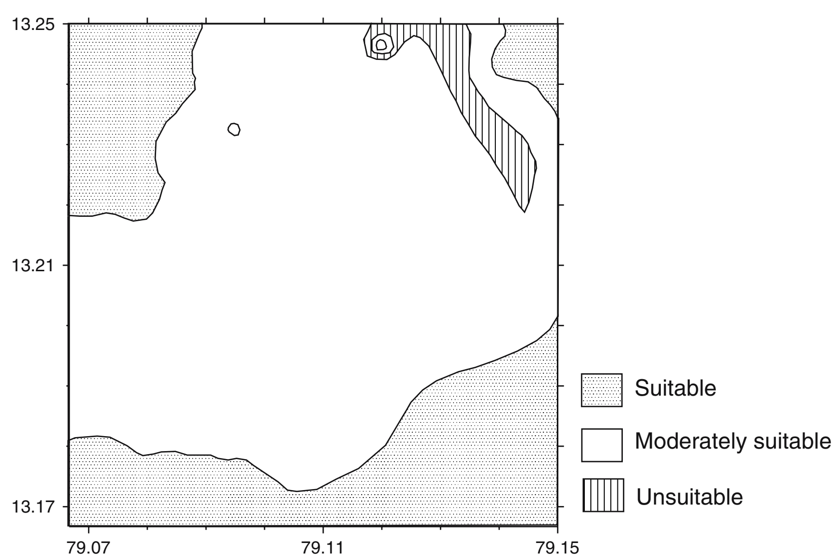

Fig. 4 Suitable zones for domestic purposes based on groundwater quality, Chittoor area, Chittoor district, Andhra pradesh, India

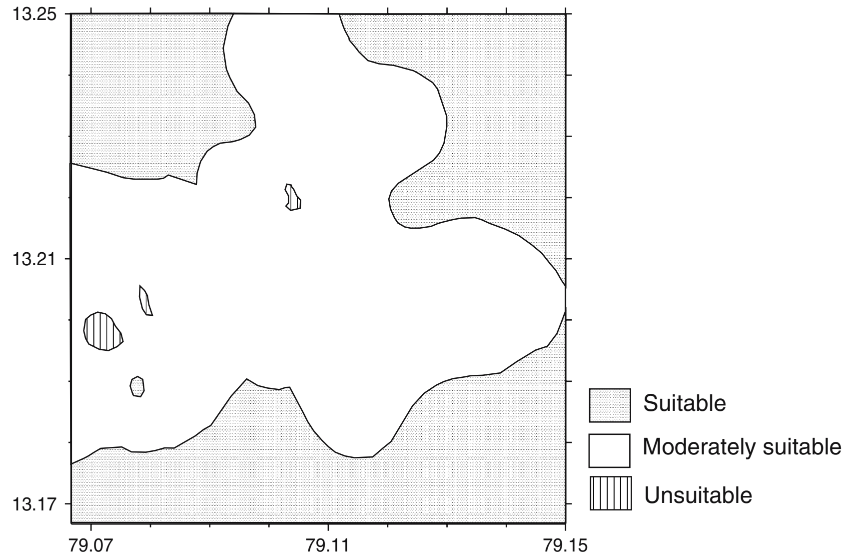

Fig. 5 Suitable zones for irrigation purposes based on groundwater quality, Chittoor Area, Chittoor district, Andhra pradesh, India

"suitable for domestic" and "suitable for irrigation" were overlaid and integrated for preparation of a common map for domestic and irrigation purposes and classified into different categories.

Suitable quality of groundwater for both purposes (Fig. 6) is available at the NE, SE, S, SW and NW portions (i.e., 27.14% of the area), which are not affected by pollution. Suitable for domestic and moderately suitable for irrigation is at NW, SW and SE portions as strips (2.92% of the area) (Table 8). Groundwater moderately suitable for domestic and suitable for irrigation purposes is available at NE, S and NW portions (i.e., 16.37 % of the area). Groundwater moderately suitable for both domestic and irrigation is available in the center of the study area (i.e., 50.44% of the area). Groundwater moderately suitable for domestic and unsuitable for irrigation is available only at some pointed locations (i.e., 0.64% of the area). Groundwater unsuitable for domestic and suitable for irrigation is present in NE portion of the study area as a band (i.e., 2.49% of the area). This is a polluted zone due to the impact of industrial and municipal sewage effluents.

Conclusions

The groundwater quality studies indicate that the groundwater is alkaline and sodium and bicarbonate are the dominant cation and anions. Gibbs variation diagram shows that the control of the chemistry of groundwater in the study area is the weathering of rocks of granitic gneisses and also the leaching of evaporated and crystallized ions from the topsoils of the irrigated areas and improperly treated industrial effluent ponds. Application of GIS has been applied

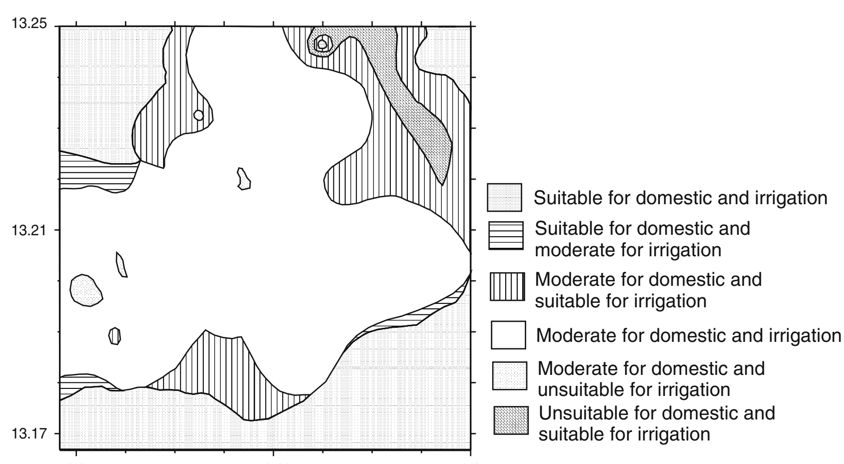

Fig. 6 Suitable zones for domestic and irrigation purposes, Chittoor area, Chittoor district, Andhra pradesh

and identified the suitable zones of groundwater quality for domestic and irrigation purpose. Suitable quality of groundwater for domestic and irrigation purpose is available in 22.716 km^2 of the area at the NE, SE, S, SW and NW portions (i.e., 27.14% of the area). Groundwater suitable for domestic and moderately suitable for irrigation is at NW, SW and SE portions as pockets in 2.444 km^2 of the area (2.92% of the area). Groundwater moderately suitable for domestic and suitable for irrigation is available at NE, S and NW portions in 13.702 km^2 of the area (i.e., 16.37% of the area). Groundwater moderately suitable for domestic and irrigation is available in the center of the study area in 42.218 km^2 (i.e., 50.44%) of the area. Groundwater moderately suitable for domestic and unsuitable for irrigation is available only at some pointed locations in 0.536 km^2 (i.e., 0.64%) of the area. Groundwater unsuitable for domestic and suitable for irrigation is present in NE portion of the study area as a band in 2.084 km^2 (i.e., 2.49% of the area). So, it is suggested that the groundwater in the study area has to be utilized and managed in a scientific manner and immediate precaution has to be taken to control the improperly treated effluents release in the study area.

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