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RESEARCH ARTICLE

GROUNDWATER QUALITY ASSESSMENT FOR AGRICULTURAL PURPOSES USING GIS IN UPPER THIRUMANIMUTHAR SUB-BASIN CAUVERY RIVER, SOUTHINDIA

A. Thirunavukkarasu[1], R. Suresh[1] and M.Suresh[2]

[1]Department of Geology, Periyar University, Salem-636 011
[2]Department of Civil Engineering, Jayalakshmi Institute of Technology, Thoppur – 636 352,

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Irrigation, salinity, Wilcox, USSL (U.S. Salinity Laboratory diagram), SAR (Sodium Adsorption Ratio), Spatial distribution map.

A B S T R A C T

An attempt has been made to work out the groundwater quality assessment for agriculture representing from a total area of about 340.46 km^2 in upper Thirumanimuthar sub-basin, Cauvery River. The 51 groundwater samples were collected from variation location of the study area during pre-monsoon (May) 2014 and were analysed for major cations and anions, EC, Kelley’s ratio, SAR values, Mg-Hazards, HCO_3 and RSC calculated. The study has shown that salinity of groundwater under “increasing problem” zone at majority of sites. The data were interpreted using Wilcox and USSL Classifications. The groundwater samples fall under good to permissible (Wilcox Diagram) zone. The SAR values were plotted in the USSL staff diagram and found most of the groundwater samples belongs to C_3-S_1 (58.82%). These results were taken into GIS platform, to prepare the spatial distribution maps. Finally GIS output maps result reveals that 181.5 Km^2 areas fall in (Wilcox) Good to Permissible category and 213.68 Km^2 area falls in (USSL) C_3-S_1 category. Above said areas indicate that the groundwater could be used for all types of crops.

INTRODUCTION

Groundwater is a key resource in much uses of the world. Irrigation provides the foundation for reliable agricultural production and regional economic security (Hillel, 2000; Tanji, 1990). It is well documented that environmental pollution depends mainly on human activities (industry, agricultural cultivations, and domestic use) and to a lesser extent, to other natural phenomena, which contribute to this, like volcanoes, earthquakes (Drever, 1997). The suitability of irrigation water depends upon many factors including the quality of water, soil type, salt tolerance characteristics of the plants, climate and drainage characteristics of the soil (Michael, 1990). Groundwater always contains small amount of soluble salts dissolved in it. The kind and quality of these salts depend upon the sources for recharge of the groundwater and the strata through which it flows. The excess quantity of soluble salts may be harmful for many crops. Hence, a better understanding of the chemistry of groundwater is very essential to properly evaluate groundwater quality for irrigation purpose. In the present study, Groundwater quality for irrigation was investigated in the upper Thirumanimuthar Sub-Basin, Cauvery River basin in pre monsoon season (May) 2014, to identify the suitable and unsuitable zone for irrigation uses of groundwater quality using GIS technology.

Study Area

The part of upper Thirumanimuthar sub-basin, central Tamilnadu, India has been selected for the present investigation. It lies between 11°31’57” and 11°48’05” N latitudes and 78°02’33” and 78°21’13” E longitudes, covering an area of 346.40 Km^2 (Fig.1). The study area falls in Salem district of central Tamil Nadu. The major source for groundwater in the area is rainfall during monsoon. The average annual rainfall is about 852 mm. The study area is underlaid by the Archaean crystalline rocks surrounded by hills such as Shevaroys (1033 m) and Nagaramalai (619 m) on north, Jarugumalai (583 m) on the south, Kanjamalai (883 m) on the west, and Goudamalai (568 m) on the east.

METHODOLOGY

The study area base map was prepared from Survey of India toposheets 58 I/1, 2, 5 and 6 of 1:50,000 scale. Using drainages the boundary was demarcated (Upper Thirumanimuthar) and sample locations in GIS environment. The 51 groundwater samples from various locations also were located in the upper Thirumanimuthar Sub-basin area were collected from open wells (Shallow depth) during pre-monsoon season (May 2014). The locations of groundwater sampling stations are shown in Fig. 1. The groundwater samples were collected from open wells, which are being extensively utilized for drinking and irrigation purposes. pH and Electrical Conductance were measured within a few hours by using Elico pH meter and conductivity meter. Ca and Mg were determined titrimetrically using standard EDTA method and chloride was determined by silver nitrate titration (Vogel,

Table 1 Anions & Cations Concentration in Groundwater Samples (All values in the table are expressed in epm except EC in μScm^{-1} and pH)

Sample No	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	pH	EC*	TDS	K. Ratio	RSC*	SAR*	Na%	Mg - Hazards
1	4.4	2.1	4.35	0.05	4.9	00	1	5	7.5	1100	588	0.67	-1.6	2.41	47.29	32.31
2	5	7.9	5.65	0.23	9	00	2.69	8.25	7.4	1900	1026	0.44	-3.9	2.22	41.45	61.24
3	5	9.2	9.5	0.18	7.4	00	4.13	12.5	7.6	2400	1300	0.67	-6.8	3.57	51.54	64.79
4	2	9.5	4.35	0.08	4.5	00	3.94	7.5	7.7	1600	849	0.38	-7.0	1.81	39.87	82.61
5	8	11	9.75	0.56	9.4	00	7.06	12.5	7.9	2900	1599	0.52	-9.2	3.20	45.98	56.99
6	3	5.9	0.43	0.31	3	0.7	2.5	3.75	8.5	1000	518	0.05	-5.2	0.20	14.30	66.29
7	9.2	1.3	3.25	0.08	8.3	00	1.63	4	7.6	1400	746	0.31	-2.2	1.42	28.01	12.38
8	6.4	11	1.78	0.23	10	00	2.69	6.25	7.2	1900	956	0.11	-6.9	0.61	16.32	62.13
9	4.5	10	8.17	0.23	9	00	3.94	10	7.2	2300	1222	0.56	-5.5	3.03	48.18	68.97
10	5.1	4.3	0.48	0.05	5.6	00	1.63	2.75	7.7	1000	511	0.05	-3.8	0.22	7.76	45.74
11	6.2	4.3	15.3	0.08	9.4	00	4.56	12	7.3	2600	1456	1.45	-1.1	6.66	66.72	40.95
12	6.4	5.3	5.17	0.1	4.4	0.7	1.63	10.3	8.3	1700	910	0.44	-6.6	2.14	38.93	45.30
13	3	6.4	7.4	0.13	4.9	00	3.31	8.75	7.5	1700	929	0.79	-4.5	3.41	55.96	68.09
14	8.1	2.1	2.5	0.13	5.8	00	1.84	5.2	7.4	1300	697	0.25	-4.4	1.11	24.99	20.59
15	4.5	3.8	5.45	0.13	5.6	00	3.13	5.25	7.7	1400	771	0.66	-2.7	2.68	48.88	45.78
16	2	6.6	0.96	0.26	5.8	0.4	1.25	2.5	8.0	1000	487	0.11	-2.4	0.46	21.13	76.74
17	6.5	6.7	1.57	0.13	5.8	00	2.88	6.25	7.3	1500	786	0.12	-7.4	0.61	16.29	50.76
18	4	3.2	3.7	0.05	3.5	00	2.5	5	7.7	1100	608	0.51	-3.7	1.95	42.23	44.44
19	5.6	4	14.3	0.15	6.1	00	4.56	13.3	7.1	2400	1366	1.48	-3.5	6.50	67.47	41.67
20	5.3	3.8	5	0.82	7.8	00	2.25	5	7.9	1500	818	0.55	-1.3	2.34	49.11	41.76
21	6.4	3	7.4	0.08	5.6	00	2.88	8.5	7.6	1700	945	0.79	-3.8	3.41	51.27	31.91
22	9.5	6.5	3.7	0.08	7.3	00	4.13	8.5	7.2	2000	1076	0.23	-8.7	1.31	24.67	40.63
23	8	1.6	3.25	0.08	6.8	00	1.25	5	7.3	1300	698	0.34	-2.8	1.48	30.23	16.67
24	4.5	5.2	0.83	0.08	5.2	00	2.06	3.75	7.8	1100	563	0.09	-4.5	0.38	12.65	53.61
25	7.4	9.9	4.35	0.31	8.9	00	3.13	10	7.5	2200	1152	0.25	-8.4	1.48	29.45	57.23
26	5.2	2	0.35	0.03	2.9	00	1.25	3.75	7.6	800	417	0.05	-4.3	0.18	6.70	27.78
27	8	2.4	2.4	0.08	7.5	00	2.25	3.2	7.1	1300	694	0.23	-2.9	1.05	23.54	23.08
28	9.6	5.9	4.39	0.08	6.7	00	3.31	10	7.2	2000	1082	0.28	-8.8	1.58	28.27	38.06
29	5.5	12	14.3	0.26	7.6	00	4.38	20	7.6	3200	1738	0.82	-9.7	4.85	57.12	68.21
30	6.7	18	28.3	0.33	12.5	00	2.88	37.5	7.5	5300	2854	1.16	-11.9	8.09	65.47	72.54
31	15	2	13.7	0.41	9.5	00	3.94	17.5	7.2	3100	1746	0.82	-7.3	4.73	50.78	11.90
32	31	34	7.4	0.64	9.2	00	6.25	57.7	7.1	7300	3844	0.11	-55.4	1.30	15.97	52.48
33	9	11	18.5	0.62	9.4	00	4.56	25	7.4	3900	2148	0.93	-10.4	5.88	59.07	54.55
34	2.2	4.1	16.3	0.44	15	00	2.25	5.71	7.4	2300	1244	2.58	8.7	9.16	80.63	65.08
35	4.7	8	6.8	0.5	12.8	00	2.25	5	7.7	2000	1036	0.54	0.1	2.70	47.89	62.99
36	5.1	5.4	25	0.41	11.6	00	3.13	21.3	7.7	3600	2010	2.38	1.1	10.91	77.88	51.43
37	8.9	3.8	18.5	0.46	12.2	00	3.5	16.3	7.4	3200	1777	1.46	-0.5	7.34	66.39	29.92
38	26	22	22.6	0.67	13.3	00	2.69	55	7.3	7100	3805	0.47	-34.4	4.63	41.12	46.33
39	2.2	7.2	18.5	0.08	9.5	1.2	4.75	12.5	8.2	2800	1552	1.97	1.3	8.53	76.50	76.60
40	2.2	11	0.61	0.54	7.1	00	1.88	5	8.0	1400	688	0.05	-5.7	0.24	16.89	82.81
41	7.2	19	3.5	0.33	10	00	3.31	16.8	7.6	3000	1521	0.13	-16.2	0.97	19.93	72.52
42	6	21	8.75	0.21	10.4	00	4.56	21	7.3	3600	1860	0.32	-16.6	2.38	35.80	77.78
43	5.5	6	3.37	0.08	6	00	2.25	6.75	7.6	1500	791	0.29	-5.5	1.41	30.57	52.17
44	3.5	5.4	1.95	0.08	4.4	00	1.63	5	7.7	1100	571	0.22	-4.5	0.92	26.11	60.67
45	4.2	15	7.04	0.18	9	00	4.38	12.5	7.7	2600	1353	0.37	-9.8	2.30	39.23	77.66
46	5.4	5	3.25	0.31	7	0.4	1.63	5	8.1	1400	733	0.31	-3.0	1.43	33.95	48.08
47	2.8	3.2	0.78	0.13	4.5	00	0.79	1.75	7.2	700	353	0.13	-1.5	0.45	19.50	53.33
48	6.7	7.3	16.3	0.67	10.6	00	2.88	17.5	7.9	3100	1699	1.16	-3.4	6.14	64.20	52.14
49	10	13	5.26	0.59	9	00	5	15	7.8	2900	1546	0.23	-14.0	1.55	28.53	55.22
50	10	4.7	3.9	0.13	8.5	00	3.63	6.8	7.3	1900	1026	0.26	-6.4	1.43	26.60	31.54
51	3	8	2.6	0.28	6.8	00	1.88	5.25	7.6	1400	708	0.24	-4.2	1.11	31.01	72.73

EC* – Electrical conductivity, RSC* – Residual Sodium Carbonate, SAR* – Sodium Adsorption Ratio.

Table 2 Salinity Levels of Groundwater Samples of Upper Thirumanimuthar (Ayers 1977)

Salinity Zone (EC, μScm^{-1})	Effects	Sample Numbers (Locations samples)	Percentage (%)
0-750	No Problem	47	2
750-2750	Increasing Problem	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17,18,19,20,21,22,23,24,25,26,27,28,34, 35,40,43,44,45,46,50,51.	72.5
Above 2750	Severe Problem	29,30,31,32,33,36,37,38,39,41,42,48,49.	25.5

Table 3 Classification of Irrigation Groundwater Based on Wilcox Diagram Interpretation (1955)

S. No.	Category of Irrigation Water	Pre Monsoon (Locations samples)	Percentage (%)
1	Excellent to Good	-	-
2	Good to Permissible	1,2,4,6,7,8,10,12,14,15,16,17,18,20,21,22,23,24,26, 27,28,35,40,43,44,46,47,50,51.	56.86
3	Permissible to Doubtful	13.	1.96
4	Doubtful to Unsuitable	3,5,9,11,19,25,34,39,41,45,49.	21.57
5	Unsuitable	29,30,31,32,33,36,37,38,42,48.	19.61

Table 4 Spatial Distribution Results Based on Wilcox Diagram

S.No.	Category of Irrigation Water	Area in Km^2
1	Excellent to Good	-
2	Good to Permissible	181.51
3	Permissible to Doubtful	12.41
4	Doubtful to Unsuitable	105.84
5	Unsuitable	46.64

Table 5 Groundwater Classification Based on USSL Diagram Interpretation (1954)

S. No.	Category	Pre Monsoon (Locations samples)	Percentage (%)
1	C2-S1	47.	1.96
2	C3-S1	1,4,6,7,8,10,12,13,14,15,16,17,18 ,20,21,22,23,24,25,26,27,28,35,40, 42,43,44,45,50,51.	58.82
3	C4-S1	2,3,5,9,32,41,46,49.	15.69
4	C4-S2	11,19,29,31,33,37,38,48.	15.69
5	C4-S3	30,34,36,39.	7.84

Table 6 Spatial Distribution Results Based on USSL Diagram

S.No.	Category	Area in Km^2
1	C3-S1	213.68
2	C2-S1	16.80
3	C4-S1	56.05
4	C4-S2	56.82
5	C4-S3	3.06

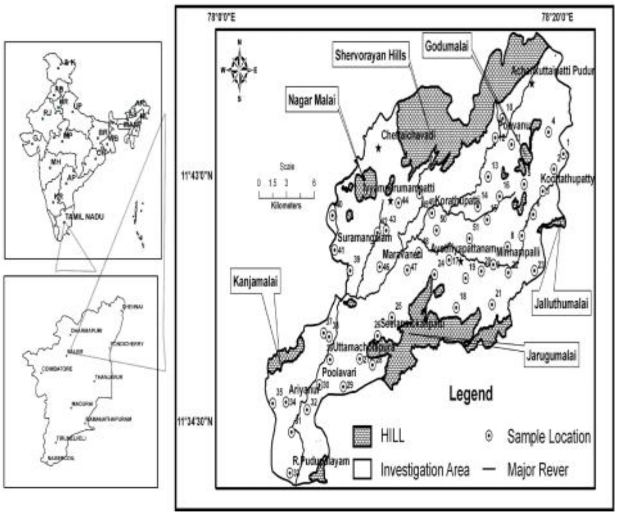

Figure1 Study Area Upper Thirumanimuthar Sub-basin and Groundwater Sample Locations

1968) method. Carbonate and bicarbonate were estimated with standard sulphuric acid. Sulphate was determined a gravimetrically by precipitating $BaSO_4$ from $BaCl_2$. Na and K were determined by Elico flame photometer using APHA, 1996 procedure. Analyzed groundwater chemistry results are given in Table 1.

RESULTS AND DISCUSSION

Salinity

This analysis has shown that thirteen samples fall under "severe problem" category (Table 2). The high salinity at these few sites may be due to domestic pollution caused in the rural

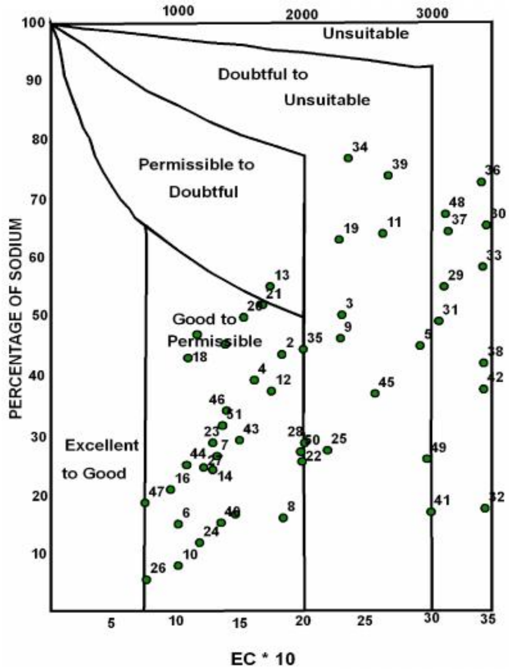

Figure 2 Wilcox diagram

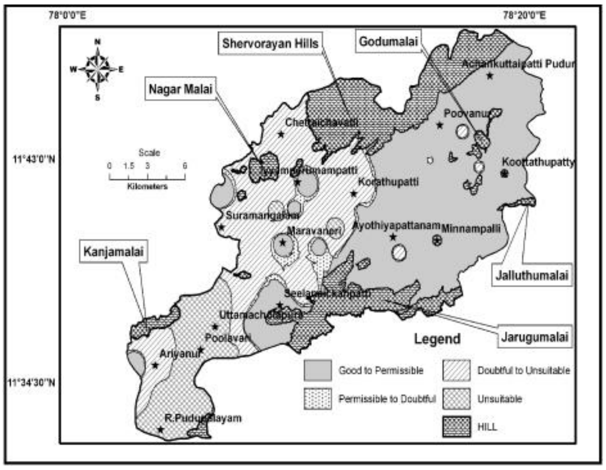

Figure 3 Spatial Distribution map based on Wilcox diagram Result

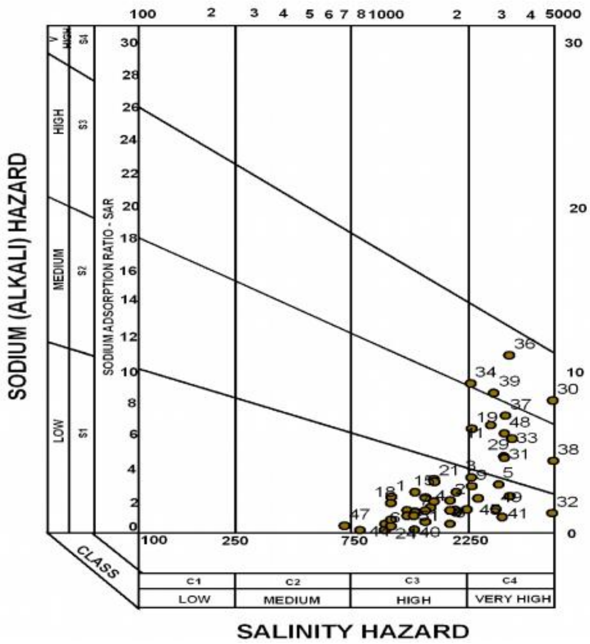

Figure 4 USSL Diagram

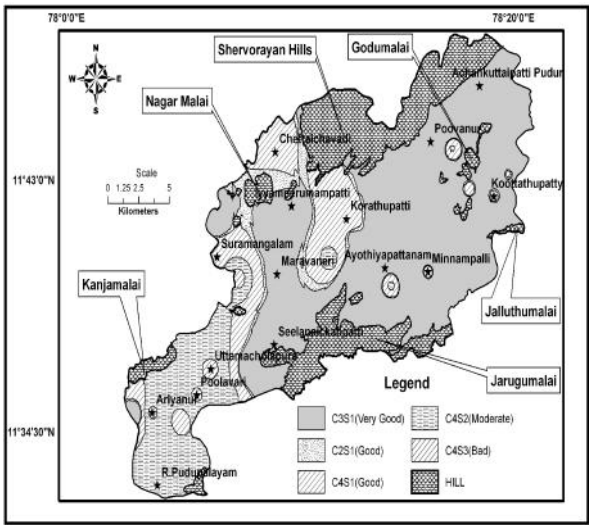

Figure 5 Spatial Distribution map based on USSL diagram Result

areas associated with limited use/abandoned nature of wells. 72.5% of the samples fall under "increasing problem" category respectively.

Sodium Adsorption Ratio

The sodium or alkali hazard in groundwater for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If groundwater used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium.

$$SAR= \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

(All ions in epm)

A simple method of evaluating the high sodium in water is the Sodium Adsorption Ratio. (SAR). Calculation of SAR value for a given groundwater provides a useful index of the sodium hazard of that water for soils and crops. A low SAR value of 2 to 10 indicates little danger from sodium; medium hazards are between 10 to 18, high hazards are between 18 to 26 and very high hazards are above 26. The lower the ionic strength of solution, the greater sodium hazards for a given SAR. The value of SAR in the groundwater samples of the study area ranges from 0.18 to 10.91 during pre-monsoon season (Table 1). Majority of the samples in the study area falls under the category of low sodium hazards except is one sample. The high sodium water may produce harmful levels of exchangeable sodium in most soils and requires special soil management, like good drainage, high leaching and organic matter addition.

Wilcox Diagram

Wilcox (1955) used sodium % and specific conductance in evaluating the suitability of groundwater to irrigation. Sodium-percentage determines the ratio of sodium to total cations viz., sodium, potassium, calcium and magnesium. All concentration values are expressed in equivalents per million.

$$Na\% \quad = \frac{Na+K}{Ca+Mg+Na+K} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The results (Table 3) show that the groundwater near the upstream is good for irrigation and the contamination are found to be high near the downstream (Fig.2). This may be due to the effluents from the industries as well as the domestic sewages directed into the river.

Above said results were taken in to GIS environment for spatial distribution map preparation. The spatial distribution map results are given in the Table 4. In the present investigation, the spatial distribution map (Fig.3) indicates that the "Good to permissible" covers 181.51 Km^2.

USSL DIAGRAM

U.S. Salinity Laboratory diagram (1954) interpretation is given in the Fig.4. The two most significant parameters of sodium and salinity hazards indicate us ability for agricultural purposes. USSL classification of groundwater in the study area is given in Table 5. Thirty sites (58.82 percent) samples occur within C_3–S_1 category. This category is predominant in the study area and accordingly it is suitable for irrigations purposes.

In the USSL diagram results 16 fields based on USSL classification suitable weightages are given as C_1S_1, C_1S_2, C_1S_3, and C1S4 ….etc. These suitability results were taken in to GIS environment for spatial distribution map preparation. The spatial distribution results are given in Table 6. This spatial distribution map (Fig.5) results of C_3-S_1 (213.68 Km^2) class is good and could be used for all types of crops.

CONCLUSION

In this study, the assessment of groundwater for irrigation has been performed on the basis of various guidelines. The Wilcox classification has shown 56.86% of groundwater samples and spatially an area 181.51 Km^2 under "Good to Permissible" category. However, another classification has shown salinity of groundwater under "Increasing Problem" zone at 72.5% sites during the study period respectively. According to U.S. Salinity Laboratory diagram, the majority of groundwater samples belongs to C_3–S_1 (High Salinity – Low SAR) category and spatially covers an area 213.68 Km^2 under "Suitable" zone. In the present study, it is evident that high salinity of groundwater persists at majority of sites. Hence, for high to very high salinity of waters, soil must be permeable with adequate drainage facilities for satisfactory crop growth.

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