HYDROGEOCHEMICAL ZONAL DEMARCATION OF GROUNDWATER IN THE GNEISS AQUIFER, TIRUCHENGODE TALUK, NAMAKKAL DISTRICT, TAMILNADU, INDIA

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Abstract: *In India Fluoride occurrence in aquifer systems is endemic in many areas of Andhra Pradesh, Tamilnadu, Karnataka, Gujarat, Rajasthan, Punjab, Haryana, Bihar and Kerala. Fluoride in groundwater evokes considerable interest due to its unique character as regards to its impact on the physiological system of living beings. Rock minerals weather and form calcium and magnesium carbonates, which serve as good sinks for fluoride ions. Fluoride ions from these minerals leach into the groundwater contributing to high fluoride concentrations. The water samples from the Gneiss aquifer system of Tiruchengode Taluk of Namakkal district, was analyzed for fluoride content (F^-)and other water quality parameters such as pH, EC, HCO_3^-, Cl^-, Na^+, Ca^{2+}, Mg^{2+}, $SO_4^{2-}$and RSC. It was found that the F^-concentration of ground water varied between 0.2 and 2.2 mgl^{-1} which exceeded the maximum desirable limits of 1.0 mgl^{-1} of F^-as laid down by BIS and about 8.6% of ground water exceeded maximum permissible limits of 1.5 mgl^{-1} as prescribed by WHO. High fluoride (F) concentrations of natural origin (up to 3.1 mg/L) are common in ground water of the study area. The major exposures in the study area are Peninsular gneiss which have fluoride bearing minerals that are very susceptible to weathering and leaching processes. Mica content is significant in the peninsular gneiss. This study focuses on an area in Tamilnadu, which has been demarcated as an endemic fluorosis zone, to evaluate the fluoride concentrations, its relation to other ions, and its spatial distribution. Comparison of geochemical data shows that majority of the groundwater samples are unsuitable for drinking, but it is recommended for irrigation purposes.*

Keywords: Fluoride, Groundwater, Tiruchengode, Gneiss Aquifer, Chemical weathering

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Introduction

Water is a prime natural resource and essential for life on earth. About 80% of the diseases in the world are due to poor quality of drinking water [1]. Recently there has been overall development in various fields such as agriculture, industry and urbanization in India. This has lead to increase in the demand of water supply which is met mostly from exploitation of groundwater resources. Hydrochemical study is a useful tool to identify the suitability of the groundwater [2]. The physical parameters taken into consideration in the present study are colour, odour, turbidity and temperature. The chemical parameters taken into consideration are hydrogen ion concentration (pH), Electrical Conductance (EC), Total dissolved solids (TDS), Total Hardness (TH) and all major cations and anions.

Fluoride ion occurs in natural waters commonly in concentration less than 1.0 mg/l and seldom outside the range from 0.01 to 10.0 mg/l [3]. The amount of fluoride occurring naturally in groundwater is governed principally by climate, composition of the host rock, hydrogeology. Fluoride in groundwater evokes considerable interest due to its unique character as regards to its impact on physiological system of living beings. Due to excessive fluoride intake, enamel loses its luster. Dental and Skeletal fluorosis are common when the fluoride level is more than the permissible limit. Besides skeletal and dental fluorosis, excessive consumption of fluoride may lead to muscle fiber degeneration, low hemoglobin levels, excessive thirst, headache, skin rashes, nervousness, depression etc [4].

Many investigations have been made related to origin and hydrogeochemistry of high fluoride in groundwater from different parts of the world [5-15]. In these researches groundwater samples were obtained from dug/bore wells and examined for fluoride ions and high fluoride have been identified to be originated from water-rock interaction and anthropogenic sources like application of fertilizers, industrial effluents, and household domestic effluents. The study area Tiruchengode taluk in Namakkal district is not well known for prevalent fluoride zones in Tamilnadu, India even though next to Dharmapuri and Salem, Namakkal is one of the high fluoride zones in Tamilnadu due to occurrence of diverse rock types and also it is very closer to these districts. The major exposure of the study area are peninsular gneiss, which have been marked for widespread fluoride bearing minerals indicating their accessibility to water by weathering along with leaching process. Hence it is essential to discriminate fluoride-vulnerable zones and to identify major geochemical process controlling the incidence of fluoride in the groundwater of the study area. Hence, in the present study, an attempt has been made to discuss about the fluoride concentration with respect to major lithology, relation of fluoride with other ions, and spatial distribution of fluoride ions.

Spatial location and salient features of the investigation area

The investigated area is spatially located in Namakkal district of Tamilnadu state (Fig 1), covering an aerial extent of 844.16 sq km and geographically extending between 11° 22'49.8" North latitude and 77° 53' 42.45" East longitudes. The study area falls under subtropical climatic condition with mean annual rainfall of 742.3 mm and mean annual temperature is 27.88°C.The altitude is about 150–200 meters msl. The overall groundwater potential of the area is generally poor.

Geology and hydrology

The area covered by hard rock formation and faces acute water scarcity problem both for irrigation as well as for drinking purposes. Irrigation in this area is principally dependent on groundwater. More than fifty bore wells exist within the study area. The bore well waters are primarily utilized for agriculture and drinking purpose. Cauvery river water is the another important source available for drinking purpose. The average depth of the bore wells is about 40 to 950 feet. The density of the bore wells is increasing day by day. Maximum exploitation of groundwater has resulted in sharp decline in the water table, dropping down to more than 900 feet at some places. Due to this reason, the percentage of groundwater-dependent agricultural activities is declining and quality of the groundwater varies considerably.

Materials and methods

A total of 69 groundwater samples were collected periodically during the premonsoon season, following the standard water sampling procedures. Water samples have been collected in 2L, Polythene bottles by considering lithological formation from sites spread all over the study area. These samples were analysed to determine the diverse range of Physico-chemical parameters (Table 1), by employing Standard procedures as per APHA (1995) and Trivedi and Goel [16]. pH was measured using the ELICO make pH meter and EC was measured using ELICO make Conductivity meter, while the quantity of TDS was computed by multiplying the EC values by a factor of 0.64. Chloride was determined by volumetric method by titration of 0.02 N, $AgNO_3$ solution in the presence of Potassium chromate. Sulphate was determined volumetrically using Vogel's method. Calcium was determined volumetrically by EDTA titration using muroxide indicator. Total hardness (TH) was volumetrically determined by titrating against 0.01 M EDTA solution with EBT indicator. Magnesium was calculated by considering the volume of EDTA solution used in the determination of Ca and Hardness. Nitrate was determined by colorimetric method using phenol disulphonic acid. The fluoride content was measured by Ion Selective Electrode method using a dual channel (Ion/ pH) ion meter (ORION make, model 720 pH/ ISE meter) and ORION make 9409 electrode.

Geological Setup

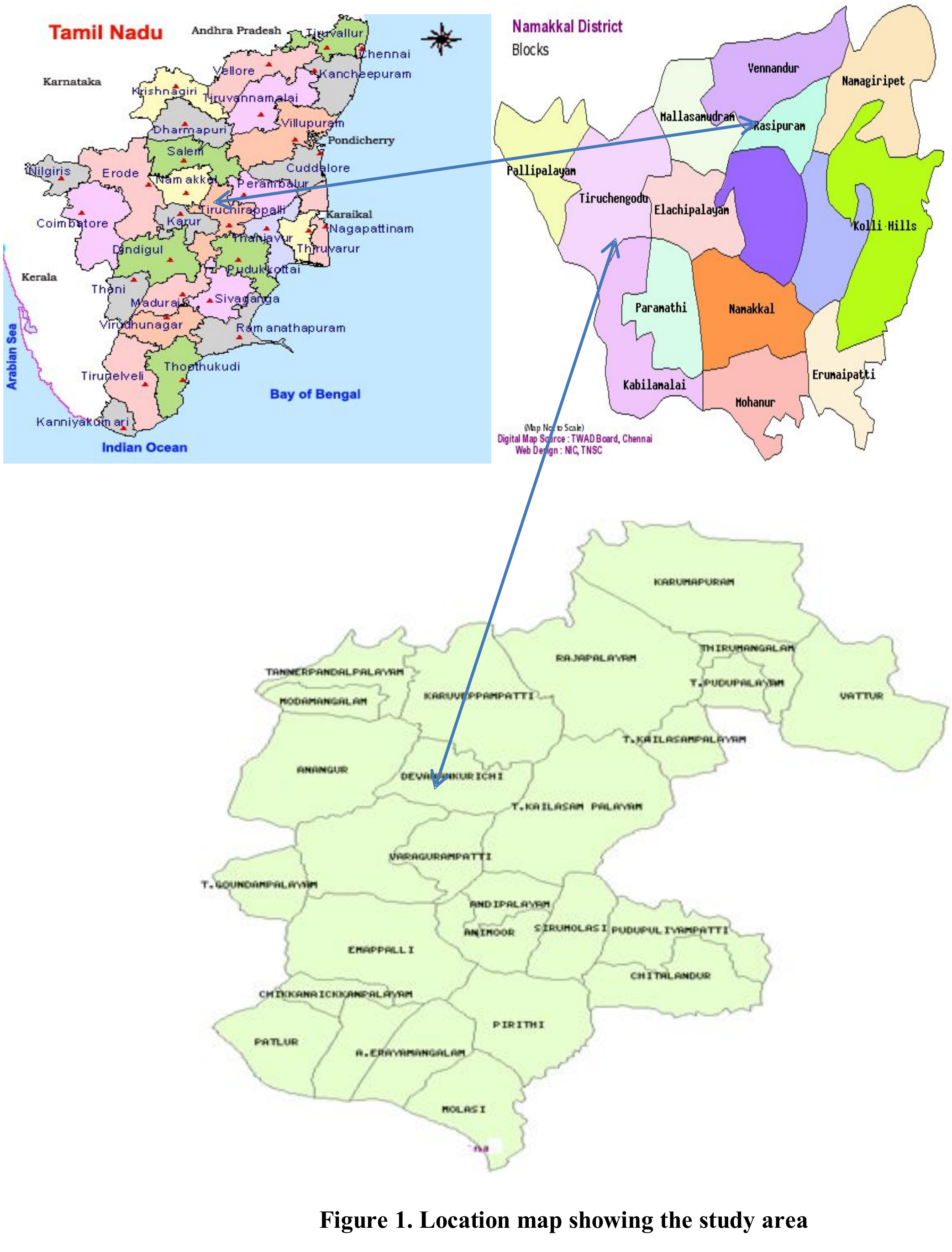

Figure 1. Location map showing the study area

Results and Discussion

The statistical parameter of various physico-chemical parameters that were analyzed with are given in Table 1. The fluoride concentration in water samples varied between 0.2 to 2.2 mg/l with mean value of 0.92 mg/l. It was observed that 8.69 % of the samples exceeded the maximum desirable limit of WHO and nearly 11.59 % of the samples exceeded the minimum desirable limit of WHO standards. Fluorine is the most electronegative element and thus it reacts immediately to form fluoride compounds and therefore making presence of free fluorine an obsolete possibility but under favourable physico-chemical conditions with long residence time it may occur as dissolved form in groundwater [17]. In case of natural waters, the variation in the fluoride content from region to region is dependent upon factors such as the source of water, type of geological formation and the amount of rainfall. The average geochemical behaviour of groundwater in the study area (Figure 4) shows that Cl^{-}> HCO_3^{-}>SO_4^{2-} trend of anions and that of cations is Mg^{2+}>Ca^{2+}>Na^{+}.

Table 1: Physico-chemical characteristics of the groundwater samples during Pre- Monsoon (March-May 2013)

Sample	pH	EC	TDS	Na	K	Ca	Mg	HCO3	Cl	SO4	NO3	F	TH	TEMP
C-1	7.1	2560	1780	116	19	50.1	71.95	180	653.2	39.95	0.25	0.67	420	34.2
C-2	6.8	2360	1630	83	18	112.22	76.07	120	646.1	26.47	0.38	1.2	592	34.1
C-3	7.0	551	397	76	15	38.07	27.55	120	106.5	33.21	0.37	1.8	208	34.3
D-1	7.0	1569	1110	68	33	84.16	36.56	180	319.5	33.69	4.6	1.2	360	33.9
D-2	7.0	566	403	42	2	42.08	27.06	100	99.4	28.4	1.42	1.3	216	34.1
D-3	6.7	1683	1200	32	34	84.16	72.67	140	461.5	30.8	1.8	0.9	508	34.2
E-1	6.6	2110	1510	81	21	112.22	68.26	140	589.3	29.36	3.1	1.1	560	34.1
E-2	6.5	2050	1460	79	13	108.21	74.61	120	560.9	37.54	2.1	1.1	576	34.0
E-3	7.1	2290	1580	76	17	132.26	93.14	100	688.7	28.4	3	0.7	712	33.1
F-1	7.0	2650	1870	94	42	62.12	97.81	100	596.4	40.91	4.5	0.8	556	33.4
F-2	7.7	3020	2140	128	51	26.05	28.05	60	511.2	50.54	1.81	0.6	180	33.3
F-3	7.1	2060	1450	40	12	64.12	70.24	120	418.9	38.5	4.5	1.7	448	33.6
G-1	6.9	944	672	42	3	36.07	55.12	120	134.9	38.02	4.5	1.6	316	33.4
G-2	6.8	895	632	39	3	24.04	69.29	120	99.4	36.1	3.9	0.8	344	33.3
G-3	6.8	1176	833	36	6	48.09	56.58	140	177.5	39.95	4.7	1.4	352	33.6
H-1	7.2	957	676	31	32	62.12	41.2	140	149.1	41.39	4.5	1.3	324	33.2
H-2	7.1	930	648	29	27	74.14	33.88	160	163.3	34.65	1.8	1.6	324	33.7
H-3	7.2	1166	814	36	3	38.07	46.1	120	184.6	28.88	2.1	1.4	284	33.3
I-1	7.1	760	534	31	6	44.08	46.34	100	142	37.06	1.6	0.9	300	33.5
I-2	7.3	894	625	43	38	24.04	38.05	160	149.1	31.28	1	0.5	216	33.1
I-3	7.1	924	650	68	32	82.16	34.85	120	163.3	40.91	2.1	0.3	348	33.4
J-1	6.6	1806	1280	64	26	128.25	82.9	100	397.6	42.35	5	0.7	660	33.4
J-2	6.9	1561	1130	56	19	104.2	50.7	120	326.6	38.98	5	1.2	468	33.3
J-3	6.8	1390	985	29	26	78.15	64.62	100	326.6	33.21	4.8	1.9	460	33.6
K-1	8.6	1480	1050	79	10	48.09	29.26	120	340.8	37.06	0.25	2.2	240	32.4
K-2	7.5	1575	1140	83	7	80.16	34.12	80	390.5	30.8	0.25	0.8	340	32.1
K-3	7.5	1210	875	78	13	64.12	63.41	120	276.9	35.62	3	1.1	420	32.4

L-1	7.1	1590	1140	56	19	64.12	63.41	180	369.2	33.21	1.1	0.6	530	32.2
L-2	7.8	1492	1060	78	13	44.08	46.34	160	298.2	46.21	0.22	0.5	380	32.2
L-3	7.3	2540	1800	64	26	76.15	104.88	180	653.2	57.76	0.25	0.9	620	32.1
M-1	7.3	3800	2700	164	15	104.2	85.35	80	1214.1	47.17	0.25	1.2	610	32.3
M-2	7.2	1030	740	52	8	68.13	34.13	200	220.1	36.1	0.8	0.8	310	32.5
M-3	6.9	3310	2260	56	10	128.25	82.9	140	1029.5	43.8	3	0.6	106	32.9
N-1	6.8	1445	1020	52	6	80.16	34.12	160	255.6	38.02	1.8	1.1	460	32.1
N-2	6.7	1450	1030	49	7	120.24	41.42	180	255.6	38.98	2	1	470	32.0
N-3	6.9	1485	1030	64	22	68.13	34.13	160	298.2	35.13	4.5	0.6	470	32.1
O-1	7.0	3500	2460	142	23	112.22	68.26	120	1008.2	47.17	0.25	0.2	520	32.0
O-2	7.3	898	638	34	12	56.11	51.21	60	191.7	31.76	3	0.6	350	32.0
O-3	7.2	1244	880	82	33	60.12	41.45	40	191.7	40.91	1.8	0.8	320	32.1
P-1	7.0	3370	2370	137	22	60.12	41.45	60	1015.3	41.39	3	0.9	500	32.1
P-2	7.2	1540	1080	66	13	56.11	51.21	100	276.9	39.95	3	1.1	370	32.2
P-3	6.8	1602	1150	46	7	76.15	104.88	140	291.1	38.02	1.8	1.3	520	32.0
Q-1	6.9	1624	1150	62	76	48.09	29.26	180	326.6	34.17	0.8	1	600	32.0
Q-2	7.1	1178	836	43	18	60.12	41.45	40	213	36.58	3	0.8	460	31.9
Q-3	7.1	1610	1140	88	7	60.12	41.45	140	418.9	30.8	1.2	1	490	32.1
R-1	6.8	1190	845	48	8	76.15	104.88	100	213	34.65	1.1	0.8	500	32.1
R-2	6.8	1926	1360	63	8	100.2	104.87	80	582.2	33.21	3	1	680	32.1
R-3	6.6	1460	1040	67	32	104.2	85.35	120	312.4	27.43	1.8	0.3	680	32.3
S-1	7.0	3120	2120	66	6	64.12	63.41	80	724.2	35.62	2.8	0.5	420	31.8
S-2	7.2	1612	1260	51	14	44.08	46.34	140	383.4	45.1	1.3	0.7	380	32.1
S-3	6.9	3240	2145	43	38	64.12	63.41	120	355	33.21	1.8	0.4	530	32.0
T-1	7.1	1490	1350	72	57	104.2	85.35	100	440.2	46.7	4.6	0.6	610	32.2
T-2	7.6	1610	1230	62	19	44.08	46.34	80	291.1	35.1	2	0.3	360	32.4
T-3	7.3	2420	1800	76	13	130.14	115.91	120	241.4	30.87	2.2	0.6	800	31.8

U-1	7.3	3710	2670	49	7	76.15	104.88	200	454.4	38.02	1.7	1	520	32.3
U-2	7.2	1075	890	49	6	50.1	71.95	60	284	34.08	2.8	0.8	400	32.1
U-3	6.9	3200	2167	29	27	44.08	46.34	120	291.1	33.52	2	1.2	370	32.0
V-1	6.7	1567	1140	40	10	104.2	85.35	100	262.7	46.28	1.8	1.1	600	32.1
V-2	6.6	1485	1062	47	10	104.2	85.35	40	305.3	27.1	1.8	0.6	580	32.4
V-3	6.8	1620	1170	52	8	78.15	64.62	180	319.5	38.46	1.7	1.1	450	31.9
W-1	7.1	2642	1800	71	14	60.12	41.45	160	639	35.26	1.3	1.4	510	33.4
W-2	7.6	2900	2120	79	13	101.09	83.24	80	639	55.91	0.26	0.6	620	33.0
W-3	7.1	2160	1510	31	6	64.12	77.48	120	582.2	37.54	1	0.4	570	33.6
X-1	6.7	2167	1492	79	20	64.12	70.24	140	582.2	40.91	1.8	0.4	480	33.1
X-2	6.5	2270	1530	64	16	112.22	68.26	120	589.3	39.42	4.4	0.2	520	33.3
X-3	6.9	2132	1710	83	8	104.2	85.35	180	553.8	46.28	2.8	1.1	600	33.0
Y-1	7.1	2520	1820	83	13	60.24	41.37	80	852	40.74	1.69	1.3	320	33.6
Y-2	7.7	2910	2060	96	10	60.12	41.45	120	788.1	31.16	2.8	0.9	480	33.2
Y-3	7.0	2650	1510	31	32	84.16	36.56	200	759.7	33.72	2	0.7	360	33.4

Table 2: Latitude and Longitude of study areas

Sample code	Station Name	Latitude	Longitude
C	Anangur	11° 23. 638'N	77° 48. 994'E
D	Devanankurichi	11° 24. 383' N	77° 51. 669'E
E	Srinivasampalayam	11° 22.547' N	77° 52. 659' E
F	Pirithi	11° 16. 575' N	77° 51. 845' E
G	Molasi	11° 15. 725' N	77° 50. 741' E
H	Eryamangalam	11° 16. 197' N	77° 50. 533' E
I	Patlur	11° 16. 880' N	77° 47. 161' E
J	Chitalandur	11° 19. 237' N	77° 55. 009' E
K	Pudupuliyampatti	11° 20. 770' N	77° 53. 954' E
L	Sirumolasi	11° 20. 245' N	77° 52. 610' E
M	Animoor	11° 22. 304' N	77° 53. 100' E
N	Chickanaikanpalayam	11° 16. 001' N	77° 48. 502' E
O	T Goundampalayam	11° 19. 753' N	77° 50. 021' E
P	Emapalli	11° 20. 260' N	77° 59. 927' E
Q	Andipalayam	11° 21. 671' N	77° 48. 230' E
R	Thaneerpandalpalayam	11° 25. 564' N	77° 51. 013' E
S	Valrasapalayam	11° 25. 153' N	77° 49. 478' E
T	Modamangalam	11° 25.025' N	77° 49. 478' E
U	Karuvepampatti	11° 24. 146' N	77° 52. 939' E
V	Vattur	11° 26. 251' N	77° 57. 278' E
W	T Kailasampalayam	11° 24. 789' N	77° 54. 037' E
X	Thirumangalam	11° 26. 027' N	77° 55. 948' E
Y	Karumapuram	11° 25. 316' N	77° 56. 270' E

Table 3: Statistical analysis of groundwater samples of Tiruchengode taluk, Namakkal district

Parameters	Max.	Min.	Median	Mode	SD
pH	8.6	6.5	7	7.1	0.34
EC	3800	551	1610	2650	811
TDS	2700	397	1150	1140	559.29
Cl	1214.1	99.4	326.6	326.6	248.4

SO4	57.76	26.47	37.06	33.21	6.4
NO3	5	0.22	1.81	1.8	1.4
F	2.2	0.2	0.9	0.6	0.41
Ca	132.26	24.04	64.12	64.12	27.88
Mg	115.91	27.06	63.41	85.35	23.65
Na	164	29	63	83	27.81
K	76	2	14	13	13.71
TH	800	106	460	520	139.28

Suitability of groundwater for irrigation purpose

Considering the wide use of groundwater for irrigation purpose in the study area, it was determined on the basis of sodium absorption ratio (SAR), Soluble Sodium Percentage (SSP) and Kelly's ratio (KR) (Table 3).

Sodium Absorption Ratio (SAR)

Excess sodium in water produces undesirable effects of changing soil properties and reducing soil permeability [18]. Sodium hazard of irrigation water can be well understood by knowing SAR. Sodium absorption ratio (SAR) is given by the following relation [19].

$$SAR= Na^{+}/(Ca^{2+}+Mg^{2+})^{1/2}/2$$

Sodium absorption ratio also influences infiltration rate of water. So, low SAR is always desirable. In the studied samples, SAR values are varied from 1.21 to 8.70 meq/l(Table 3). The SAR value is excellent in all water samples. Hence it is good for domestic uses.

Percent Sodium

Sodium percentage values reflected that the water was under the category of 'good' (20-40 Na %), 'permissible' (40-60 Na %) and 'doubtful' (60-80 Na %) class [20]. The sodium percentage is calculated by following equation.

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

Here all the concentrations are expressed in meq/l. the values of sodium percent vary from 20.70 to 76.79 % (Table 3). 43 groundwater samples fall under good category water and only 26 sample lies in the permissible category. (Table4). When the concentration of sodium ions is high in irrigation water, Na^{+} tends to be absorbed by clay particles, displacing magnesium and calcium ions. This exchange process of sodium in water for Ca^{2+} and Mg^{2+} in soils reduces the permeability and eventually results in soil with poor internal drainage.

Permeability index (PI)

The PI values also indicate suitability of groundwater for irrigation, as the soil permeability is affected by long-term use of irrigation water, influenced by the Na^{+}, Ca^{2+}, Mg^{2+} and HCO_3^{-} contents of the soil. The permeability index (PI), as developed by Doneen (1964) indicates the suitability of groundwater for irrigation [21].

$$PI= Na^{+}+ (HCO_3^{-})^{1/2}/(Ca^{2+}+Mg^{2+}+Na^{+})x100$$

According to permeability indices the groundwater may be divided into Class I, Class II and Class III types. Class I and Class II water types are suitable for irrigation with 75% or more of maximum permeability, and Class III types of water with 25% maximum permeability. The permeability index of the Tiruchengode area ranges from 19.60 to 72.41% with an average value of 35.44 %. According to the permeability index values, 86.95% of the samples fall under class 2 (PI ranged from 25 to 75%) and 13.05% belong to class I (PI >7.5%) in the Pre-monsoon in 2013.

Residual Sodium Bicarbonate (RSC)

The residual sodium bicarbonate (RSC) values are calculated to determine the water quality for irrigation purposes (Eq. 1). The positive RSBC value indicates the dissolved calcium and magnesium ions which is less than that of carbonate and bicarbonate contents.

$$RSC =HCO_3^{-}- Ca^{2+} \text{----}\quad (1)$$

The RSC value of the water samples were found to be positive(45%) and negative values(55%), which indicates that 55% samples in the study area are not good for irrigation purpose and 45% samples in the study area are good for irrigation purposes, based on the RSBC classification proposed by Gupta and Gupta [22].

Table 4: Groundwater quality parameters for irrigation purposes

Samples	SAR	Na%	PI	RSC
C-1	5.249998	52.51897	51.54724	0.5795
C-2	3.024367	34.91306	32.61352	-0.6829
C-3	4.691001	58.10241	57.53229	0.5438
D-1	3.094492	45.55295	39.5868	0.5928
D-2	2.525542	38.88987	42.289	0.3086
D-3	1.277631	29.61899	20.07948	-0.1683
E-1	3.014675	36.10875	33.24005	-0.4048
E-2	2.921361	33.47646	32.26538	-0.6282
E-3	2.531084	29.20854	26.87459	-1.254
F-1	3.716489	45.95681	38.98712	-0.5993

F-2	8.701244	76.79108	72.41789	0.059
F-3	1.725421	27.90298	26.08237	-0.1436
G-1	2.199104	33.04207	35.64624	0.2881
G-2	2.018478	31.03525	33.61084	0.2667
G-3	1.759387	28.63571	29.79745	0.3533
H-1	1.524893	37.87879	27.48368	0.3668
H-2	1.395134	34.14218	25.78058	0.5198
H-3	1.961977	31.66355	34.51546	0.3583
I-1	1.630044	29.03783	29.64915	0.0958
I-2	2.728523	56.60773	46.93554	0.9791
I-3	3.143167	46.08083	39.71527	0.0299
J-1	2.202188	29.88544	25.07723	-1.1115
J-2	2.24974	32.62288	29.14994	-0.349
J-3	1.213527	27.81008	19.79391	-0.4277
K-1	4.491247	53.50165	54.03084	0.4265
K-2	3.882067	44.05718	44.33908	-0.3428
K-3	3.453492	41.64188	40.61559	-0.0753
L-1	2.47943	37.03155	34.16782	0.5247
L-2	4.101402	50.15985	50.06802	0.6958
L-3	2.378344	33.20666	28.85696	-0.0103
M-1	5.955963	48.56872	47.65157	-1.0955
M-2	2.571109	36.97769	38.29319	0.9774
M-3	1.926915	23.81382	23.17652	-0.7115
N-1	2.432138	33.66612	35.07611	0.4572
N-2	1.926925	25.7282	26.4446	0.1834
N-3	3.164442	45.6815	42.29794	0.5774
O-1	5.284986	47.75964	45.73221	-0.6048
O-2	1.641	30.00261	26.79945	-0.4732
O-3	4.068189	53.10061	46.39226	-0.6157
P-1	6.796852	61.02007	59.04891	-0.4157
P-2	3.185471	42.40017	40.96469	-0.0732
P-3	1.709435	22.64667	22.8675	-0.4103
Q-1	3.524776	64.08173	49.30621	1.0265
Q-2	2.133319	37.5223	31.93074	-0.6157
Q-3	4.365861	48.32884	49.54164	0.3843
R-1	1.783758	23.6257	23.14107	-0.8103
R-2	2.19968	25.71811	25.1696	-1.2507
R-3	2.433229	34.30948	28.25072	-0.6955
S-1	2.922185	36.0848	36.41406	-0.4753
S-2	2.681686	41.82216	40.24613	0.4958
S-3	1.903848	38.84333	28.42739	-0.0753
T-1	2.614813	40.496	29.43988	-0.8955
T-2	3.260089	47.25236	43.61116	-0.1042
T-3	2.422545	26.5632	25.29956	-1.2605
U-1	1.82092	23.6257	24.37555	0.1897
U-2	2.217671	31.06467	30.91084	-0.6205
U-3	1.52488	38.24614	28.87056	0.2958
V-1	1.452674	20.87247	19.60357	-0.8955
V-2	1.706892	23.11904	21.20578	-1.4955
V-3	2.17598	29.59018	30.14232	0.3723
W-1	3.522456	45.55931	44.80765	0.5843
W-2	2.909371	33.29353	31.69868	-1.0433
W-3	1.302567	20.71669	21.13397	-0.216
X-1	3.407706	42.42372	39.79944	0.0564
X-2	2.381965	30.71253	28.41837	-0.6048
X-3	3.014298	32.43629	32.9144	-0.0955

Y-1	4.116991	48.58054	47.38212	-0.2161
Y-2	4.762758	51.06711	51.36267	0.1843
Y-3	1.410724	34.29131	25.09298	0.7928

Table 5: Classification of groundwater based upon SAR, Na% and KR

Parameter	Hazard Class	Range (meq/l)	Water class	Samples
Sodium hazards	Sodium hazard class			
	C1	<10	Excellent	All
	C2	10-18	Good	-
	C3	18-26	Doubtful	-
	C4	>26	Unsuitable	-
Percentage sodium		Range (%)		
	C1	<20	Excellent	-
	C2	20-40	Good	43
	C3	40-60	Permissible	26
	C4	60-80	Doubtful	-

Hydrochemistry of the study area

Piper diagram

Major cations and anions such as Ca^{2+}, Mg^{2+}, Na^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-} and Cl^{-} in mg/l were plotted in piper tri linear diagram (Piper 1994) to evaluate the geochemistry of groundwater of the study area with the help of Aquachem software [23](**Fig 3**). The piper diagram reveals that major cations are magnesium, sodium, potassium and major anions are chloride and sulfate. Nearly 60% samples are ranged with excess of strong acids (SO_4^{2-} and Cl^{-}). Approximately 40% samples contain majority of alkaline earth metals (Mg^{2+} and Ca^{2+}).

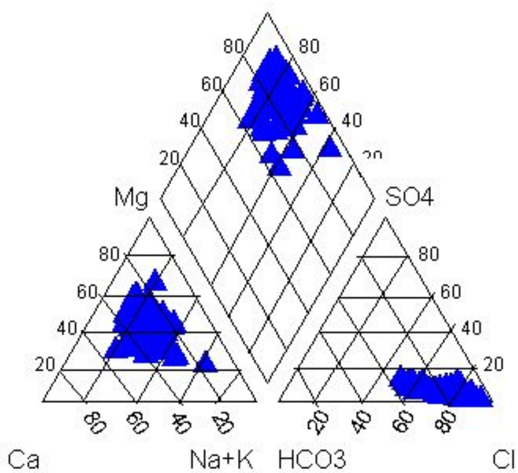

Figure 2. Piper Diagram

Durov plot

Durov diagram is an alternative form of the piper tri-linear diagram. It plots the major ions as percentage of meq L^{-1} in two base triangles and total cations and total anions are set equal to 100%. The data points in the two base triangles are projected into square of the main field which lies perpendicular to the third axis in each triangle. The final result of this diagram (**Fig 4**) specifies that majority of the groundwater samples in the study area dominated by Mg^{2+} and Cl^{-} ions representing that groundwater be related to reverse ion exchange process.

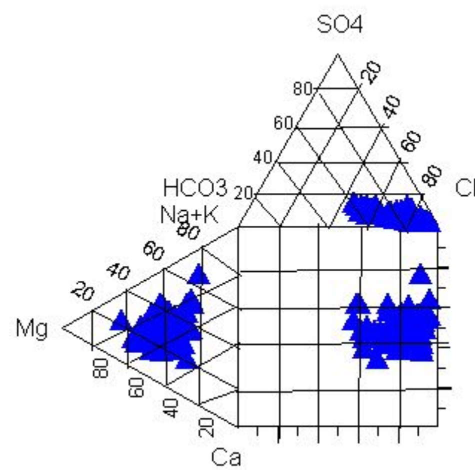

Figure 3. Durov Diagram

Box and Whisker plot

Box and whisker plots are uniform in their use of the box: the bottom and top of the box are always the 25th and 75th percentile (the lower and upper quartiles, respectively), and the band near the middle of the box is always the 50th percentile (the median). The minimum and maximum of all the data (as in Figure 5) shows the lowest datum still within 0.6 IQR of the lower quartile, and the highest datum still within 10.0

IQR of the upper quartile. The box plot is a quick way of examining one or more sets of data graphically. Box plots may seem more primitive than a histogram or kernel density estimate but they do have some advantages.

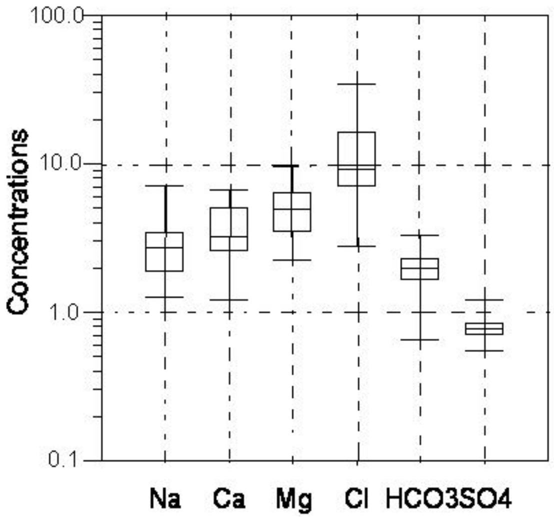

Figure 4.Box and Whisker Plot

Wilcox Diagram

A Wilcox plot can be used to quickly determine the viability of water for irrigation purposes. The Wilcox plot is also known as the U.S. Department of Agriculture diagram. The Wilcox plot (Figure 5) is a simple scatter plot of Sodium Hazard (SAR) on the Y-axis versus Salinity Hazard (Cond) on the X-axis. The Conductivity (COND) is plotted by default in a log scale.

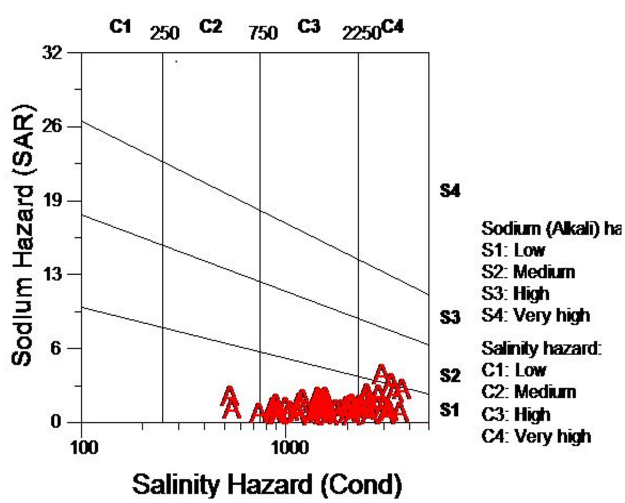

Figure 5. Wilcox Diagram

The classification of groundwater samples with respect to percent sodium (Figure 6) is shown in Table 4. The groundwater for irrigation purposes by correlating percent sodium and electrical conductivity. A perusal of Wilcox's 1955 diagram shows that majority of the samples falls under good to permissible category and most of the samples falls in the doubtful to unsuitable category. Very few samples lies in the unsuitable category.

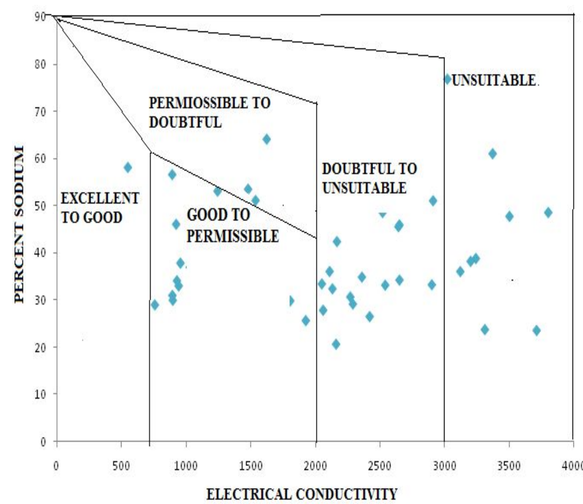

Figure 6. Percent Sodium and electrical conductivity plot

Conclusion

The present study has been carried out to evaluate hydrochemical characteristics of groundwaters of the Gneiss aquifers in Tiruchengode taluk, Namakkal district, Tamilnadu. A total of 69 groundwater samples were collected and analyzed for various physico-chemical parameters. Very wide ranges and high standard deviations of hydrochemical parameters such as TDS, EC, Cl, K, SO4, Mg suggests the groundwater in the study area shows agriculture intrusion and anthropogenic contamination. Most of the water samples exceeds the maximum permissible limit of WHO standards. Results suggest that the groundwater in this study area is very hard and alkaline in nature. Based on the USSL diagram, 80% of the total samples of the present study area falls under the category of high to very high salinity with low sodium hazards. To overcome this problem we need to plan for better drainage. Based on SAR values all of the groundwater samples are good for irrigation. From the Wilcox plot, it is observed that 50% of the samples fall in the Good to permissible category and 50% of the samples fall under doubtful category.

However, permeability index (PI) values indicate that almost all the groundwater sample fall under the class II and suitable for irrigation. Finally, it is concluded that most of the groundwater sample collected within the study area are not suitable for drinking purpose. But it can be used for irrigation and industrial purposes.

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