International Research Journal of Earth Sciences ISSN 2321–2527
Vol. 2(10), 8-15, November (2014) Int. Res.J. Earth Sci.

Groundwater Quality Assessment in Lower Tamirabharani River Basin Tamil Nadu, India

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Available online at: www.isca.in, www.isca.me
Received 8th September 2014, revised 12th October 2014, accepted 23rd November 2014

Abstract

For analyzing the multiple thematic maps at a time, GIS is a prevailing tool. GIS investigation is carried out in the present study area to locate the best quality of groundwater zones in Lower Tamirabharani River basin. Totally 48 Groundwater samples have been collected from various places of Lower Tamirabharani river basin. Groundwater study of the area, water samples were collected in an area of 1255.26 km^2 and analyzed for major cations and anions. The values of analyzed Groundwater samples are compared with WHO water quality standards. It is observed that, most of the groundwater quality values are not suitable for drinking purpose. ArcGIS was employed, to understand the spatial distribution of incompatible zones. Attributes were linked in ArcGIS and spatial interpolation mapping was done. To locate the best quality groundwater domain, GIS analyses are supportive. The final integrated map reveals that good for groundwater quality zones covered in area about 113.73 Km^2. Moderate class combinations cover an area of 702.30 Km^2. Bad and very bad class of groundwater is not suitable for the drinking purpose and covers an area of 335.26 Km^2 and 103.97 Km^2. The saline area is differentiating using the EC groundwater quality data. Totally 72.92% of the samples are suitable for irrigation purposes. Compare to SAR and sodium percentage, 91.67% of the samples are within the acceptable limit and the groundwater is suitable for irrigation purpose.

Keywords: GIS (Geographic Information System); spatial distribution Map; SAR (Sodium Adsorption Ratio).

Introduction

Groundwater is an essential natural resource. Depending upon its usage and consumption it can be a renewable or a non renewable resource. Groundwater is the world's most extracted raw material with withdrawal rate currently in the estimated range of 982km3/year[1]. In many nations, more than half of the groundwater withdrawn is for domestic water supplies and globally it provides 25% to 40% of the world's drinking water. Among the various reasons, the most important are non-availability of potable water in surface and a general belief that groundwater is purer and safer than the surface water due to the soil cover protective qualities[2].

The quality of groundwater is the resulting the processes and reaction that act on the water from the moment it squeeze in the atmosphere to the time it is discharged by a well. Therefore, determination of groundwater quality is important to observe the suitability of water for a particular utilize. The problems of ground water quality are more acute in areas of which dense populated and thick industrialized area have shallow groundwater tube wells[3]. Geochemical studies of groundwater provide information about the possible changes in quality as development progress. With help of groundwater geochemistry the Suitability of groundwater for domestic and irrigation purposes is determined. Anthropogenic activities can alter the relative contributions of the natural causes and also introduce the effects of pollution[4].

Geochemical processes in groundwater involve the interaction of country rocks with water, leading to the development of secondary mineral phases. The principles governing the chemical characteristics of groundwater were well documented in many parts of the world[5-12,]. This paper examines the possible chemical processes of groundwater interaction in hard rock terrain.

GIS has come out as a powerful technology for instruction, for research, and for building the stature of programs[13-17] have conducted GIS based study and interpretation of groundwater quality data.

The present study of groundwater samples have been collected and analyzed for various parameters such as, EC, pH, TDS, Ca, Mg, HCO_3, Cl, Na and K etc., the analyzed results were in use into GIS environment. Spatial distribution maps were prepared for the above parameters in GIS. Analysis of multiple thematic maps overlay carried out to find the bat suitable zone with respect to all elements.

Study Area: The major portion of the study area falls in Tuticorin district and parts of Tirunelveli District in Tamil Nadu. It lies between 8°26'35" and 8°54'09" N latitudes, and 77°38'50" and 78°8'22" E longitudes covering an area of 1255.26 Sq km (Fig.1). Eastern part of the study area is coastal

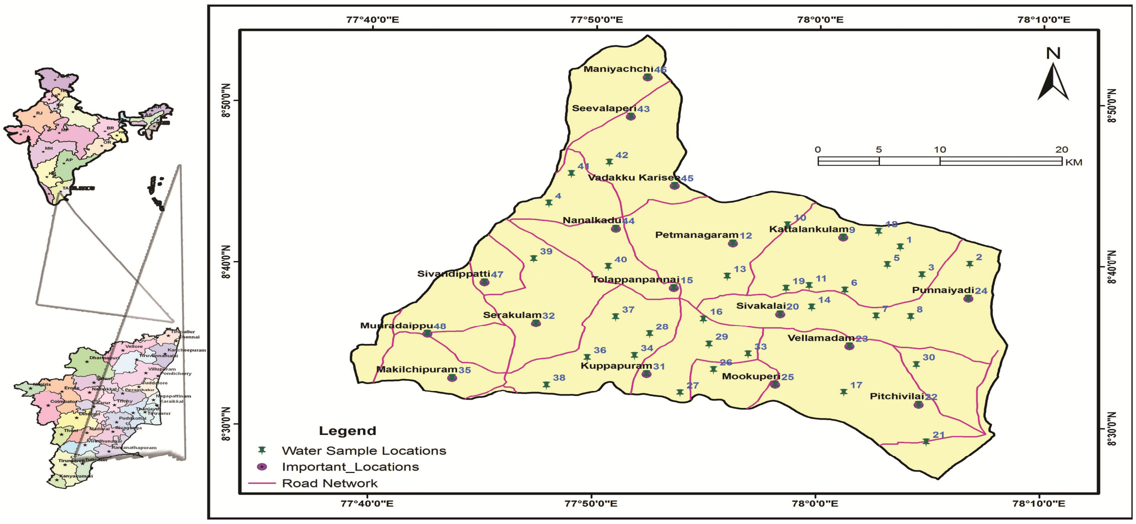

Figure-1
Study area of Lower Tamirabharani River basin and Sample locations

zone of the Bay of Bengal. The coastal zone includes recent age of coastal sand, calcareous sandstone with and without shells, clay, and kankar. The calcareous sandstone is seen at Kurumbur, Kayamoli, Ammanpuram and a few other places. Western part of the study area is underline by the Archaean crystalline rocks. The Archaean complex includes ridges of quartzite, charnockite, calc-granulite and the basement peninsular gneiss.

Methodology

48 groundwater samples from open and bore wells of various locations which are extensively used for drinking and also irrigation purposes in the Lower Tamirabharani river basin area were collected during pre-monsoon season (May 2013). Power of Hydrogen (pH) and Electrical conductivity (EC) were calculated within a few hours of collection by using Elico pH meter and conductivity meter. Calcium (Ca), Magnesium (Mg) and Chloride (Cl) were determined using standard EDTA and silver nitrate in volumetric analysis[18]. Carbonate, Bicarbonate and sulfate were determined with standard sulphuric acid and gravimetrically by precipitating Barium Sulfate ($BaSO_4$) from Barium Chloride ($BaCl_2$). By using Elico flame photometer Sodium (Na) and Potassium (K) was determined and Iron (Fe), Fluoride (F) and Nitrate (NO_3) were determined by standard processor[19]. The base map was prepared with help of toposheet number 58 L/1, L/2, and 58 H/13, H/14 on 1:50,000 scale. Their points are added and analyzed in ArcGIS software. The maps prepared in ArcGIS are correlated one over the other to find the best combination for groundwater quality.

Results and Discussion

Water Quality Analysis for Drinking Purpose: Groundwater hydro-chemical analysis data of samples for the pre-monsoon season are represented in table-1. The pH values of water sample for pre-monsoon are in the range of 6.28 - 7.74 representing an acidic to alkaline in nature. The same as per the[20] standards, all samples fall within the recommended limit except 1, 22 samples (6.5 - 8.5) for human utilize. The conductivity value of the samples varies from 196 - 9360 µScm[1]. The TDS value varies from 137.2 - 6552 mg/l during the pre-monsoon season. Most of the Samples showed abnormal values of Conductivity and TDS (samples no: 1, 2, 10, 17, 20, 22) falling within the permitted limits. The alkalinity value varies from 52 - 2520 mg/l during the pre-monsoon season in 2013. The presence of carbonates (Ca), bicarbonates (HCo_3) and hydroxides (OH-) are the most common parameters of alkalinity in natural water.

Bicarbonates signify the major form since they are formed in extensive amounts from the action of carbonates upon the basic resources in the soil.

The groundwater sodium concentration in the study area varies between 22 - 942 mg/l. It can be observed from the tables, that sodium concentrations are very high in the groundwater of pre-monsoon season and unsuitable for some of the domestic applications. The parameters such as Calcium, magnesium, nitrate, total dissolved solids and total hardness in the groundwater are inter-related. Most of the samples are indicate for normal values of calcium, magnesium and total hardness within permissible limits and thus the groundwater is not much hard. Based on the WHO standard 1, 2, 10, 17, 22, 26 and 30 samples are high concentration or contamination of groundwater for calcium, magnesium, nitrate, total dissolved solids and total hardness ions. The content chloride value range from 24 - 1560 mg/I. 81.25% of samples falls within the permissible limit for drinking purpose[20]. Iron (Fe) concentration of the groundwater ranging from 0 to 4.2 mg/l, but most of the samples fell in not potable category. Fluoride ionic concentration of the present investigation reveals that 56% of the samples fell in potable zone.

Spatial Analysis of Groundwater Quality for Drinking Use: It is an analytical technique associated with the location study and their associated attributes (like table analysis, classification, polygon classification and weight classification). The Parameters of pH, TDS, Ca, Mg, Na, K, Cl, SO_4, Fe, F and NO_3 are prepared as thematic maps to describe. These were reclassified and assigned suitable weightages for the spatial distribution map preparation are given results (table-2).

Data and Maps Analysis for drinking purpose: Each thematic map such as power of hydrogen (pH) figure.2, total dissolved solids (TDS) figure-3, calcium (Ca) figure-4, magnesium (Mg) figure-5, sodium (Na) figure-6, potassium (K) figure-7, chloride (Cl) figure-8, sulfate (SO_4) figure-9, iron (Fe) figure-10, fluoride (F) Figure-11 and nitrate (NO_3) figure-12 provides certain clues for the quality of groundwater. In order to collect all these information unified, it is important to combine these data with appropriate factor. Therefore, numerically this information is integrated through the application of GIS. Various thematic maps are reclassified on the basis of their weightage assigned, and brought into the "Raster Calculator" purpose of Spatial Analyses tool for integration. A simple arithmetical model has been adopted to combine various thematic maps. The final (Domestic quality) map (figure-13) expose that 113.73 Km^2 area fall under good category and 335.26 Km^2, 103.97 Km^2 areas fallowed by bad and very bad category, the rest of the portion in moderate quality of groundwater Table 3. This methodology it is highly helpful to assessing the best quality groundwater zone in the study area.

Table-1
Chemical Composition of Groundwater (Ionic concentrations are expressed in mg/L and EC in μScm^{-1})

Station	Ca	Mg	Na	K	Fe	HCO3	CO3	SO4	Cl	F	pH	EC*	TDS	K. Ratio	RSC*	SAR*	Na%	TH
Pullaveli	716	178	880	90	3.5	2817.26	0.00	280	1380	3.2	6.28	8740	6118	0.76	-4.18	7.63	44.62	3580
Pazhayakayal	182	50	254	27	1.8	638.03	0.00	120	424	1.2	6.92	2480	1736	0.84	-2.71	4.30	47.14	910
Agaram	95	29	151	17	1.5	493.57	0.00	52	176	2.5	7.34	1452	1016	0.92	0.97	3.48	49.61	476
Arasankulam	49	18	78	10	0.3	305.25	0.00	36	64	2.8	7.56	719	503	0.86	1.08	2.42	48.13	246
Sakkamalpuram	58	20	90	11	0.3	299.19	0.00	64	88	3.5	7.58	844	591	0.87	0.40	2.62	48.33	288
Siruthondanallur	71	23	112	13	3.8	458.34	0.00	27	92	1.6	7.47	1062	743	0.89	2.06	2.95	48.90	356
Sethukkuvaithan	27	13	48	7	0.2	222.08	0.00	6	32	0.4	7.64	424	297	0.88	1.25	1.93	48.84	136
MelaAuthoor	48	17	70	9	4.2	285.86	0.00	28	64	0.4	7.59	638	447	0.80	0.88	2.20	46.16	238
Kattalankulam	62	21	96	12	0.3	386.81	0.00	28	84	0.6	7.44	896	627	0.86	1.50	2.67	47.92	312
Pandaravilai	220	59	359	38	2.5	712.18	0.00	150	624	2.2	6.89	3530	2471	0.99	-4.14	5.55	51.18	1100
Perunkulam	53	19	77	10	1.6	317.46	0.00	36	64	1.2	7.52	708	496	0.80	1.03	2.31	46.24	264
Petmanagaram	54	19	85	11	1.4	325.41	0.00	32	80	1.0	7.46	792	554	0.87	1.05	2.53	48.13	272
Srivaikundam	51	18	81	10	0.5	284.09	0.00	40	84	2.0	7.53	754	528	0.87	0.60	2.48	48.34	256
Mottachikudiyiruppu	47	17	71	9	1.8	282.74	0.00	32	64	1.4	7.42	651	456	0.82	0.85	2.25	46.79	236
Tholappanpannai	38	15	75	9	0.3	247.33	0.00	28	72	1.8	7.47	689	482	1.03	0.89	2.59	52.49	192
Sivaganapuram	78	25	112	13	0.3	433.21	0.00	65	96	0.2	7.33	1060	742	0.82	1.15	2.82	46.66	392
Manakkadu	184	50	266	29	2.4	717.79	0.00	90	424	2.8	7.02	2598	1819	0.87	-1.54	4.48	48.01	920
Piramayapuram	51	18	74	9	0	349.24	0.00	22	48	1.6	7.48	684	479	0.80	1.66	2.27	46.13	256
Varatharajapuram	51	18	75	10	3.0	292.86	0.00	30	76	1.4	7.54	691	484	0.80	0.74	2.29	46.36	256
Sivakalai	10	6	22	4	0	76.56	0.00	6	24	0.4	7.29	196	137	0.96	0.26	1.36	51.74	48
Therikudiyiruppu	11	9	32	5	0	101.52	0.00	12	32	0.6	7.35	264	185	1.11	0.39	1.77	54.78	56
Pitchivilai	842	208	942	96	1.8	3166.26	0.00	320	1560	1.2	6.35	9360	6552	0.69	-7.24	7.53	42.34	4210
Vellamadam	71	23	130	15	0.3	333.75	0.00	24	196	1.0	7.42	1242	869	1.04	0.02	3.43	52.58	356
Punnaiyadi	73	23	127	15	0.2	434.68	0.00	90	88	0.2	7.36	1214	850	1.00	1.56	3.32	51.54	364
Mookuperi	85	26	125	14	0.3	454.01	0.00	76	112	2.2	7.44	1185	830	0.85	1.04	3.03	47.47	424
Sundapuram	224	60	305	33	1.5	774.97	0.00	130	524	1.0	6.85	2990	2093	0.82	-3.39	4.67	46.69	1120
Thoppur	74	24	110	13	0.2	359.48	0.00	40	144	1.2	7.41	1039	727	0.84	0.22	2.84	47.39	372
Kulathukudiyiruppu	72	23	113	13	0.2	385.52	0.00	40	128	2.6	7.3	1070	749	0.89	0.81	2.96	48.82	360
Athinathapuram	54	19	89	11	0	343.06	0.00	85	36	1.4	7.28	825	578	0.90	1.34	2.63	49.07	272
Athalikulam	118	34	193	21	0.6	521.01	0.00	60	280	1.0	7.06	1872	1310	0.96	-0.20	4.02	50.58	592
Kuppapuram	94	28	166	19	0.2	314.16	0.00	68	288	1.2	7.42	1596	1117	1.03	-1.86	3.85	52.26	468
Serakulam	138	39	212	23	1.2	522.62	0.00	90	336	1.6	7.01	2060	1442	0.91	-1.54	4.10	49.27	690
Udayarkulam	144	41	230	25	0.8	566.39	0.00	110	340	0.4	6.94	2240	1568	0.95	-1.24	4.36	50.28	720
Vallakulam	50	18	76	10	0	291.28	0.00	27	76	1.8	7.67	696	487	0.83	0.83	2.34	47.22	248
Makilchipuram	66	22	89	11	0	408.98	0.00	29	68	0.2	7.42	833	583	0.77	1.64	2.44	45.12	328
Ariyanayagipuram	54	19	85	11	3.6	293.07	0.00	36	96	1.8	7.42	793	555	0.87	0.52	2.53	48.16	272
Kalvi	82	26	128	15	0.3	425.11	0.00	56	144	2.8	7.44	1224	857	0.90	0.74	3.16	48.90	412
Athichanallur	49	18	72	9	0	327.93	0.00	25	48	1.8	7.28	658	461	0.80	1.48	2.24	46.31	244
Achimadam	87	27	122	14	0.2	436.94	0.00	80	120	2.2	7.35	1155	809	0.80	0.59	2.92	46.23	436
Saithunganallur	118	34	196	22	1.4	558.89	0.00	40	276	2.6	7.37	1904	1333	0.98	0.48	4.10	51.15	588
Maruthakulam	69	23	96	12	0	438.26	0.00	36	64	1.2	7.42	896	627	0.79	1.90	2.56	45.73	344
Ulakudi	40	16	63	8	0	248.69	0.00	22	60	1.6	7.54	569	398	0.83	0.80	2.14	47.33	200
Karaimanakkadu	52	18	76	10	0	332.08	0.00	30	56	0.8	7.48	696	487	0.80	1.33	2.29	46.19	260
Nanalkadu	45	17	69	9	0.3	309.14	0.00	22	48	0.6	7.35	632	442	0.83	1.43	2.23	47.06	226
Kaliyavoor	65	22	92	11	0	362.07	0.00	90	52	1.8	7.4	856	599	0.80	0.93	2.52	46.02	324
Fatimakovai	26	12	47	7	0	204.47	0.00	6	36	0.2	7.62	410	287	0.90	1.07	1.92	49.32	128
Keelanatham	28	13	52	7	0	218.58	0.00	9	40	0.2	7.74	462	323	0.93	1.14	2.05	50.11	140
Palayanchettikulam	45	17	72	9	0.2	266.10	0.00	28	72	1.0	7.38	659	461	0.87	0.75	2.33	48.19	224

EC* – Electrical conductivity, RSC* – Residual Sodium Carbonate, SAR* – Sodium Adsorption, Ratio, TH* - Total Hardness

Table-2-Chemical Quality – GIS Spatial Distribution Results

Elements	Acceptable Area in Km^2	Allowable Area in Km^2	Not Potable Area in Km^2
Power of Hydrogen (pH)	1251.17	-	4.10
Total Dissolved Solids (TDS)	137.51	933.90	183.86
Calcium (Ca)	648.49	502.47	104.31
Magnesium (Mg)	876.88	253.91	124.47
Sodium (Na)	1122.14	-	133.14
Potassium (K)	160.19	-	1095.08
Chloride (Cl)	972.46	-	282.81
Sulphate (SO_4)	1255.28	-	-
Iron (Fe)	316.27	-	939.01
Fluoride (F)	754.53	-	500.75
Nitrate (NO_3)	1118.45	-	136.82

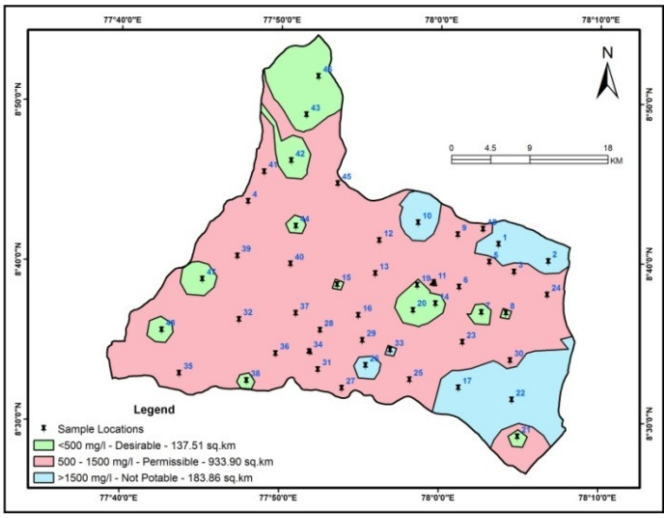

Figure-2
pH Quality – Spatial Distribution Map

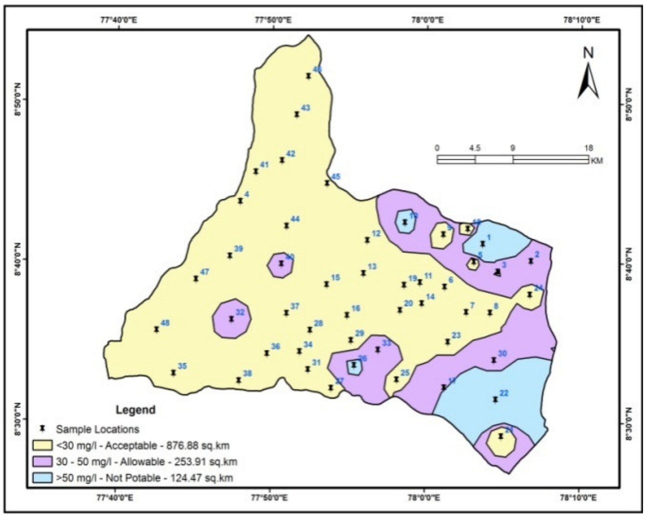

Figure-4
Calcium Quality – Spatial Distribution Map

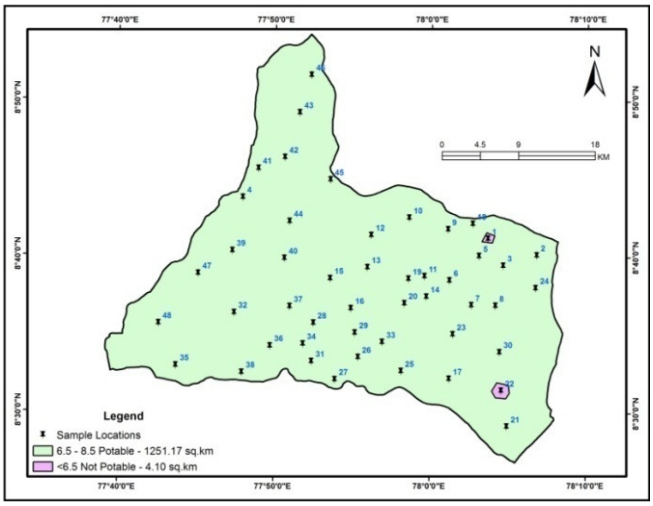

Figure-3
TDS Quality – Spatial Distribution Map

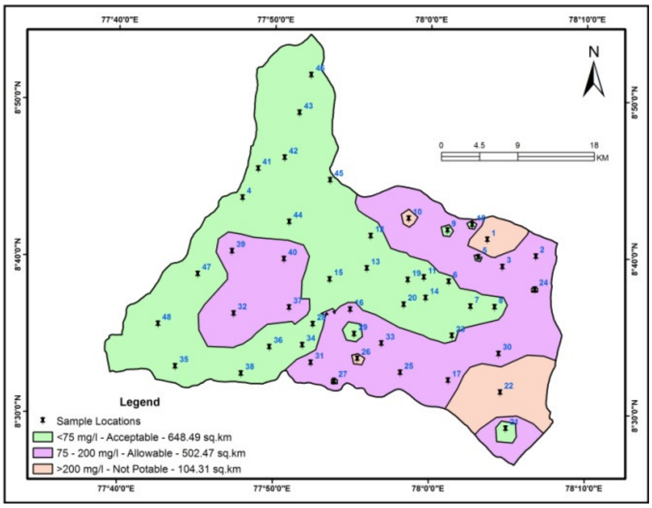

Figure-5
Magnesium Quality – Spatial Distribution Map

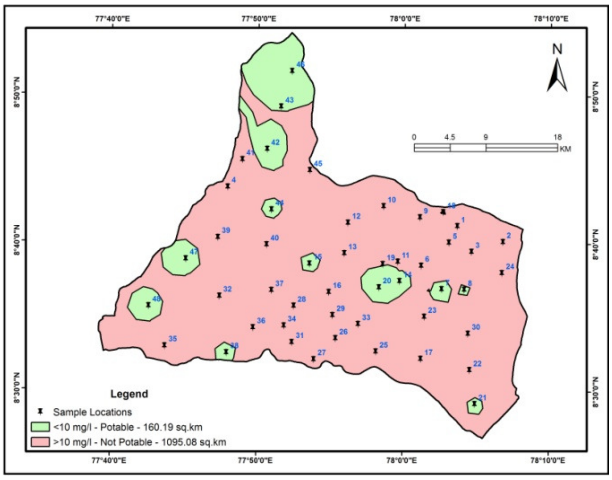

Figure-6
Sodium Quality – Spatial Distribution Map

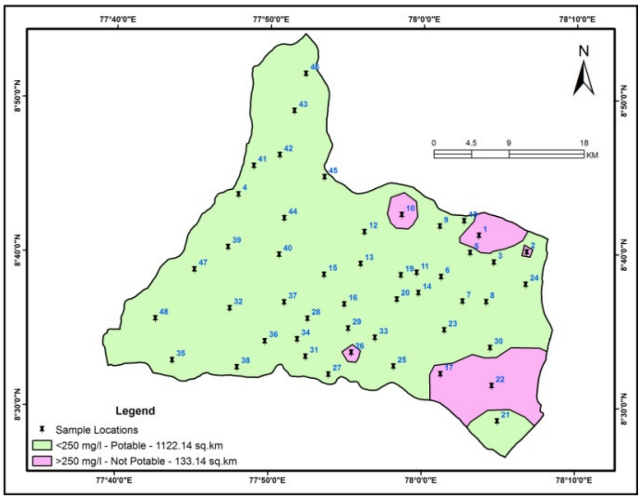

Figure-7
Potassium Quality – Spatial Distribution Map

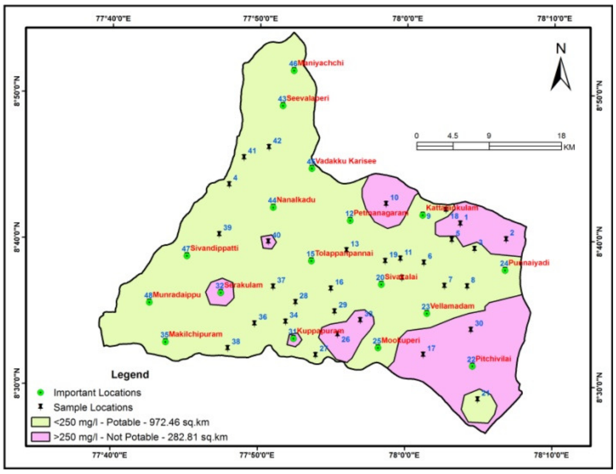

Figure-8
Chloride Quality – Spatial Distribution Map

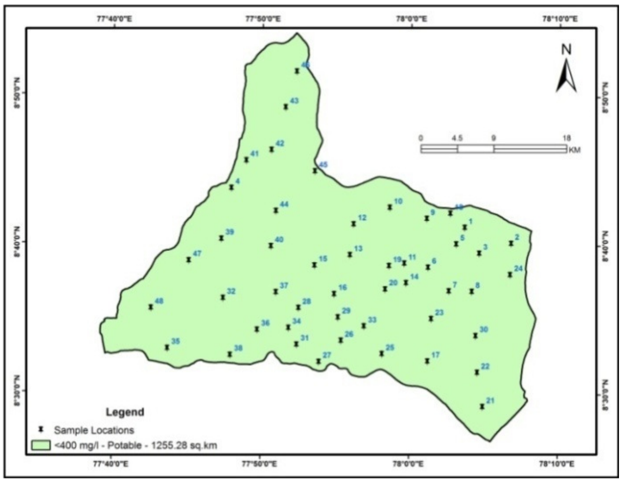

Figure-9
Sulphate Quality – Spatial Distribution Map

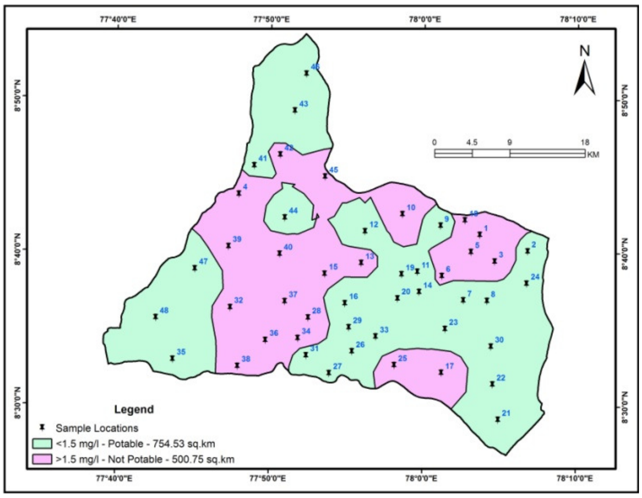

Figure-10
Fe Quality – Spatial Distribution Map

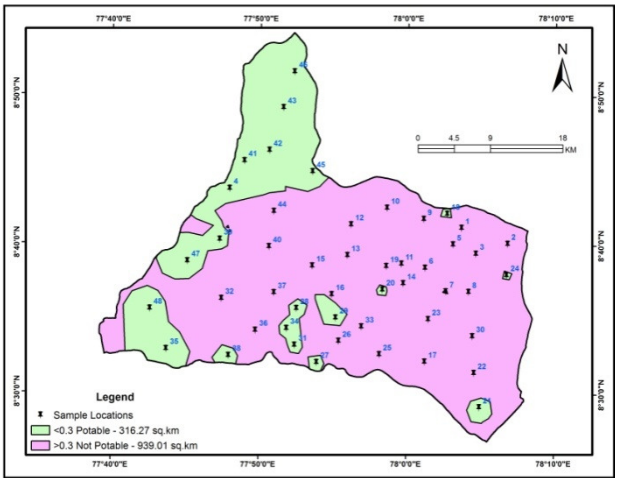

Figure-11
F Quality – Spatial Distribution Map

Table-3
Result of Final Groundwater Quality Zones

Sl.No.	Class	Area in Km^2
1	Good	113.73
2	Moderate	702.30
3	Bad	335.26
4	Very bad	103.97

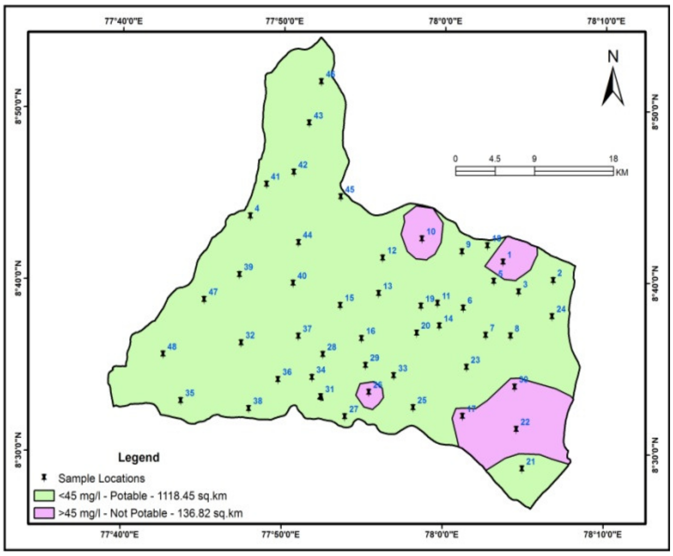

Figure-12
NO_3 Quality – Spatial Distribution Map

Water Quality Analysis for the purpose of Irrigation: Groundwater always contains assessable quantities of dissolved substances, which are called salts. The salts present in the water, besides affecting the growth of the plants directly, affect the soil structure, permeability and aeration, which indirectly affect the plant growth. The total concentration of soluble salts in irrigation water can be expressed for the purpose of classification (Table 4) as follows: less than 250 µ Scm^{-1} were classified as low salinity area. These area's crops yield is low. Second and third categories of groundwater are suitable for all crop cultivation and respectable yield. Final class of the groundwater must be not suitable for irrigational purposes due to very high salinity.

The sodium or alkali hazard limit 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. This can destroy the soil structure owing to dispersion of the clay particles[21].

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad (1)$$

A simple method of evaluating high sodium water is the SAR. Calculating the SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR value (2 - 10) indicates little danger from sodium; 10-18 indicating medium hazards; high hazards are between 18 - 26 and very high hazards more than 26. The lower the ionic strength of the solution is greater the sodium hazards for a given SAR. The value of SAR in the groundwater samples of the study area ranges from 1.36 - 7.63 during pre-monsoon seasons (Table 5). Based on the table, the groundwater of the study area falls under the category of small danger except four samples (7, 20, 21, and 46). Water which have high sodium may produce harmful levels of exchangeable sodium in most soils and will require special soil management like good drainage, high leaching, and organic matter additions[21].

Calculating the Sodium Percentage;

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

All ionic concentrations are expressed in Millieqivalent per litre. The sodium percentage in the study area varies from 52.04 - 56.85. As per the Bureau of Indian Standards, 1991 standards, a sodium percentage of 60 is the maximum recommended limit for water in irrigation. The high value sodium saturation in the water samples directly causes calcium deficiency.

Table-4
Groundwater Electrical Conductivity Classification for Irrigational Purpose

Sl. No.	Conductivity (µScm^{-1})	Class	No. of Samples	Total No. of Sample	Percentage
1	< 250	Low Salinity Zone	20	1	2.08
2	250-750	Medium Salinity Zone	4,7,8,11,14,15,18,19,21,34, 38,42,43,44,46,47,48	17	35.42
3	750-2250	High Salinity Zone	5,6,9,12,13,16,23,24,25,27, 28,29,35,36,37,39,41,45	18	37.50
4	2250-5000	Very High Salinity Zone	1,2,3,10,17,22,26,30,31, 32,33,40	12	25.00

Table-5
Groundwater Classification for Irrigational Purpose

Sl.No.	SAR Value	Class	No. of Samples	Total No. of Sample	Percentage
1	< 2	Good	7,20,21,46	4	8.33
	2 - 10	Little danger	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18,19, 22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37, 38,39,40,41,42,43,44,45,47,48	44	91.67
2	10 - 18	Medium hazards	-	-	-
3	18 - 26	High hazards	-	-	-
4	> 26	Very high hazards	-	-	-

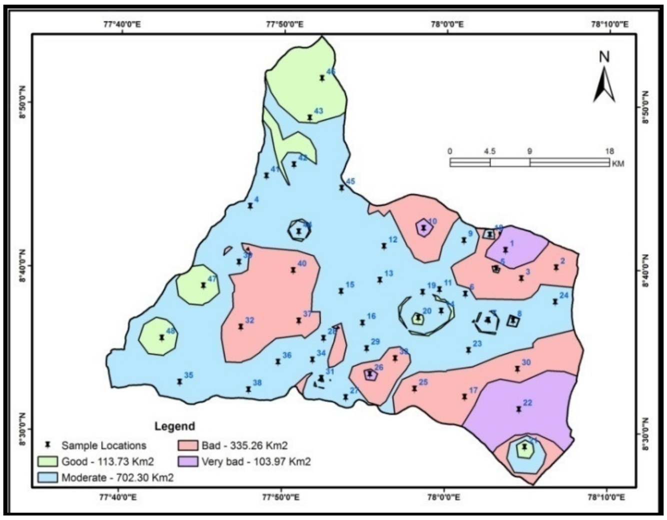

Figure-13
Drinking Purposes Groundwater Quality Map

Conclusions

The parameters of groundwater quality in the study area with reference to the[21] standards, were used to prepare the spatial distribution map. The final integrated map figure - 13 reveals that good for groundwater quality zones covered in area about 113.73 Km^2. Moderate class combinations cover an area of 702.30 Km^2. Bad and very bad class of groundwater is unsuitable for the drinking use and covers an area of 335.26 Km^2 and 103.97 Km^2. The saline area is demarcated using the EC groundwater quality data. The 72.92% of the samples are suitable for irrigation purposes. With respect to SAR and sodium percentage, more than 91.67% of the samples are fall within the permissible limit and finally the groundwater is suitable for irrigation purpose.

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