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Evaluation of Physico-Chemical Characteristics in Groundwater Using GIS - A case Study of Chinnar Sub-basin of Cauvery River, Tamil Nadu, India

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Abstract

A detailed GIS based study on hydrochemistry of groundwater in Chinnar sub-basin of Cauvery river, Tamil Nadu, India has been carried out to assess the quality of groundwater for determining its suitability for drinking purpose. Further, the spatial variation of various groundwater quality parameters over the basin has also been studied for November 2010. Fifty seven groundwater samples were collected and analysed for pH, conductance, total dissolved solids, total hardness, calcium, magnesium, fluoride, iron, carbonate, bicarbonate, total alkalinity, chloride, sodium, potassium, sulphate and nitrate etc., The values analyzed were evaluated in detail and compared with WHO water quality standards. TDS widely varied from 301 mg/L to 1505 mg/L with an average value of 703.51 mg/L. About 87% of the samples and spatially 789.32 km^2 areas are within the maximum allowable limit for drinking (1000 mg/L). Groundwater of the basin belongs to hard to very hard water category since the total hardness (TH) exceeds the permissible limit of 500 mg/L prescribed for drinking water. Magnesium content in groundwater fifty samples out of 57 samples exceeded the maximum allowable limit of 50 mg/L. Concentration of potassium ion in groundwater ranges from 3 mg/L to 24 mg/L with an average value of 9.11 mg/L. Thirty nine samples out of 57 samples exceeded the maximum allowable limit of 10 mg/L. Fluoride is (> 1.5 mg/L) in groundwater at 5 locations, which may cause dental and skeletal fluorosis.

Key words: Geographic Information System (GIS); World Health Organization (WHO); Spatial Variation; Dental and Skeletal Fluorosis.

Introduction

Water has a profound influence on human health and quality of the water supplied is important in determining the health of individuals and whole communities. Safe water quality is a major concern with reference to public health importance as health and well being of the human race is closely tied up with the quality of water used[21]. Despite major efforts to deliver safe piped, community water to the world's population, the reality is that water supplies delivering safe water will not be available to all people in the near term[1].

The quality of groundwater depends on various chemical constituents and their concentration, which are mostly derived from the geological data of the particular region. Groundwater occurs in weathered portion, along the joints and fractures of the rocks. In fact, industrial waste and the municipal solid waste have emerged as one of the leading cause of pollution of surface and ground water. The principles governing the chemical characteristics of groundwater were well documented in many parts of the world[10,23,26,8,12,22,17,30,13,18].

GIS has emerged as a powerful technology for instruction, for research, and for building the stature of programs[16,14,25,4]. Saraf *et al.*,[19] have conducted GIS based study and interpretation of groundwater quality data. Durbude *et al.*,[7] mapped the groundwater quality parameters in Ghataprabha command area in GIS environment.

In the present study, groundwater samples have been collected and analyzed for various parameters such as, EC, pH, TDS, Ca, Mg, HCO_3, Cl, Na, K, Fe, F and NO_2 *etc.*, the analysed results were taken in to GIS environment. In GIS, Spatial variation of groundwater quality parameters and their interrelationship have not been included. Further, it is observed that the concentration of major ions in groundwater of the area is high at many locations leading to unsuitability of groundwater for drinking. Thus, a GIS based study has been attempted to understand spatial variation of groundwater quality parameters over the Chinnar Sub-basin.

Study Area :

The study area falls in Dharmapuri district of Tamil Nadu. Chinnar sub-basin, have been selected for the present investigation. It lies between 12°13'38" and 12°41'44" N latitudes, and 77°42'38" and 78°04'13" E longitudes covering an area of 893.65 Sq km out of which plain area covers 811.07 Sq km (Fig. 1). Chinnar sub-basin is one of the major tributaries of Cauvery River. The basin comes under parts of Palakkode taluk and Pennagaram taluk of Dharmapuri district in Tamil Nadu State, India.

Methodology :

57 groundwater samples from open and bore wells of various locations which are extensively used for drinking and also irrigation purposes in the Chinnar sub-basin area were collected during post-monsoon season (Nov. 2010). The locations of groundwater sampling stations are shown in the Fig. 1. Field parameters such as pH, Electrical Conductance (EC) and Total Dissolved Solids (TDS) were measured

immediately at sampling site using portable meters. Collected samples were brought to the laboratory on the same day, Ca and Mg were determined titrimetrically using standard EDTA, and chloride was determined by silver nitrate titration (Volgel, 1968). Carbonate and bicarbonate were estimated with standard sulphuric acid and sulphate was determined gravimetrically by precipitating $BaSO_4$ from $BaCl_2$. Na and K by Elico flame photometer[3].

The base map was prepared using toposheets. Their attributes are added and analyzed in ArcGIS software. Spatial analysis tools were used for the preparation of interpolation map. The maps were interpolated by using inverse distance methods to generate the spatial distribution map.

Results and Discussion

Understanding the quality of groundwater is as important as that of its quantity, since, it is the main factor determining the suitability of water for drinking, domestic, agricultural and industrial purposes[24]. The pH value is an important index of acidity or alkalinity and the concentration of hydrogen ion in groundwater[15]. The lower value (pH < 4.0) will produce sour taste and higher value (pH > 8.5) an alkaline taste. The acceptable range of pH is normally 6.5 to 8.5 (WHO 1983). It is observed that the pH values of groundwater samples of the basin lie within the prescribed range showing an average value of 7.27.

The Electrical Conductivity (EC) is a measure of capability of water to transmit electrical current. It represents the total concentration of soluble salts in water. It is used to measure the salinity hazard to crops as it reflects the TDS in groundwater[2]. The EC values in the study area vary widely from 430 μS/cm to 2150 μS/cm with an average value of 999.93 μS/cm. The higher values of EC may be due to long residence time and existing lithology of the region[5].

Summary of the analytical results of various groundwater quality parameters is presented in Table 1. and the undesirable effects caused to humans when the parameters exceed the allowable limits (WHO 1983) are presented in Table 2. It is observed that potassium is 32% of samples present in exceeding permissible limit and TDS, Mg, K and Fe exceed the maximum allowable limits in more than 12% of the samples.

Total Dissolved Solids (TDS) range from 301 mg/L to 1505 mg/L with an average value of 703.51 mg/L. About 87% of the samples are within the maximum allowable limit for drinking 1000 mg/L) based on their TDS values (WHO 1983). The TDS spatial distribution map prepared using GIS (Fig. 2 and Table 5) reveals that groundwater in 21.74 km2 of the area is unfit for drinking purposes. As per Freeze and Cherry (1979), 50 samples out of 57 represent the freshwater category (TDS < 1000 mg/L), and the remaining brackish water (TDS 1000 mg/L to 10000 mg/L) category (Table 3).

Total Hardness (TH) also exhibits variation from 128 mg/L to 584 mg/L with an average value of 334.46 mg/L. Acceptable limit of TH for drinking is 500 mg/L (WHO 1983). The groundwater of the area is hard to very hard in nature because 54 samples (Table 4)

Table 1. Hydrogeochemistry of Chinnar Sub-basin
(Ionic concentrations are expressed in mg/L and EC in μScm^{-1})

Station	Ca	Mg	Na	K	Fe	HCO_3	CO_3	SO_4	Cl	NO_3	F	pH	EC*	TDS	TH
Achchattipalli	90	40	104	12	0	344	0	64	108	17	1.2	6.58	1165	816	384
Onnalvadi	91	44	87	10	0	368	0	80	148	23	1.2	7.11	1273	891	412
Oddarpalayam	58	24	104	12	0	268	0	130	76	15	1.2	7.23	956	669	244
Gulisandiram	85	37	69	8	0	324	0	60	88	15	1.2	7.27	1009	706	368
Bairamangalam	86	39	63	8	0	336	0	78	96	17	1.2	7.04	1045	732	380
Vanamangalam	109	49	94	12	0.2	352	0	130	148	29	1.2	7.2	1372	960	476
Masimayakkanappalli	86	32	76	9	0.4	328	0	56	92	17	1.2	7.39	1013	709	376
Karupalli	91	42	112	14	0.6	388	0	78	128	29	1.2	7.28	1310	917	404
Kelamangalam	101	43	63	8	0	344	0	50	104	23	1.2	6.98	1093	965	340
Belur	114	49	74	9	0.1	396	0	80	156	29	2.1	7.41	1328	930	488
Onnupalli	104	40	124	14	0.3	388	0	95	136	32	1.2	7.36	1514	1060	448
Adaikkalapuram	104	40	118	14	0.2	396	0	74	132	27	0.7	7.44	1297	908	448
Hosahalli	131	58	178	24	0.4	612	0	110	208	27	1.6	7.21	1963	1374	568
Anusonai	37	14	36	5	0	168	0	27	32	3	0.7	7.45	444	311	152
Ulimangalam	72	32	65	8	0	260	0	110	80	15	1.2	7.25	949	664	312
Modigapalayam	42	19	52	6	0	208	0	21	48	6	0.7	6.62	574	402	184
Makalgavundanu	69	30	64	7	0	236	0	52	100	9	0.5	6.99	860	602	292
Girisettipalli	59	24	46	5	0	232	0	22	52	8	1.4	7.04	656	459	256
Lakshmipuram	59	24	46	5	0	232	0	21	52	8	1.2	7.07	662	463	256
Puram	72	32	52	7	0	268	0	52	92	11	1.6	6.97	898	629	312
Kammandur	59	24	45	5	0	232	0	26	52	8	1.2	7.33	657	460	256
Peddabaleguli	134	60	158	22	0.3	532	0	120	244	38	1.2	6.95	1997	1398	584
Basabanapalli	35	14	43	6	0	188	0	25	36	6	1.2	7.46	552	386	164
Doddakallupalli	30	13	32	4	0	148	0	12	28	3	1.2	7.78	430	301	132
Timijepalli	72	29	36	5	0	264	0	38	48	8	0.5	7.05	744	521	300
Odayandahalli	88	36	72	9	0.3	316	0	50	112	17	0.5	7.42	1005	704	368
Sandanapallu	45	20	38	4	0	228	0	18	40	4	1.2	6.86	579	405	196
Tippasandiram	58	21	49	6	0.2	268	0	24	32	8	1.2	7.46	682	477	232

Tattasandiram	72	31	47	6	0	272	0	45	84	10	0.5	7.21	845	592	308
Panchalli	122	57	93	12	0.3	392	0	80	148	32	1.6	7.29	1480	1036	540
Palaiyam	106	45	78	9	0.2	408	0	95	104	29	0.5	6.89	1287	901	452
Chudinur	91	43	95	12	0.4	392	0	76	96	23	0.5	7.11	1259	881	436
Unsatti	29	13	48	5	0	180	0	20	28	4	0.5	7.33	486	340	152
Nellukunti	37	15	42	5	0	184	0	18	32	4	0.5	7.26	498	349	156
Karadinattam	106	45	79	10	0.3	408	0	72	136	29	1.2	7.89	1304	913	452
Chinnabattagandahalli	30	13	43	5	0	164	0	22	32	4	2.3	7.82	447	313	128
Tottabadahalli	45	20	52	7	0	228	0	30	44	6	1.2	7.42	608	426	196
Agarharama	122	57	93	12	0.4	392	0	80	148	42	1.2	7.39	1404	983	540
Kombinaguddai	101	44	66	8	0	320	0	60	124	27	1.2	7.31	1107	775	436
Karadiguddai	51	27	70	9	0.2	248	0	47	92	10	0.5	7.05	844	591	232
Agaram	86	42	94	12	0.4	352	0	76	116	21	1.2	7.51	1185	830	392
Marandahalli	107	52	112	16	0.2	376	0	85	204	36	1.2	7.43	1482	1037	484
Bupanur	45	20	58	7	0	216	0	21	72	5	1.2	7.35	671	470	196
Gaalligattam	32	14	27	3	0	172	0	11	28	4	0.5	7.72	449	314	140
Sastramutlu	67	29	98	12	0	312	0	54	112	19	1.2	7.36	1007	705	388
Upparahalli	102	49	85	10	0.4	428	0	80	124	27	1.2	6.88	1291	904	460
Kesaraguli	67	30	64	8	0	448	0	130	88	12	1.2	7.05	954	668	292
Kariguddanur	48	20	29	3	0	240	0	21	24	6	0.5	7.14	556	389	200
Tirumalavadi	42	18	53	6	0	196	0	23	68	5	1.2	7.38	636	445	180
Attukottai	70	33	43	5	0	272	0	60	92	8	1.2	7.43	883	618	312
Eruduguttapatti	59	27	40	5	0	248	0	90	44	6	1.2	7.69	763	534	260
Budikal	56	23	31	4	0	220	0	32	36	4	0.5	7.29	577	404	236
Kadiyampatti	74	34	30	4	0	284	0	43	48	40	1.2	7.32	801	561	324
Siriyanahalli	128	56	192	24	0	436	0	85	308	44	1.2	7.65	2150	1505	532
Ponnaiyankottai	110	93	136	18	0.1	404	0	52	196	32	1.2	7.24	1520	1064	480
Erranahalli	86	36	93	12	0	340	0	48	140	23	0.9	7.56	1140	798	368
Chakkilinattam	112	43	90	12	0.1	372	0	64	156	27	1.2	7.26	1335	935	460

EC* - Electrical conductivity, TH - Total Hardness

Table 2. Groundwater samples of the study area exceeding the permissible limits prescribed by WHO standards for drinking purposes and the resulting undesirable effect on humans

Parameters	WHO International Standards (1983,1996)		No. of samples Exceeding Permissible Limits	Total No. of Samples	Undesirable Effect on Human
	Most Desirable Limits	Maximum Allowable Limits			
pH	6.5 - 8.5	-	Nil	Nil	Taste
TDS (mg/l)	500	1000	11,13,22,30,42,54,55.	7	Gastrointestinal Irritation
TH (mg/l)	100	500	13,22,30,38,54.	5	Scale Formation
Ca^{2+} (mg/l)	75	200	Nil	Nil	Scale Formation
Mg^{2+} (mg/l)	30	50	13,22,30,38,42,54,55.	7	Scale Formation
Na^{+} (mg/l)	-	200	Nil	Nil	-
K^{+} (mg/l)	-	10	1,3,6,8,11,12,13,22,30, 32,38,41,42,45,54,55, 56,57.	18	-
Fe^{2+} (mg/l)	-	0.3	7,8,13,32,38,41,46.	7	Staining problem
Cl^{-} (mg/l)	-	250	54.	1	Salty taste
SO_4^{2-} (mg/l)	-	400	Nil	Nil	Laxative effect
NO_3^{-} (mg/l)	-	45	Nil	Nil	Blue baby disease
F- (mg/l)	-	1.5	10,13,20,30,36.	5	Fluorosis

Table 3. TDS Quality of groundwater based on Freeze and Cherry (1979),

TDS (mg/L)	Nature of water	Nov. 2010 Representing Locations	Total No. Locations
< 1000	Fresh water	1,2,3,4,5,6,7,8,9,10,12,14,15,16,17, 18,19,20,21,23,24,25,26,27,28,29,31, 32,33,34,35,36,37,38,39,40,41,43,44, 45,46,47,48,49,50,51,52,53,56,57.	50
1000 - 10000	Brackish water	11,13,22,30,42,54,55.	7
10000 - 100000	Saline water	-	-
> 100000	Brine water	-	-

Table 4. Classification of groundwater based on hardness

Total Hardness as $CaCO_3$ (mg/l)	Water Class	Representing Locations Nov. 2010	Total No. of Locations
< 75	Soft	Nil	Nil
75 - 150	Moderately hard	24,36,44.	3
150 - 300	Hard	3,14,16,17,18,19,21,23, 25,27,28,33,34,37,40,43, 47,48,49,51,52.	21
> 300	Very hard	1,2,4,5,6,7,8,9,10,11,12, 13,15,20,22,26,29,30,31, 32,35,38,39,41,42,45,46, 50,53,54,55,56,57.	33

Table 5. Chemical Quality - GIS Spatial Distribution Results

Class	TDS - Results Area in km^2	TH - Results Area in km^2	Mg - Results Area in km^2	K - Results Area in km^2	Cl - Results Area in km^2	Fe - Results Area in km^2	F - Results Area in km^2
Most Desirable Limits	98.54	0.07	284.55	-	-	-	-
Maximum Allowable Limits	690.78	803.93	500.34	540.47	809.59	774.35	785.92
Exceeding Permissible	21.74	7.08	26.18	270.59	1.48	36.72	25.15

have the TH values greater than 150 mg/L [20]. The study area is delineated into three zones using GIS, based on the desirable (100 mg/L) and maximum permissible (500 mg/L) limits of TH as suggested by WHO (1983). The TH spatial distribution map (Fig. 3 and Table 5). illustrates that groundwater in 7.08 km^2 of the area is unsuitable for drinking purposes. Magnesium content in groundwater of the area varies from 13 mg/L to 93 mg/L with an average value of 34.35 mg/L. Fifty out of 57 samples exceeded the maximum allowable limit of 50 mg/L for drinking as per[28,29] the WHO (1996) standard. The Mg spatial distribution map (Fig. 4 and Table 5). illustrates that groundwater in 26.18 km2 of the area is unsuitable for drinking

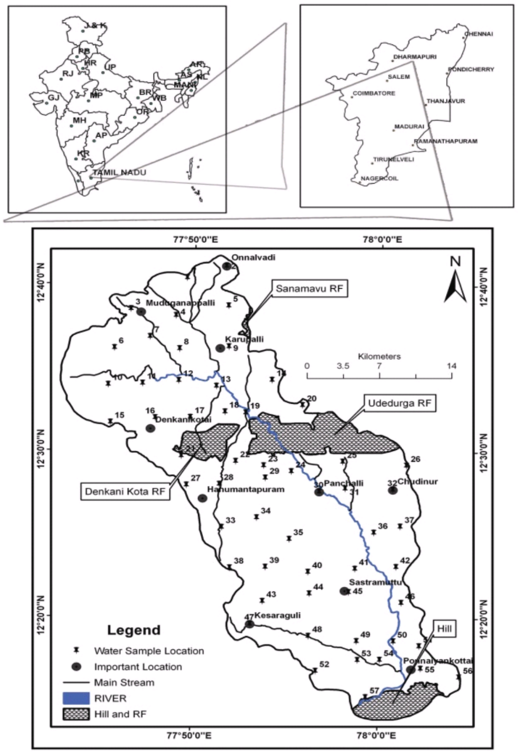

Fig. 1. Study Area and Water Sample Location Map

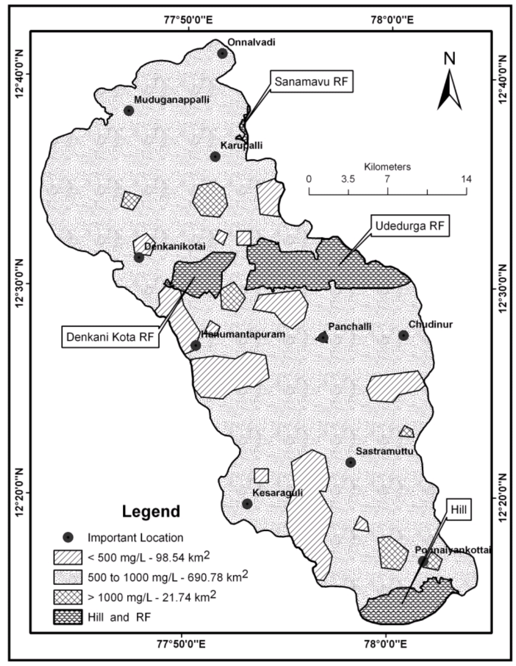

Fig. 2. TDS Spatial Distribution Map

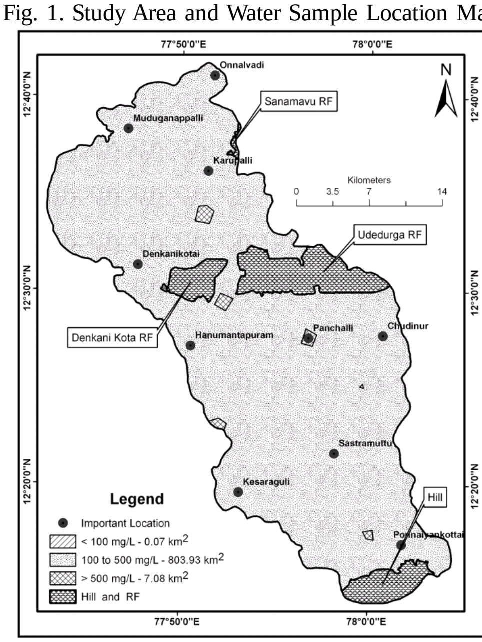

Fig. 3. TH Spatial Distribution Map

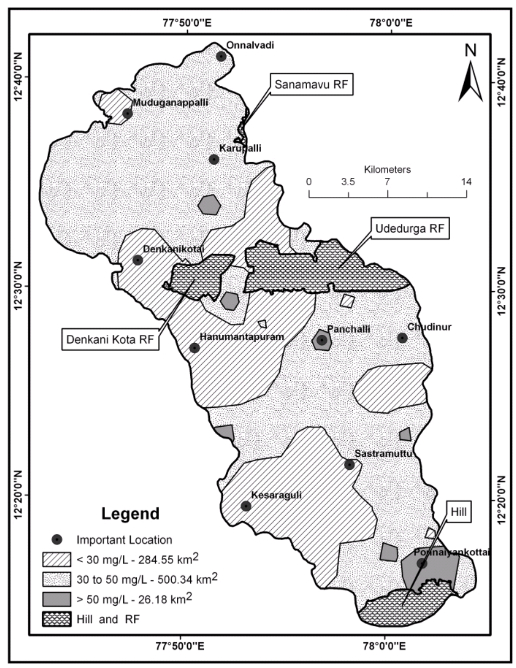

Fig. 4. Mg Spatial Distribution Map

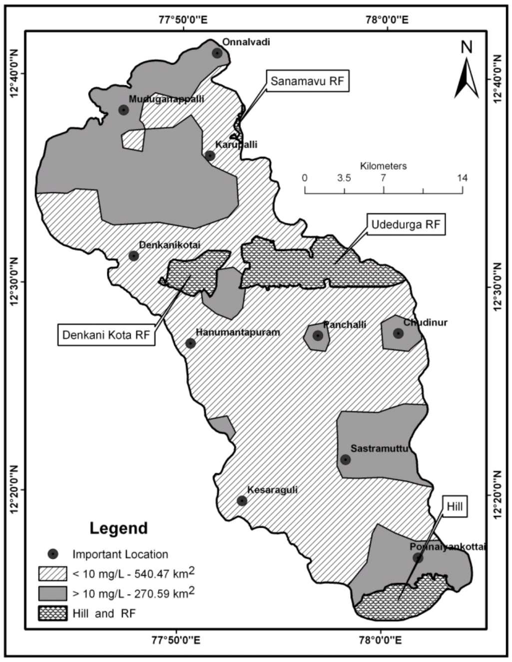

Fig. 5. K Spatial Distribution Map

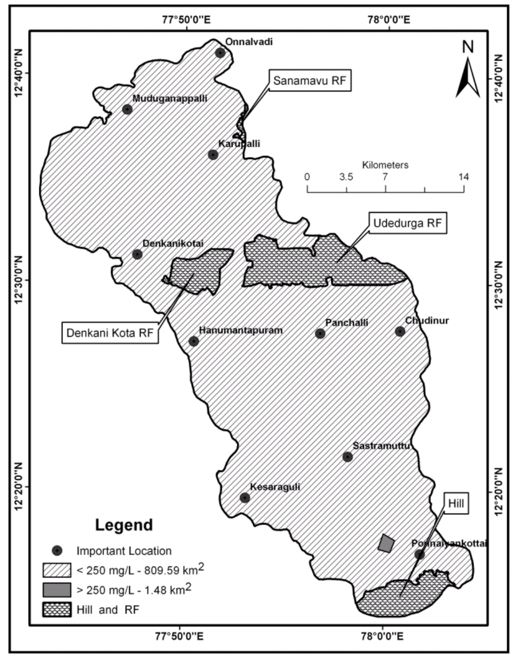

Fig. 6. Cl Spatial Distribution Map

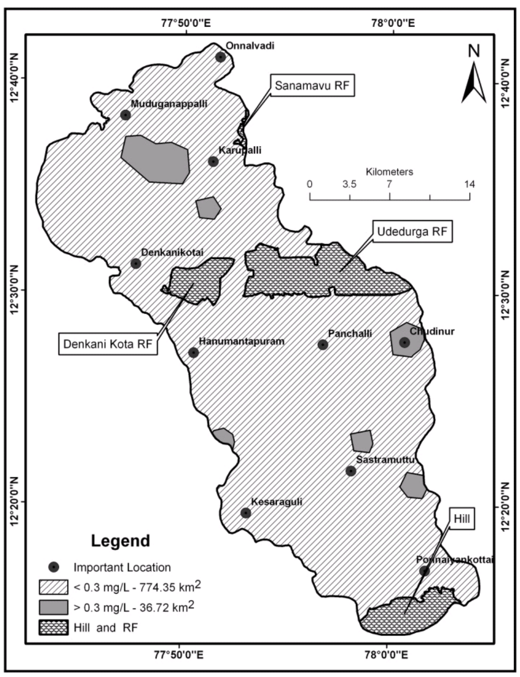

Fig. 7. Fe Spatial Distribution Map

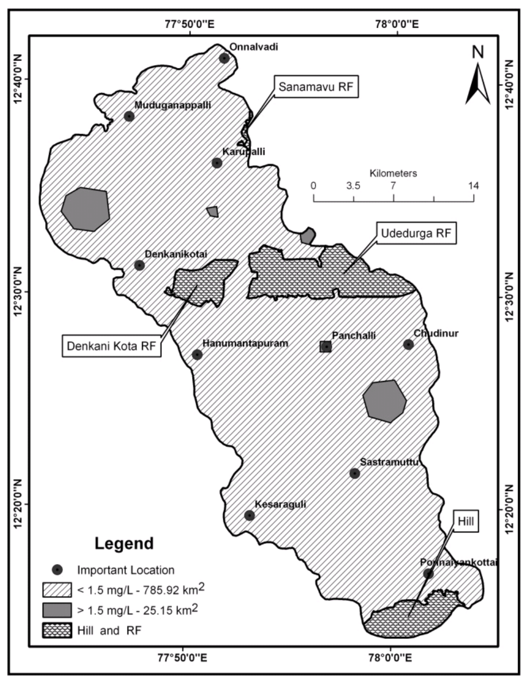

Fig. 8. F Spatial Distribution Map

purposes. Concentration of potassium ion in groundwater ranges from 3 mg/L to 24 mg/L with an average value of 9.11 mg/L. Thirty nine out of 57 samples exceeded the maximum allowable limit of 10 mg/L for drinking as per the WHO (1996) standard. The K spatial distribution map shows that groundwater quality based on K WHO limit 270.59 km^2 areas in the basin (Fig. 5 and Table 5).

Iron (Fe) content in groundwater of the area varies from 0 mg/L to 0.6 mg/L with an average value of 0.11 mg/L. Fifty out of 57 samples exceeded the maximum allowable limit of 0.3 mg/L for drinking as per the WHO (1983) standard. The Fe spatial distribution map (Fig. 6 and Table 5). reveals that 36.72 km^2 area is unsuitable for drinking purposes.

The chloride concentration varies from 24 mg/L to 308 mg/L. The average value is 98.11 mg/L. Fifty six samples exceeded the maximum allowable limit of 250 mg/L. The spatial distribution map indicates that 1.4 km2 area is unsuitable for drinking purposes in the basin (Fig. 7 and Table 5).

Bedrock containing fluoride minerals is generally responsible for its high concentration in groundwater[11,27,6]. The concentration of fluoride in groundwater of the basin varied from 0.46 mg/L to 2.3 mg/L with an average value of 1.04 mg/L. Ninety percent of the samples (5 out of 57) exhibited suitability for drinking purposes. The spatial distribution of fluoride concentration in groundwater during November 2010 is shows that 25.15 km2 in Fig. 8 and Table 5.

Conclusions

The aforesaid statement reveals that the chemical composition of the Chinnar basin area is hard, fresh to brackish, and slightly alkaline in nature. TDS about 87% of the samples and spatially 789.32 km^2 areas are within the maximum allowable limit for drinking 1000 mg/L). Total Hardness (TH) 7.08 km^2 area falls in exceeds the permissible limit of 500 mg/L prescribed for drinking water. Magnesium content in groundwater fifty out of 57 samples and 26.18 km^2 area fell in exceeded the maximum allowable limit of 50 mg/L. Concentration of potassium ion in groundwater ranges from 3 mg/L to 24 mg/L with an average value of 9.11 mg/L. Thirty nine out of 57 samples and 270.59 km2 area fell in exceeded the maximum allowable limit of 10 mg/L. Fluoride is (> 1.5 mg/L) in groundwater at 5 locations and spatially 25.15 km^2 areas peoples affected for the dental and skeletal fluorosis in the Chinnar sub-basin this classification based on WHO standard for drinking purposes.

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