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International Journal of Current Research
Vol. 5, Issue, 12, pp.3950-3956, December, 2013

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

GROUNDWATER QUALITY IMPACT ASSESSMENT ON LEKKUR SUB BASIN USING *HYCH* PROGRAM: A CASE STUDY FROM TAMIL NADU, INDIA

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ARTICLE INFO

Article History:
Received 24th September, 2013
Received in revised form
30th October, 2013
Accepted 12th November, 2013
Published online 25th December, 2013

Key words:
Hydrogeochemistry,
Lekkur sub basin,
Charnockites,
HYCH Program and
Spatial Analysis.

ABSTRACT

A detailed hydrogeochemical study was carried out in Lekkur sub basin which is part of Vellar basin. Groundwater is the major source of water supply for agricultural and domestic uses. The agricultural and urbanization activities have made a lot of impact on groundwater quality of the study area. In order to understand the groundwater quality variations in the sub basin area, twenty groundwater samples were collected from dug wells and hand pumps during pre-monsoon season. These water samples were analysed for major cations and anions. The water analysis data were processed using a computer program *HYCH*. In this program, numerical steps are adopted for the hydrochemical facies classification using the criteria of Handa, Piper, Stuyfzand and USSL schemes. The results show that according to Stuyfzand classification, 50 % of water samples are oligohaline to fresh type. Based on USSL classification, 40 % of water samples fall in good to moderate (C2S1 and C3S1) categories and the rest of the samples exhibit poor quality. This shows serious problems for domestic and agricultural uses during pre-monsoon period.

INTRODUCTION

Groundwater is the prime source of drinking water supply for many of the Indian rural and urban habitats, like in other parts of the world (Abdul Saleem *et al*., 2012). Regarding stage of groundwater development, India is overexploited and it is the largest user of groundwater (www.worldbank.org.in). According to World Bank report, during the past two decades the ground water level in several parts of India has been falling rapidly due to an increase in extraction. The extraction of groundwater is continuously on the rise which poses threats to the sustainability of groundwater resources. The groundwater crisis is not the result of natural factors; it has been caused by anthropogenic activities. Water quality is a term used to describe the chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose (Sargaonkar and Deshpande, 2003; Khan *et al*., 2003). Water quality plays an important role in promoting agricultural production and of human health (Raju *et al*., 2009). The water quality may yield information about the environment through which the water has circulated. Each groundwater system in the area has a unique chemistry, acquired as a result of chemical alteration of meteoric water recharging the system (Back, 1966; Drever, 1982). The chemical alteration of the rainwater depends on several factors such as soil-water interaction, dissolution of mineral species and anthropogenic activities (Faure, 1998; Subba Rao, 2001; Umar and Ahmed, 2007). In crystalline hard rock terrain, availability of groundwater is limited and its occurrence is essentially confined to fractures and weathered zones (Javed and Wani, 2009). Water scarcity and quality deterioration are common in hard rock terrain. The chosen study area (Lekkur sub basin, Tamil Nadu, S. India) falls in crystalline hard rock area. People of this area suffer with poor quality and scarcity of water for domestic and irrigation purposes. An attempt has been made to delineate the groundwater quality zones in the study area, with the help of a computer based program, namely *HYCH*. The groundwater quality zonation map will help the planners and the decision makers to understand the groundwater quality impact as a result of spatial analysis and distribution.

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MATERIALS AND METHODS

To prepare groundwater quality zonation map for Lekkur sub basin, twenty representative groundwater samples were collected during pre-monsoon period (June 2012). The location's coordinates were recorded with GPS receiver. The Electrical Conductivity (EC) and pH were measured immediately on collection of water samples in the field using portable consort C-425 digital pH meter. The collected samples were chemically analysed by standard analytical method-APHA (1995). The analytical results have been processed by using *HYCH* computer program (Balasubramanian *et al*., 1991). This program is capable of providing most of the needed output using the major ion chemistry data. It aids in the interpretation of water quality based on water chemistry, facies, mechanisms of origin, type, suitability and usage factors like corrosivity and permeability. *HYCH* Program data processing flow chart is shown in Figure 1. With the output result, GIS technique has been used for preparation of thematic maps and the following maps have been prepared and discussed in detail: (i) Total Dissolved Solids, (ii) Total Hardness, (iii) Scholler Water Type Classification, (iv) Stuyzand Water Classification, (v) USSL Classification, (iv) Corrosivity Ratio and (vii) Gibbs plot.

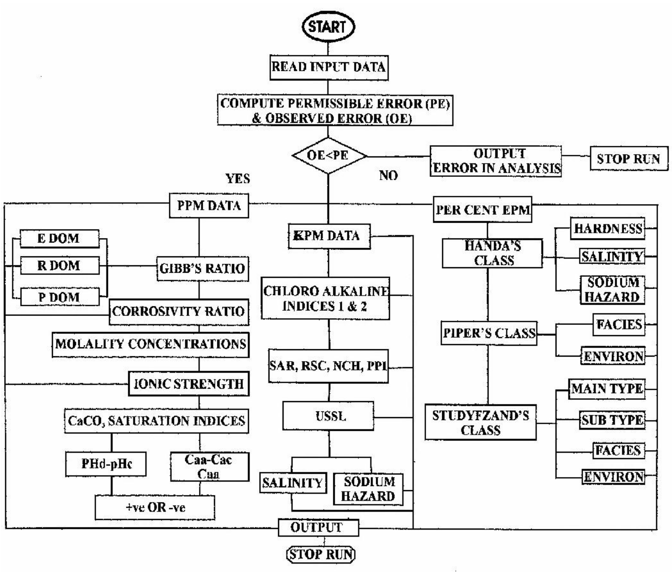

Figure 1. Flow chart shows HYCH program hydrochemical data processing method

Study Area

The present study was carried out in the Lekkur sub basin, which lies at about 110 km southwest of Cuddalore town, Tamil Nadu State, South India covering an area of 100 km^2. The study area is situated between 11° 21′ 55″ to 11° 03′ 59″ N latitudes and 78° 51′ 40″ to 79° 03′ 60″ E longitudes forming part of Survey of India (SOI) toposheets № 58½ and 58M/2 (Figure 2).

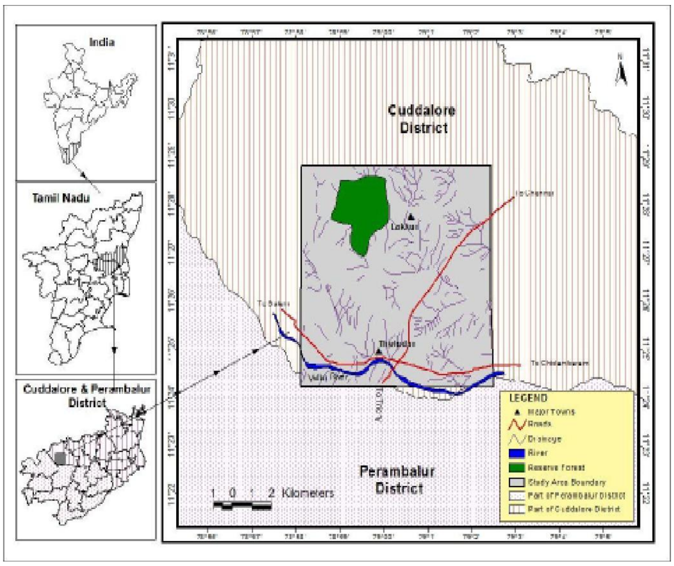

Figure 2. Location map of the study area

This semi-arid area exhibits flat topography with altitudes ranging from 62 to 121m above mean sea level. The area receives average annual rainfall of 900mm from the northwest monsoon. No perennial rivers and streams flow in the sub basin area. Seasonal River Vellar and Periya Odai flow in the area. Wellington reservoir is the major tank serving as major source of irrigation. The area has dendritic and sub dendritic drainage patterns. Geomorphological features consist of old flood plains, pediments, duri crusts, and pediments covered by forest land. A variety of soils occurs in the area like Paralithic Ustochrept, Paralithic Ustorthent, Vertic Haplustalf, etc. Paddy, sugarcane, groundnut, chillies and cotton are grown as commercial crops in the basin (Senthilkumar, 2012).

Geological Setting

Geologically, the Lekkur basin area is relatively homogenous, comprising of early to middle-Precambrian rocks represented by charnockites and charnockite gneisses. The charnockites are intermediate to acid in composition, dark in colour, coarse to medium grained and form highland topography. The charnockite rocks are the oldest and subjected to granulitic facies metamorphism. The gneisses occur as products of retrogression of charnockites indicating an event of retrogression in the metamorphic history of the area. The charnockitic rocks are massive to foliated and trending ENE – WSW with an average dip of 45° towards southeast. The charnockites show different depths of weathering. Generally the charnockites in the study area are highly massive and compact and devoid of joints and fractures which make them impervious and which in turn results in poor groundwater potential (Senthilkumar, 2012).

RESULTS

pH and EC

The various physico-chemical parameters of groundwater samples of the Lekkur sub basin are presented in Table 1. The *HYCH* software processed output of pre-monsoon groundwater sample results are shown in Table 2. The pH value of pre-monsoon groundwater samples varies from 6.9 to 8.3 with an average of 7.42. However, all samples fall within the recommended limits (6.5 to 8.5) for human consumption. The electrical conductivity (EC) values range from 540 to 5200 µmhos/cm at 25°C. High EC values arise from high level of mineralization in the phreatic zone due to the heavy leaching of Ca, SO_4, HCO_3, CO_3, NO_3, Fe and F (Hem, 1991). Maximum EC of 5200 µmhos/cm was noted in Alathur village (loc.14) dug well. A high salt content (high EC) in irrigation water leads to formation of saline soil. This affects the salt intake capacity of the plants through their roots. On the basis of electrical conductivity values, Richards (1954) classified irrigation water into four groups. As per Richards's classification, all the samples fail to fall in good class, 17 samples show medium salinity and one sample exhibits high salinity. Groundwater samples falling in medium salinity hazard can be used, if a moderate amount of leaching occurs. High salinity waters cannot be used on soil with restricted drainage. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Saleh *et al*., 1999).

Table 1. Major ion (ppm) concentrations of pre-monsoon groundwater samples in Lekkur sub basin

Sl. No.	Habitation	EC (µS/cm at 25ºC)	TDS	pH	TH	Ca	Mg	Na+K	HCO_3	CO_3	Cl	NO_3	SO_4	SAR	RSC	PI	CR
1	Orangur	2500	1750	8	566	149	46	428	840	0	508	14	124	7.870241	2.54626	74.85036	1.0055
2	M.Pudur	1725	1208	7.5	404	64	28	202	604	0	119	15	43	5.297239	4.400732	83.53329	0.3517
3	M.Podaiyur	965	676	7.1	202	23	7	112	324.5	0	22	19	20	5.245323	3.593884	108.8313	0.1597
4	Kallur	745	522	6.9	212	17	7	72	208.8	0	22	19	15	3.70951	1.997513	109.342	0.2232
5	Nangur R.F	1330	931	7.3	303	28	7	119	372.4	0	11	22	21	5.208907	4.129699	106.9565	0.1003
6	Lekkur	1825	1278	7.5	404	67	19	304	511.2	0	302	7	58	8.43845	3.470807	88.89676	0.9503
7	Alambadi	1395	977	7.4	313	38	17	195	390.8	0	162	9	35	6.605229	3.109363	93.50745	0.6771
8	Pulikarambalur	1285	900	7.2	374	66	14	135	432	0	86	7	38	3.93684	2.634209	82.69824	0.372
9	Tachchur	540	378	7	141	28	10	23	151.2	0	11	15	14	0.9491409	0.2577958	79.93984	0.1989
10	Venganur	1175	823	7.7	384	45	15	148	329.2	0	97	8	84	4.878322	1.915132	88.32916	0.6808
11	Vaidhyanadhapuram	1350	945	7.3	854	53	19	219	378	0	173	15	121	6.564241	1.986518	87.478	0.9781
12	Eluttur	1440	1008	7.1	475	60	22	200	403.2	0	194	18	60	5.610486	1.803334	83.45334	0.8327
13	Near Korukkai	1000	700	7.2	233	36	3	102	280	0	43	13	29	4.387575	2.54539	101.5259	0.3242
14	Alathur	5200	3640	8.3	717	244	80	1173	1456	0	1166	18	615	16.65269	5.102385	80.11161	1.5679
15	Tholudur	1890	1323	7.8	556	131	35	277	635	0	313	13	101	5.55023	0.9900923	71.15166	0.8599
16	Vagaiyur	1225	858	7.2	354	25	5	117	343.2	0	11	19	29	5.5844	3.96444	110.564	0.1332
17	Akkanur	1140	798	7.4	242	32	11	111	319.2	0	43	21	31	4.314885	2.729104	97.0686	0.2909
18	Peraiyur	2400	1680	7.9	566	80	36	402	672	0	421	1	76	9.373126	4.058419	85.11903	1.0002
19	Labbaikudikadu	850	595	7	333	58	17	95	285.6	0	97	15	42	2.819197	0.3873343	74.71764	0.6315
20	Nathamedu	1190	833	7.5	394	32	19	40	160	0	43	12	47	1.383519	0.5381768	68.54755	0.6845

Table 2. The HYCH output results of pre-monsoon groundwater samples in Lekkur sub basin

Sl. No.	Habitation	HANDA'S	CR	Schoeller's	Stuyfzand's	USSL	Gibb's
1	Orangur	Temporary	1.0055	III	Brackish	C4S2	Evaporation
2	M.Pudur	Temporary	0.3517	III	Fresh	C3S2	Evaporation
3	M.Podaiyur	Temporary	0.1597	III	Oligohaline	C3S1	Evaporation
4	Kallur	Temporary	0.2232	III	Oligohaline	C2S1	Rock interaction
5	Nangur R.F	Temporary	0.1003	II	Oligohaline	C3S2	Evaporation
6	Lekkur	Temporary	0.9503	II	Oligohaline	C3S2	Evaporation
7	Alambadi	Temporary	0.6771	III	Fresh-brackish	C3S2	Rock interaction
8	Pulikarambalur	Temporary	0.372	III	Fresh	C3S1	Evaporation
9	Tachchur	Temporary	0.1989	III	Oligohaline	C2S1	Rock interaction
10	Venganur	Temporary	0.6808	III	Fresh	C3S1	Rock interaction
11	Vaidhyanadhapuram	Temporary	0.9781	III	Fresh-brackish	C3S2	Rock interaction
12	Eluttur	Temporary	0.8327	III	Fresh-brackish	C3S2	Rock interaction
13	Near Korukkai	Temporary	0.3242	III	Fresh	C3S1	Rock interaction
14	Alathur	Temporary	1.5679	III	Brackish-salt	C5S4	Evaporation
15	Tholudur	Temporary	0.8599	III	Brackish	C3S2	Rock interaction
16	Vagaiyur	Temporary	0.1332	II	Oligohaline	C3S2	Evaporation
17	Akkanur	Temporary	0.2909	III	Fresh	C3S1	Evaporation
18	Peraiyur	Temporary	1.0002	III	Brackish	C4S3	Evaporation
19	Labbaikudikadu	Temporary	0.6315	III	Fresh	C3S1	Rock interaction
20	Nathamedu	Permanent	0.6845	III	Fresh	C3S1	Rock interaction

Total Dissolved Solids (TDS)

The determination of total dissolved solids is a measure of all salts in solution. The study area water samples of pre-monsoon period show a wide range of TDS values (378 to 3640 mg/l). The TDS values below 1000 mg/l have been observed in 13 locations out of 20, the locations are: (03, 04, 05, 07, 08, 09, 10, 11, 13, 16, 17, 19 and 20). Nearly 65 % of groundwater samples fall under fresh water category according to Davis and De Wiest (1966) classification. Six samples exhibit TDS values between 1000 to 3000 mg/l, which fall under slightly saline water condition. The only water sample that shows higher concentration of TDS more than 3000 mg/l (moderately saline) is from location 14 (Alathur). TDS variations clearly indicate that rainfall plays dominant role in dilution of TDS in groundwater (Aswathanarayana, 2001). The study area pre-monsoon TDS map is shown in Fig. 3.

Total Hardness (TH)

The study area pre-monsoon groundwater hardness is classified into soft water, moderate hard water, hard water and very hard water based on Sawyer and McCarthy (1967). The hard water occupies more areal extent (Figure. 4) comparing with other classes of water. Soft water is exhibited in very limited areal extent, pertaining to two isolated patches near locations 5 and 16. Moderate hard water is exhibited in seven locations; hard water covers major portions (eight locations) of the study area, followed by very hard water which occurs in five locations. Very hard water occupies south, southwest and northwest parts of the region. In general the hardness cannot be removed easily by boiling of water. Excess concentration of total hardness has no adverse effect on health, but it prevents the formation of lather with soap and increases the boiling point of the water (Subbaa Rao *et al*., 2002).

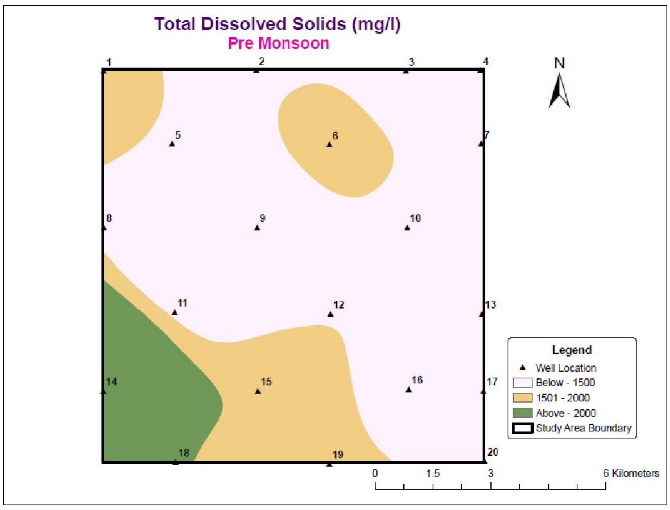

Figure 3. Pre-monsoon TDS map

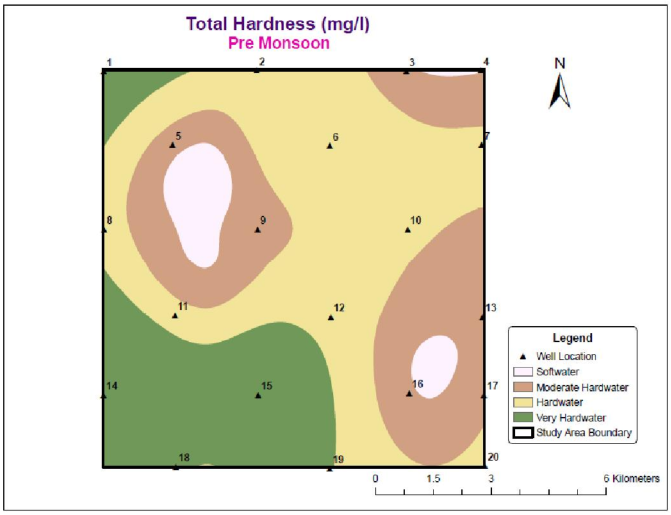

Figure 4. Pre-monsoon total hardness map

Groundwater Type (Schoeller Water Type)

From the *HYCH* output the groundwater types of the study area have been found out according to Schoeller's (1967) water type classification and shown in Figure 5. Based on Schoeller's water type classification, the study area pre-monsoon water samples belong to Type-II and Type-III water. The Type-III water occupies almost 85 per cent of the study area. The Type-II water occurs in three locations (5, 16 and 19) particularly in the northwest and southeast parts of the study area. Type-I and Type-IV water do not occur in the area during pre-monsoon period. As per the Schoeller's water type mode, chloride and carbonate ions are the dominant constituents of the water samples of the study area.

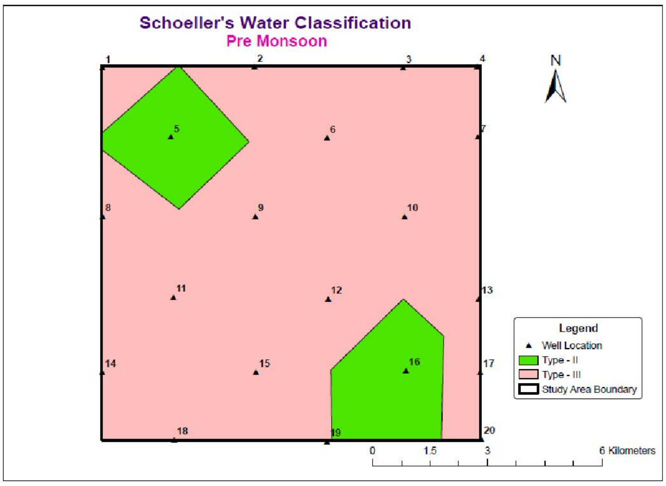

Figure 5. Pre-monsoon Schoeller's water type map

Groundwater Classification (Stuyfzand Classification)

Stuyfzand (1989) has proposed a method for classifying groundwater and identified eight main types on the basis of Cl concentration as given below Table 3.

Table 3. Stuyfzand (1989) classification of groundwater

Main Type	Cl in mg/l	Main type	Cl in mg/l
Very Oligohaline	<5	Brackish	$300\text{-}10^3$
Oligohaline	5-30	Brackish-salt	$10^3\text{-}10^4$
Fresh	30-150	Salt	$10^4\text{-}2.10^4$
Fresh-brackish	150-300	Hyperhaline	$>2.10^4$

From the prepared thematic map (Fig.6) it is inferred that the pre-monsoon water samples of the study area fall under five categories and the details are presented in the Table 4. Regarding chloride concentration, nearly 80 per cent of samples from the study area fall under desirable limit for drinking purpose (250 mg/l) as per ISI-1983 Standard. Remaining 20 per cent samples fall under brackish and brackish-salt category. Generally, the concentration of Cl^- imparts a salty taste to water. For people who are not accustomed to high concentrations of Cl^- in water it may cause a laxative effect.

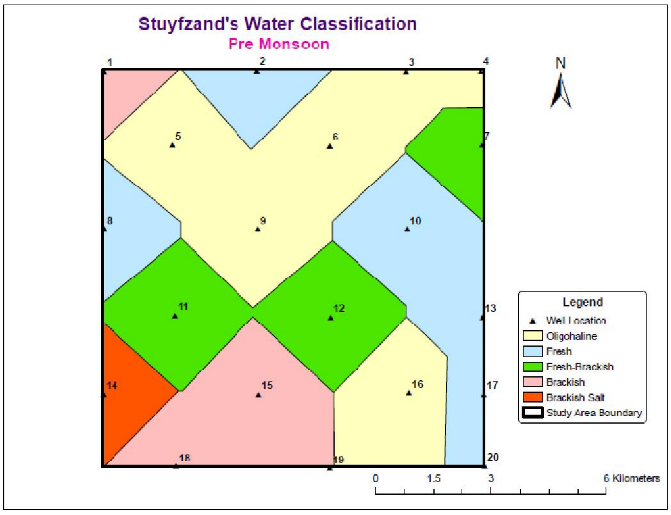

Figure 6. Pre-monsoon Stuyfzand's water classification

Table 4. Number of locations falling in various types of water as per Stuyfzand (1989) classification

Sl. No	Main type	Cl in mg/l	Total No. of Locations	Percentage
1	Oligohaline	5-30	7	35
2	Fresh	30-150	6	30
3	Fresh-brackish	150-300	3	15
4	Brackish	300-10^3	3	15
5	Brackish-salt	10^3-10^4	1	05

USSL Classification

The United States Salinity Laboratory (USSL) has proposed a classification for rating irrigation water with reference to salinity and sodium hazard (Richards, 1954). In USSL classification, the classes C1, C2, C3 and C4 are formed based on salinity. Classes S1, S2, S3 and S4 are designated based on sodium absorption ratio with values < 10, 10-18, 18-26, and > 26 respectively. Water used for irrigation can be rated as C2S1 (medium salinity – low sodium water), C3S1 (high salinity - low sodium water), C3S2 (high salinity – medium sodium water), C3S3 (high salinity – high sodium water) and C4S4 (very high salinity – very high sodium water). According to USSL classification the study area presents six classes of water during pre- monsoon period (Fig. 7), the classes are C2S1, C3S1, C3S2, C4S2, C4S3 and C5S4.

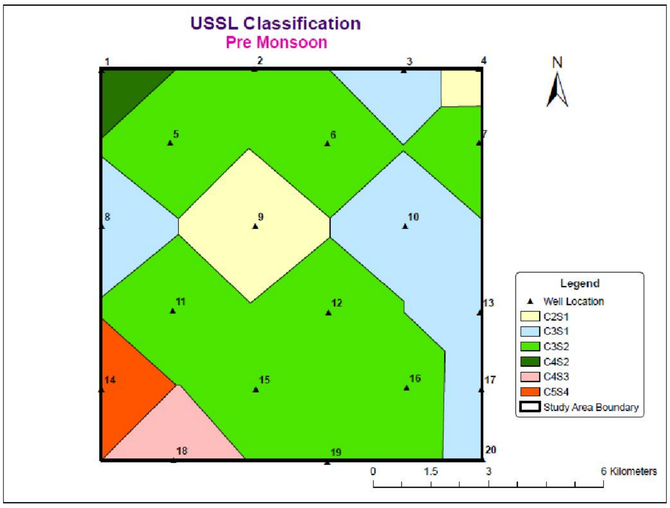

Figure 7. Pre-monsoon USSL classification map

Table 5. Category and locations of pre-monsoon groundwater sample as per USSL classification diagram

Category	Location No.	Percentage
C2S1	04 & 09	10
C3S1	03, 08, 10, 13, 17 & 20	30
C3S2	02, 05, 06, 07, 11, 12, 15, 16 & 19	45
C4S2	01	5
C4S3	18	5
C5S4	14	5

The C2S1 class pertains to two locations (loc.4 and 9); this class of water could be used if a moderate amount of leaching occurs with low risk of developing harmful levels of sodium. The class C3S1 falls in six locations; this class of irrigation water cannot be used on soils with restricted drainage otherwise harmful levels of sodium may be developed. The class is observed C3S2 in nine locations occupying more areal extent of the study area. This type of water may be used on coarse texture or organic soils with good permeability (Karanth, 1989). The C4S2, C4S3 and C5S4 categories fall in one location each (Loc. 1, 18 and 14 respectively). These belong to poor water quality category and the water is not suitable for irrigation under ordinary condition but it may be used occasionally under very special circumstances. The category and locations of pre-monsoon groundwater samples shown in below Table 5.

Corrosivity Ratio

The pre-monsoon period groundwater shows both non-corrosive (CR<1) and corrosive (CR>1) type water (Fig.8). The pre-monsoon non-corrosive water occurs in almost the entire study area except few locations namely 11 (Vaidhyanadhapuram), 14 (Alathur) and 18 (Peraiyur). Non-corrosive type water dominates the study area. The southwest part of the study area exhibits water with corrosivity ratio less than 1 does not corrode metallic pipes and hence metallic pipelines could be used to convey water with corrosivity ratio less than 1. Water with corrosivity ratio greater than 1 corrodes metallic pipes, and in such cases, non-corrosive PVC pipes could be used to transmit water. In the said few locations of the study area exhibiting corrosive water, non-corrosive PVC pipes can be used to convey water for irrigation or domestic purpose.

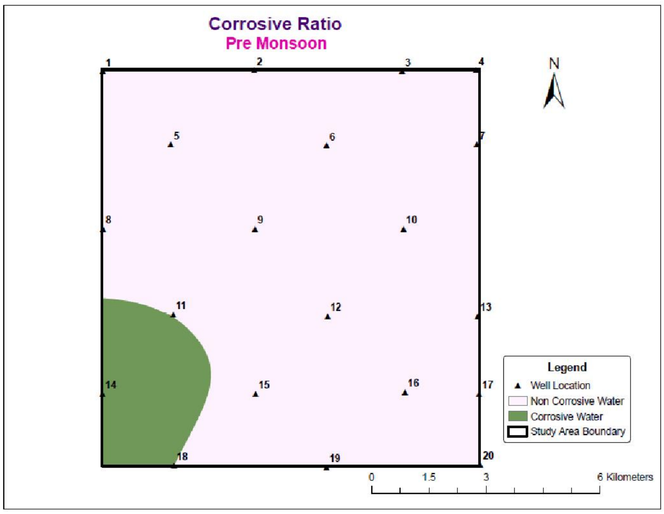

Figure 8. Pre-monsoon corrosive ratio map

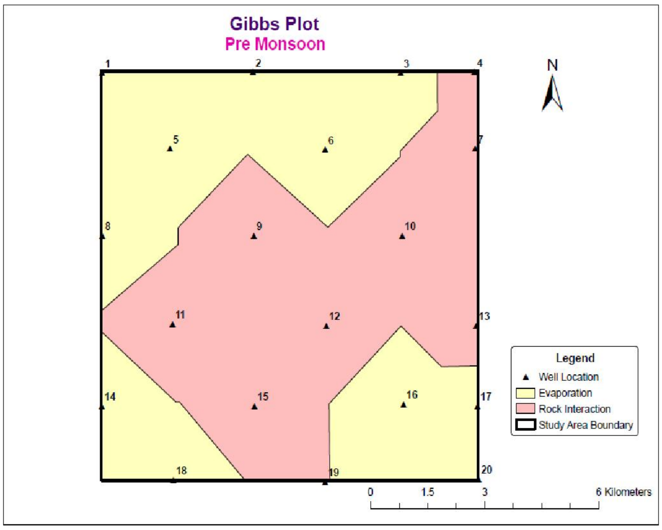

Figure 9. Pre-monsoon Gibbs plot

Gibbs Plot

According to Gibbs plot the pre-monsoon season water samples indicate evaporation and rock-water interaction processes. Evaporation category samples are observed in eleven locations, whereas rock water interaction type samples are noticed in nine locations (Fig.9). Rock water interaction category samples occupy the northeast, central, eastern, southern and western parts of the study area. Remaining portion is covered by evaporation category. During pre-monsoon period, in the study area, rock-water interaction is main process that influences the quality of groundwater.

Conclusions

The assessment of groundwater quality zones in the study area Lekkur sub basin by using *HYCH* program shows that the pre-monsoon groundwater physico-chemical properties are well within the permissible limits except carbonate ion. Regarding TDS concentration, about sixty five percent of groundwater samples fall in fresh water category. According to Sawyer and McCarthy (1967), the hard water occupies more areal extent in pre-monsoon season. Based on Schoeller's (1967) water type classification Type-III water occupies almost 85 per cent of the study area, remaining occupied by Type-II water. The Type-I and Type-IV water do not exist in the area during pre-monsoon period. This indicates that chloride and carbonate are the predominant ions in the groundwater of the study area. According to Stuyfzand's (1989) classification it is noted that chloride concentration of eighty per cent of pre-monsoon samples lies within desirable limit for drinking purpose. As per ISI-1983 standard, the chloride concentration in drinking water should be within 250 mg/l. Remaining 20 per cent samples fall under brackish and brackish-salt categories.

USSL classification of the pre-monsoon water samples, 10 per cent of water samples fall under good category (C2S1), 30 per cent of samples fall under moderate category (C3S1) and 60 percent of water samples belong to poor quality water categories (C3S2 and C5S4). Non-corrosive water dominates the area (85 %). Gibbs plot reveals that rock-water interaction is the main process operating in the northeast, central, eastern, southern and western parts of the study area. The remaining portion experiences evaporation process. From *HYCH* program output and spatial data analysis it is observed that the southwestern parts of the study area are found to have poor quality of groundwater comparing to other parts. It is to conclude that artificial recharge to groundwater through scientifically designed structures at geologically favourable locations could be implemented to improve the groundwater quality in the sub basin area.

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