GISBASED STUDY ON GEOCHEMICAL CHARACTERIZATION OF GROUNDWATER IN AND AROUND VILATHIKULAM REGION OF THOOTHUKUDI DISTRICT, TAMILNADU, INDIA

Article Particulars: Received: 12.01.2018 Accepted: 18.01.2018 Published: 20.01.2018

U.KUTTALINGAM, A.V.UDAYANAPILLAI & M.THANGAVEL
P.G Studies and Research Department of Geology
V.O.C College, Thoothukudi, Tamil Nadu, India

D.MURUGAN
Deparment of Computer Sciences and Engineering
M.S University, Tirunelveli, Tamil Nadu, India

Abstract

The GIS based evaluation of geochemical studies of groundwater was carried out in the sedimentary and metamorphic terrain area of Vilathikulam region, Thoothukudi district,Tamilnadu,India.The geological setting of the study area is given.The average analytical data of 21 groundwater samples from the open wells as well as from the bore wells, for the period of both pre monsoon and post monsoon,such as P^H,EC,TDS,cations Na^+,Ca^{2+},Mg^{2+},K anions HCO_3^-,SO_4^{2-},Cl^-,F and NO_3 were tabulated.The ArcGIS 10.1 software was used for the generation of the various thematic maps.The interpolation techniques such as Inverse Distance Weighting (IDW) method were used to obtain the spatial distribution of integrated parameters of groundwater quality maps.These water analysis data was processed by using a computer programme Hych. Based on the output of this programme, Handas classification, Corrosivity Ratio, Schoellers classification, Stuyfzand classification, USSL classification, Gibbsmechanisms, Sodium Adsorption Ratio, Residual Sodium Carbonate, Permeability Indexand Piper classification of groundwater in geochemical studies were discussed.Various thematic spatial maps were prepared for the Hych output.

***Keywords**: Cations, Anions, IDW, HYCH, Spatial maps*

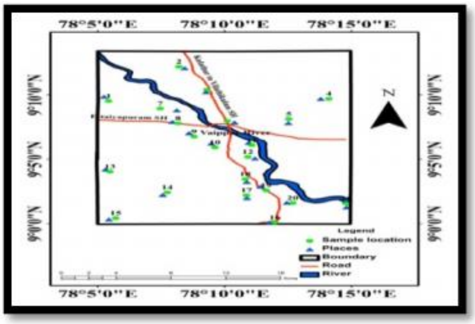
Introduction

Groundwater is more vital and widespread resources of the earth.Due to the rapid urbanization over population density and environmental degradation, waterstress, is emerging as a real threat throughout the world.Many places of our country have also already been under severe water stress (Kaliammal and Udayanapillai, 2016). The quality of groundwater is highly affected spatially and temporally by various factors such as lithology, chemistry, rock water interaction, pollution and sea water ingress (Udayanapillai et al 2012, 2016).These above complex processes make different hydrogeochemical condition occurring in the various rock types from the ages of Archean crystalline rock to Recent alluvium. There are many villages located near Vilathikulam region of thoothukudi district, utilizing groundwater long time for domestic and irrigation purposes. Keeping with this aim in mind for the welfare of the people of the study area, an attempt was made in this paper to evaluate the geochemical studies of groundwater utilizingGIS based techniques. Additionally, the analytical data was processed by the using computer programmHYCH (Balasubramanaian et al 1991b).Later many researchers utilized this computer programm for groundwater quality analysis (Lawrence, 1995; Senthilkumar et al 2015; Balasubramanaian et al 2015; Balaguru and Senthilkumar, 2013; Senthilkumar et al 2014). This complied computer programm helps in the interpretation of groundwaterquality based on the water chemistry facies, mechanisms of origin, types, suitability and usage of factors, likeCorrosivity and Permeability.

Study Area

The study area is situated within the Vaippar river basin and extends over a distance of 453 sq.km located around by Vilathikulam region, Thoothukudi district of Tamilnadu, India.Vilathikulam is located at the distance of 45 km from Tuticorintown. The area is well connected with good roadnetworks.It falls in the survey ofIndia toposheet no 58 k\4, prepared in the scale of 1:50,000.It encompasses within the latitudefrom 9° 0’N to 9° 10’ Nand longitudefrom 78° 5’ E to 78° 15’ E (Fig-1). Physiography of the study area is generally flat and plain with the top covered by soil outcrop.The topographical relief ranges from 11m to 38 m above the MSL. The average annual rainfall is about 661 mm of which more than 80% is received during north-east monsoon. The ephemeralriver Vaippar River flows northeast-southeastdirection in the centre part of the study area. The drainage pattern is mostly dendritic. The drainage slope direction is generally towards south east direction. The area experiences the arid and semi-arid climate withthe temperature ranges from 25°c to 38°c, whereas the average relative humidity of the study area is 65%. Rain fed tank and well irrigation is generally practiced in most part of the study area.The geomorphology of the study area consists of old river alluvium on either side of the Vaippar river, pediments and burried pediments in the western part and palaeo-sedimentary basin in the eastern part and inlandteri sand dune in the south east corner of the study area.

Fig 1 Location Map of the Study Area



Geological Setting

The Proterozoicbasement rocks consist of quartzite, meta- sedimentary crystalline limestone, calc-granulite, hornblende biotite gnesis, charnockite or pyroxene granulite and later intrusion of pink granite, white granite and pegmatite veins. The weathered, fissured, cracks, shear zones and joints in the basement rocks act as a good groundwater potential zone in the study area. The Proterozoic rock is overlain by thick regolith calcrete or duricrust outcrop which is believed to the age of the Holocene to Pleistocene age. Calcrete is overlain by the black soil and the detached batches of redor terisand dune. In the eastern part, the palaeo –tertiary sedimentary basin is associated with basement of Proterozoic formation. The tertiary sedimentary basin consists of argillaceous and arenaceous shell limestone covered by the top black soil and detached batches of red Teri sand dunes in the southeast cornerpart. The general stratigraphic succession of the studyarea is shown (Table-1).

Table 1 The General Stratigraphic Succession of the Study Area

Strata	Thickness	Age	Depth
Black soil/ Teri soil	1.25 m	Recent	1.25 m
Calcrete layer	1.20 m	Holocene to Pleistocene	1.25-2.45 m
Argillaceous / Arenaceous L.St	1.20-60 m	Tertiary	2.45-25 m
Sap rock or basement rock	Infinitive	Proterozoic	Below 25 m

Material and Methods

Twenty one representative groundwater samples collected during both pre-monsoon and post monsoon periods were analysed by adopting the standard analytical procedure (APHA, 1998). As there is no abnormal variationin both seasons, the average data of both seasons are taken into the consideration for geochemical distribution (Table-2). Physical parameters such as P^H,TDS and EC,cations Ca^{2+},Mg^{2+},Na^{+} and K^{+},anions HCO_3^-,SO_4^-,Cl^-,F^- and NO_3^- of the groundwater samples were analysed.TheGIS based geospatial iso quality distribution contour maps by using Arcgis10.1 software for the integrated parameters of cations Ca^{2+} and Mg^{2+}, Na^{+} and K^{+},and anions HCO_3^-,SO_4^-,Cl^-(Fig.2a-c)are prepared by the IDW interpolation techniques and overlay analysis. Then, the computer programme HYCH was used for the water quality interpretation based on the water chemistry,facies,mechanisms of origin,types, suitability and usage factors like corrosivity and permeability. The flow chart of HYCH programme is shown in Fig-3. Then, with the help of output results (Table-3).GIS based thematic maps such as the charactersof Total Dissolved Solids, Total Hardness, Schoellers water type classification, Stuyfzand classification, USSL classification, Corrosivity ratio,Gibbs plot and Piper plot have been generated and discussed in details.

Spatial distribution of Cations and Anions

The analytical values of the parameters of cations Ca, Mg, Na and K, anions HCO_3, SO_4 and Cl are given Table-2.The spatial distribution maps for the integrated parameters of Ca- Mg, Na-K and HCO_3- SO_4– Cl are shown in the figure(2a-c). The spatial map of Ca-Mg level of < 200 ppm covers, more areas predominantly than the other values, whereas Na-K level of < 50 ppm spatial distribution covers the maximum areas than the other values. The spatial distribution map of integrated parameters of HCO_3- SO_4- Cl indicates that the level of 250ppm -500 ppm range of above parameter covers, more areas predominantly than the other level values. Dissolution of calc-granulite, crystalline limestone, shell limestone and weathering of Hornblende – Biotite Gnesis ,Charnockite, Granite, Calcrete, Black soil and Red soil causes for the all sources in ground water of the study area. This has been supported by many researchers (Garrel.1976; Lakshmanan et al 2003; Al-Katheeri et al 2009; Ayyandurai et al 2011; Udayanapillai et al 2012; Kaliammal and Udayanapillai, 2016)

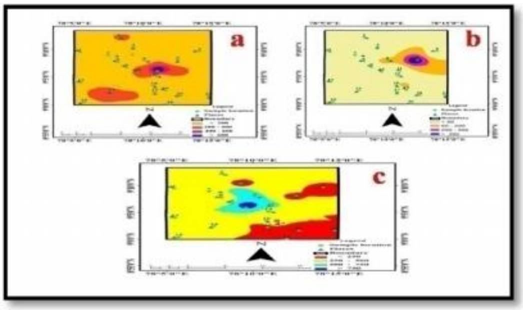


Fig-2. Integrated parameter maps of the study area.a- Ca^{2+} and Mg^{2+}, b- Na^{+} and K^{+}, c- HCO_3^{-},SO_4^{-}andCl.

Table 2 The Average Data both Pre Monsoon and Post Monsoon of the Groundwater Samples (Values in ppm)

Location	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	No_3	TDS	PH	EC
Guruvarpatti	168	60	26.4	18	288	103	145	1.5	12	673	7.3	1198
AyanBommiapuram	140	94	25	12	193	150	102	1.5	73	697	7.5	1850
Sengalpadai Jamin	174.4	102	50	5	698	400	200.0	0	1.9	1278	8.2	4640
Kamalapuram	22.4	10	30	13	342	175	156	0	0.2	573	8.2	1210
K.Subramaniyapuram	126.4	64	40	5	317	755	652.3	0	0	1800	8.1	4000
Chittayanayakanpatti	161.6	102	30	5	476	113	105	0	0	748	7.9	3887
Pillayarnatham	19.2	9	35	1	354	36	14.2	0	0.5	290	8.4	712
Keela vilathikulam	32	18	54	2	207	180	142.5	0	0	530	7.8	1062
Sangurunatham	51.2	36	376	16	220	150	794.1	0	0.2	1534	8.1	2649
Vilathikulam	38	19	150	15	451	418	28.4	0	0	894	8.5	1354
Kottanatham	604	302	60	7	427	520	680	0	0	2381	8	1241
Mandikulam	99.2	45	45	3	305	412	227	0	0	983	8.1	1917
Athanur	122	61	112	20	327	322	414	1.5	40	1249	7.2	1873
Sakkamalpuram	216	108	54	18	325	290	402	1.4	56	1308	7.5	2158
Suppalapuram	220	110	58	20	330	295	410	1.4	59	1337	7.5	2225
Kumarasakkanapuram	20	12	22.5	10	173	21	30	1.5	0	200	7.2	418
Vadamalaisamudram	49.6	20	164	6	244	145	382.9	0	0	883	8.4	1538
Poosanoor	12	5	50	1.5	383	50	70	1.5	1.5	382	7.5	627
Kulathoor	176	80	60	14	233	577	815	1.5	9	1849	7.2	2742
Puliankulam	88	44	47.5	14	122	371	335	1.5	5.6	964	7.7	1425
Vaippar-1	16	8	24.5	5	122	35	50	1.5	7.6	203	7.5	335

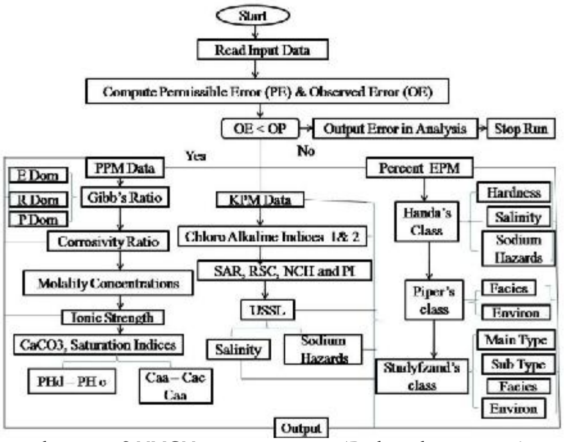


Fig-3.The flow charts of HYCH programme (Balasubramanaian et al 1991b)

Table-3 HYCH output data

S.No	Habitation	HANDA's classification	CR	Schoeller classification	Stuyezand classification	USSL	GIBB'S	SAR	RSC	PI	Piper
1	Guruvarpatti	Permanent	1.09	III	Fresh	C3S1	Rock interaction	0.63	-4.91	32.35	Static and disco-ordinate regimes
2	AyanBommiapuram	Permanent	1.55	II	Fresh	C3S1	Rock interaction	0.47	-6.08	27.12	Static and disco-ordinate regimes
3	Sengalpadai Jamin	Permanent	1.00	II	Fresh-brackish	C5S1	Evaporation	0.93	-10.83	25.51	Static and disco-ordinate regimes
4	Kamalapuram	Permanent	1.18	III	Fresh-brackish	C3S1	Rock interaction	3.61	-1.27	66.8	Static and disco-ordinate regimes
5	K.Subramaniyapuram	Permanent	5.38	III	Brackish	C5S1	Rock interaction	1.38	-28.34	20.24	Water contaminated with gypsum
6	Chittanayakkanpatti	Permanent	0.56	III	Fresh	C4S1	Rock interaction	0.45	-4.13	29.81	Static and disco-ordinate regimes
7	Pillaiyarnatham	Temporary	0.16	II	Oligohaline	C2S1	Rock interaction	2.48	2.24	83.23	Dissolution and mixing
8	Kila vilathikulam	Permanent	1.88	III	Fresh	C3S1	Rock interaction	2.81	-2.76	61.03	Static and disco-ordinate regimes
9	Sangurunatham	Permanent	5.79	IV	Brackish	C4S3	Rock interaction	11.69	-3.47	82.19	Water contaminated with gypsum
10	Vilathikulam	Temporary	1.05	II	Oligohaline	C3S2	Evaporation	6.89	1.93	83.72	Dissolution and mixing
11	Kottanatham	Permanent	3.51	III	Brackish	C5S2	Rock interaction	0.44	-28.01	12.14	Water contaminated with gypsum
12	Mandikulam	Permanent	2.46	II	Fresh-brackish	C3S1	Rock interaction	1.34	-11.01	30.71	Water contaminated with gypsum
13	Athanur	Permanent	2.81	III	Brackish	C3S1	Rock interaction	2.93	-10.66	43.65	Water contaminated with gypsum
14	Sakkamalpuram	Permanent	2.67	III	Brackish	C3S1	Rock interaction	1	-14.34	23.86	Water contaminated with gypsum
15	Suppalapuram	Permanent	2.68	III	Brackish	C3S1	Rock interaction	1.072	-14.62	24.41	Water contaminated with gypsum
16	Kumarasakkanapuram	Temporary	0.37	III	Fresh	C2S1	Rock interaction	1.56	0.49	83.54	Dissolution and mixing
17	Vadamalaisamudram	Permanent	2.83	III	Brackish	C3S2	Rock interaction	6.46	-2.26	75.92	Water contaminated with gypsum
18	Poosanoor	Temporary	0.39	III	Fresh	C2S1	Rock interaction	5.36	3.43	96.28	Dissolution and mixing
19	Kulathoor	Permanent	7.51	III	Brackish	C4S1	Rock interaction	1.68	-28.34	22.35	Water contaminated with gypsum
20	Puliankulam	Permanent	7.04	III	Brackish	C3S1	Rock interaction	1.78	-12.39	32.33	Water contaminated with gypsum
21	Vaippar-1	Permanent	0.88	III	Fresh	C2S1	Rock interaction	1.87	-0.19	81.38	Static and disco-ordinate regimes

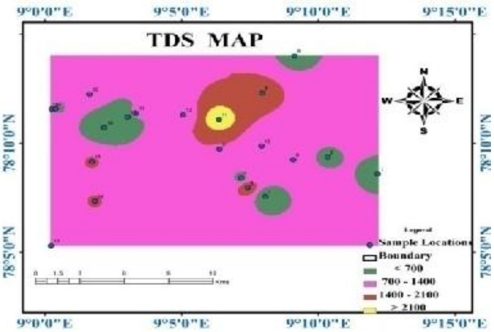
PH and EC

The average data of the P^H and EC values of two seasons various from 7.2 to 8.5and from 335 цmho to 4640 цmhorespectively .The P^H level falls within the recommended limit of 6.5 to 8.5 for human consumption (Senthilkumar et al 2015). Electrical conductivity is a parameter related to TDS (Kaliammal and Udayanapillai 2016). The importance ofelectrical conductivity is an indirect measure of salinity (Langengger 1990; Gnanachandrasamy 2014). According Langenggerclassification 1990, based on the EC values,0-330 цscm as excellent; 333-500 цscm good;500-1100 цscm permissible;1100-1500 цscm brackish;1500-10000 цscm saline.As per the study, 52% of samplesfall in the saline category,whereas 24% of wells and another 24% of wells fall in the permissible and excellent categories respectively. The presence of more salinity categories may be due to the inland salinity from the palaeo-coastal tertiary sub surface outcrop.

TDS

TDS means total concentration of the all constituentsdissolved in water (Kaliammal and Udayanapillai 2016). Many researchers discussed the drinking water and other water quality standards (Caroll 1962; Todd 1980; Wilcox 1995; ICMR 1975; Freeze et al 1979). But the desirable and permissible limit of TDS values of drinking ofBIS and WHOstandards are 500 – 2000 ppm and 500 – 1500 ppm respectively. Nearly 80% wells (Fig-4)fall within the limit of WHO standards of desirable to permissible categories. The low TDS content is generally observed in the recharge areas.

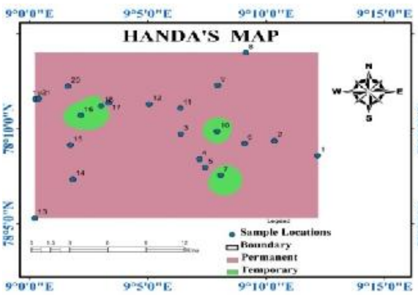
Fig 4 The spatial distribution of the TDS map



Total Hardness

Hardness is a complex mixture of cations and anions (Senthilkumar et al 2015). Hardness results from the presence of divalent metallic cation of which Ca and Mg are the most abundant in groundwater (Vaithyanathan, 2004).There are two types of hardness in groundwater namely temporary and permanent. Temporary hardness is formed by the Calcium or Magnesium carbonate. But sulphate and chlorite makes the water as permanent hardness water or NCH. According Handasclassification, the entire sample falls in the temporary hardness categories (Fig-5). Thehardness less than 50 is considered as a soft water.

Fig 5 The average distribution map of the Handa's classification



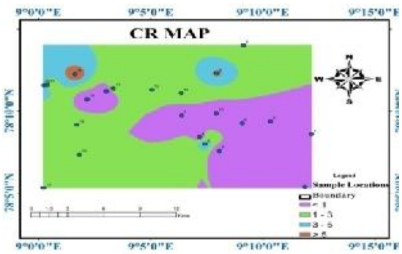
Corrosivity Ratio

Corrosion is an electrolytic process which corrodes metallicmaterials. The Cl, SO_4, CO_3, and HCO_3 are determinative ions in the Corrosivity ratio (Ryzner, 1944). The Corrosivity ratio is calculated using the formula as mentioned below

Corrosivity ratio (CR) = $Cl\ (Mg/L)/35.5 + 2SO_4\ (Mg/L)/96\ /\ 2[CO_3+HCO_3/100]$ mg/l

If CR is < 1, then the water is non corrosive and if the CR> 1, then the water is corrosive nature. From the HYCH output, the average spatial distribution map of the corrosivity ratio of groundwater for the two seasons is given (Fig-6). Thirty eight percentages of wells show corrosivity ratio < 1, whereas another thirty eight percentage of wells show the corrosivity ratio from 1 – 30. The 14% wells and 10% of wells show the high corrosivity ratios as 3-5 and > 5 respectively. In general, sixty two percentage of wells show more corrosive nature in the metallicpipes. So, corrosive water canbe transported only through PVC pipes.

Fig-6 The Average Distribution map of the Corrosivity Ratio



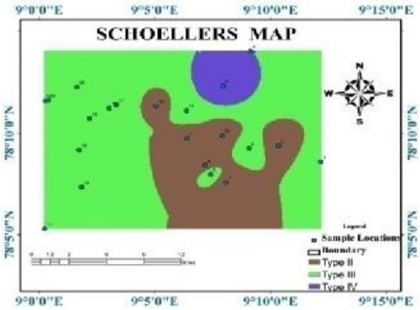
Schoellers Classification

From the Hych output, the groundwater types of the study area are formed according to Schoellers water type classification.Schoellers has already described that the first and foremost waters are those in which

1. rCO_3> rSO_4→ Types I
2. Asthe total concentration increases, the above relation becomes
3. r SO_4> r Cl →Type II
4. Still at the higher concentration, the water may change to
5. r Cl >r SO_4> r CO_3→Type III
6. And in these final stages,the relation would be
7. r Cl > r SO_4> r CO_3 and r Na > r Mg > r Ca → Type IV

The spatial map of the schoellers water types are shown in (fig-7).The study area falls in the type ii, type iii and type iv and theirpercentage of area covered wells are 57%,33% and 10% respectively. Since the study area is associated with metamorphic and tertiary marine sedimentary belt and black soil coverage. The major portion of the study area shows 57% type ii of groundwater.

Fig-7 The Spatial Map of the Schoellers Water Types



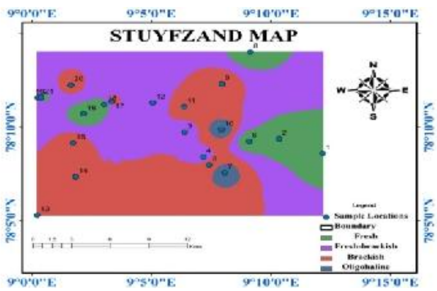
Stuyfzand classification

Stuyfzand (1986) has classified as groundwater based on the chloride concentration as given below.

S.No	Main type	Cl in mg\l	No of wells	(%)
1	Very Oligohaline	< 5	0	0
2	Oligohaline	5-30	2	10
3	Fresh	30-150	7	33
4	Fresh-brackish	150-300	3	14
5	Brackish	300-103	9	43

From the spatial thematic map (Fig-8) The samples of the study area fall in the categories of Oligohaline, fresh, fresh-brackish and brackish salt nature. Both brackish and fresh-brackish types are predominant in the study area due to the area coverage occurs in the hard metamorphic rock andpalaeo-coastal marine tertiary formation.

Fig-8 The spatial map of the Stuyfzand classification

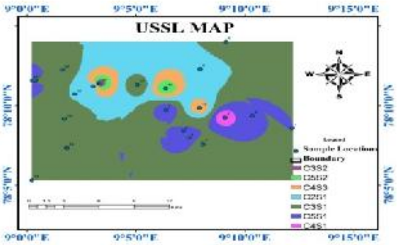


USSL classification

The spatial thematic distribution map of the study area was prepared (Fig-9), based on the United States Salinity Laboratory (USSL)classification. Thisclassification is based on the Salinity and Sodium Hazards classification (Richard, 1954).The classes C3S1 (high salinity and low sodium water) predominate over the other classes (42.9%) in the study area. The order of predominant classes in the study area are represented in the descending order as follows

1. C3S1 –Medium to High salinity and Low sodium - 42.9 %
2. C2S1 - Moderate salinity and Low sodium - 19%
3. C5S1 - Very high salinity and Lowsodium - 14.3%
4. C3S2 - Medium to High salinity and Medium sodium - 9.5%
5. C5S2 - Very high salinity and Medium sodium - 4.8%
6. C4S3 - High salinity and High sodium - 4.8%
7. C4S1 - High salinity and Low sodium - 4.8%

Fig-9 The Spatial Thematic Distribution Map of the USSL Classification



Piper

From the HYCH output data of piper classification different environmental condition of groundwater are classified as Recent Recharge water, Ion Exchange, Recent Dolomitic waters, Static and Disco-ordinate Regimes,Dissolution and Mixing, Dynamic and Co-ordinate regimes (Balasubramanaian et al 1996b).The HYCH output of piper data of the study area reveals that 48% of well falls in the environmental condition of water contamination with gypsum, 33% of well covers the environmental condition of static and disco-ordinate regimes and remaining 19% of well falls in the dissolution and mixing environment(Fig-10). Since the study area encompasses both sedimentary and metamorphic terrain, such above environmental condition of groundwater is obtained.

Gibbs plot

From theHYCH output, the mechanisms that controls water chemistry (Gibbs, 1970) in the study area was evaluated based on the Gibbs ratio and a spatial distribution map was prepared (Fig-11). Numeraous researchers have discussed the Gibbs mechanism (Mackenzie and Masoud Eid Al-Ahmadi, 2013; Srinivas et al 2011; Ramesh and Thirumangai, 2014; Senthilkumar et al 2014; Udayanapillai et al 2012 and 2014; Senthilkumar et al 2015). The high TDS concentration indicates that there is a limited dilution process by soil leaching by surface water or meteoric water (Udayanapillai and Kaliammal, 2016). Majority of the well falls on the field of rock water interaction dominance followed along with the little evaporation dominancecharacters. The presence of the more thickness of calcrete profile in the regolith part of the study area proves that the evaporation activity of groundwater involved under tropical climate conditions.

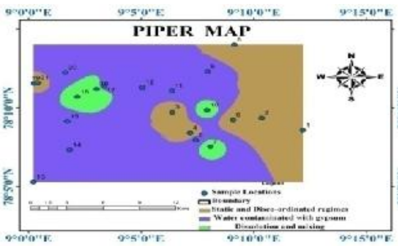


Fig-10.The spatial thematic distribution map of the Piper classificationion

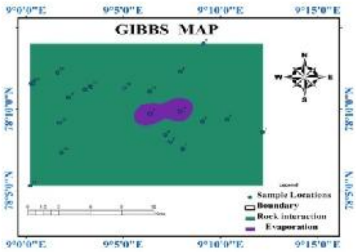


Fig-11.The spatial thematic distribution map of the Gibbs classificat

SAR, RSC and PI

From the Hych output of SAR, RSC and PI,the thematic spatial maps were prepared respectively (Fig-12, 13 and 14).The SAR, RSC and PI have been used to the check for the suitability of groundwater for irrigation.The SAR values of the area generally show (< 10) range which indicates excellent categories for the irrigation. The RSC values of the area show (< 1.25) which indicategood for irrigation. The Permeability Index (Doneen, 1962) falls on the classes of ii and iii (0-72 and 70-120). Many of the wells of the study area are estimated as good for agriculture quality.

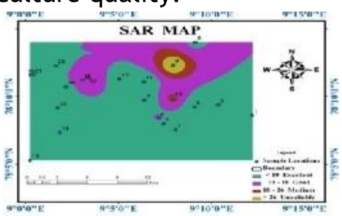


Fig-12 SAR thematic Spatial Maps

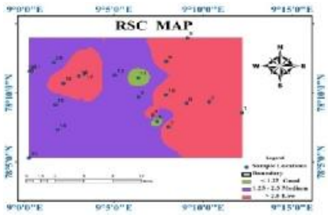
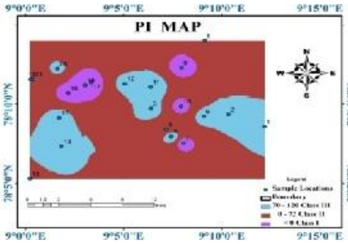


Fig-13 RSC thematic Spatial Maps

Fig 14 PI thematic Spatial Maps



Summary and conclusions

The average data of both pre monsoon and post monsoon groundwater samples quality assessment has been done in Vilathikulam region of Tuticorin district during 2015. The overall assessment of the study reveals that 80% wells fall within the limit of WHO standards of desirable to permissible categories and the occurrence of fresh water is generally observed in the recharge areas. According to Handas classification 76% of wells show permanent hardness The Corrosive Ratio study elucidates that 60% wells reveals corrosive nature in metallic pipes. Schoellers classification study indicates that 57% of groundwater shows type II which dominates over other types. The Stuyfzand classification illustrate that brackish and fresh – brackish types are pre-dominant in the study area. The USSL classification manifests the predominance of C3S1 categories (42.9 %) and cover with Medium to High salinity and Low sodium. The Gibbs mechanism reveals that rock-water interaction dominance followed along with little evaporation dominance characters. The Piper analysis from the HYCH output indicates the predominance character of the water contamination with gypsum (48%) in the study area. From the HYCH output of SAR, RSC and PI character, it is established that the ground wells of the study area is generally good for agriculture utility.

References

1. APHA (1995). Standard method for the examination of waste and wastewater, 19th edition American Public Health Association, WASHINGTON, D.C.
2. Ayyandurai R, Suresh M and Venkateswaran S (2013). Evaluation of Groundwater for Irrigational Purposes in Cumbum Valley Theni District Tamilnadu, India. International Journal of Innovative Technology and Exploring Engineering (IJITEE) 2(3), p. 182-185.
3. Al-Katheeri E.S, Howari F.M and Murad A.A (2009). Hydrogeochemistry and pollution assessment of quaternary-tertiary aquifer in the Liwa area United Arab Emirates. Environment Earth Science 59, p. 581-592.
4. Balasubramanaian A, Subramanian S and Sastri J.C.V (1991b). Hych-Basic Computer Program for Hydrogeochemical Studies, Proc. Vol. Nat. Sem. On Water. Govtof Kerala, Trivandrum.
5. Balasubramanaian N, Sivasubramanian P, John Prince Soundranayagam N, Chandrasekhar N and Gowtham B (2015). Groundwater classification and its suitability in Kadaladi, Ramanathapuram,India, Using GIS techniques. Environmental Earth Sciences, Volume 74, Issue 4, pp. 3263-3285.
6. Bureau of Indian Standard (BIS) (2012). Indian Standard specification for drinking water Delhi BIS, IS 10500, 2-4.
7. Balaguru M and Senthil Kumar G.R(2013). Groundwater quality impact assessment on lekkur sub basin using hych program: a case study from Tamilnadu, India. International Journal of Current Research Vol. 5, Issue, 12, pp.3950-3956.
8. Carroll D (1962). Rainwater as a chemical agent of geological processes – a review, us geological survey of water supply paper, 520-f, pp.97-104
9. Doneen L.D (1962). The influence of crop and soil on percolating water *in* Schiff, Leonard, ed., Biennial conference on ground-water recharges proceedings, 1961: U.S. Dept. Agriculture, Southwest Branch, Soil and Water Conserve. Research Div, 7 p.
10. Gibbs R.J (1970). Mechanisms controlling worlds water chemistry, sciences 170, pp.1088 -1090.
11. Freeze R.A and Cherry J.A (1979). Groundwater potential hall, Inc New Jersey, p.604.
12. Gnanachandrasamy G, Ramkumar T, Venkataraman S, Vasudevan S, Chung S.Y and Bagyaraj M (2014), Accessing groundwater quality in lower part of Nagapattinam district Southern India usinghydrogeochemistry and GIS interpolation techniques, Applied Water Science, pp.1-17.
13. Garrels R. M (1976). A survey of low-temperature water-mineral reactions. In Interpretation of Environmental Isotope and Hydrochemical Data in Ground-Water Hydrology. Vienna International Atomic Energy Agency p. 65-84.
14. ICMR (1975). Manual of Standards for drinking water supplies Indian Council of Medical Research New Delhi, 44.
15. Kaliammal M and Udayanapillai A.V (2016). GIS Based Evaluation on Geochemical Studies of Groundwater in and around Pandalgudi region of Viruthunagar District, Tamilnadu, India. Int. Res. J. Environment Sci. Vol. 5(2), pp.1-11.

16. Lakshmanan E, Kannan R and Kumar M. S (2003). Major ion chemistry and classification of hydrochemical processes of groundwater in a part of Kancheepuram District Tamilnadu India. Journal of Environmental Geosciences 10(4), p. 157-166.
17. Lawrence J.F (1995). Digital Evaluation of Ground Water Resources in Ramanathpuram District, Tamilnadu, unpublished Ph.D Thesis, M.S University., Tirunelveli, 291p.
18. Masoud Eid AL-Ahmadi (2013).Hydrochemical characteristics and evaluation of groundwater quality in Wadi as Sab'an Weatern Saudi Arabia. International Journal of Scientific & Engineering Research, 4(1).
19. Ramesh K and Thirumangai V (2014). Trace metals contamination of groundwater in and around Tannery industrial area of Pallavaram, Chennai city India. International Journal of Research in Engineering and Technology 3(5), p. 163-169.
20. Richards (1954). Diagnosis and improvement of saline and alkali soils, U.S, Dept of Agri Hand Book, No.60, U.S. Govt of Printing Office, Washington, D.C.
21. Ryzner J.W (1944). A new index for determining amount of calcium carbonate scale formed by a water, Jour, Amer, W.W, Assn,36, pp.472-486.
22. Senthilkumar G, Ramanathan A.L, Nainwal H.C and Chidambaram S (2014). Hydrogeochemical Characteristics and Evolution of Coastal Groundwater at Cuddalore Area Tamilnadu India. International Journal of Engineering Research and General Science 2(2), p. 235-240.
23. Senthilkumar G.R, Nsengimana Serge and Uwamungu Placide (2015). Chemical characteristics and groundwater quality assessment in Mangalore Block, Cuddalore District. International Research Journal of Engineering and Technology (IRJET), Vol.02, Issue.05, pp.950-959.
24. Srinivas Y, Hudson Oliver D, Stanley Raj A and Chandrasekhar N (2014). Quality assessment and hydrogeochemical characteristics of groundwater in Agastheeswaram taluks, Kanyakumari district Tamilnadu India, Chin. Journal of Geochemistry, 33, 221-235.
25. Stuyfzand P.J (1989). A new hydrochemical classification of water type, Proc, IAHS 3 Science Association, Baltimore, U.S.A, pp.33-42.
26. Todd D.K (1980). Groundwater hydrology (2^{nd} edn): John Wiley and Sons, New York, 535 P.
27. Udayanapillai A.V, Venkataraman P, Jeyaranjeetham J and Perumal V (2012). Geochemistry of Groundwater in and around Vilathikulam and Ottaipidaram Taluks, Thoothukudi District, Tamilnadu, India, Journal ofOutreach, 5, pp.113-116.
28. Udayanapillai A.V, Selvam S, Balasubramanaian T, Emi Princess Prasanna A, Venkataraman P, Manimaran G and Sivasubramanian P (2014). Geochemistry of Groundwater in and around Petmanagaram, Thoothukudi district, Tamilnadu, India, Journal of Outreach, III, pp. 46- 50.
29. Udayanapillai A.V and Kaliammal M (2016). Groundwater Characterization and Quality Assessment by using GIS and Geo Statistics from Pandalgudi Region, Viruthunagar District, Tamilnadu, India. International Journal of Research in Environmental Science (IJRES) Volume 2, Issue 4, pp. 1-16.
30. Wilcox L.V (1995). Classification and use of irrigation waters, US Department of Agriculture, Washington DC, 19.
31. WHO (2004).Guidelines for Drinking Water Quality, Third Edition,World Health Organization,Geneva.