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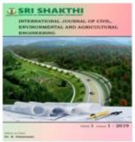

Assessment of seasonal groundwater quality using CHIDAM software in Virudhunagar district of Tamil Nadu.

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Abstract: Hard rock aquifer is the most predominant in the southern peninsula exclusively in Tamil Nadu, India. Virudhunagar district is situated in the South west part of Tamil Nadu, mostly of hard rock topography. Groundwater plays a major role in this area contributing to domestic, irrigation and industrial practices. Running down of groundwater by extreme consumption and less recharge in the study area has reduced the level of groundwater. On the other hand, intensive domestic, agriculture and industrial practices impacts the quality of quality of groundwater as well. Hydro geochemistry plays an important role in evaluation of suitability of groundwater for its usage in several purposes. A total of 72 samples from North East Monsoon (NEM) and Post Monsoon (POM) has been analyzed hydrochemically. The irrigation quality parameters such as sodium adsorption ratio (SAR), %Na, Residual Sodium Carbonate (RSC), Kelley's index and Magnesium hazard were calculated using CHIDAM software 2020 in conjunction with USSL and Doneen diagrams. During NEM, EC and TDS ranges from 273 to 5869 mg/L and 194 to 4159 mg/L and during POM is from 235 to 6850 mg/L and 233.8 to 6916 mg/L. The hydrogeochemical facies represents that Ca-HCO_3 and mixed Ca-Mg-Cl facies are predominant during NEM and Na-Cl and mixed Ca-Mg-Cl are predominant during POM. The higher concentration of TDS and EC in the samples reflects the unsuitability of groundwater in both seasons.

Keywords: CHIDAM software, Virudhunagar Groundwater, Seasonal Groundwater, Hydrogeochemical

Introduction

The economic growth of the region has resulted in an increased demand for water; for potable supplies, for irrigation and industry. Groundwater is generally of tremendous microbiological feature and suitable of chemical quality for both irrigation and drinking purposes. Still, groundwater quality is one of the challenging features because of anthropogenic pollution, saline Intrusion and also by naturally-occurring contamination, associated to hydrogeochemical evolution in certain types of aquifers. The significance of water quality in social health has recently intent vast deal of awareness. Increasing population and industries have led to a prompt decline in groundwater level due to over-exploitation and also caused in quality falls. The water resources available in India are not adequate to achieve the needs of the entire population [1] Numerous studies have been conducted by various researchers in different parts of the world on groundwater quality [2-5]. The water quality will also help us to obtain information regarding the environments through which the water has circulated [6-11]. The relationship between the regional lithology, groundwater quality, characteristics of the soil and rock masses present along the pathway of groundwater and its saturation zone has been studied by many researches [12-24]. The association of geo-physical approach to determine the lithological contact and groundwater quality has been studied by [25-27). There are various complications for the accessibility of groundwater in hard rock [28,29]. The current study area Virudhunagar district is predominated by agriculture-based population, predominant with gneissic group of rocks which include feldspathic gneiss and Charnokite. The foremost objective of the current work is to make a groundwater quality assessment for utility like drinking, domestic, and irrigation using CHIDAM software, based on the available physicochemical data for North East Monsoon and Post monsoon seasons for Virudunagar district.

Study area

Virudhunagar district was bifurcated from Ramanathapuram district, Tamil Nadu. Virudhunagar town serves as the district Headquarters. The study area is located between the latitude 9°24’27.85” N to 9°11’10.19” N and longitude of 78°24’9.55” E to 78°5’24.45” E (Figure 1). The study area spread over an area of 4234 sq. km. The Virudhunagar district is comprised of 8 Taluks with an average elevation is of 102 m of the above mean sea level. This district has a total population of 17, 51,301. The Vaippar, The Gundar, and The Arjunanadi are the three major rivers flowing along the northwest to south east of the district. The annual temperature varies from 23.78°C to 33.95°C. The major soil types in the district are Red soil, Black Cotton soil and Red sandy soil. The study region is mostly covered by the physiographic units of plains, uplands, hills and valleys. The landuse of the study area is comprised of built-up land, agricultural land, forest, wastelands, and water bodies [30]. Geologically the entire Virudhunagar district can be broadly classified into hard rock and sedimentary formation of alluvium and tertiary. The major part of the district is covered by a gneissic group of rocks which include feldspathic gneiss, Charnokite and the pink granite. Tertiary formation is observed in the eastern part of the district. The typical water level during pre-monsoon is 12m below ground level (bgl) and 8m bgl during post monsoon. The groundwater is observed in both the porous, sedimentary and fissured, hardrock formations. The study region is known for the match box industries, fireworks and printing press.

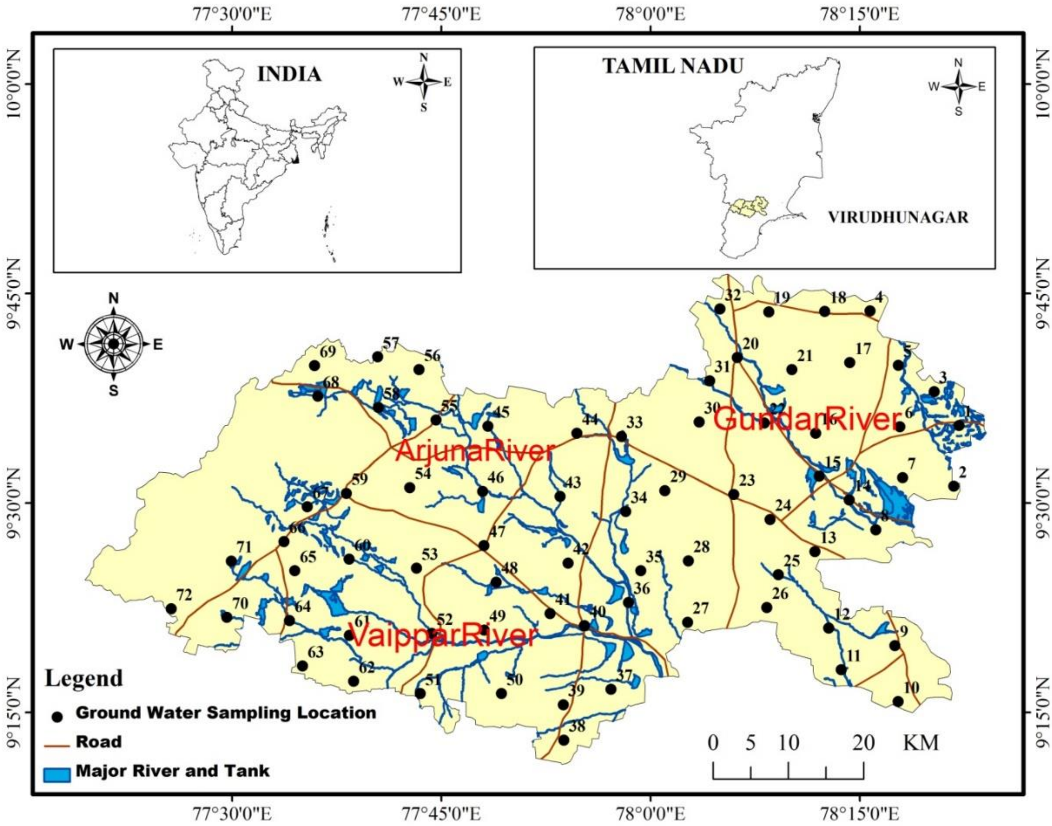

Figure1. Groundwater sampling location and drainage map of the Study area

Materials and Methods

Groundwater samples were collected from bore wells and hand pumps during North East Monsoon (NEM) and Post Monsoon (POM). A total of 144 groundwater samples were collected and analyzed for major cations and anions by using the standard procedures [31]. The physical parameters (EC, pH, TDS) were analyzed by using the field multi-parameter (PCSTestr™ 35). The major cations like Ca and Mg were determined by used titration method. Na and K was analyzed using Flame photometer (Elico CL 378). The major anions like Cl and HCO_3 were analyzed titration Methods. SO_4, PO_4, and SiO_2 were analyzed used instrument spectrophotometer (UV 1800 spec). The data obtained by the analysis of the samples served as an input to calculate the different indices to determine the suitability for different purpose using [32].

Results and Discussion

The general geochemical characters of the analyzed parameters like minimum, maximum and average of physio-chemical parameters, major ion concentrations are tabulated in Table 1. The ionic dominance in the groundwater during NEM for cations is in the following order Na>Ca>Mg>K and anions are Cl >HCO_3> SO_4>PO_4. The POM shows that the cation is in the following order Na>K>Ca>Mg and that of anion is Cl>HCO_3>PO_4>SO_4. Table 2 explains that Calcium-Sodium and Calcium –Magnesium Facies is the dominant cation facies during NEM and Calcium-Sodium facies is the predominant facies during POM. The Anion facies during NEM shows Chloride-Sulfate-Bicarbonate facies and in POM shows Chloride-Sulfate-Bicarbonate facies and Chloride facies.

Classification for Drinking Water Purpose

Groundwater samples were classified for the drinking purpose based on the standards of [33]. Table 1 exhibits the range of ionic concentration in groundwater of the study area and compared with the prescribed limits of [33]. Groundwater shows near acidic to alkaline nature with the pH level of 6.8 to 8.4 during NEM and 7.5 to 8.9 in POM and the level of pH during NEM is within the permissible limit of WHO. 5.5% of samples during POM show the exceeding level of pH.

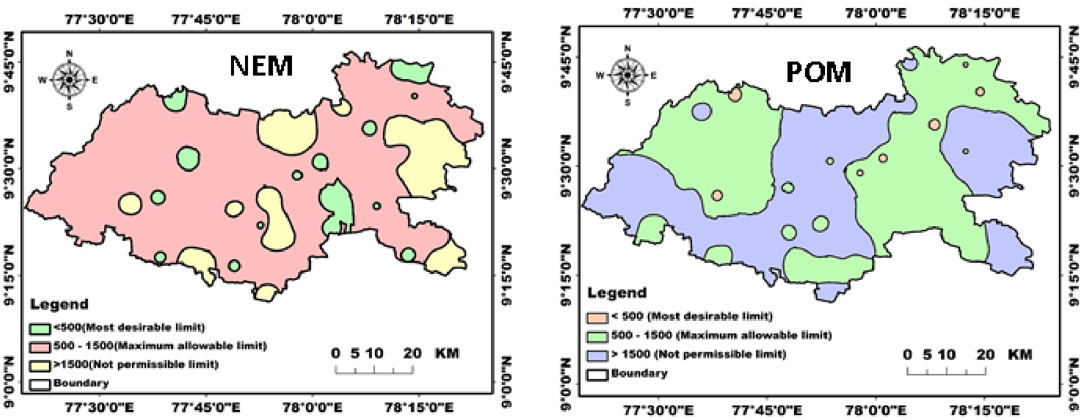

Figure 2. Spatial distribution of TDS (mg/L) in groundwater samples with respect to North East Monsoon (NEM) and Post Monsoon (POM) seasons.

pH greater than permissible limit indicates the higher cation concentration. Total Dissolved Solids of the samples during NEM ranges between 194 and 4160 mg/L and during POM ranges from 234 to 6916 mg/Groundwater samples shows that 21% and 29% of the sample during NEM and POM are exceeding the permissible limit. The higher level of TDS is due to the effect of anthropogenic activities like the of impact of limestone tailings from quarries, cement and firework industries. During NEM higher TDS is noted at isolated patches of Northern, Eastern and Central part of the study region (Figure. 2) and during POM higher TDS is noted in Central and Eastern part of the study area.

Table 1. Maximum, minimum and average values of the hydrochemical parameters in groundwater samples. (all the values are in mg/L except pH and EC in µS/cm)

		Ca	Mg	Na	K	Cl	HCO_3	PO_4	SO_4	SiO_2	pH	EC	TDS
NEM	Maxium	892	450	944	296	2980	1198	22.7	35	84.2	8.4	5870.0	4160.0
	Minimum	20	4.8	9.1	2.8	53.2	134	5.5	3.7	9.9	6.8	273.0	194.0
	Average	153	90.7	151	16.6	441	539	7.1	19.5	49.6	7.5	1593.0	1136.0
POM	Maximum	252	230	1201	325	1987	783	25	17	32.3	8.9	6850.0	6916.0
	Minimum	16	7.2	3.4	1.9	70.9	73.2	0.1	BDL	5.8	7.5	235.0	233.8
	Average	58.1	65.1	274	23	467	286	2.1	1.6	23.5	8.1	1621.4	1585.4
	WHO (2014)	200	150	200	10	600	500	-	400	NG	6.5-8.5	1500.0	1500.0
NEM	Percent of Samples exceeding WHO standard	22%	11%	24%	17%	19%	35%		BDL			36%	21%
POM	Percent of Samples exceeding WHO standard	6%	7%	57%	17%	40%	4%		BDL		5.50%	38%	29%

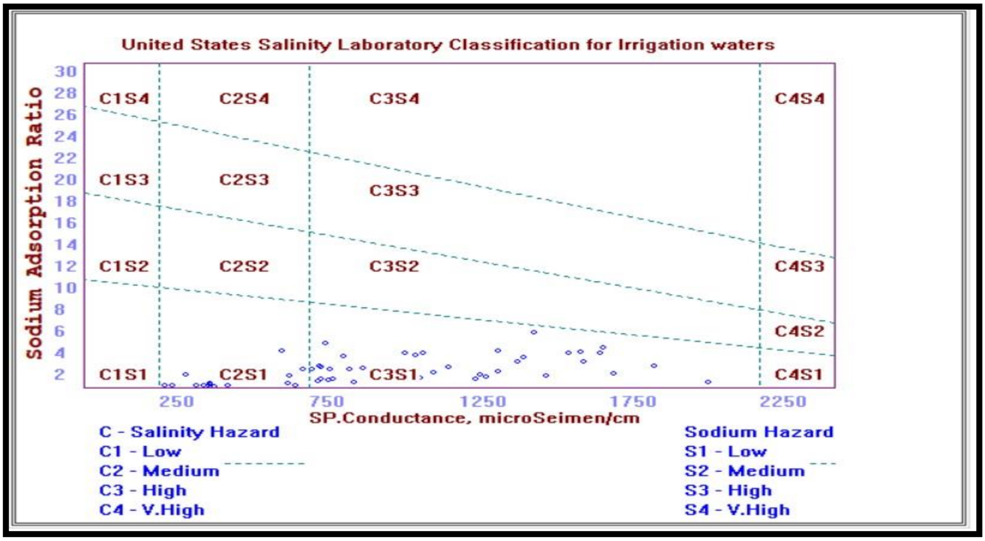

Figure 3a. Classification of ground water samples for irrigation adopting salinity and sodim hazard during NEM.

Most of the samples from NEM and POM are within the permissible limit of the major cation like Ca, Mg, Na and K, but the samples during NEM shows that 22%, 11%, 24% and 17% are above the permissible limit of cations. During POM 6%, 7%, 57% and 17% of samples (Table 1) exceeds the permissible limit of Ca, Mg, Na and K. The anions like SO_4 and PO_4 in both the seasons are within the permissible limit of all the groundwater samples but the Cl and HCO_3 shows that 19% and 35%, of the samples during NEM and 40% and 4% of samples during POM are exceeding the permissible limit of drinking water quality of WHO (2014) [33] (Table 1).

Irrigation purpose

The classification of groundwater for the irrigation purpose is determined from the values of Sodium Adsorption Ratio (Alkali hazard) and groundwater Electrical Conductivity (Salinity hazard) which is plotted in USSL diagram. SAR values ranges between 0-18 which represents the good to excellent category in NEM and during POM the samples falls between 0 to >26

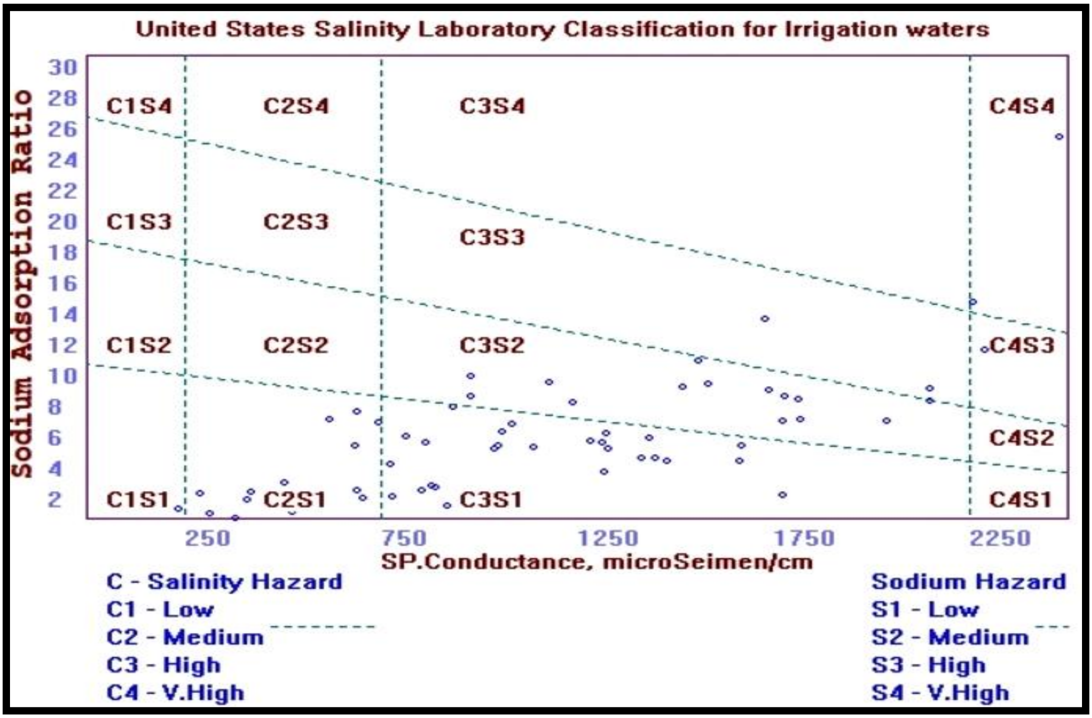

Figure 3b. Classification of ground water samples for irrigation adopting salinity and sodim hazard during POM.

indicating that 95% of samples are good to excellent category and 5 % of samples are fall under poor to fair zone of Sodium Adsorption Ratio (Table 2).

Table: 2. Suitability of groundwater for drinking and irrigation based on the results from CHIDAM software (Chidambaram et al., 2020)

Category	Range	Percentage of Samples (NEM)	Percentage of Sample (POM)	Category	Range	Percentage of Samples (NEM)	Percentage of Samples (POM)
Na% (Wilcox,1955)				Indices of Base Exchange (IBE) Schoeller (1965)			
Excellent	0-20	42%	7%	Exchange between Na and K in rock with Mg or Ca in groundwater		24%	46%
Good	20-40	38%	18%	Exchange between Na and K in groundwater with Mg or Ca in rock		76%	54%
Permissible	40-60	17%	25%	TDS Classification(USSL 1954)			
Doubtful	60-80	3%	43%	<200		1%	
Unsuitable	>80	1%	7%	200-500		21%	8%
Na% (Eaton,1950)				500-1500		54%	53%
Safe	<60	96%	50%	1500-3000		15%	28%
Unsafe	>60	4%	50%	>3000		8%	11%
Kelly Ratio (Kelly,1946)				Chloride classification (Stuyfzand,1989c)			
Safe	<1	92%	39%	Extremely Fresh	<0.141	0	
Unsafe	>1	8%	61%	Very Fresh	0.141-0.846	0	
Magnesium Adsorption Ratio (Lloyd& Heathcoat (1985)				Fresh	0.846-4.231	39%	18%
Safe	<50	42%	39%	Fresh Brackish	4.231-8.462	17%	25%
Unsafe	>50	58%	61%	Brackish	8.462-28.206	36%	50%
Sodium Adsorption Ratio (Richards 1954)				Brackish Salt	28.206-282.064	8%	11%
Excellent	0-10	96%	85%	Salt	282.064-564.127	0	0
Good	10-18	4%	10%	Hyperhaline	>564.127	0	0
Fair	18-26		4%	Cation Facies			
Poor	>26		1%	Calcium-Magnesium Facies		40%	7%
Residual Sodium Carbonate (Richards,1954)				Calcium-Sodium Facies		60%	89%
Good	<1.25	79%	83%	Sodium-Calcium Facies		0	4%
Medium	1.25-2.5	10%	10%	Sodium Facies		0	0
Bad	>2.5	11%	7%				
Electrical Conductivity (Wilcox,1955)				Anion Facies			
Excellent	<250		1%	Bicarbonate Facies		0	0
Good	250-750	25%	29%	Bicarbonate-Chloride-Sulfate Facies		0	0
Permissible	750-2250	54%	60%	Chloride-Sulfate-Bicarbonate Facies		92%	72%
Doubtful	2250-5000	17%	14%	Chloride Facies		8%	28%
Unsuitable	>5000	4%	4%	Corrosivity Ratio Ryner (1944)			
Sawyer and McCarty Hardness				Corrosivity Ratio greater than 1	Unsafe	39%	74%
Soft	<75			Corrosivity Ratio less than 1	Safe	61%	26%
Slightly Hard	75-150		4%	Hardness Classification Handa (1964)			
Moderately Hard	150-300	15%	33%	Permanent Hardness (NCH)			
Very Hard	>300	85%	63%	A1		28%	4.2%
Schoeller Classification (1967)				A2		42%	32%
$HCO_3 > SO_4$	Type-I	100%	100%	A3			37.5%
$SO_4 > Cl$	Type-II			Temporary Hardness (CH)			
$Cl > SO_4$ & $SO_4 > HCO_3$	Type III			B1		22%	1.38%
Na>Mg & Mg>Cl	Type-IV			B2		5.5%	12.5%
				B3		2.5%	9.7%

Electrical conductivity classification by Wilcox (1955) [34] for the NEM samples shows the category of Good to Unsuitable, 25% samples are of Good (Table 2), 54% of permissible, 17% of Doubtful and 4% of Unsuitable category. During POM 1% samples fall in Excellent category, 29% of Good, 60% of permissible, 14% of Doubtful and 4% of samples are in Unsuitable zone. According to the groundwater samples during NEM most of the samples fall in the low sodium hazards and high salinity hazard (Figure 3a) zone where the less sodium hazard samples are mostly useful for the irrigation purposes which have high salt tolerant crops [35,36]. During POM, Majority of samples during this season fall under C2S1, C3S1, C3S1, and few samples present in the C3S3, C4S3, C4S4 Categories (Figure 3b). About 18% of samples shows the high salinity and medium sodium hazard. It is observed that 8.3% of samples during POM are not suitable for the irrigation which shows the high sodic and salinity hazard category.

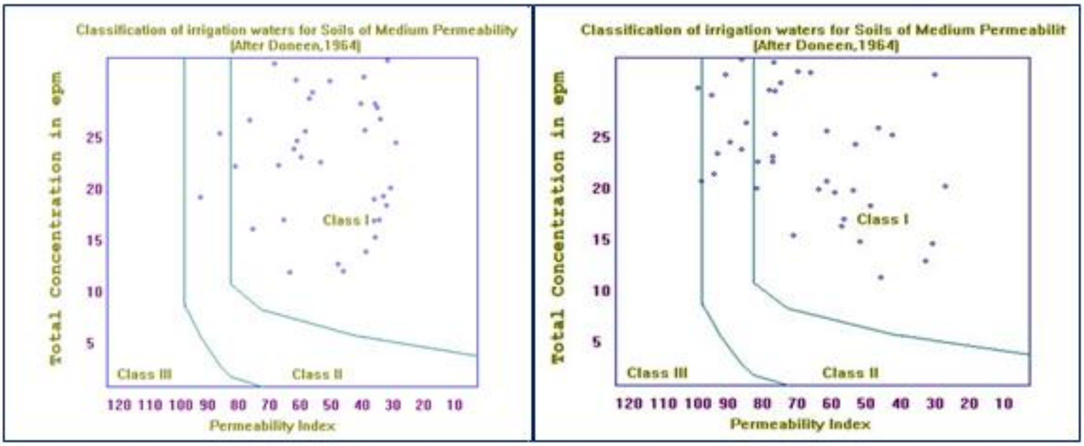

Figure 4. Doneens Permeability Index for the groundwater samples during (a) NEM and (b)POM

Doneen (1964) [37] suggested classification of the groundwater samples based on accumulation calcium, magnesium, sodium and bicarbonate of the soil. The samples plotted in Doneen plot represents that during NEM majority of the groundwater samples (97%) falls in Class I (Fig 4a). During POM, 80% of the samples falls in the Class I, 17.3% of the samples falls in the Class II, and 2.7% of samples falls in the Class III (Fig 4b) represents the larger permeability index is connected with groundwater systemic features, which facilitate widespread pollution of groundwater [38]. As per the PI ranges, the groundwater sample fall in Classes I and class II excellent to good category, Class III unsuitable for the irrigation. Comparing both the season NEM samples is more suitable for the irrigation.

The Na% is also considered to calculate the fitness of groundwater for agriculture purpose. Table 2 shows that the Na% (Wilcox 1955) in 43% groundwater samples during NEM is of excellent category, 38% of good,15% of permissible, 3% of doubtful and 1% of unsuitable category. During POM, 7%, 18%, 25%, 43% and 7% of samples falls in excellent, good, permissible, doubtful and unsuitable category respectively. Most of POM samples represent doubful to unsuitable category. Dissolution and weathering of different minerals and extensive application of chemical fertilisers leads to high Na% in groundwater [39,40]. Most of the NEM samples are represented in permissible to excellent category which signifies the suitablity of groundwater for irrigation (Table 2). According to Na% (Eaton 1950) NEM samples are in safe category for irrigation puropose but during POM 50% of the samples are unsafe for the agriculture activities (Table 2).

Residual Sodium Carbonate (RSC) is goverened by the CO_3 and HCO_3 and their relationship to Ca and Mg which controles the irrigation quality of water [41]. Table 2 represents, during NEM, 79 % of samples are good, 10 % of samples are medium and 11% of bad Category. During POM, 83%,10% and 7% of samples are from good, medium and bad category respectively. Most of the samples are in good category for both seasons representing lesser dominance of carbonate than the alkaline earth. Higher RSC decreases the permeability of soil and reduce the yield [1].

Kelly proposed the ratio based on Ca,Mg and Na for the suitability of agriculture activities of the groundwater. According to the Kelly ratio samples with value <1 is not suitable for the irrigation. During NEM about 92% (Table 2) of samples are safe for irrigation and remaining 8 % of samples are unsafe. During POM only 39 % of samples are in safe zone and 61% of samples are unsafe.

Magnesium in groundwater significantly affects the harvest of crops [38]. The magnesium hazard value > 50 is assumed to be inappropriate for the irrigation purpose, however in the study area, NEM and POM samples reveals that 58% and 61% of groundwater are not suitable for the irrigation purposes (Table 2).

Index of base exchange (IBE) was proposed by Schoeller (1965) to delineate the metamorphic responses in the groundwater. There is an exchange of Na and K in goundwater during more in both the seasons with Mg or Ca in rock, 76% and 54 % respectively (Table 2). Few of the groundwater samples in both the seasons represents that the Na and K in mainly derived from the ion exchange process i.e Ca or Mg in groundwater is exchanged for Na and K in the rock matrix with a percentage of 22% and 46%.

In Stuyvesant (1989c) [42] chloride classification, both the NEM and POM samples were classified between fresh and brackish salt category. During NEM about 39% of samples are fresh, 17% of samples are fresh to brackish, 36% of samples are brackish and 8% of samples are from Brackish salt category (Table 2). During POM, 18% of samples are fresh, 25% of samples are fresh to brackish, 50% of samples are brackish and 11% of samples are from brackish salt. Maximum number of samples from POM shows the brackish nature of groundwater. Long residence time and anthropogenic pollutants infiltration are the foremost source for higher chloride level in the groundwater samples.

Domestic Purpose

Water hardness is the amount of dissolved calcium and magnesium in the water [43]. Hard water is high in dissolved ions largely calcium and magnesium. Depending on the hardness of the water, soap develops a film of residue left on the skin. In hard water, soap reacts with the calcium (which is relatively high in hard water) to form soap scum. When using hard water, more soap or detergent is needed for cleaning [44,45]. Based on Sawyer and McCarthy's classification of groundwater hardness (Table 2) represents that 85% of samples of NEM represent very hard water and 15% of samples are moderately hard and during POM, 63% of samples are very hard, 33% of samples are moderately hard and 4% of samples are slightly hard. According to [46], the hardness can be classified into permanent and temporary hardness. During NEM ,70% of the samples are represented in permanent hardness category (Table 2), 30% of the samples shows the temporary hardness and during POM. Similarly, 73% and 27% of samples are in permanent and temporary hardness category. Maximum samples represent Non-Carbonate Hardness (NCH) indicating dominance of Ca and Na facies due to to rock–water interaction [47].

The suitability of water quality for the transportation is influenced by the corrosive nature of the sample. This can be measured by means of the corrosivity ratio (CR) proposed by [48]. The groundwater shows that 61% of samples are in safe category i.e., corrosivity ratio less than one during NEM and 26% of samples during POM (Table 2). Since POM 74% of samples have value greater than one indicating that they are unsafe for the storage and transportation purpose.

Conclusion

This study categorizes the groundwater samples collected from the study area conferring the quality and utility for two different seasons during North east monsoon and the post monsoon periods, using CHIDAM software. The results suggest that the TDS in groundwater is found higher in POM than NEM is due to the influence of the precipitation. During NEM, Ca and Mg is the dominant cation and during POM, Ca and Na is the dominant cation, considering the anion Cl and HCO_3 is predominant in both the seasons. Based on WHO comparison, most of the major ion concentration suggests that predominant samples from NEM belong to the suitable category for drinking and domestic purposes then the POM. The irrigation water quality parameters indicated that the majority of the water samples are suitable for irrigation purposes in NEM. Most of samples from POM are brackish to brackish salt nature. An overall seasonal observation on the geochemistry of the groundwater samples shows that NEM samples are more suitable for drinking and irrigation than the POM.

References

[1] K. Ramesh, L. Elango, Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu India, Environmental Monitoring

and Assessment, 184 (2012) 3887–3899, https://doi.org/10.1007/s10661-011-2231-3 https://pubmed.ncbi.nlm.nih.gov/21850434/

[2] M. Çelik, T. Yıldırım, Hydrochemical evaluation of groundwater quality in the Çavuşçayı basin, Sungurlu-Çorum, Turkey, Environmental Geology, 50 (2006) 323-330. http://dx.doi.org/10.1007/s00254-006-0211-7

[3] P. J. Edmunds, R. D. Gates, D.F. Gleason, The tissue composition of Montastraea franksi during a natural bleaching event in the Florida Keys, Coral Reefs, 22 (2003) 54–62. https://doi.org/10.1007/s00338-003-0278-5

[4] A. Mishra, M. Bajpai, Flocculation behaviour of model textile wastewater treated with a food grade polysaccharide, Journal of Hazardous Materials, 118 (2005) 213-217. https://doi.org/10.1016/j.jhazmat.2004.11.003 https://pubmed.ncbi.nlm.nih.gov/15721546/

[5] C.M. Leung, J.J. Jiao, Heavy metal and trace element distributions in groundwater in natural slopes and highly urbanized spaces in Mid-Levels area, Hong Kong, Water Research, 40 (2006) 753-767. https://doi.org/10.1016/j.watres.2005.12.016 https://pubmed.ncbi.nlm.nih.gov/16448684/

[6] M. Vasanthavigar, K. Srinivasamoorthy, K. Vijayaragavan, R. Rajiv Ganthi, S. Chidambaram, P. Anandhan, R. Manivannan, S. Vasudevan, Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India, Environmental Monitoring and Assessment, 171 (2010) 595–609. https://doi.org/10.1007/s10661-009-1302-1

[7] S. Chidambaram, U. Karmegam, M.V. Prasanna, P. Sasidhar, M. Vasanthavigar, A study on hydrochemical elucidation of coastal groundwater in and around Kalpakkam region Southern India, Environmental Earth Sciences, 64 (2011) 1419–1431. https://doi.org/10.1007/s12665-011-0966-3.

[8] C. Singaraja, S. Chidambaram, P. Anandhan, M.V. Prasanna, C. Thivya, R. Thilagavathi, J. Sarathidasan, Hydrochemistry of groundwater in a coastal region and its repercussion on quality, a case study—Thoothukudi district, Tamil Nadu, India, Arabian Journal of Geosciences, 7 (2014a) 939-950. http://doi.org/10.1007/s12517-012-0794-0

[9] C. Singaraja, S. Chidambaram, P. Anandhan, M.V. Prasanna, C. Thivya, R. Thilagavathi, J. Sarathidasan, Determination of the utility of groundwater with respect to the geochemical parameters: a case study from Tuticorin District of Tamil Nadu (India), Environmental Earth Sciences, 16 (2014b) 689-721. https://doi.org/10.1007/s10668-013-9502-9

[10] C. Thivya, S. Chidambaram, R. Thilagavathi, M. Nepolian, V.S. Adithya, Evaluation of drinking water quality index (DWQI) and its seasonal variations in hard rock aquifers of Madurai district, Tamilnadu, International Journal of Advanced Geosciences, 2 (2014) 48-52. http://dx.doi.org/10.14419/ijag.v2i2.2294

[11] K. Tirumalesh, K. L. Ramkumar, S. Chidambaram, S. Pethaperuamal, R. Thilagavathi, Understanding the hydrochemical behavior of groundwater and its suitability for drinking and agricultural purposes in Pondicherry area, South India – A step towards sustainable development, Groundwater for Sustainable Development, 2 (2016) 143-153. https://doi.org/10.1016/j.gsd.2016.08.001

[12] A. I. Olayinka, A.F. Abimbola, R.A. Isibor, A.R. Rafiu, A geoelectrical-hydrogeochemical investigation of shallow groundwater occurrence in Ibadan, southwestern Nigeria, Environmental Geology 37 (1999) 31-39. https://doi.org/10.1007/s002540050357

[13] G. D. Foster, E. C. Roberts, B. Gruessner, D. J. Velinsky, Hydrogeochemistry and transport of organic contaminants in an urban watershed of Chesapeake Bay (USA), Applied Geochemistry, 15 (2000) 901-915. https://doi.org/10.1016/S0883-2927(99)00107-9

[14] S. Chidambaram, A.L. Ramanathan, M.V. Prasanna, P. Anandhan, K. Srinivasa Moorthy, S. Vasudevan, Identification of Hydro geochemically Active Regimes in Groundwaters of Erode District, Tamandu – A Statistical Approach Research Article, Asian Journal of Water, Environment and Pollution, 5 (2008) 93-102.

[15] S. Chidambaram, A John Peter, M. V. Prasanna, U. Karmegam, K. Balaji, R. Ramesh, P. Paramaguru, S. Pethaperumal, A Study on the Impact of Landuse Pattern in the Groundwater Quality in and Around Madurai Region, South India-Using GIS Techniques, Online Journal of Earth Sciences. 4 (2010) 27-31. http://dx.doi.org/10.3923/ojesci.2010.27.31

[16] S. Chidambaram, J. Sarathidasan, K. Srinivasamoorthy, C. Thivya, R. Thilagavathi, M.V. Prasanna, C. Singaraja, M. Nepolian, Assessment of hydrogeochemical status of groundwater in a coastal region of Southeast coast of India, Applied Water Science, 8 (2018) 1- 14. https://doi.org/10.1007/s13201-018-0649-2

[17] S. Manikandan, S. Chidambaram, M.V. Prasanna, C. Thivya, U. Karmegam, Hydrochemical Characteristics and Groundwater Quality Assessment in Krishnagiri District, Tamilnadu, India, International Journal of Earth Sciences and Engineering, 4 (2011).

[18] K. Srinivasamoorthy, S. Chidambaram, M.V. Prasanna, M. Vasanthavihar, John Peter, P. Anandhan, Identification of major sources controlling groundwater chemistry from a hard rock terrain – A case study from Mettur taluk, Salem district, Tamil Nadu, India, Journal Earth System Science, 117 (2008) 49-58. https://doi.org/10.1007/s12040-008-0012-3

[19] K. Srinivasamoorthy, C. Nanthakumar, M. Vasanthavigar, K. Vijayaraghavan, R. Rajivgandhi, S. Chidambaram, P. Anandhan, R. Manivannan, S. Vasudevan, Groundwater quality assessment from a hard rock terrain, Salem district of Tamilnadu, India, Arabian Journal of Geosciences, 4 (2011) 91–102. https://doi.org/10.1007/s12517-009-0076-7

[20] M. V. Prasanna, S. Chidambaram, A. Shahul Hameed, K. Srinivasamoorthy, Study of evaluation of groundwater in Gadilam basin using hydrogeochemical and isotope data, Environmental Monitoring and Assessment, 168 (2010) 63-90. https://doi.org/10.1007/s10661-009-1092-5

[21] R. Thilagavathi, S. Chidambaram, M.V. Prasanna, C. Thivya, C. Singaraja, A study on groundwater geochemistry and water quality in layered aquifers system of Pondicherry region, southeast India, Applied Water Science, 2 (2012) 253-269. https://doi.org/10.1007/s13201-012-0045-2

[22] C. Thivya, S. Chidambaram, C. Singaraja, R. Thilagavathi, M.V. Prasanna, P. Anandhan, I. Jainab, A study on the significance of lithology in groundwater quality of Madurai district, Tamil Nadu (India), Environment, Development and Sustainability, 15 (2013) 1365–1387. https://doi.org/10.1007/s10668-013-9439-z

[23] N. Devaraj, C. Thivya, R. Thilagavathi, V.S. Aditya, S. Chidambaram, A study on the hydrogeochemical processes groundwater quality of Ariyalur region, Tamilnadu, International Journal of Current Research and Development, 4 (2016) 1- 13.

[24] B. Panda, S. Chidambaram, R. Thilagavathi, C. Thivya, N. Ganesh, N. Devraj, Geochemical signatures of groundwater along mountain front and riparian zone of Courtallam, Tamil Nadu, Groundwater for Sustainable Development, 7 (2017) 372-386. https://doi.org/10.1016/j.gsd.2017.10.003

[25] K. Srinivasamoorthy, S. Chidambaram, M. Vasanthavigar, P. Anandhan, V. S. Sarma, Geophysical investigations for groundwater in a hard rock terrain, Salem district, Tamil Nadu, India, Bulletin of Engineering Geology and the Environment, 73 (2014) 357–368. https://doi.org/10.1007/s10064-013-0488-1

[26] R. Thilagavathi, S. Chidambaram, M.V. Prasanna, S. Pethaperumal, A study on the interpretation of spontaneous potential and resistivity logs in layered aquifer sequence

of Pondicherry Region, South India, Arabian Journal of Geosciences, 7 (2013) 3715-3729. https://doi.org/10.1007/s12517-013-1041-z

[27] N. Devaraj, S. Chidambaram, B. Panda, C. Thivya, R. Thilagavathi, N. Ganesh, Geo-electrical approach to determine the lithological contact and groundwater quality along the KT boundary of Tamilnadu, India, Modeling Earth Systems and Environment, 4 (2018) 269-279. https://doi.org/10.1007/s40808-018-0424-2

[28] S. Das, S.N. Sar, (1988) Groundwater exploration in Orissa. Tech. Annual, Inst. of En0gineers, Bhubaneswar (pp. 84–95).

[29] C. Thivya, S. Chidambaram, R. Thilagavathi, M. Nepolian, Determination of utility of groundwater with special emphasis on domestic and irrigation purposes in hard rock aquifers of Madurai district, Tamilnadu, Geochimica et Cosmochimica Acta, 3 (2016) 71-80.

[30] N. S. Magesh, N. Chandrasekhar, S. Krishna Kumar, M. Glory, Trace element contamination in the estuarine sediments along Tuticorin coast—Gulf of Mannar, southeast coast of India, Marine Pollution Bulletin, 73 (2013) 355-361. https://doi.org/10.1016/j.marpolbul.2013.05.041

[31] Apha, Awwa, Wef, (1998) Standard methods for the estimation of water and waste water. American Public Health Association, American Water Works Association, Water Environment Federation.

[32] S. Chidambaram, Harish Bhandary, Khaled Hadi, CHIDAM -A software for Chemical Interpretation of the Dissolved ions in Aqueous Media, Groundwater for sustainable development, 13 (2021) 100496. https://doi.org/10.1016/j.gsd.2020.100496.

[33] World Health Organization (WHO) (2014) Guidelines for drinking water quality, https://www.who.int/water_sanitation_health/dwq/fulltext.pdf

[34] L.V. Wilcox, Classification and use of irrigation water, US Department of Agriculture, 969 (1955) 19.

[35] C. Jeon, Maimoona Raza, Jin-Yong Lee, Heejung Kim, Chang-Seong Kim, Bora Kim, Jeong-Woo Kim, Rak-Hyeon Kim, Sun-Woo Lee, Countrywide Groundwater Quality Trend and Suitability for Use in Key Sectors of Korea Water, 12 (2020) 1193. https://doi.org/10.3390/w12041193

[36] H. Zhu, S. Pan, S. Gu, E.M. Bradbury, X. Chen, Amino acid residue specific stable isotope labeling for quantitative proteomics, rapid Communication in mass spectrometry,16 (2002) 2115-2123. https://doi.org/10.1002/rcm.831

[37] L.D. Doneen, (1964) Water quality for agriculture, Department of irrigation, University of California, Davis, 48.

[38] A. Nagaraju, S. Suresh, K. Killham, K. Hudson-Edwards, Hydrogeochemistry of waters of mangampeta barite mining area, Cuddapah Basin, Andhra Pradesh, India, Turkish Journal of Engineering and Environmental Sciences, 30 (2006) 203-219.

[39] N.S. Rao, J.P. Rao, D.J. Devadas, K.S. Rao, C. Krishna, Hydrogeochemistry and groundwater quality in a developing urban environment of a semi-arid region, Guntur, Andhra Pradesh, Journal of the Geological Society of India, 59 (2002) 159-166.

[40] M.A. Bhat, M. S. Grewal, R. Ramprakash, S. A. Wani, E. A. Dar, Assessment of Groundwater Quality for Irrigation Purposes using Chemical Indices, Indian Journal of Ecology, 43 (2016) 574-579.

[41] M. Eaton frank, Significance of Carbonates in Irrigation Waters, soil science, 69 (1950) 123-134. http://dx.doi.org/10.1097/00010694-195002000-00004

[42] P.J. Stuyfzand, (1989) Nonpoint sources of trace elements in potable groundwaters in the Netherlands. Proceedings 18th TWSA Water Workings, Testing and Research Institute KIWA

[43] J.D. Hem, (1991) Study and interpretation of the chemical characteristics of natural water, U.S. Geological Survey Water Supply Paper 2254, 264.

[44] H.A. Schroeder, Relations between hardness of water and death rates from certain chronic and degenerative diseases in the United States, Journal of Chronic Diseases, 12 (1960) 586-591. https://doi.org/10.1016/0021-9681(60)90002-3 https://pubmed.ncbi.nlm.nih.gov/13748670/

[45] D. L. Muss, Relationship Between Water Quality and Deaths from Cardiovascular Disease, Journal - American Water Works Association, 54 (1962) 1371–1378. https://doi.org/10.1002/j.1551-8833.1962.tb00977.x

[46] B.K. Handa, (1964. B) Calcium Carbonate saturation of aquifers in India. Rep 22nd Int. Nat. Geol. Cong. 1964, Part 12, Geohydrology, pp. 88-101.

[47] G. Mahadevaswamy, D. Nagaraju, S. Siddalingamurthy, Lakshmamma, Mohammad Subhan lone, P.C. Nagesh, Krishna Rao, Groundwater quality studies in Nanjangud Taluk, Mysore District, Karnataka, India, international journal of environmental sciences, 1 (2011) 1582- 1591.

[48] J.W. Ryznre, New index for determining amount of calcium carbonate scale formed by Water, Journal-American Water Works Association, 36 (1944) 472-486. https://doi.org/10.1002/j.1551-8833.1944.tb20016.x

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