

Geochemical Characterization of Groundwater's of Shallow Coastal Aquifer in and Around Kalpakkam, South India

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Abstract: Groundwater acts as a lifeline in the coastal regions to meet out the domestic, drinking, irrigational and industrial needs. In this scenario 29 shallow coastal groundwater samples were collected and analysed for major and minor cations. The samples analysed were classified with SAR, RSC, TH, CI, IBE, EC and facies to determine their utility. The geochemical facies of the groundwater was attempted and found that Ca-HCO₃ as the dominant type. The factors responsible for their geochemical characterization were also attempted by using standard plot and it was found that the ion exchange plays a significant role along with few signatures of recharge and sea water intrusion.

Key words: Coastal aquifers, geochemistry, utility, water quality

INTRODUCTION

It is estimated that approximately one third of the world's population use groundwater for drinking (Nickson *et al.*, 2005). Groundwater moves downward due to the pull of gravity. But it can also move up because it will flow from higher- pressure areas to lower pressure areas. The rate of groundwater flow is controlled by two properties of the rock: porosity and permeability (Pore space) (EPA, 1994) Generally, groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes (Twarakavi and Kaluarachchi, 2006). Groundwater is the primary source of water for domestic, agricultural and industrial uses in many countries and its contamination has been recognized as one of the most serious problems in Iran (Jalali, 2008). The industrial waste water, sewage sludge and solid waste materials are currently being discharged into the environment indiscriminately. These materials enter subsurface aquifers, resulting in the pollution of irrigation and drinking water (Forstner and Wittman, 1981). Temporal changes in the origin and constitution of the recharged water, hydrologic and human factors, may cause periodic changes in groundwater quality. These changes may be related to human or nature phenomena. Generally, shallow groundwater is affected more by contamination compared with deep groundwater (Kinzelbach, 1989). The coastal groundwater system is fragile and its evaluation will help in the proper planning and sustainable management. The water quality assessment studies in the nearby coastal aquifers

were carried out by several authours (Pethaperumal *et al.*, 2008; Chidambaram *et al.*, 2005, 2009; Prasanna *et al.*, 2008). The preliminary investigation of the salinity in the groundwaters of the Kalpakkam region was studied by (Arumugham *et al.*, 1997). The study on the sea water freshwater interface was attempted by (Gurumoorthy *et al.*, 1994). The present study characterizes the groundwater quality to determine its utility, it also aims in finds in out the major geochemical process and evolution in the study area.

MATERIALS AND METHODS

Study area: The study area falls between the geographical coordinates, 12° 25' and 12° 37' N latitude and 80° 00' to 80° 12' E longitude (Fig. 1). The river Palar with its tributaries, drain into the sea in the study area. This coastal region is entirely composed of alluvium, which helps in easy infiltration of the surface water. The geomorphic features such as dunes and beach ridges are found along the coastal part of the study area. Apart from its importance as a coastal region it is also significant to note that the natural calamities like cyclones are frequently disturbing the normal ecosystem. The aquiferal behavior and its response to natural calamities in this region will help us to identify the region for natural/artificial recharge. The historically follow Mahabalipuram limits the northeastern boundary and the Palar river bounds the southern part of the study area. The subsurface lithology of the study area shows six types of geological formations including sand, clayey sand, clay,

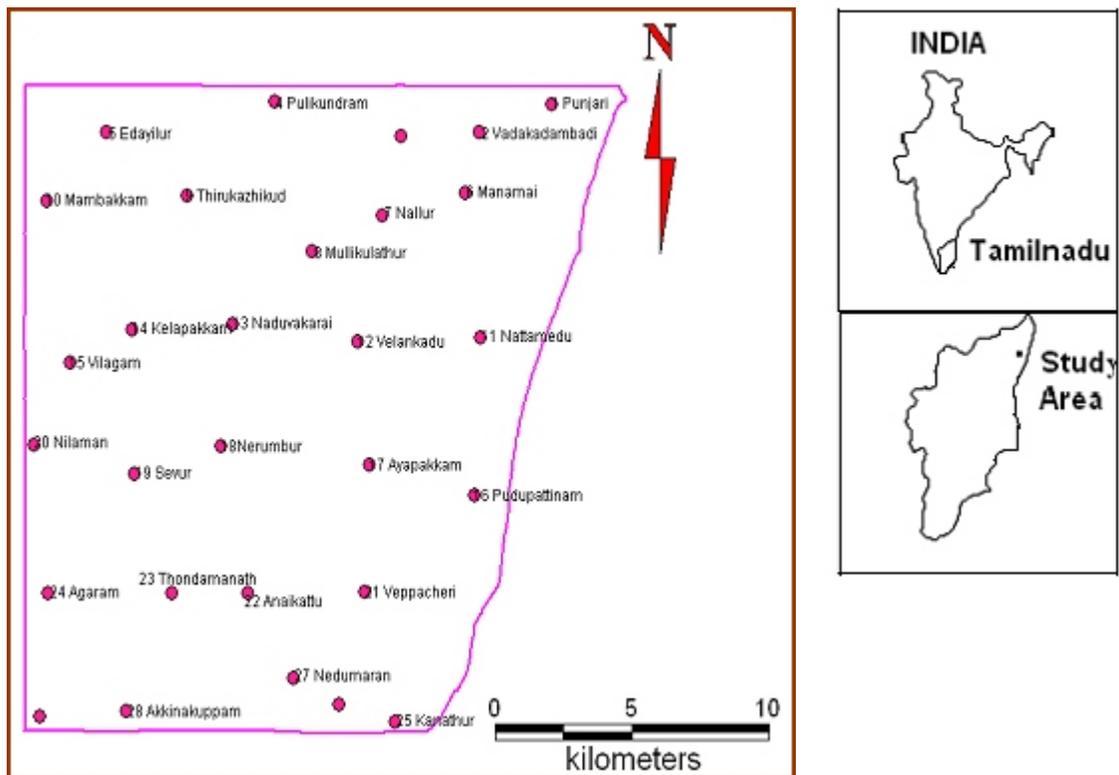


Fig. 1: Samples location map

Table 1: Chemical values minimum maximum and average

	PH	Ec	TDS	ca	mg	Na	k	cl	HCO ₃	po ₄	so ₄
Mini	6.85	255.7	129.3	4	2.4	32.1	3.2	35.45	109.8	0.1	0.2
Max	8.1	3273	1643	120	96	212	38.9	455.8	489	3.4	29.8
Ave	7.55	1185.5	594.52	38.96	41.75	126.84	7.33	178.42	314.80	0.67	7.32

sandy clay, weathered rock and Charnockite. Earlier studies by (Gurumoorthy *et al.*, 2004) has revealed that the Charnockite rock mass in this area is hard and compact and occurs at depths in the range greater than 15-20 m below land surface.

Methodology: Ground water sample were collected along three tracts from north to south along 3 km from coastal (A), 6 km from coastal (B) and 12 km from coastal (C) (Fig. 1) systematically using clear acid washed polythene bottles. Sampling was carried during Feb 2008 and analysis was carried out using standard procedures (APHA, 1998). The parameter, such as Temperature and pH were measured in the field. Electrical conductivity and Total dissolved solids were measured in the laboratory. Salinity was determined by using refractometer. Na⁺ and K⁺ were determined by using flame photometer. Ca⁺ Mg⁺ Cl⁻ and HCO₃⁻ were determined by volumetric titration methods. The data generated was processed to obtain Sodium Absorption Ratio (SAR), Residual Sodium

Carbonate (RSC), Sodium percentage (Na%) and Total Hardness by using WATCLAST (Chidambaram *et al.*, 2003). Different thematic layers were produced for SAR, RSC, Na%, and EC. Mapinfo (GIS) Software V.8 and Vertical mapper was used for spatial distribution. Water analyses were carried out by using standard procedures (Ramanathan, 1992; Ramesh and Anbu, 1996).

RESULTS AND DISCUSSION

Groundwater in the study area is generally alkaline in nature with pH ranging from 6.85 to 8.1 with an average of 7.55 (Table 1). EC is an indirect measure of ionic strength and mineralization of natural water. EC of pure water is around 0.05 µs/cm (Hem, 1991). EC ranges from 255.7 to 3273 µs/cm with an average of 1185.56 µs/cm. Total Dissolved Solids (TDS), which is generally the sum of dissolved ionic concentration varies between 129.3 to 1643 mg/L with an average of 594.541 mg/L. The

dominance of cations and anions are as follows $\text{Na}^+ > \text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+}$. $\text{HCO}_3^- > \text{Cl}^- > \text{SiO}_4 > \text{SO}_4$.

Residual sodium carbonate: All Values expressed in epm. The water having excess of Carbonate and Bicarbonate cover the alkaline earth mainly Ca and Mg in excess of allowable limits affects agriculture unfavorably (Richards, 1954).

$$\text{RSC} = (\text{CO}_3 + \text{HCO}_3) - (\text{Ca} + \text{Mg})$$

The tendency of alkaline earth influences the suitability of water for irrigation purpose. The water gets more precipitated with Ca and Mg and as a result Na in water gets increased in the form of sodium carbonate. The variation of RSC, was drawn using (Richards, 1954) as good, medium and bad categories. in 93% of the groundwater samples of the study area fall in Good category, 3.5% falls in medium category and 3.5% in the bad category.

Sodium absorption ratio: Salinity of groundwater and SAR determines its utility for agricultural purposes. Salinity originates in groundwater due to weathering of rocks and leaching from top soil, anthropogenic sources along with minor influence on climate. The level of Na^+ and HCO_3^- in irrigation (Kelly, 1976; Tijani, 1994) groundwater affects permeability of soil and drainage of the area.

SAR is an estimate of the extent to which sodium ion present in the water would be adsorbed by the soil and is expressed as follow;

$$\text{SAR} = \text{Na} / \sqrt{\text{Ca} + \text{Mg}} / 2$$

Where concentration are expressed in equivalent per million (epm)

The distribution of SAR, was plotted, using (Richard, 1954) Classification. It was found that samples fall in excellent and good categories. More than 90% of samples the falls under excellent class and remaining 10% percentage falls under good category.

Sodium percentage: Na% (Eaton, 1950) classification of groundwater for irrigation purpose was calculated as

$$\text{Na \%} = \frac{(\text{Na} + \text{K}) * 100}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})}$$

The ratio of sodium and potassium in the sum of cation is an the important factor in considering water for agriculture uses, for example, relatively affected soil structure and permeability, resulting in this alkaline soil. The sodium concentration of irrigation water is of prime importance and plays a significant part in determining the permeability of soil Na absorbed on clay surface, as a

substitute for Ca and Mg may damage the soil structure making it compact and impervious. The distribution of Na% classification (Richard, 1954) was used as excellent good, Permissible, Doubtful, and Unsuitable categories shows that % of Na content is a parameter to assess its suitability for agriculture purpose (Wilcox, 1948) sodium combining with CO_3 can add to the formation of alkaline soils and sodium combining with Cl form saline soils. Both these soils do not helping growth of plants. A maximum of 60% of Na in groundwater is allowed for agriculture purpose (Ramakrishna, 1998). 3% of the samples fall in excellent category in study area. The permissible category is represented by 24% of the samples. 59% of the samples falls in doubtful region and 14% in unsuitable category.

Hardness: of water is related to its reaction with soap and to the scale of incrustation accumulating in containers (or) conducts where water is heated or transported. Since soap is precipitated by Ca and Mg ion. Hardness is defined as the sum of concentration of their ion expressed an Mg/L of CaCO_3 . Hardness increases by metallic ion dissolved in water. Hardness is used as an indicator of the rate of scale formation in hot water heater in low-pressure boiler. USGS Hardness (Handa, 1964) shows four categories of hardness as; soft, slightly hard, moderately hard and very hard, Scaling and deposition problems in air conditioning plants are associated with total hardness of the water. Total hardness of more than 180 mg CaCO_3/L can be treated as very hard water and it can lead to scaling problems in air conditioning plants. (Hem, 1970). The slightly hard is represented by 14% of the samples, 17% by moderately hard and 69% in hard category.

Spatial distribution of EC: The spatial distribution of Electrical Conductivity (EC), was drawn, using classification as excellent, good, permissible, doubtful and poor categories (Fig. 2) EC ranged from 255.7 to 3273 $\mu\text{s}/\text{cm}$ average of 1185.56 EC of rain water is 0.05 $\mu\text{s}/\text{cm}$ (Hem, 1991). The most of the samples falls in southwest part range from 250-1250 due to the infiltration of present Palar river basin in coastal aquifer of the study area and few samples were falls above 1250 range in north east part of the study area, due to the saline water intrusion of the study area and because of the tourist area the water is contamination in Mamallapuram. Studies of (Gupta, 1990) show that the different plants tolerance of salinity is different and the amount of a particular plant tolerance of salinity at different stages are different. Also salinity is effective on growth and yield of plants thorough increasing osmotic pressure and concentration of specific ions. Studies of (Fracois, 1989) that is done on sugar beet, wheat, barley and tomato shows that sugar beet in germination stage and wheat, barley and tomatoes in the next stage of germination are sensitive to salinity.

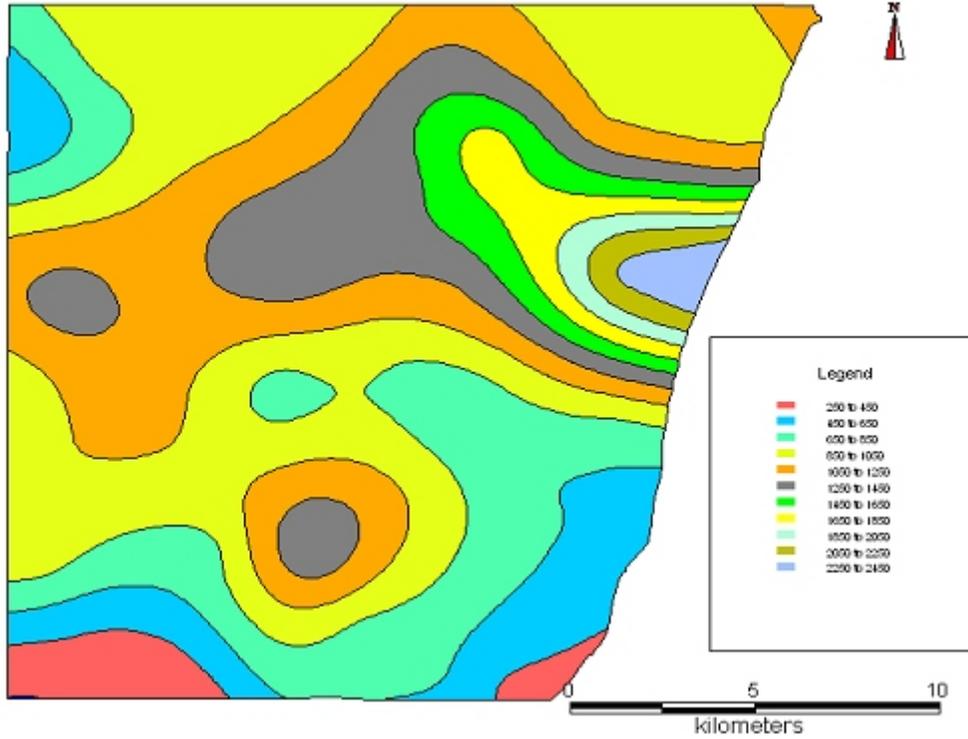


Fig. 2: Spatial distribution of Electrical Conductivity in $\mu\text{s}/\text{cm}$

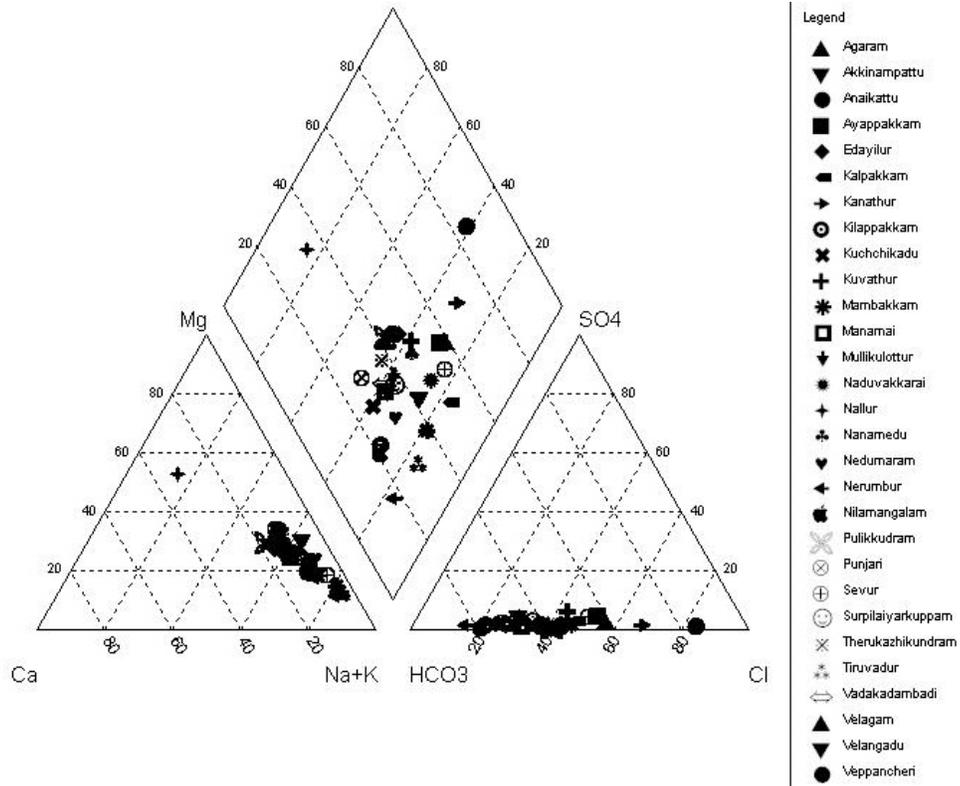


Fig. 3: Piper plot shows groundwater samples

Table 2: Result of computer program WATCLAST

Geochemical classification					
Category	Grade	N = 29	Category	Grade	N = 29
Na% Wilcox (1955)			Anion facies		
Excellent	0-20	1	HCO ₃ Facies		0
Good	20-40	0	HCO ₃ -Cl-SO ₄ Facies		0
Permissible	40-60	7	Cl-SO ₄ -HCO ₃ Facies		21
Doubtful	60-80	17	Cl- Facies		8
Unsuitable	>80	4	Corrosivity ratio (1990)		
USGS Hardness			Safe	<1	25
Soft	<75	0	Unsafe	>1	4
Slightly Hard	75-150	4	R.S.C. Richards(1954)		
Moderately Hard	150-300	5	Good	<1.25	27
Very Hard	>300	20	Medium	1.25-2.5	1
TDS Classification (USSL, 1954)			Bad	>2.5	1
<200		6	Hardness Classification (Handa,1964)		
200-500		7	Permanent Hardness (NCH)		
500-1500		15	A1		1
1500-3000		1	A2		0
IBE Schoeller (1965)			A3		5
(Na+k)rock->Mg/Ca g.w.		28	Temporary Hardness (CH)		
(Na+k)g.w.->Mg/Ca rock		1	B1		0
Cation Facies			B2		7
Ca-Mg Facies		0	B3		1
Ca-Na Facies		15	Chloride Classification (Stuyfzand, 1989)		
Na-Ca Facies		14	Extremely fresh	<0.14	0
Na Facies		0	Very fresh	0.14-0.84	1
Na% Eaton (1950)			Fresh	0.84-4.23	22
Safe	<60	8	Fresh	0.84-4.23	22
Unsafe	>60	21	Fresh Brackish	4.23-8.46	5
Schoeller classification (1967)			Brackish	8.46-28.21	1
Type I		21	Brackish-salt	28.21-282.1	0
Type II		8	Salt	282.1-564.1	0
Type III		0	Hyperhaline	>564.3	0
Type IV		0	EC Wilcox (1955)		
S.A.R. Richards (1954)			Excellent	<250	0
Excellent	0-10	26	Good	250-750	10
Good	10-18	3	Permissible	750-2250	15
Fair	18-26	0	Doubtful	2250-5000	4
Poor	>26	0	Unsuitable	>5000	0

Geochemical classification: The geochemical evolution of groundwater can be understood by plotting the concentrations of major cations and anions in the Piper trilinear diagram. The plot shows that most of the samples fall in the field of mixed Ca-Na-HCO₃ type. Some samples are also representing NaCl type (Fig. 3). It indicates the dominance of Ca in the cations and interplay of HCO₃ and Cl in anions. From the plot alkali (Na) exceeds the alkaline earths (Ca and Mg) and strong acid Cl exceeds the weak acids (HCO₃ and SO₄). The chief function of the Piper diagram is to identify the facies of groundwater, it also help us to understand the several geochemical process along the flow path of the ground water. This diagram is also used to classify the water types (Wen *et al.*, 2005), which are generally distinct zones that cation and anion concentrations are described within the defined composition categories. Almost all the samples fall in the Na-HCO₃ type with few representations in Ca-Na-HCO₃ and Na-Cl type, clearly indicating the ion exchange process.

The suitability of groundwater for irrigation purpose is mainly based upon estimation of parameters like SAR,

Na%, RSC (Table 2). Total Na⁺ concentration and EC is important in classifying the irrigation water (Wilcox, 1955). Salinity of groundwater and SAR determines its utility for agricultural purposes. Salinity originates in groundwater due to weathering of rocks and leaching from topsoil, anthropogenic sources along with minor influence on climate. The level of Na⁺ and HCO₃⁻ in irrigation groundwater affects permeability of soil and drainage of the area. Na⁺ is an important cation, which in excess, deteriorates soil structure and reduces crop yield. (Schoeller, 1965) proposed a measure called "Index of Base Exchange" (IBE) to describe metamorphic reactions taking place in groundwater. There are substances, which absorb and exchange their cations with cations present in groundwater. Those substances are called Permutolites eg. Clay minerals like Kaolinite, Illite, Chlorite, Halloysite, Glauconite, Zeolites and organic substances. In this Kaolinite, Illite, Chlorite and Halloysite are the clay minerals in which ions are held at edges and their ionic exchange capacity is low. This case is reverse in Montmorllianite and Vermiculite; the exchange capacity is higher when the number of ions held on the surface is

more. Chloro-alkaline indices, CAI1 and CAI2 are used to measure extent of Base Exchange during rock water interaction. Where there is an exchange of Na^+ and K^+ in groundwater with Mg^{2+} or Ca^{2+} in rock/alluvium both the indices are positive. All ionic concentration is expressed in epm. The indices to Base Exchange indicate that there is a significant exchange of Na+K in rock to the Ca+Mg in groundwater (Chidambaram, 2000). There is also less notable introduction of Na+K in groundwater into the Ca+Mg in rock from the matrix where as the reverse is more prominent. The Scholler water type indicates that all the samples fall in class Type I. The Styfzands classification shows that most of the samples are fresh though there is representation of samples from very fresh to brackish nature.

Chadda's hydrogeochemical process evaluation: A hydrochemical diagram proposed by (Chadha, 1999) has been applied in this study to test if any of the interpreted hydrochemical processes can be identified by this method. The same procedure was successfully applied by (Vandenbohede *et al.*, 2010) in a coastal aquifer to determine the evolution of two different hydrogeochemical processes within a freshwater lens. Data was converted to percentage reaction values (milliequivalent percentages), and expressed as the difference between alkaline earths (Ca + Mg) and alkali metals (Na + K) for cations, and the difference between weak acidic anions ($\text{HCO}_3 + \text{CO}_3$) and strong acidic anions (Cl + SO_4). The hydrochemical processes suggested by (Chadha, 1999) are indicated in each of the four quadrants of the graph. These are broadly summarised as:

- Field 1 – Ca- HCO_3 type recharging waters
- Field 2 – Ca-Mg-Cl type reverse ion-exchange waters
- Field 3 – Na-Cl type end-member waters (sea water)
- Field 4 – Na- HCO_3 type base ion-exchange waters

The resultant diagram is exhibited in (Fig. 4). Field 1 (recharging water) when water enters in to the ground from the surface it carries dissolved carbonate in the form of HCO_3 and the geochemically mobile Ca. Field 2 (reverse ion-exchange) waters are less easily defined and less common, but represent groundwater where Ca+Mg is in excess to Na+K either due to the preferential release of Ca and Mg from mineral weathering of exposed bedrock or possibly reverse base cation-exchange reactions of Ca+Mg into solution and subsequent adsorption of Na onto mineral surfaces.

Field 3 (Na-Cl) waters are typical sea water mixing and are mostly constrained to the coastal areas, Field 4 (Na- HCO_3) waters which is more prominent in the study area forms a wide band between western part of the study area and the sea coast and possibly represent base

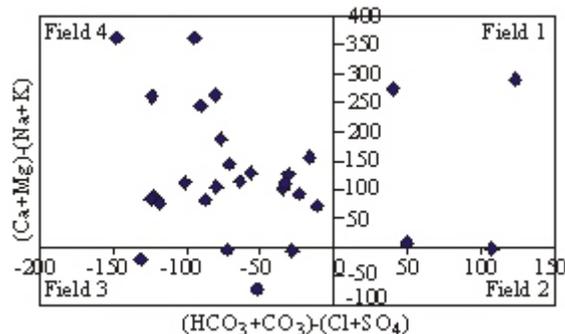


Fig. 4: Chadda's plot of process evaluation

exchange reactions or an evolutionary path of groundwater from Ca- HCO_3 type fresh water to Na-Cl mixed sea water where Na- HCO_3 is produced by ion-exchange processes.

Minor representation of samples are also found in Field 3 this is indicating (Na-Cl) groundwaters with typical sea water mixing and are mostly constrained to the coastal areas. recharge characteristics were noted in less samples falling in Field 1, with no representation in Field 2 indicating the absence of reverse ion exchange.

CONCLUSION

The SAR classification majority of the samples grouped in excellent to good category. Classification of Electrical Conductivity most of the samples fall within “permissible” to “good” limit with minor representations in doubtful category. In Na% classification of groundwater for irrigation purposes, majority of the samples grouped in unsafe zone and minor representations also falls in safe zone. The dominant cation facies is the Ca-Na and Na-Ca facies and the Anion facies is dominated by Chloride, sulfate and bicarbonate ion. According to Chloride classification by (Stuyfzand, 1989) majority of samples grouped in fresh-to-fresh brackish category, indicating the usage of this water agricultural activity. In USGS hardness classification most of the samples grouped in very hard to moderately hard and few representations fall in the slightly hard category. The majority of the groundwater in this region is having Corrosivity Ratio $\text{CR} < 1$, safe category, few samples having $\text{CR} > 1$, fall in unsafe category. The ground water of this region shows chiefly ion exchange characters, few of the samples show seawater intrusion and few represent recharge.

REFERENCES

APHA, 1998. Standard Methods for the Examination of Water and Wastewater. 19th Edn., APHA, Washington D.C., USASS.

- Arumugham, V., P. Sasidhar, K.B. Lal, J. Ahmed, C. Gurumoorthy and R.K. Mathur, 1997. Preliminary investigation on trend of ground Water Salinity in Deep Boreholes Drilled at Kokkilimedu, Kalpakkam, Proceeding of International Conference on Advances in Environmental Science, Trivandrum, India, pp: 173-179.
- Chadha, D.K., 1999. A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. *Hydrogeol. J.*, 7(5): 431-439.
- Chidambaram, S., A.L. Ramanathan, P. Anandhan, K. Srinivasamoorthy and M.V. Prasanna, 2005. A comparative study on the coastal surface and ground water in and around Puduchattiram region, Tamilnadu. *Int. J. Ecol. Environ. Sci.*, Special issue, 31(3): 299-306.
- Chidambaram, S., 2000. Hydrogeochemical studies of groundwater in Periyar district, amilnadu, India, unpublished Ph.D. Thesis, Department of Geology, Annamalai University.
- Chidambaram, S., A.L. Ramanathan and K. Srinivasamoorthy, 2003. Lithological influence on the groundwater chemistry - Periyar district a case study. Conference on coastal and freshwater issues, pp: 173.
- Chidambaram, S., M.V. Prasanna, A.L. Ramanathan, K. Vasu, S. Hameed, U.K. Warriar, K. Srinivasamoorthy, R. Manivannan, K. Tirumalesh, P. Anandhan and G. Johnsonbabu, 2009. A study on the factors affecting the stable isotopic composition in precipitation of Tamil Nadu, India. *Hydrol. Process.*, 23(12): 1792-1800. DOI: 10.1002/hyp.7300.
- Eaton, EM., 1950. Significance of Carbonate in irrigation water. *Soil Sci.*, 69: 123-133.
- EPA, 1994. *Groundwater: Methodology*. Vol: 2, Washington DC. USA.
- Forstner, U.K. and G.T.W. Wittman, 1981. *Metal Pollution in the Aquatic Environment*. Springer Verlag, Berli, Heidelberg, pp: 255.
- Fracois, L.E., T. Donovan, K. Lorenz and E.V. Maas, 1989. Salinity effects on grain yield, quality, vegetative growth and emergence. *Agron. J.*, 81: 707-712.
- Gupta, I.C., 1990. *Use of Saline Water in Agriculture, A Study of Arid and Semiarid Zones of India*. Revised Edn., Oxford and IBH Publishing Co, Pvt. Ltd.
- Gurumoorthy, C., P. Sasidhar, V. Arumugham and K.B. Lal, 1994. Studies on sea water/Fresh Water interfaces at Kalpakkam. Proceedings of 3rd National Symposium on Environment, Thiruvananthapuram, India, pp: 206-208.
- Gurumoorthy, C., P. Sasidher, V. Arumugum and R.K. Mathur, 2004. Sub-Surface investigation on deep saline groundwater of charnockite rock formation. Kalpakkam, India. *Environ. Monit. Assess.*, 91(1-3): 211-222.
- Handa, B.K., 1964. Modified classification procedure for rating irrigation waters. *Soil Sci.*, 98(2): 264-269.
- Hem, I.D., 1991. *Study and Interpretation of the Chemical Characteristic of Natural Waters*. 3rd Edn., US Geol Survey, Water Supply Paper 2254. Scientific Pub, Jodhpur.
- Hem JD., 1970. *Study and Interpretation of the Chemical Characteristics of Natural Water*. 2nd Edn., USGS Water Supply, 1473: 363.
- Jalali, M., 2008. Geochemistry characterization of groundwater in an agricultural area of Razan, Hamadan, Iran. *Environ. Geol.*, 51: 433-446.
- Kelly, W.E., 1976. Geoelectric sounding for delineating groundwater contamination. *Ground Water*, 14(1): 6-11.
- Kinzelbach, W., 1989. *Groundwater Modeling: An Introduction with Sample Program in Basic*. Elsevier Pub., NY.
- Nickson, R.T., J.M. McArthur, B. Shrestha, T.O. Kyaw-Nyint and D. Lowry, 2005. Arsenic and other drinking water quality issues, Muzaffargarh District, Pakistan. *Appl. Geochem.*, 20(1): 55-68.
- Pethaperumal, S., S. Chidambaram, M.V. Prasanna, V.N. Verma, K. Balaji, R. Ramesh, U. Karmegam and P. Paramaguru, 2008. A study on groundwater quality in the Pondicherry region. *Eco-Chronicle*, 3(2): 85-90.
- Prasanna, M.V., S. Chidambaram, S. Pethaperumal, K. Srinivasamoorthy, A. John Peter, P. Anandhan and M. Vasanthavigar, 2008. Integrated geophysical and chemical study in the lower subbasin of Gadilam River, Tamilnadu, India. *Environ. Geosci.*, 15(4): 145-152.
- Ramakrishna, 1998. *Ground Water. Hand Book*, India, pp: 556.
- Ramanathan, A.L., 1992. *Geochemical studies in the Cauvery river basin*. Unpublished Ph.D. Thesis, Punjab University Chandigarh.
- Ramesh, R. and M. Anbu, 1996. Chemical methods for environmental analysis. *Water and Sediment*, pp: 161.
- Richards, L.A., 1954. *Diagnosis and Improvement of Saline and Alkali Soils Agriculture Handbook 60*, Department of Agricultural, Washington DC, US, pp: 160.
- Scholler, H., 1965. *Hydrodynamic Dam Lekar Collogue Doboronik 1*, pp: 3-20.
- Stuyfzand, P.J., 1989. Nonpoint sources of trace elements in potable groundwaters in the Netherlands. Proceedings 18th TWSA Water Workings. Testing and Research Institute KIWA.
- Tijani, J., 1994. Hydrochemical assessment of groundwater in Moro area, Kwara state, Nigeria. *Environ. Geol.*, 24: 194-202.

- Twarakavi, N.K.C. and J.J. Kaluarachchi, 2006. Sustainability of groundwater quality considering land use changes and public health risks. *J. Environ. Manag.*, 81: 405-419.
- Vandenbohede, A., C. Courtens and L. William de Breuck, 2010. Fresh-salt water distribution in the central belgian coastal plain: an update. *Geol. Belg.*, 11(3): 163-172.
- Wen, X., Y. Wu, J. Su, Y. Zhang and F. Liu, 2005. Hydrochemical characteristics and salinity of groundwater in the Ejina Basin, Northwestern China. *Environ. Geol.*, 48: 665-675. DOI: 10.1007/s00254-005-0001-7.
- Wilcox, L.V., 1955. Classification and use of irrigation water. US Geological Department Agri. Circ., 969: 19.
- Wilcox, L.V., 1948. The Quality of water for irrigation, use. US Department of Agriculture, Washington, DC, Tech. Bull., 1962: 19.