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Appraisal of Groundwater Quality in the Cuddalore District of TN, India

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Abstract

The recent studies have occupied the attention on the geochemical characteristics and the present study focuses on groundwater evaluation of drinking water quality and Irrigation purposes in Cuddalore district. An attempt has been made by collecting 93 groundwater samples. In this study, the samples were analyzed for major cations and anions, which include Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3, SO_4^{-}, PO_4^{-}, F^{-}, NO_3^{-} *and* H_4Sio_4*.The results were evaluated and compared with WHO (2011) and BIS (2014) standards to get the suitability for water utilization. In Gibbs diagram most of the samples represent the rock–water interaction process and minor evaporation field. The delineation of samples in piper tri-linear diagram evaluated groundwater type of study area. By the help of WQI, category and suitability of groundwater for drinking and irrigational purposes were determined. The results of the analysis were also interpreted with help of geology of the area. The residual sodium carbonates (RSC) and Chloro-Alkaline Indices ratio (CAI), Scholler classification were also considered to get the water quality.*

Keywords: Water Quality, Geochemistry, Ion Exchange, Cuddalore, Saline.

Introduction

The quality of groundwater is a major concern for humanity because variation in quality can give hazardous effect to human health and society as well. In India groundwater is having a great value as it is the major source of drinking and irrigation purposes. In recent times exploitation works for groundwater has been increased significantly, especially for agricultural purposes as many regions. The frequent failure of monsoon has resulted in the decrease of the groundwater recharge. This component serves as a essential contributor for the domestic, irrigation and industrial sector[1]. There is an approximate increase of 40 Mha in the groundwater dependent irrigation from 1950 to 2001[2,3]. Thus the increase in need of this basic resource has resulted in the depletion of Quantity, deteriorates of Quality. The Quality of groundwater is determined by physical, chemical and biological parameters. This quality affects determines the utility of groundwater. The chemistry of groundwater have a important function in classification and assessment of water quality. The determination of utility of groundwater for a specific purpose will not be suitable for other purposes. Further the Classification of utility studies based on a signals ion reduces the scope of the understanding of quality, hence the quality studies should integrate the different ions analysed to understand the parameter used for different utility purposes[4]. The coastal aquifers are basically insubstantial in nature and the depletion of shallow aquifers continues as a consequence of overexploitation of ground water in many parts of India and world as well[5,6]. There are different sources salinisation like sea water intrusion, dissolution of salts, brackish water and paleo -saline (Connate water)[7, 8]. The aim of this study is to identify the suitability of groundwater for different utility purposes like, drinking, domestic and agriculture applications.

Study area: The area chosen for study in Cuddalore district, which falls in between South of the Ponnaiyar river and North of the Vellar River. It covers an area about 3678 Sq.km, and lies between 15^0 5" and 12^0 35" N, 78^0 38" and 80^0 00" E it falls in Survey of India Map No: 56M/10, 14,58M/11 and 15. The Significant role for East of Pichavaram Mangroves; south of Cuddalore port, SIPCOT Industries, followed by Colereon River flowing is there. Major part of the study area is devoted to agricultural activities, which include paddy, sugarcane, and groundnut and gingili cultivation[9].

Climate and rainfall: The study area has a hot tropical climate and its temperature with highest of 40.34°C and lowest in 26.68°Cin recorded during 2011. Relatively humidity of the area differs within 67% to 87%. The average annual rainfall of the study area is about 1212 mm in2014. The maximum recorded annual actual rainfall was average amount of 169.0 mm during Pre monsoon and average amount of rainfall recorded 135.0 mm in during NE Monsoon 2014[10].

Geology: The geology of the area plays a significant role for assessing groundwater potential zone of the region. This district underline by different range of age from oldest Archean rocks to recent sediments. Tertiary and quaternary sedimentary rocks

mainly make up the study area (Figure-1)**.** The tertiary formations are composed of sandstone, grit sands, and Clays gently dipping towards ESE. The depth of these tertiary rocks ranges from 100 to 457 m. Litho log data from Neyveli region reflects thick deposit of sandstones, sands, Clays, Gravel continuing to a depth of 300 m [11].

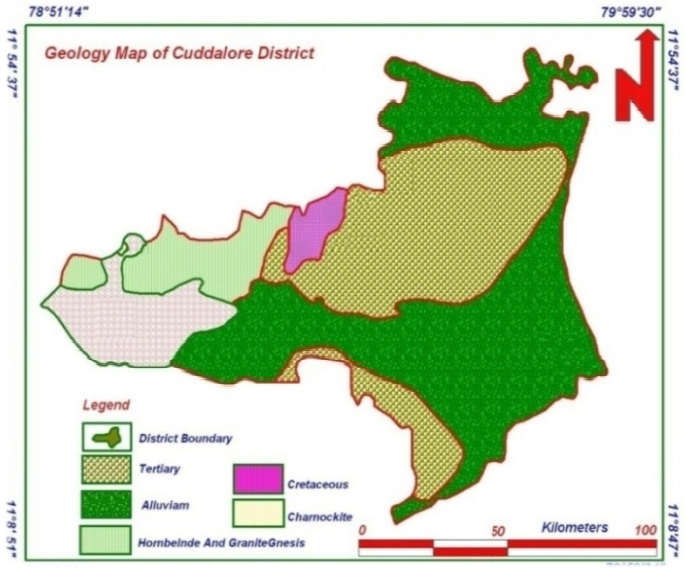

Figure-1
Geology map of the study area

Geomorphology: There are three different categories of geomorphic features in the study area: i. western Pediplains ii. central-sedimentary high ground and iii. eastern coastal Plains. The pediplain are represented in the western part of the study area, the central highland has sedimentary formation > 80 m amsl, and the eastern part is dominated by the alluvium formed by fluvial deposits of the rivers Pennaiyar, Vellar and Kollidam[12] (Figure-2).

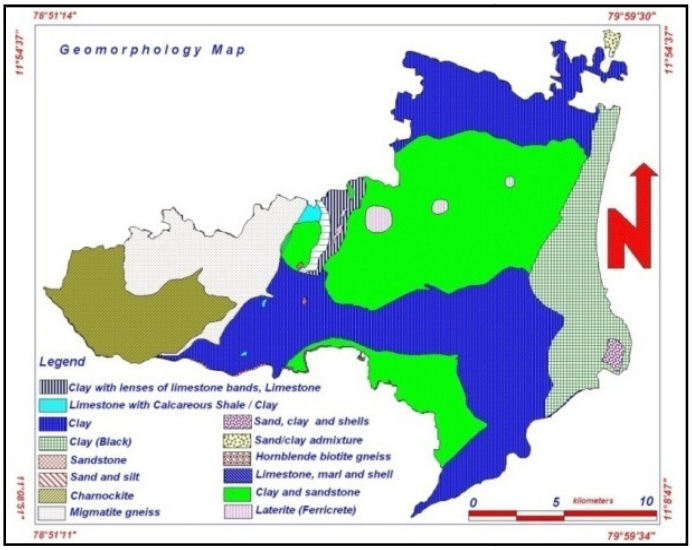

Figure-2
Geomorphology

Groundwater status: The movement and occurrence of groundwater are controlled by various factors; climate, geology and structural features. The occurrences of groundwater are identified in fractured and the weathered hard rock aquifer matrix. It's also found in the Phreatic and confined to semi – confined condition in the Sedimentary aquifer. The fluctuation of water level is noted between 3 to 85 mbgl[13].

Materials and Methods

In total 93 samples of groundwater were taken into consideration collected from the study area pre-monsoon 2015. Samples were collected using polythene bottles washed with clear acid and standard procedures were used for analysis[14]. The parameter, such as Temperature, pH, EC (Electrical Conductivity) and TDS (Total Dissolved Solids were analyzed in Thermo Orion ion electrode probe Portable kit) were measured in the field. Ca^{2+}, Mg^{2+}, HCO_3^- Cl^- , were analyzed in titrimetric Methods[15]. SO_4^{2-}, PO_4^-, H_4SiO_4, and NO_3were determined by using UV Spectrophotometer HACH 6000 Instrument. The analytical precision for the measurements of ions was determined by calculating the ionic balance error, which is generally within ±5 %. The fluoride ions were analyzed in Thermo Orion ion electrode (F). The Na and K were analyzed in Flame photometer (Elico CL 378). The maps were prepared by Map info professional 8.5 and piper plot done by Aquachem 4.0. Calculation & graphical representations were done by a computer program WATCLAST in C++[16].

Results and Discussion

Groundwater Chemistry: To assess the chemistry of groundwater studied during the season of Pre-monsoon 2015. The pH range between lowest for 5.59 maximum of 8.7 and with an average of 7.05 observed in the study area. A Water with a pH > 8.5 could indicate that the water is hard and acidic to alkaline in nature. The Hardness of the water results in aesthetic issues. The Electrical conductivity (EC) values range from 95.7µs/cm to 4890 µs/cm at 25^0C, averaging of about 1253µs/cm. The EC values reported in channels near location 27 are high & inconsistent because of industrial discharge and urban waste disposition which results in leaching and accumulation of chemicals[17]. The most abundant cation in ground water is sodium (Na) with an average value of 67.9 mg/l (1.2 – 295 mg/l). Calcium comes next in abundance with an average concentration of 48.55 mg/l (8.0 – 168 mg/l). The major source of alkali earth is groundwater could be from weathering of minerals in hard rock matrix and the Alkali could be due to the process of ion exchange. Range for Magnesium concentration varies from 2.4 to 94 mg/l, which has an average of 27 mg/l. Potassium range differs within 0.2 to 50 mg/l with an average value of 6.7mg/l. The concentration of potassium is groundwater is low because of the resistance of the potassium bearing minerals such as biotite, orthoclase and microcline, but anomalous concentrations in few locations may come

possibly due to involvement of human[18]. Chloride concentration ranges from 17.73 to 905.7 mg/l in groundwater of the study area, with an average value of 169.3 mg/l. But abnormal high concentrations of chlorine may be reported in certain locations which might have been procured from anthropogenic origin due to lack of Cl-bearing minerals[19]. Bi-carbonate ion concentration range differs within 24 to 408mg/l which has an average value of 168 mg/l. The probable source of bicarbonate comprises HCO_3 presence of organic matter in the groundwater which is oxidized to produce carbon dioxide along weathering of minerals in hard rock aquifer.

Nitrate concentration range differs within 0.44 to 332.1 mg/l in groundwater with an average value of 32.17 mg/l and is not fit for drinking as it is exceeding the standards[20]. It may result blue baby disease/ methaemoglobinaemia in children[21]. NO_3 concentration is high in those areas where fertilizers are being used for intensive agricultural purposes. Sulphate concentration in groundwater ranges from 0.06 to 6.21 mg/l having an average value of 1.24 mg/l whereas Fluoride differs within 0.1 to 4.3mg/l with an average of 1.7 mg/l. Silica dissolution ranges from 5.02 to 590 mg/l with an average of 74.29 mg/l, Higher concentration reflects the presence of silicate minerals in the litho units of the study area. The geochemistry of water samples to obtain abundance of the major cations and anions in the groundwater are of the following order: The order of ion dominance ion of groundwater samples like**,**

Cl^-> H_4SiO_4 >HCO_3^-> NO_3^- > Na^+> Ca^{2+}> Mg^{2+}> K^+>SO_4^-> F^-> PO_4^- respectively.

Drinking water quality: WHO (2011) and BIS (2014) have analyzed standards of drinking water, the results of analysed parameters were compared[20,22]. The hydrogeochemistry of the region shows that some of the groundwater is chemically potable & appropriate for domestic and agricultural purposes. Incaution cation concentrations of 13 % for Potassium and 3.2% of the Sodium run over the legitimate limit. 2.1 % concentrations of anion exceeded the permissible limit and Ca, Mg, HCO_3, SO_4 concentrations are within the limit as per the standards (Table-1).

Spatial distribution of Electrical conductivity: The figure indicates that Electrical conductivity ranges for majority of samples are represented in northwest and central region. It is EC ranges between from 95.7 µs/cm -4890 µs/cm. The spatial distribution of Electrical conductivity proportion indicates that minimum of (0- 95.7 µs/cm) observed in northern part and maximum of > 1841 µs/cm represent in south eastern part of the study area (Figure-3).

Piper Plot: The major cations (Ca^{2+},Mg^{2+}, Na^++ K^+) and (CO_3-+HCO_3-,Cl-, SO_4^{2-}) were considered while plotting Piper diagrams. The plot stipulates towards the groundwater type which cover geochemical evolution can be seen clearly from the plot (Figure-4). The dominant water types are 1, 2 and 4, represented by 1.Ca–HCO3 type and 2. Na- Cl type and 3.Mixed Ca-Mg-Cl type 4. Ca- Mg- Cl type 5. CA- Cl type 6. Na-HCO_3 the indicating dominance of freshwater recharge region and indicating the Saline nature in the groundwater[23]. However, in the present study water types were confined to the first four types.

Table-1
Comparative statement of Groundwater Samples with (WHO 2004) and (BIS 2014) for Pre monsoon season (all values are in mg/l) except pH)

Present study			**Permissible Limit**		**Polluted Samples**
	Range	**BIS (2014)**	**WHO (2011)**	**ISI (1983)**	**As per WHO (2011)**
pH	5.59-8.7	6.5-8.5	6.5-8.5	6.5–9.2	G26,
TDS	50.1-2410	500	1000	1500	G21
Na^+	1.2 -295	200	200	-	G47, G75, G81,
K+	0.2-50	-	12	-	G2, G14, G21, G23, G26, G61, G81, G84, G87, G88, G90, G92
Ca^+	8 -168	100	200	200	-
Mg^+	2.4 -94	50	150	150	-
HCO_3	24-408	-	500	-	-
SO_4	0.06 -621	200	250	400	-
Cl^-	17.73 - 905.7	200	600	1000	G81, G86

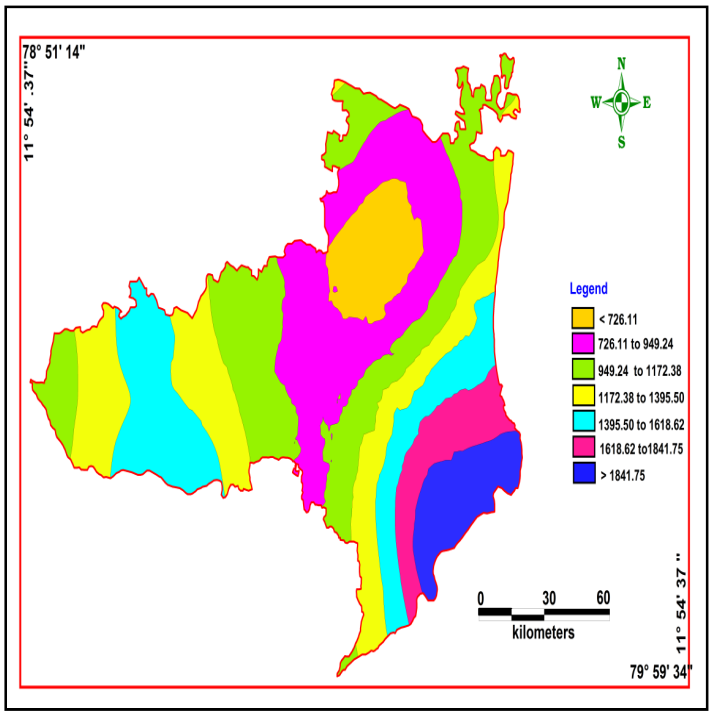

Figure-3
Spatial distribution of Electrical conductivity in the study area

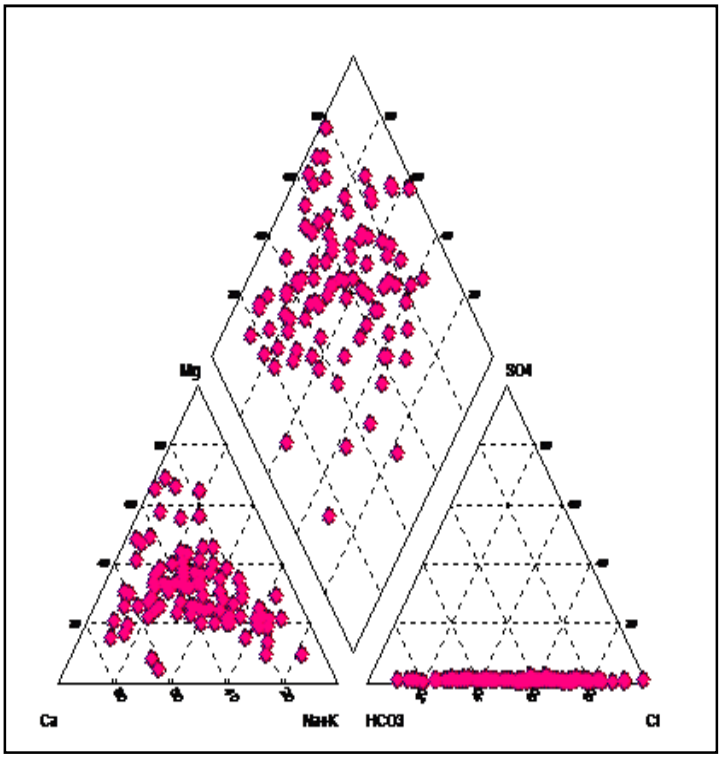

Figure-4
Shows Piper diagram for groundwater samples of the region

Hydro geochemical Processes: Mechanisms of controlling groundwater chemistry (Gibbs ratio): The Gibbs diagram shows the ratio between Cl/ (Cl+HCO3) and Na+K/Na+K+Ca as a major function of TDS and this is useful to access the main sources of dissolved ions, which are precipitation dominance, rock dominance and evaporation dominance[24]. For groundwater samples from cuddalore district (Figure-5) it shows that major amount of the samples fall in rock dominance and evaporation category, stipulating the authoritative factor for the groundwater chemistry.

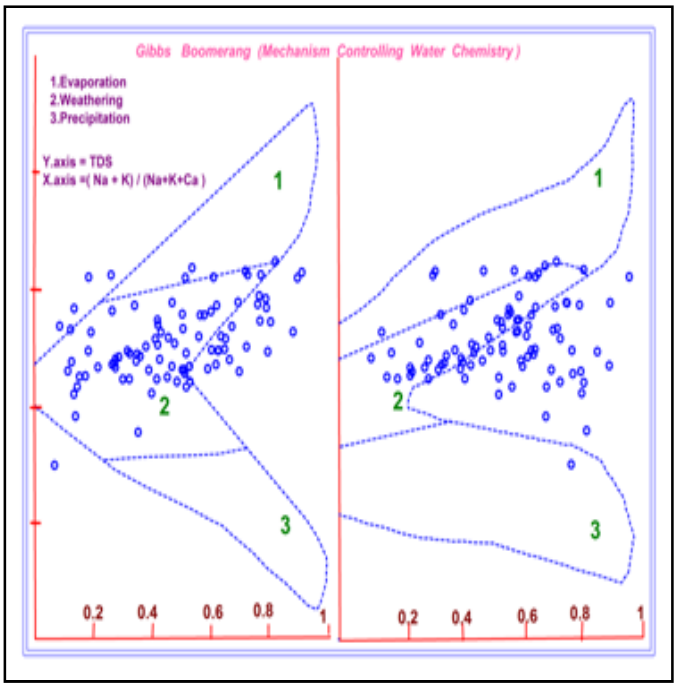

Figure-5
Gibbs plot illustrating classification of irrigation water quality

Therefore the chemical weathering of the rocks maybe one of the major process which contribute ions to the groundwater of the study region. The description of Gibbs plot indicates 85 % of the groundwater samples fall in rock – water interaction due to weathering process, it which suggests that the weathering of rocks primarily controls the major ion chemistry of groundwater in this region.

Ion Exchange: This process plays a significant role in determining the concentration of ions in groundwater. Chloro Alkaline Index (CAI) are calculated by using the following formula with the epm values of the ions,

$$CAI = C1^- - (Na^+ + K^+)/C1^- \quad (1)$$

(All values are expressed in meq/l)

The negative index signifies the change of Ca+ Mg in water to Na + K in rock and if it is position it indicates a reverse ion exchange process[25]. The derived CAI values range from –4.67 to 25.46[26].

Table-2
Summary of Geochemical classification by using WATCLAST Program for Pre- monsoon 2015 (Chidambaram et al., 2003)

Category	**Grade**	**PRM**	**Category**	**Grade**	**PRM**	**Category**	**PRM**
		N=93			**N=93**	**N=93**	
Na% Wilcox (1955)			**USGS Hardness**			**TDS Classification (USSL,1954)**	
Excellent	0-20	24	Soft	<75	1	<200	7
Good	20-40	37	Slightly Hard	75-150	29	200-500	40
Permissible	40-60	21	Moderately Hard	150-300	45	500-1500	44
Doubtful	60-80	10	Very Hard	>300	124	1500-3000	2
Unsuitable	>80	1	**IBE Schoeller (1965)**			**Cation Facies**	
Na% Eaton (1950)			(Na+K) rock->Ca/Mg g.w.		17	Ca-Mg Facies	24
Safe	<60	82	(Na+K)g.w.->Ca/Mg rock		76	Ca-Na Facies	69
Unsafe	>60	11	**Schoeller Classification (1967)**			Na-Ca Facies	0
S.A.R. Richards (1954)			Type I		93	Na Facies	0
Excellent	0-10	93	Type II		0	**Anion facies**	
Good	10-18	0	Type III		0	HCO_3 Facies	0
Fair	18-26	0	Type IV		0	HCO_3, ^-Cl, $^-SO_4$ Facies	0
Poor	>26	0	**Corrosivity Ratio (1990)**			Cl^-, SO_4,$^-HCO_3$ Facies	83
R.S.C. Richards(1954)			**Safe**	<1	27	Cl^- Facies	10
Good	<1.25	88	**Unsafe**	>1	66	**Hardness Classification (Handa,1964)**	
Medium	1.25-2.5	3	**Chloride Classification (Stuyfzand,1989)**			**Permanent Hardness (NCH)**	
Bad	>2.5	2	Extremely fresh	0		**A1**	27
EC Wilcox (1955)			Very fresh	4		**A2**	44
Excellent	<250	8	Fresh	55		**A3**	12
Good	250-750	26	Fresh Brackish	20		**Temporary Hardness (CH)**	
Permissible	750-2250	48	Brackish	14		**B1**	3
Doubtful	2250-5000	11	Brackish-salt	0		**B2**	4
Unsuitable	>5000	0	Salt	0		**B3**	2
			Hyperhaline	0		**EC- TDS Relation**	
						< 0.60	77
						0.60-0.80	3
						>0.80	13

Water Quality studies for Irrigation: Sodium Absorption Ratio (SAR)%: Sodium absorption ratio helps is determining the utility of water for irrigation purpose. There are different processed by which salinity can be enhanced in water viz., Climate, weathering, manmade activities and leaching of salts[13]. To maximize the crop productivity of the region, proper quality irrigation water is required. Salinity, chlorinity and sodicity indices were used to assess the ground water suitability of the study area for irrigation purposes. Majority of the samples in study area inferred suitable for irrigation.

$$(SAR = Na^+/ (Na^+ + Ca^{2+})/2) \quad (2)$$

Based on the SAR equation derived values between 4.5 - 84.5meql represents, it is good for irrigation[27]. Samples are entirely fall in excellent grade. Hence, the present study is consider for <10 (RSC) and it can be classified as excellent category [26].

Na Percentage (%): The structure of the soil is considerably affected by the presence of Sodium. Na concentration is important in classifying water for irrigation purposes. The Na% range from <60 of 88% of Safe limit, and rest 12 % of samples are unsuitable[28] (Table-2).

Wilcox classification of electrical conductivity shows that, 27.95% of samples comes in good category, 51.6% in permissible category 11.82 % in the suspicious category, and the remaining 8.6 % falls under excellent category[29] (Table-2).

Irrigation water Quality: For better crop yield, good quality of water should be used for irrigation. The suitability of water for Irrigation is assessed by the following parameters, like PI and RSC. However, with the result of quality Irrigation pattern can be proceed without any side effect in the study area because samples mostly represent good category in the USDA Classification (Table-3).

Table-3
Suitability for water - Irrigation purpose using USDA standard

EC (µs/cm)	Salinity Class	Percentage of Samples (%)	Remarks on quality
<250	C1	8.56	Excellent or low
250-750	C2	27.95	Good or Medium
750-2250	C3	51.6	Permissible or High
2250-5000	C4	11.82	Unsuitable or Very high

Residual Sodium Carbonate (RSC): Higher concentration of CO_3^- and HCO_3^- in groundwater is due to high Ca and Mg, which may affect agriculture unfavorably. The fluctuation in RSC can be seen by the help of categories like good, medium and poor. 95 % are represented in good category; 3% in the medium category and 2 % comes under bad category.

Permeability Index (PI): Permeability index is a major function, which has influence over the Utility of water for agriculture. There are three basic types of classes such as Class I, Class II and Class III to favorability for agricultural practices[30] (Table-2).
The utility of groundwater for irrigation was calculated as follows, where all values were in epm.

$$PI = \frac{Na+\sqrt{HCO3-X100}}{Ca+Mg+Na} \quad (3)$$

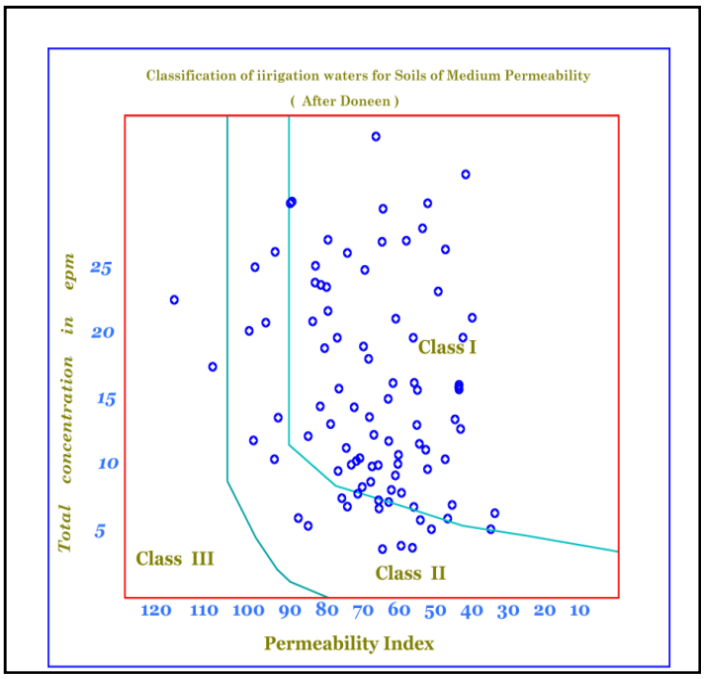

Figure-6
Doneen plot illustrating the Irrigation based on Classification of water quality with PI.

The Figure-6 shows that groundwater falls within the permissible category for irrigational utility. The majorities of the samples are represented in Class I and Class II, which represents good and moderate category respectively and rest of them were not suitable for irrigational purpose.

Conclusion

The present study Hydro chemical introspection of groundwater in the Cuddalore area indicated that it varied from soft to alkaline in nature. The major ion dominance concentrations in the order of $Cl^- > H_4SiO_4 > HCO_3^- > NO_3^- > Na^+ > Ca^+ > Mg^+ > K^+ > SO_4^- > F^- > PO_4^-$. In such that, we have observed that water chemistry results reveals in predominance of cations of Silicate, Na and Ca and in order of anion such as: Chloride and Bi-carbonate occurring the Cuddalore region. The Piper-trilinear

diagram showed the predominance of Ca- HCO_3 and Na- Cl^-, mixed Ca^{2+},Mg^{2+},Cl^-, water type. Hydro chemical characterization of water body presents the condition of water with respect to its quality measuring parameters considered under the study. The Gibbs plot suggesting that rock weathering is the prime process for contributing the ions into the water. The chloro alkaline Index and SAR ratio represents the groundwater were mostly fell within the permissible limit and good in quality for human consumption as well as for livestock farming. The health aspect evaluate 12 samples were Exceeding the WHO& BIS standard limitations. Finally, it's inferred that are in the poor water quality and rest of them falls good category suitable for and found drinking, livestock and agricultural Practices.

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