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Impact of Groundwater Quality from Industrial East Coastal Town, Southern India

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ABSTRACT
Contamination of drinking water by human and industrial activities is a serious concern now-a-day. Indiscriminate use of groundwater deteriorates the quality and quantity of water. The study was carried out to assess the impacts of industrial activities on the groundwater quality in and around Cuddalore coast town during September 2012 and February 2013. The quality was assessed in terms of physio-chemical parameters and compared with BIS. The groundwater samples are classified into Ca^{2+}-HCO_3^{2-} type, Ca^{2+}-Mg^{2+}-Cl^- type based on its hydrogeochemical characteristics. . The groundwater at many locations in the study area is not suitable for drinking because of its high salinity, hardness and chloride, which is mainly caused by industries discharge, agricultural activities and seawater intrusion. The WQI reflected that most of the samples are of poor water to very poor water. The Wilcox diagram, USSL diagrams and PI shows that most of the samples are suitable for irrigation. It was found that the groundwater was contaminated at few sample locations. The consequence of industrialization and urbanization leads to degradation of water quality. Hence the local government needs to initiate remedial measures.

***Keywords* -** Physiochemical characteristics, seawater intrusion, suitability drinking and irrigation, coastal town.

I. INTRODUCTION

Water is a precious and most commonly used resource. Water is one of the most abundant chemical substances on earth, as it covers two third of the earth surface. Of the total amount of global water, only 2.4% is distributed on the main land, of which only a small portion can be utilized as fresh water. The available fresh water to man is hardly 0.3-0.5% of the total water available on the earth and therefore, its judicious use is imperative [1]. Groundwater plays significant role in the living organisms that existing in this world. Groundwater has become a necessary resource over the past decades due to the increase in its usage for drinking, irrigation, industrial use etc. In the last few decades, there has been a tremendous increase in demand for fresh water due to rapid growth of population and the accelerated pace of industrialization. Human health is threatened by most of the agricultural development activities particularly in relation to excessive application of fertilizers and unsanitary conditions. Rapid urbanization, especially in developing countries like India, has affected the availability and quality of groundwater due to its overexploitation and improper disposal in urban areas. Many of the groundwater in the coastal aquifer is suffering from seawater intrusion both by natural process and anthropogenic activities [2].

According to [3], 80% of all disease in human being is water-borne. Once the groundwater is polluted; its quality cannot be restored by stopping the pollutants from the source. Also most of the industries operating in the area discharge their effluent directly into the sea or creek without considering the effects of these wastes on the coastal shallow aquifers and aquatic lives. In the coastal regions the availability of fresh water is always threatened by over extraction or by seawater intrusion and in some cases the risk is from the agricultural and industrial activities. The objective of the present work is to discuss the suitability of groundwater for human consumption and irrigation quality.

II. II.STUDY AREA

The present study was carried out in east coastal region of Cuddalore that lies 125 kilometers south of Chennai on the coast of the Bay of Bengal (Figure 1). The study area forms a part of Cuddalore district which lies in between north Latitudes of 11˚44’04” and 11˚68’01”and east longitudes 79˚70’09” and 79˚77’05” with a total extent of 46 sq.km. The area form a part of the Survey of India topo-sheet no 58 M/10. The area has a tropical climate with an annual average precipitation of 1160 mm and most of the rainfall occurs during northeast monsoon (October to January). The temperature ranges from 21ºC to 39ºC with an average of 28ºC. The humidity of the region varies from 67% to 85%. The area falls under seismic zone-II with a plain terrain. Agricultural activities, especially paddy, sugarcane, groundnut cultivation are most common. The area is entirely underlain by

this pollution impact the health status of the surrounding area of industrial region.

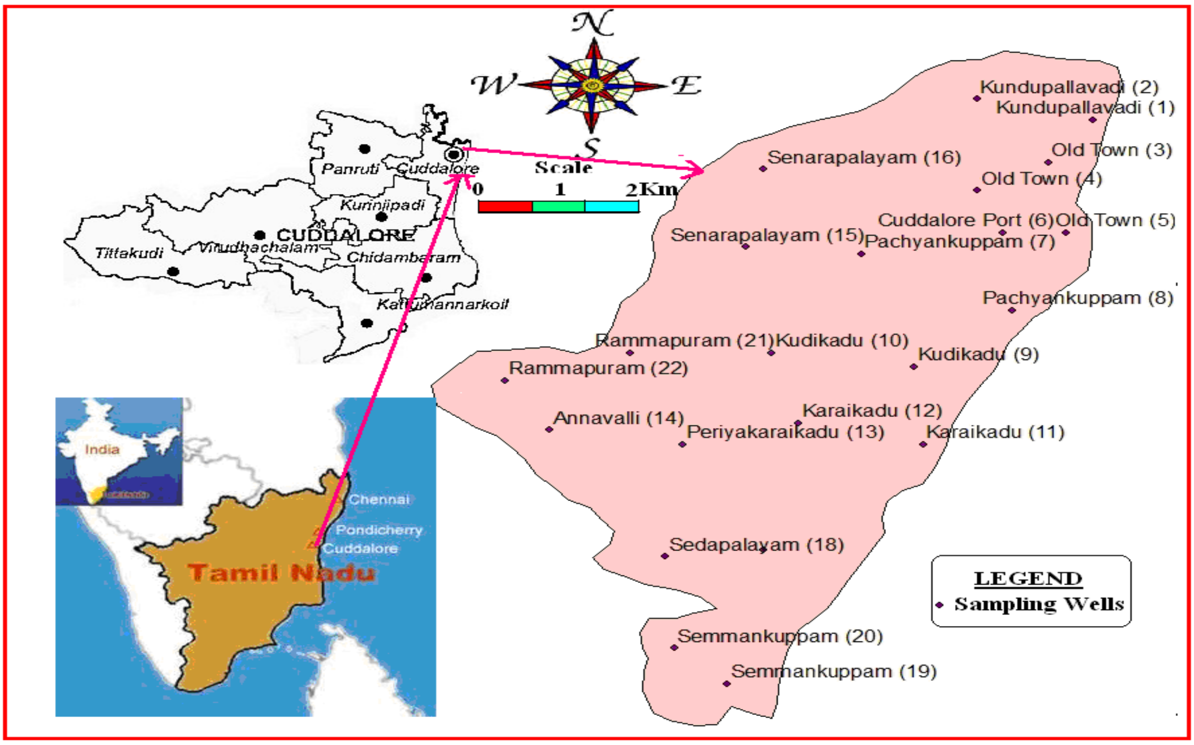

Figure.1 Location Map of Study Area

Sedimentary formations, which include calcareous sandstone, coastal alluvium, and laterite soil of tertiary and quaternary age. The most common outcrops in the area are limestone, sandstone and clays. The soil types are red sandy loam, loamy sand, lateritic, clay loam and clayey soil. The general phreatic aquifers with moderate to shallow water table conditions exist in this area. The depth of bore wells ranges from 40 to 170 m below groundwater level and deeper bores ranges from 400 to 500 m. Groundwater has been used for various purposes, such as domestic, agricultural and industrial needs. Groundwater in this area is overexploited for industrial and agricultural purposes are predominant land use in this area. The industrial pollution and seawater intrusion are the main reasons for deterioration of water quality. An industrial estate SIPCOT (Small Industries Promotion Corporation of Tamil Nadu) with groups of industries near the coast, which generate chemicals and raw materials are distributed along the coastal area. Most of industries are wet process industries and hence consume large quantity of water. The entire water requirement of these SPICOT industries is met by ground water. The groundwater availability and quality of the area is adversely affected by the industrialization and urbanization of the town. The villagers particularly children have skin problem and constant itching and

III. METHODOLOGY

Groundwater samples were collected from 22 locations in and around Cuddalore coastal town during pre-monsoon period (Sep 2012) and post-monsoon (Feb 2013) and the parameters EC were measured on the spot at the time of sample collection using potable kit. The collected groundwater samples were transferred into plastic container for analysis of chemical characters and the water samples collected in the field were analyzed for electrical conductivity (EC), pH, total dissolved solids (TDS), major cations like calcium(Ca^{2+}), magnesium(Mg^{2+}), sodium(Na^{+}), potassium(K^{+}) and anions like bicarbonate(HCO_3^{-}), carbonate(CO_3^{2-}), chloride(Cl^{-}) and sulphate (SO_4^{2-}), in the laboratory using the standard methods given by the American Public Health Association [4]. Analysis of heavy metals is tested in the Atomic Absorption Spectrometry such as Nitrate (NO_3^{-}), Iron (Fe^{-}), Phosphate (PO_4^{-}) and fluoride (F^{-}) is to identify the heavy metals concentration in the groundwater. The heavy metal concentrations are generally leads to anthropogenic activities.

IV. RESULT AND DISCUSSION

Groundwater Chemistry

World health organization [5] has reported that about 80% of the health hazards occur in world due to the poor quality of water used for consumption. The pH indicates the acidic or alkaline material present in the water. The pH of groundwater samples in this area ranges from 4.0-8 .0 and 6-7.8 during pre and post-monsoon respectively, seasonal variation shows the pH values fluctuating at all locations. The higher pH is present in the eastern part of the study area in both monsoon seasons and is slightly acidic due to the industrial effluent and domestic sewage. Most of the area shows the permissible limit of pH in drinking water is within 6.5- 8.5 according to Bureau of Indian Standards [6]. Electrical Conductivity (EC) value of the study area varied from 320-7210µs/cm and 351-6495 µs/cm during pre and postmonsoon seasons (Figure 2). EC is a measure of water's capacity to conduct electric current since most of the salts in the water are present in the ionic form. In general, groundwater tends to have high electrical conductivity due to the presence of high amount of dissolved salts. EC is decisive parameters in determining suitability of water for a particular purpose. Drinking water quality is also affected by the presence of soluble salts. The total dissolved solids (TDS) upto 500 to 1500 mg/l is permitted for drinking as well as other domestic purposes as per the standards. Water with high TDS indicates more ionic concentration, which is inferior and can cause physiological disorders to its users [7]. TDS observed from this area is between 204-4614 mg/l and 224-3904 mg/l in pre and post-monsoon. Most of the groundwater samples are within the maximum permissible limit for drinking water as per the BIS, except four samples. In this region, the total hardness varies between 202-960 mg/l and 100-800 mg/l during pre and post-monsoon were quite high with their prescribed standards of 300 mg/l. Hardness in water is due to the natural accumulation of salts from contact with soil and geological formation or it may direct pollution by industrial effluent. Total hardness is caused primarily by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulphate in water. Water with hardness greater than 300 mg/.l may raise the risk of calcification of arteries, urinary concretions, diseases of kidney or bladder or stomach disorders [8]. The calcium concentration in water samples collected from the study area ranged from 800-500 mg/l and 100-420 mg/l in pre and post-monsoon seasons. So, most of the samples exceed the permissible limit due to rapid industrialization and urbanization and their wastes are known to account for such anthropogenic sources of calcium in water [9]. Calcium is a major constituent of various types of rocks and aquifers. Calcium is an essential cause for hardness in water, incrustation in boilers and essential constituent of human beings. In groundwater the calcium content generally exceeds the magnesium content [10]. In this present study the magnesium level in the water samples ranged from 30-495 mg/l and 25-440 mg/l in pre and post-monsoon seasons. In most of the locations magnesium exceeds the permissible limit which may result in intestinal irritation of human system particularly near the industrial area. The concentration of sodium in the area varies from 50-640 mg/l in pre-monsoon and in post-monsoon the value range from 80-650 mg/l. Groundwater in most of the areas comes under the non-safe zone for drinking with reference to the concentration of sodium, which is more than 200 mg/l. The higher concentration of sodium may pose a risk to persons suffering from cardiac, rental and circulatory diseases [11]. Person afflicted with certain diseases require low sodium concentration In present investigation potassium concentration was ranged from 15-137 mg/l and 35-130 mg/l during pre and post-monsoon. The permissible limit of potassium is 10 mg/l and in

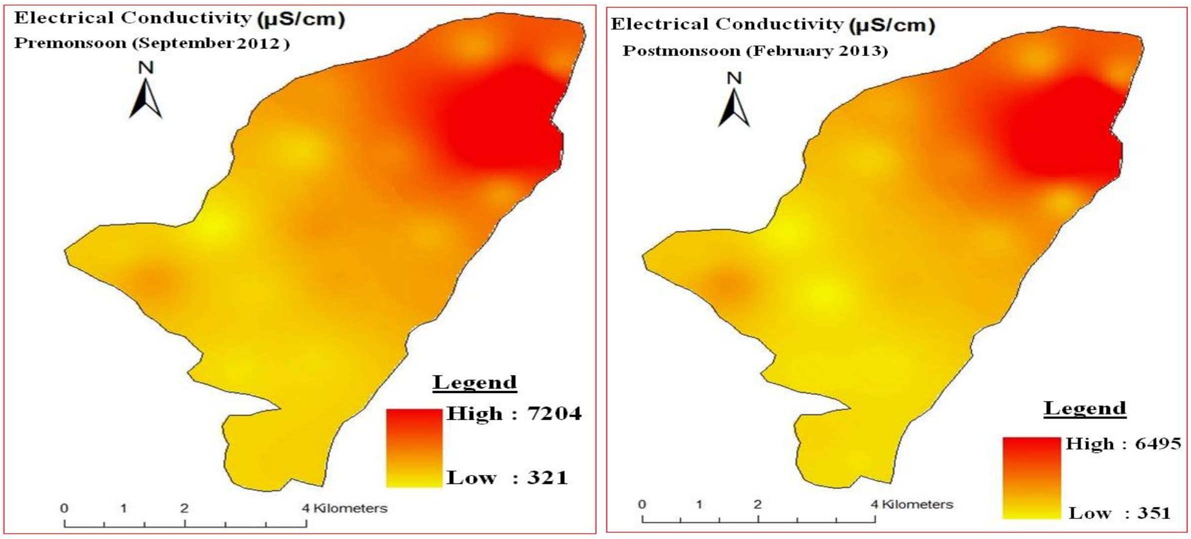

Figure.2 Spatial Variation of Electrical Conductivity

the study area nearly 50% of the samples exceed the permissible limit. K is an essential nutrient but if ingested in excess may behave as a laxative. Bicarbonate (HCO_3^-) was observed higher of 148-1000 mg/l during post-monsoon season than pre-monsoon 183-976 mg/l. The source of high concentration of bicarbonate may be due to dissolution of CO_3 of the soil and percolation due to rain water as well as irrigation [12]. The most important source of chlorides in the water is the discharge of industries effluents or sewage, fertilizers and septic tanks. The chloride concentration varied from 20-487 mg/l and 26-520 mg/l during pre and post-monsoon. The chloride ion is higher than 200 mg/l may pose risk to human health and may cause unpleasant taste of water. Its high consumption may be crucial for development of essential hypertension, risk for stroke, osteoporosis, renal stones and asthma [13]. High concentration of chlorides is considered to be the indicators of pollution due to high organic wastes of industrial or animal origin, presence of sodium chloride from rocks and saline water intrusion. High chloride content may harm metallic pipes as well as growing plants. In this study area few areas have higher concentration, which could be dangerous from health point of view. The high chloride may be attribute industrial, domestic wastes, leaching, from upper soil layers in dry climates and natural geochemical activities in this area [14]. In present investigation sulphate concentration was ranged from 33-489 mg/l and 15-450 mg/l during pre and post-monsoon. The major physiological effects resulting from the ingestion of large quantities of sulphate are catharsis, dehydration and gastrointestinal irritation. In the study area the 32% of sulphate ions exceed the permissible limit of 250 mg/l. The higher sulphate content is present due to bio-chemical, anthropogenic sources and industrial process etc and a higher concentration were seen near the industrial areas in both seasons.

The nitrate concentration in groundwater collected from the study area ranged between 40 to 96 mg/l and 45 to 92 mg/l in pre and post-monsoon (Figure 3). The permissible limit of nitrate is 45 mg/l prescribed as per standards. Increased level of nitrate at various locations may be attributed due to the surface disposal of sewage and agricultural wastes. The permissible limit of nitrate is 45 mg/l. The influence of nitrate is seen in western part of the study area where the agricultural practices. The origin of nitrate is derived may be from agricultural areas due to leaching process from plant nutrient, nitrate fertilizers, industrial effluents and poor sanitary conditions [15]. The high concentration of nitrate in drinking water causes methenoglobinemia in infants, a disease characterized by blood changes.

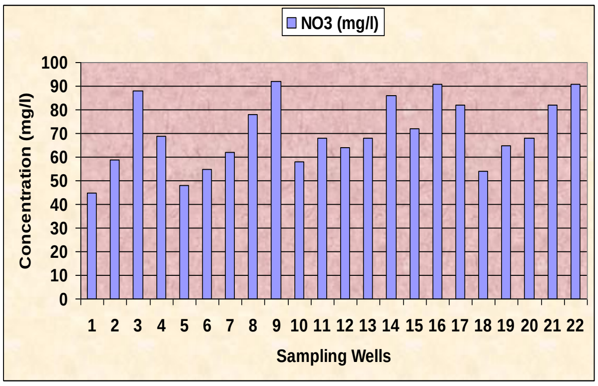

Figure. 3 Nitrate variations

Iron (Fe^-) concentration in natural water is very low. The concentration in the groundwater of the area varied from 0.1-3.5 mg/l in post-monsoon season (Figure 4), and most of the samples have low iron concentration and very few samples exceeds the permissible limit. The desirable limit of Fe for drinking water was 0.3 mg/l and maximum permissible limit was 1.0 mg/l as per Indian standards. Iron is biologically an important element which is essential to all organisms and present in hemoglobin system [16]. Iron in drinking water is due to geological, industrial wastes and domestic discharge.

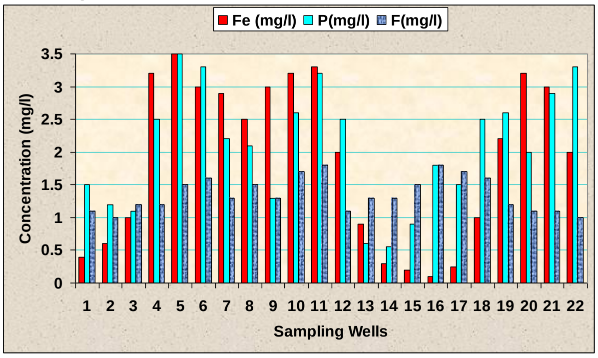

Figure .4 Iron, Phosporus and Fluoride variations in Post-monsoon season

Phosphorus is an important constituent of the lithosphere. The result indicates the presence of phosphate in the groundwater ranges from 0.55 to 3.6 mg/l during postmonsoon season as shown in figure 4.The higher phosphorus in groundwater is an indication of contamination by industrial pollutant and sewage [17]. Some samples show the beyond the limits recommended for domestic purposes. The water-soluble phosphate in the widely used fertilizers, surface water runoff, agricultural runoff and man activity could also contribute to the groundwater [18-19].

One of the main trace elements in groundwater is fluoride which generally occurs as natural constituents. Fluoride ion in drinking water is known for both beneficial and detrimental effects on health. Excess of fluoride in water causes serious damage to the teeth and bones of the human body, which shows the symptoms of disintegration and decay, diseases called dental fluorosis, muscular fluorosis and skeletal fluorosis. The fluoride concentration range in the study area was found to be 1 to 1.8 mg/l in post monsoon season (Figure 4). The BIS described the drinking water quality 1.5 mg/l nearly 22% of samples exceeds the permissible limit. According to UNESCO specifications, water containing more than 1.5 mg/l of fluoride cause mottled tooth enamel in children and not suitable for drinking purpose. Recently it has been identified that water containing fluoride 1.4 to 5.5 mg/l causes dissolution of aluminum from utensils, causing Dementia-a disease leading to loss of memory and mental impairment [20].

Hydrochemical facies

Piper diagram is used to determine hydrochemical facies of water Major ions are plotted as cations and anions percentage in meq/l in two base triangles with total ions set to equal 100 percentages (Figure 5). The data points in the two triangles are then projected to central diamond which allows comparison of a large number of samples. The chemical data is plotted on the piper trilinear diagram [21]. Major cations and anions such as Ca, Mg, Na, K, HCO3, SO4 and Cl in meq/l were plotted in piper trilinear diagram as the percent of the major constituents. Grouping of waters on the piper diagram suggests a common composition and origin. It can be used to classify and identify mixing of waters that most of groundwater samples fall in the field Ca-HCO3 and Mixed Ca-Mg-Cl and few samples fall in Ca-Cl in both the seasons.

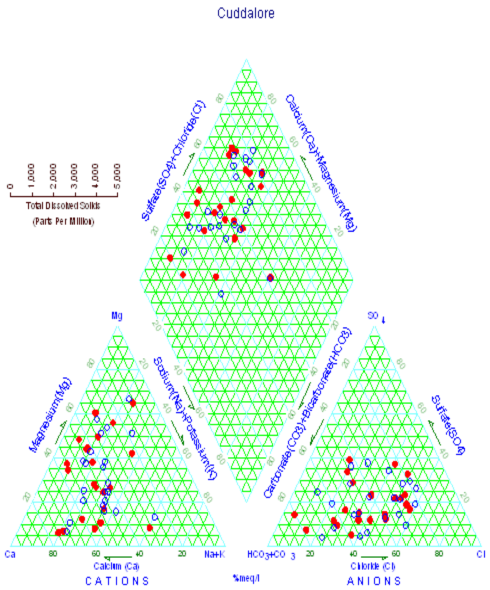

Figure. 5 Piper diagram depicting hydrochemical facies

Water Quality Index (WQI)

The WQI has been calculated to evaluate the suitability of groundwater quality for drinking purposes [22]. WQI is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall quality of water for human consumption [23]. The world health organization [24] standards for drinking purposes have been considered for the calculation of WQI. For the calculation of WQI 10 parameters such

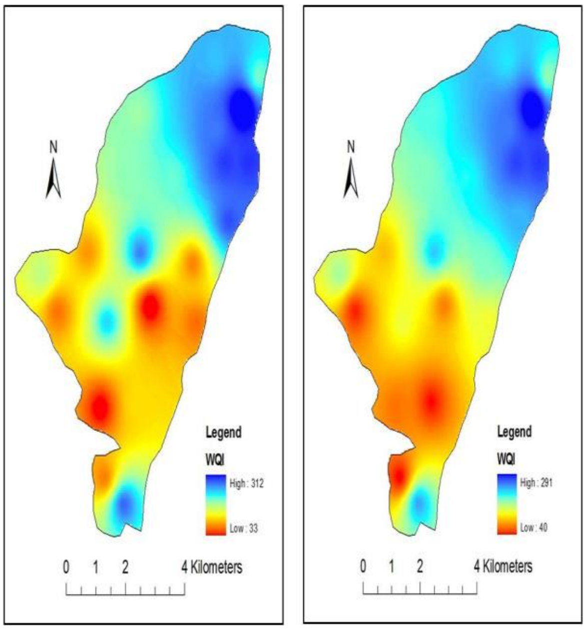

Figure.6 Spatial variations of Water Quality Index

Table 1: Water quality classification based on WQI

WQI Value	Water Quality	Sept (%)	Feb (%)
Less than 50	Excellent	9.09	13.63
50-100	Good Water	22.72	13.63
100-200	Poor Water	27.27	45.45
200-300	Very Poor Water	36.36	27.27
>300	Unsuitable for drinking	4.54	-

as pH, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-} and TDS have been considered. WQI varied from 33 to 312 during pre-monsoon season and from 46 to 291 during post-monsoon season (Figure 6) and therefore can be categorized into four types excellent to very poor water for drinking. Table 1 shows the percentage of water samples that falls under different much with season. Some samples were changed into good to excellent and unsuitable to poor water quality due to dilution processes taken place in the pre to post-monsoon. Hence, it can be seen that water quality of different locations in the industrial region quality in September 2012 and February 2013. The monsoonal dilution does not serve much towards the quality improvement in the industrially contaminated area and so the WQI of these regions does not change deteriorates in both the seasons and low value is observed in the southern part of the study area. This area is generally free from industries and sea water intrusion because it is away from the Cuddalore coastal zone. Majority of samples falls poor to very poor water in both the seasons. The higher WQI values in the samples can be attributed to the continuous discharge of industrial effluent and a little amount of sewage in the study area. The analysis reveals that the groundwater of the area needs to be treated before consumption and it also needs to be protected from the perils of contamination.

Stuyfzand Classification

Stuyfzand [25] has proposed a method of classification of groundwater and identified 8 main types on the basis of Chlorinity (Cl^-) shown in Table 2. It is used for identification of freshwater flow zone from the zone of salt-water intrusion. In both the monsoon periods the Oligohaline water types occur

Table 2: Stuyfzand Classification ofgroundwater

Main Type	Cl^- (mg/l)	Main Type	Cl^- (mg/l)
Very Oligohaline	<5	Brackish	$300\text{-}10^3$
Oligohaline	5-30	Brackish-Salt	$10^3\text{-}10^4$
Fresh	30-150	Salt	$10^4\text{-}2x10^4$
Fresh-Brackish	150-300	Hyperhaline	$>2x10^4$

only in Loc.19.fresh water occurs in location 11,14,15,16,17,18,21 and 22. Fresh-Brackish water found in sampling locations 1, 2,10,12,13 and 20. All the remaining sampling locations 3, 4, 5, 6, 7, 8 and 9 the brackish water type exists.

Criteria for Reorganization of Saltwater Intrusion

In order to identify brackish or saline waters hydro geochemical parameters are normally used [26]. A few hydrogeochemical parameters that are suggested as criteria for sea water contamination are Ca^{2+}/Mg^{2+}, $Cl^-/(CO_3^{2-} + HCO_3^{2-})$, Na^+/Cl^- ratios (Figure 7) etc. In the study area the ratios are ranging by following values.

$Cl^-/(CO_3^{2-}+HCO_3^{2-})$ ratio used as a criterion to evaluate the salt water intrusion. Chloride is most dominant in ocean water and normally occurs in small amount in groundwater, while HCO_3^{2-} is usually the most abundant negative ion in groundwater but it occurs in minor amounts in the sea water. The degree of concentration is as follows.

Table 3: Criteria for Reorganization of Saltwater Intrusion

Range of $Cl^-/(CO_3^{2-} + HCO_3^-)$ Ratio	Description
<0.05	Normally fresh groundwater
0.05-1.30	Slightly contaminated groundwater
1.30-2.80	Moderately contaminated groundwater
2.80-6.60	Injuriously contaminated groundwater
6.60-15.50	Highly contaminated groundwater
>200	Sea water

From the above limit values, majority of the area shows slightly contaminated groundwater with the values of 0.05-1.30 and 5 samples is seems to be moderately contaminated groundwater. There is no fresh groundwater and whatever water available is injuriously polluted and highly contaminated according to the ratio as shown in Table 3.

Na/Cl ratios of saltwater intrusion are usually lower than the marine values (i.e., <0.86, molar ratio). On the other hand, high (more than 1) Na^+/Cl^- ratios, typically characterize anthropogenic sources. The low Na^+/Cl^- ratios combined with other geological parameters, can foretell the arrival of saltwater intrusion. According to Na^+/Cl^- ratio, 50% of the study area is contaminated with marine source of contamination. Remaining area is contaminated due to anthropogenic sources like domestic and industrial effluents.

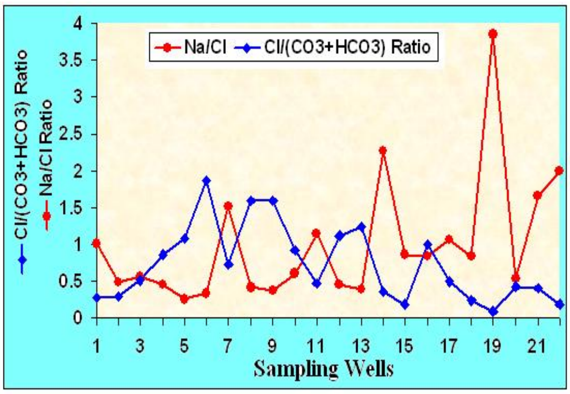

Figure.7 Source of Contamination based on ratios

Irrigation Water Quality

Irrigation water is one of the important concerns to the plant growth. The Groundwater is valuable only when its quality is suitable for a variety of purposes. Water for irrigation should satisfy the needs of basic requirements of plant growth. EC and Na^+ play a vital role in the suitability of water for irrigation. The high salt content in irrigation water causes an increase in soil solution osmotic pressure. A high salt content in water leads to formation of saline soil. The salts, besides affecting the growth of plants directly, also affect soil structure, permeability and aeration, which indirectly affect plant growth [27]. The suitability of water for irrigation can be estimated by means of many determinants, though, Sodium Adsorption Ratio (SAR), Percent Sodium (Na^+%), Permeability Index (PI), and Residual Sodium Carbonate (RSC) .

Wilcox Diagram

Wilcox [28] used percent sodium and specific conductance used evaluating irrigation water. In the Wilcox diagram Na% is plotted against specific conductance. An appraisal of the Wilcox diagram (Figure 8) shows that most of the samples from the study area fall under good to permissible

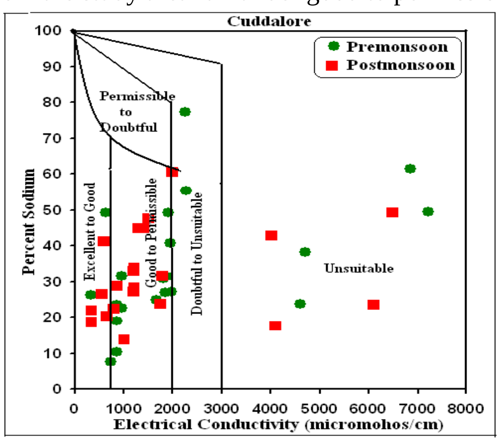

Figure.8 Wilcox Classification

Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability, texture makes the soil hard to plough and unsuitable for seeding emergence [29]. Sodium with chloride or sulphate as the predominant anion is saline soil and carbonate as the predominant anion is termed alkaline soils. Wilcox diagram (Wilcox 1955) is adopted for the classification of groundwater for irrigation, wherein the EC is plotted in x axis and % Na^+ in Y axis. Depending on the distribution of Na^+% water are classified into four classes [30] such as Excellent to Good, Good to Permissible, Doubtful to Unsuitable and Unsuitable. During both the seasons most of samples fall in categories of excellent to good and good to permissible excepting four samples which are unsuitable for irrigation purpose.

Sodium adsorption ratio and salinity hazard

The sodium/alkali hazard is typically expressed as the sodium adsorption ratio (SAR). The index quantifies the proportion of sodium (Na+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in a sample. All the values are expressed in meq/l. The diagram is a simple plot of salinity hazard (EC) on the X- axis and sodium hazard on the Y-axis USSL classification diagram of groundwater for irrigation purpose (Figure 9).Sodium concentration is important in classifying the water for irrigation purposes because sodium concentrations can reduce the soil permeability and soil structure [31]. The analytical data plotted on the US salinity diagram illustrates that most of the groundwater samples fall in the field of good water to permissible (fair) water, which can be used for irrigation on

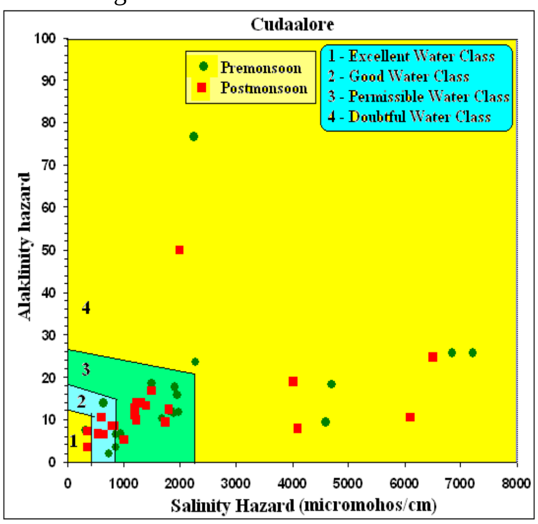

Figure.9 USSL classification

almost all types of soil with little danger of exchangeable sodium. The five samples fall in poor quality water due to the high electrical conductivity will cause salinization [32]. Irrigation water with high Na^{+}% may cause sodium accumulation and calcium deficiency in the soil leading to a breakdown of its physical properties [29]. Therefore, good drainage, high leaching and use of organic matter are required for its management in this area.

Permeability Index (PI)

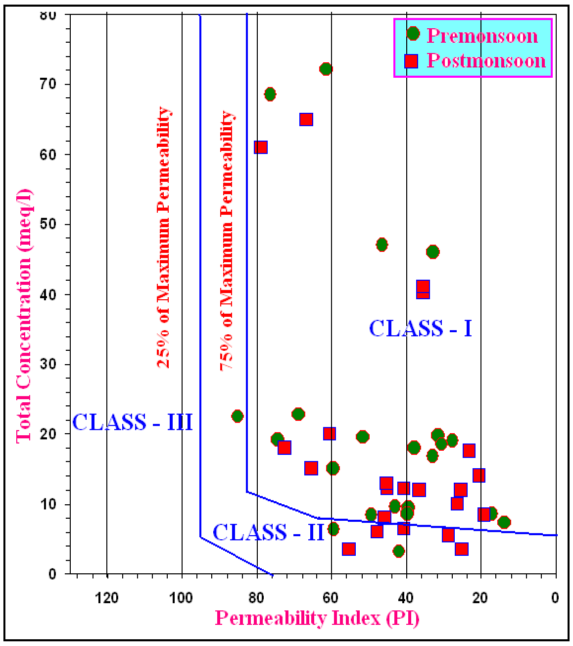

Figure.10 Permeability index.

The soil permeability is affected by the long-term use of irrigation water and the influencing constituents are the total dissolved solids, sodium bicarbonate and soil types. In the present study, the permeability index values range between 14 to 85 and 6 to 30 mg/l in pre and postmonsoon . The above results therefore suggests that water samples fall within Class I and Class II (Figure 10)and can be categorized as good irrigation water [30]. The increased percentage of groundwater samples under class I and II is due to dilution subsequent lower values of permeability index.

V. CONCLUSION

Groundwater is a precious natural resource and it is an important component of the hydrologic cycle. The type of water that predominates in the area is Ca^{2+}-HCO_3^{2-} and Mixed Ca^{2+}-Mg^{2+}-Cl^{-} type based on the hydrochemical facies. In general groundwater quality of Cuddalore coast is not harmful to human beings except few sampling location has high salinity, hardness, chloride, Nitrate were crossed prescribed limits of drinking water. The reasons due to industrial effluent discharge, urbanization and other anthropogenic activities. According to Stuyfzand classification, the area is found to be fresh-brackish and brackish water types. Regarding salt water intrusion, Cl^{-}/ (CO_3^{2-}+HCO_3^{2-}) ratio, and the groundwater is found slightly too moderately contaminated. According to Na^{+}/Cl^{-} ratio, the contamination may be due to marine source of origin, anthropogenic and geogenic sources. The groundwater samples from the Cuddalore Old Town and Port is highly polluted and unfit for drinking purpose. Though the suitability of water for irrigation is determined based on Wilcox and USSL classification diagram and Permeability Index, it is only an empirical conclusion. However looking at the results it may be concluded that majority of samples is suitable for irrigation purposes except few samples are unsuitable for irrigation purposes. The present study also indicates that quality is gradually getting deteriorated and it may continue with time. The reasons may be contamination of groundwater due to the industrial activities, urbanization, agricultural activities and increased human interventions in the groundwater. The influence of sea water in the fresh water aquifer in this coastal area needs special attention in terms of monitoring and sustainable management of groundwater. Hence the local government needs to initiate remedial measures.

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