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Assessment of Ground Water Quality in Paravanar River Sub-Basin, Cuddalore district, Tamil Nadu, India

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ABSTRACT

Ground water samples collected from different localities in and around Paravanar River sub basin, Cuddalore District, Tamil Nadu were analyzed for their physico- chemical characteristics. This analysis result was compared with the WHO standards of drinking water quality parameters with the following water quality parameters namely pH, Electrical conductivity, calcium, magnesium, alkalies, chloride, bicarbonate and sulfate equivalents, total dissolved solids and total hardness, etc., The usefulness of these parameters in predicting ground water quality characteristics were discussed. Hydrogeochemical facies of groundwater of study area reveals fresh to brackish and alkaline in nature.Piper plot shows that most of the groundwater samples fall in the mixed field of Ca-Mg-Cl type. From the plot, alkaline earths (Ca and Mg) significantly exceed the alkalis (Na and K) and strong acids (Cl) and (SO_4) exceed the weak acids (HCO_3) and (CO_3). The physical and chemical parameters of the Paravanar River Basins results shows that all the samples are under recommended limit for industrial purposes.

Key words: Physico- chemical characteristics, Groundwater quality, Hydrochemical facies Paravanar River.

INTRODUCTION

Water is the elixir for life. Adequate supply of potable safe water is absolutely essential and is the basic need for all human being on the earth. This leads to more mineralization in groundwater than surface water. Earth surface is acting as an effective filtrate to filter out particulate matters like leaves, soils, bugs, dissolved chemicals and gases. Above matters also occur in large concentrations to change the physico-chemical properties of groundwater. To understand the above process, Hydrogeochemical studies were attempted in the Paravanar basin in Tamil Nadu to monitor the concentration of various major constituents present in groundwater.

A number of investigators attempted before to check the groundwater quality assessment with reference to drinking and irrigation purposes have been carried out in different parts of India [1-5]. GIS based geochemical mapping in the hard rock area of Gadilam River basin in Tamil Nadu was done by [6]. Here Mg concentration in ground water is found to be in moderately suitable zones in the central part of study area. Groundwater quality mapping in Paravanar River Sub Basin was done to interpolate major ionic concentration by [7], [8]. Here Sulphates are found to be within prescribed limit for drinking purpose.

Study Area

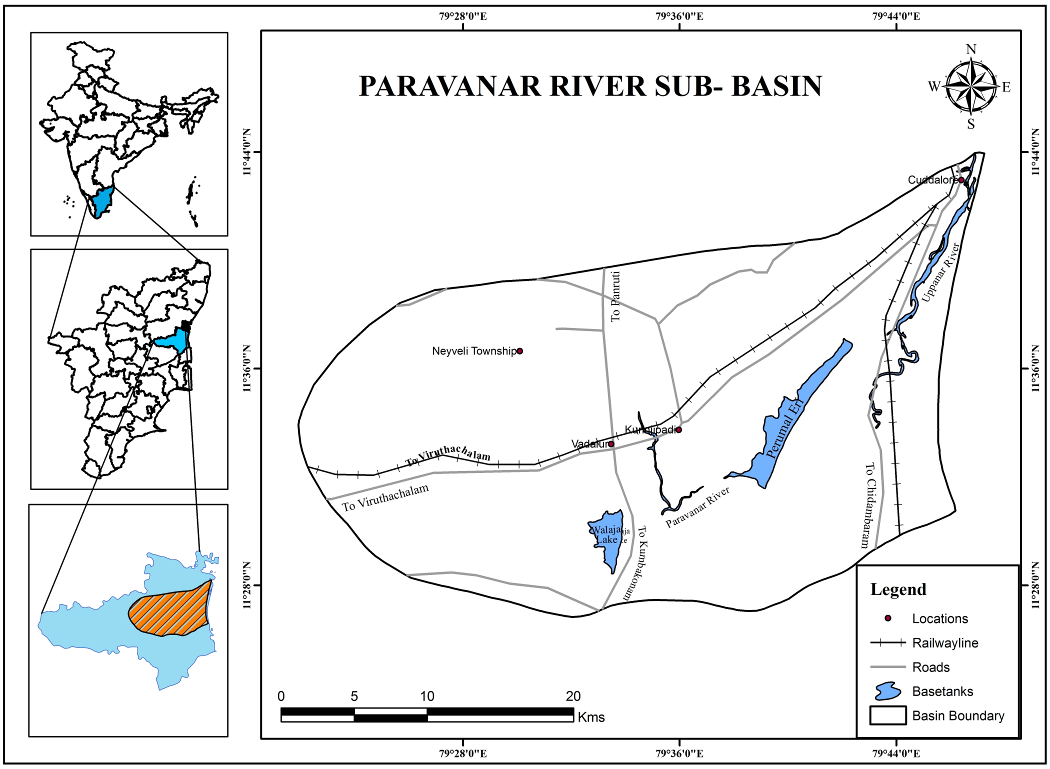

Figure.1: Location Map of the study area

The study area (Figure.1) of the Paravanar sub-basin lies in the Cuddalore District. It is bounded on the north by the main Gadilam river basin, on the south by the Vellar basin, on the east by Bay of Bengal. Most part of the study area is a flat plain, slopping very gently towards the sea on the east. The uplands are only on the northwestern border, with the Capper Mound or the Red Plateau running parallel to the sea with an elevation of < 25 meters above M.S.L., forming part of red lateritic “Cuddalore Sand Stones”. The area has a tropical climate with the highest and lowest temperatures recorded in May and January respectively. The precipitation of this study area mainly depends upon North East monsoon, which is cyclonic in nature and attributed to the development of low pressure in the Indian Ocean and Bay of Bengal. This area receives about an annual rainfall of 1,162 mm. The study area includes two very large (Mines I and II) and one small (Mine IA) opencast lignite mines, associated industries (two pit-head thermal power plants, a urea plant, and a briquetting and carbonization plant) that are operated by Neyveli Lignite Corporation Ltd. (NLC), and an independent power plant.

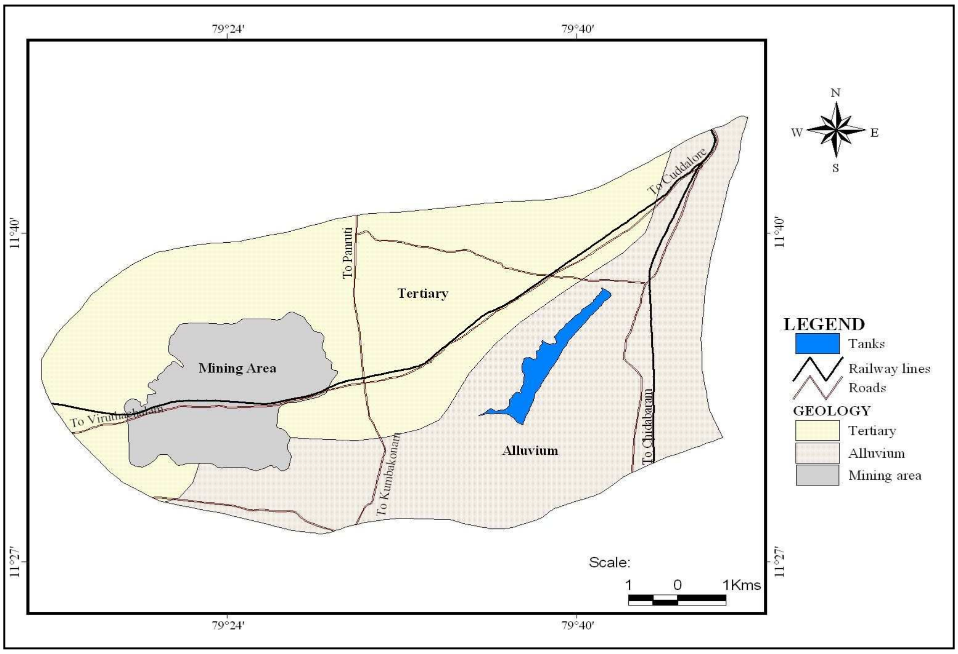

Figure.2: shows the geology of study area

The study area is underlined by geological formations, ranging in age from the Tertiary to recent alluvium sediments (Figure.2). As geological structures control the occurrence and movement of groundwater, the geological map of the study area was checked with field investigations and with the help of geological map of the Cuddalore District, which was published by Geological Society of India (2001) .The River Paravanar originates from the Cuddalore sandstone of Tertiary age. This formation is completely composed of mottled argillaceous sandstone [9]. The Cuddalore sandstone occurs at capper plateau south of Cuddalore town and is made up of sandstone, clay and silt. The lower Cuddalore sandstone is unconsolidated at few places. The sandstones are found intercalated with clay lenses and covered by lateritic formation [10].The major soil types found in this basin are Inceptisol, Entisol, Alfisol and Vertisol.

MATERIALS AND METHODS

The present work aims to evaluate the groundwater suitability for domestic, irrigation and industrial purposes of Paravanar River basin, by generating and amalgamating the groundwater quality data of Paravanar River sub basin. To achieve the above objectives, various data generated in the field were converted into information in the lab. (Table.1).The conventional techniques of histograms and trilinear techniques [11] such as Piper plots which consider only the major and minor ions with equal emphasis to interpret the group of variables to evaluate the chemical nature of groundwater has several limitations. In order to overcome these limitations of these conventional methods, factor analytical technique has been used to understand a number of geochemical processes by several professionals [12-19].

Further, total hardness (TH), sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and percent sodium (Na%) were calculated from ionic concentrations (meq/l) of Ca^+, Mg^+, Na^+, HCO_3^+, and Cl^- using the following standard procedures.

The Total Hardness (TH) of the groundwater was calculated using the formula [20],

$$TH = (Ca + Mg) \times 50$$

The Sodium Adsorption Ratio (SAR) was calculated by the following equation given by [21] as:

$$SAR = [Na^+] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2}$$

Where all the ions are expressed in meq/L.

The sodium percentage (Na %) is calculated using the formula given below [22]:

$$Na\% = [(Na^+ + K^+) / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)]\ 100$$

The Residual Sodium Bicarbonate (RSC) was calculated according to [23]:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

Where, RSC and the concentration of the constituents are expressed in meq/L.

The Permeability Index (PI) was calculated according [24] employing the following equation:

$$PI = Na^+ \{(HCO_3 \times 100)\}^{1/2} / Ca^{2+} + Mg^{2+} + Na^+$$

where, all the ions are expressed in meq/L.

Suitability of groundwater for domestic use was determined on the basis of pH, TH, TDS and comparing them with the World Health Organization (WHO) [25] standards recommendations.17 wells were selected for this study (Figure.3) and these wells are wide spread in the study area. Groundwater was sampled in the month of June 2007 (Table.1). Water samples were collected mostly from observation wells of PWD. The water samples were collected in 500 ml polyethylene bottles. Before collection sampled bottles were soaked with 1:1 HNO_3, washed using a detergent and rinsed using double distilled water. At the time of sampling, the sampling bottles were thoroughly rinsed two or three times using the groundwater to be sampled. The hydrogeochemical characteristics of water and its portability were obtained through physiochemical recordings like Electrical Conductivity (EC) and hydrogen-ion concentration (pH) using *in situ* portable meters. EC, salinity and Total Dissolved Solids (TDS) were measured using a pre-calibrated portable meter. Readings were taken for the above parameters at each 17 sites.

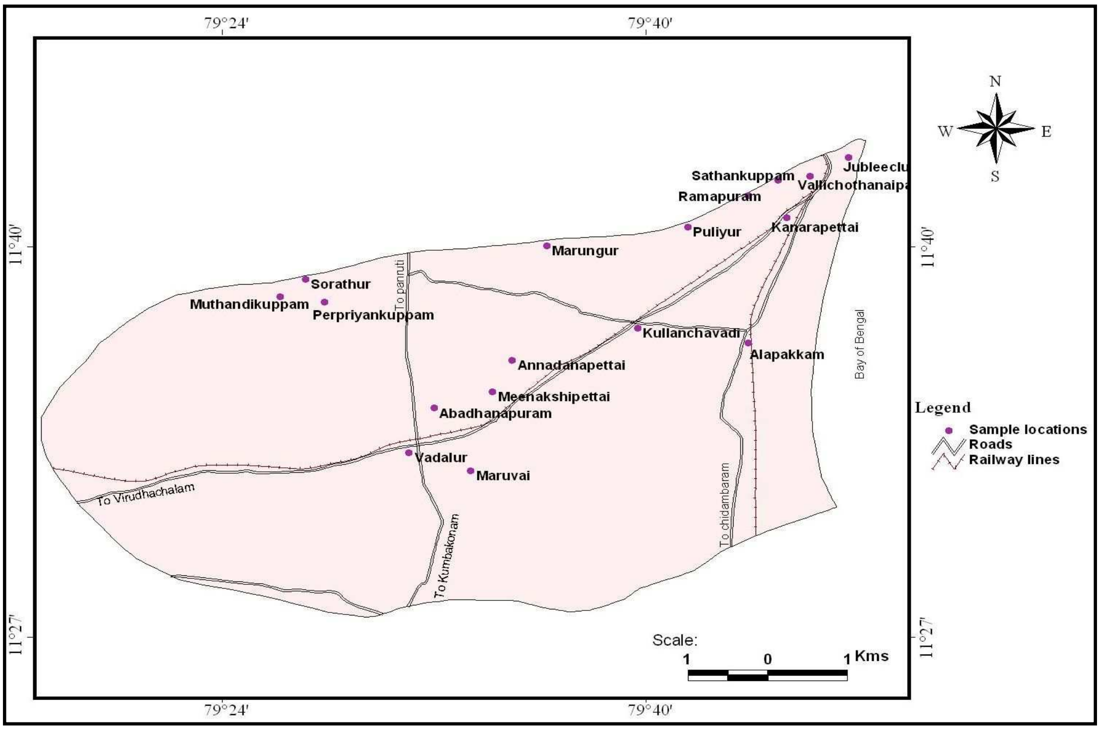

Figure .3: Well Location map in the study area

The collected groundwater samples were filtered and acidified with nitric acid for analysis. The analytical procedures used were adopted from APHA [26]. During the analyses, blanks and standards were run to check the reliability of the methods adopted. After completion of the analysis of major ions, the ionic balance error was calculated. In general, ion balance error was within 10%. The collected groundwater samples were analyzed for major ions by following the standard analytical methods and the accuracy of chemical analyses were checked as per the procedure listed by [27].

RESULTS AND DISCUSSION

Drinking water quality criteria

The analytical results of physical and chemical parameters of groundwater were compared with the standard guideline values as recommended by the WHO for drinking and public health purposes (Table. 2). The table shows the most desirable limits and maximum allowable limits of various parameters. The concentrations of cations and anions are within the maximum allowable limits for drinking except a few samples. Whether a groundwater quality of a given quality is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that use. Quality limits of water supplies for drinking water, industrial purposes, and irrigation apply to groundwater because of its extensive development for these purposes.

Table.1: Hydrogeochemical data (Post monsoon of 2007) of the Paravanar river sub-basin

S.No	LOCATION	EC	pH	Ca	Mg	Na+k	Hco_3	Co_3	So_4	Cl	No_3	TDS	TH	SAR	RSC	Na%	PI
1	Annadanapettai	360	8.3	24	0.2	23	73	12	14	36	6.12	196.7	60.7	6.6	0.4	48.7	6.2
2	Meenakshipettai	1860	8.6	40	2	222	153	15	29	527	12	1008.6	108.0	4.8	0.8	34.6	6.6
3	Kullanchavadi	760	8.3	20	0.5	0.5	134	12	48	149	6	471.8	52.0	0.2	1.6	2.4	0.5
4	Puliyur	580	7.7	28	1.3	54	116	0	53	114	0	374	75.2	14.1	0.4	64.8	9.8
5	Sathankuppam	570	7.7	26	0.6	58	128	0	4.8	114	25	364.1	67.3	15.9	0.8	68.6	10.8
6	Ramapuram	503	7.2	14	1.2	62	67	0	62	110	31	354.4	39.9	22.5	0.3	80.3	8.8
7	Vallichothanaipalayam	1080	8.2	38	0.12	200	244	42	38	320	37	927.3	95.3	4.6	3.5	34.4	8.4
8	Kanarapettai	870	8.3	76	28	60	183	12	115	106	6	594.3	304.8	8.3	-2.7	36.6	7.0
9	Vadalur	480	8.4	24	0.9	46	116	6	10	71	50	332.3	63.6	13.0	0.8	64.9	9.8
10	Abaddhapuram	300	8.4	30	1	17	123	6	0	28	0	213.4	79.0	4.3	0.6	35.4	6.1
11	Jubleeclub	2580	8.1	28	2.4	253	187	72	250	178	62	1042.5	79.7	6.5	3.9	45.4	9.2
12	Alapakkam	2176	8.39	52	3.3	18.7	287	57	53	374	0.4	1022	143.3	3.6	3.7	25.3	6.7
13	Marungur	230	7.8	10.02	40.86	32.18	16.5	0	408	38.99	0	129	193.1	6.4	-3.6	38.7	1.9
14	Muthandikuppam	160	7.9	8.02	4.86	19.59	73.2	0	17.72	20.65	9.3	88	40.0	7.7	0.4	60.3	6.9
15	Maruvai	451	7.74	16	8.2	17.1	42	0	29	34	26	316	73.6	4.9	-0.8	41.4	3.7
16	Sorathur	230	7.9	24.05	9.75	6.89	95.52	0	1	14.18	25.63	126	100.1	1.7	-0.4	16.9	2.4
17	perpriyankuppam	700	8.3	18.04	21.88	98.85	170.84	30	28.22	77.98	12.02	370	135.0	22.1	1.1	71.2	12.0

(Units of ionic concentrations of RSC are in meq/l, EC is in µS/cm, all the parameter in mg/l)

Table 2: Groundwater samples of the study area exceeding the permissible limits prescribed by WHO for drinking purposes

Parameters	WHO's international standard		Wells exceeding permissible limits
	Most desirable limits	Maximum allowable limits	
EC (µS/cm)	1000	1500	2,11,12
TDS (mg/l)	500	1000	2,11,12
TH (mg/l)	100	500	Nil
Na (mg/l)	-	200	2,7,11
Ca (mg/l)	75	200	Nil
Mg (mg/l)	50	150	Nil
Cl (mg/l)	200	600	2,7,12,13,
SO_4 (mg/l)	200	400	11,13
NO_3 (mg/l)	45	-	9,11

Evaluation of groundwater quality for domestic use

Hydrogen ion concentration (pH)

Most groundwater found in the Paravanar river sub basin has pH value ranging from about 7.2 to 8.6. For most domestic and industrial uses, water having pH between 6 and 10 generally causes no problem. Water having pH value below the range may be corrosive. Central and southern part of the study area has high pH value, which may be due to industrial and mining activity, along with lateralized sandstone as a host rock. Rest of the area is found to be alkaline in nature.

Total Dissolved Solids (TDS)

To ascertain the suitability of groundwater for any purposes, it is essential to classify the groundwater depending upon their hydrochemical properties based on their TDS values [28], [29] which are presented in Table 3. The groundwater of the area is fresh water except a few samples representing brackish water. Most of the groundwater samples are within the maximum permissible limit for drinking as per the WHO international standard, except three samples. The basin is below 500 mg/l of TDS, indicating low content of soluble salts in groundwater which can be used for drinking without any risk.

Table.3: Nature of groundwater based on TDS values

TDS (mg/l)	Nature of water	Representing wells	Total no of wells
<1000	Fresh water	1,3,4,5,6,7,8,9,10,13,14,15,16,17	14
1000-10000	Brackish water	2,11,12	3
10000-100000	Saline water	Nil	Nil
>100000	Brine water	Nil	Nil

Total hardness (TH)

The classification of groundwater (Table .4) based on total hardness (TH) shows that a majority of the groundwater samples fall in the hard water category [30].The maximum allowable limit of TH for drinking is 500 mg/l. The most desirable limit is 100 mg/l as per the WHO international standard. One sample out of 17 exceeded the maximum allowable limits (Table.4).

Table .4: Classification of groundwater based on hardness

Total hardness as $CaCO_3$ (mg/l)	Water class	Representing wells	Total no of wells
<75	Soft	1,3,5,6,9,14 and 15	7
75-150	Moderately hard	2,4,7,10,11,12,13,16and 17	9
150-300	Hard	Nil	Nil
>300	Very hard	8	1

Evaluation of groundwater quality for agricultural use

Electrical Conductivity (EC)

Electrical conductivity (EC) is a measure of the total salt content of water based on the flow of electrical current through the sample. The higher the salt content, greater will be the flow of electrical current. Measured EC values range from160 to 2580 microsiemens/cm. The highest value of 2580 microsiemens/cm is found in the sample near the coast. NE and SE (adjacent to SIPCOT industrial complex) part of the study area represents the doubtful water class regarding the concentration of EC to represent the connate nature of water adjacent to the coast to indicate the increasing age. (Table.5).

Table.5: Quality of Groundwater based on electrical conductivity

EC (micro mhos/cm)	Water class	Representing wells	Total no. of wells
< 250	Excellent	13, 14 and 16 Sorathur)	3
250 – 750	Good	1, 4, 5,6,9,10,15 & 17	8
750 – 2000	Permissible	2, 3, 7 & 8 (Kanarapettai)	4
2000– 3000	Doubtful	11 & 12 (Alapakkam)	2
>3000	Unsuitable	Nil	Nil

Sodium Absorption Ratio (SAR)

The sodium/alkali hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium (Na+*)* to calcium (Ca2+*)* and magnesium (Mg2+*)* ions in a sample. Sodium concentration is important in classifying the water for irrigation purposes because sodium concentration can reduce the soil permeability and soil structure [31], [32]. Sodium hazards are very low, and the groundwater can be used on most crops for irrigation purposes. Generally high concentrations of bicarbonate and carbonate are predominant anion in the alkali soils, and chloride and sulfate are the predominant anion in the saline soils. Based on sodium percentage, the prominent groundwater samples are suitable for irrigation except a two samples (Table 6).

Table. 6: Suitability of groundwater for irrigation based on SAR

SAR	Water Class	Representing wells	Total no of wells
0-10	Excellent	1-3,7,8,10-16	12
10 -18	Good	4,5,9	3
18-26	Fair	6,17	2
>26	Poor	Nil	Nil

Sodium Percentage (Na %)

The analytical data plotted on the US salinity diagram illustrates that most of the groundwater samples fall in the field of C3, S1, indicating high salinity and low sodium water, which can be used for irrigation on almost all types of soil with little danger of exchangeable sodium. Few samples fall in the field of C4, S1, indicating very high salinity and low alkalinity hazard. This can be suitable for plants having good salt tolerance and also restricts their suitability for irrigation, especially in soils with restricted drainage [33], [34].

It was revealed from the analysis that the groundwater of Paravanar basin was of excellent to permissible for irrigation except six samples (Table.7). Irrigation water with high Na% may cause sodium accumulation and calcium deficiency in the soil leading to a breakdown of its physical properties. Therefore, good drainage, high leaching and use of organic matter are required for its management in the area. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry [35], [36].

Table. 7: Suitability of groundwater for irrigation based on percent sodium

% Na	Water Class	Representing wells	Total no of wells
<20	Excellent	3,4 and16	3
20-40	Good	2,7,8,10 and 13	5
40-60	Permissible	1,11 and 15	3
60-80	Doubtful	4,5,9,14 and 17	5
>80	Unsuitable	7	1

Residual sodium carbonate

In addition to the % Na, the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the unsuitability of groundwater for irrigation. This is denoted as residual sodium carbonate (RSC), which is calculated as follows [37]. The classification of irrigation water according to the RSC values is presented in Table .8, where the category of groundwater is good except one sample.

Table.8: Quality of groundwater based on residual sodium Carbonate

RSC (meq/l)	Remarks on quality	Representing wells	Total no of wells
<1.25	Good	1,2,4,5,6,8,9,10,13,14,15 and 16	12
1.25-2.5	Doubtful	3,17	2
>2.5	Unsuitable	7,11 and 12	3

Permeability Index (PI)

The soil permeability is affected by the long-term use of irrigated water and the influencing constituents are the total dissolved solids, sodium bicarbonate and the soil type. In the present study, the permeability index values range between 0.5 to 12. The above result therefore suggests that water samples fall within ClassI and ClassII and can be categorized as good irrigation water [38].

Industrial water criteria

It should be apparent that the quality requirements of waters used in different industrial processes vary widely. Thus, make up water for high- pressure boilers must meet extremely exacting criteria whereas water of as low as a quality as seawater can be satisfactorialy employed for cooling of condensers. Even within each industry, criteria cannot be established; instead, only recommended limiting values or ranges can be stated. Salinity, hardness and silica are three parameters that usually are important for industrial water.

Of almost equal importance for industrial purposes as quality of a water supply is the relative constancy of the various constituents. It is often possible to treat poor quality water or adapt to it so that it is suitable for a given process, but if the quality fluctuates widely, continued attention and expense may be involved. Fluctuations of water temperature can be equally troublesome. From this standpoint, groundwater supplies are preferred to surface water supplies, which commonly display seasonal variations in chemical and physical quality. As a result, an adequate groundwater supply of suitable quality often becomes a primary consideration in selecting new industrial plant locations. The physical and chemical parameters of the Paravanar River basins results shows that all the samples are under recommended limit for industrial purposes.

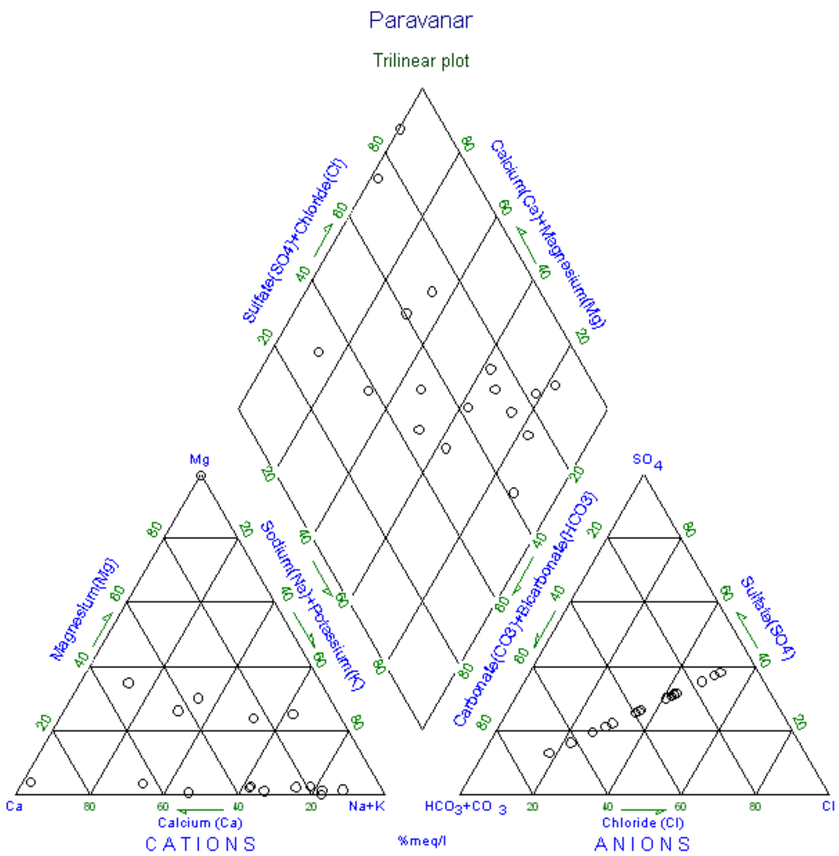

Figure.4: Chemical facies of groundwater in Piper Trilinear diagram

Graphical presentation of chemical data

Techniques used to display the chemical character of the waters in a useful way include and Piper plots [39]. As there are three separate aquifer units, it is possible that the waters of each aquifer might have different chemical characteristics.

Piper Trilinear Diagram

One of the most useful graphs for representing and comparing water quality analyses is the trilinear diagram by Piper shown in Figure.4. Here cations, expressed as percentages of total cations in milliequivalents per liter, plot as a single point on the left triangle; while anions, similarly expressed as percentages of total anions, appear as appoint to the right triangle. These two points are then projected into the central dimond-shaped area parallel to the upper edges of the central area. This single point is thus uniquely related to the total ionic distribution; a circle can be drawn at this point with its area proportional to the total dissolved solids. The trilinear diagram conveniently reveals similarities and differences among groundwater samples because those with similar qualities will tend to plot together as groups. Further, simple mixtures of two source waters can be identified.

The plot shows that most of the groundwater samples analyzed during June 2007 falls in the field of mixed Ca–Mg–Cl type of water (Figure.4). Some samples are also representing Ca–Cl and Na–Cl types. From the plot, alkaline earths (Ca^{2+} and Mg^{2+}) significantly exceed the alkalis (Na^+ and K^+) and strong acids (Cl) and (SO_4) exceed the weak acids (HCO_3) and (CO_3).

CONCLUSION

The major conclusions derived from this study, carried out in the Paravanar River sub- basin are as follows. The EC value ranges from 160 to 2,580 μS/cm in groundwater samples. The highest value of 2,580 μS/cm was recorded in wells near the coast. pH value ranges from 7.2 to 8.6. Central and southern part of the study area has high pH values, which represents the alkaline nature of groundwater. The Na% indicates that the groundwater is excellent to permissible for irrigation except one sample. The classification of irrigation water according to the RSC values shows that where the category of groundwater is good except one sample.

Interpretation of hydrochemical analysis reveals that the groundwater in Paravanar River Basin is fresh to brackish and alkaline in nature. The Piper plot shows that most of the groundwater samples fall in the field of mixed Ca–Mg–Cl type of water. Some samples are also representing Ca–Cl and Na–Cl types. From the plot, alkaline earths (Ca and Mg) significantly exceed the alkalis (Na and K) and strong acids (Cl) and (SO_4) exceed the weak acids (HCO_3) and (CO_3).

In south eastern part of the study area alkali values are slightly higher but it is within WHO's tolerable limits. The physical and chemical parameters of the Paravanar River basins results shows that all the samples are under recommended limit for industrial purposes.

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