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RESEARCH ARTICLE

Assessment of groundwater quality and its suitability for agricultural use in Nishabanathi and Kalingalar sub-basins of Vaippar river basin, TN, India

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Abstract

Groundwater samples were collected from 40 different locations in Nichabanadhi and Kalingalar sub-basins of Vaippar river basin, Tamil Nadu, India during January, 2012. The physico-chemical parameters such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), pH, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, NO_3^-, Cl^- and F^- have been analyzed to determine geological and non-geological source of contamination. The results were evaluated in detail and compared with water quality standards of World Health Organization (WHO, 2004). The Piper diagram illustrates that most of the water samples are mixed CaMgCl and NaCl Types. Overall hydro geochemical analytical study using Electrical Conductivity, Sodium Adsorption Ratio (SAR), Sodium percentage (Na%) and Residual Sodium Carbonate (RSC) values reveals that most of the groundwater samples collected from the study area are suitable for irrigation purposes. These values were taken into GIS (Geographical Information System) platform for further processing to understand the spatial variation.

Keywords: Irrigation water quality, groundwater geochemistry, GIS, Vaippar river basin, Tamil Nadu.

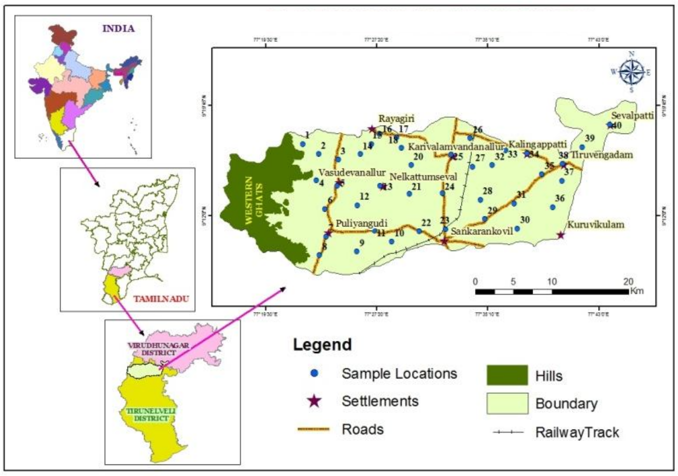
Introduction

Agriculture is the main occupation of the people in the study area. The water quality used for irrigation is essential for the yield and quantity of crops, maintenance of soil productivity, and protection of the environment (Vineesha Singh and Singh, 2008). Suitability of groundwater for domestic and irrigation purposes is determined by its geochemical constituents. Subsurface rock formations controls the composition of soil and hence that of water and vegetation. Groundwater geochemistry explains links between the chemical composition of groundwater and the health of plants, animals and people. Experimental research illuminates the significances of natural geochemical processes. The aim of the study is to evaluate the hydrogeochemical characteristics of groundwater in the study area as well as to evaluate the variation in the groundwater geochemistry data and the suitability of the groundwater for irrigation purposes.

Materials and methods

Study area: The study area is located in the Vaippar river basin of Tamil Nadu, India. There are 33 river basins in TN. For hydrological studies they are classified into 17 river basins. The Vaippar River Basin is one among them. It is situated between East longitude 77°16'17" and 78°21'43" and North latitude 08°57'45" and 09°47'29". The River originates in Vasudevanallur reserve forest on the eastern slope of Western Ghats from Neduntheri Mottai in Sivagiri taluk of Tirunelveli district at an altitude of 1650 m above MSL. This basin comprises of 13 sub-basins (IWS, 2010).

Fig. 1. Location map of the study area.



The two sub-basins, Nichabanadhi and Kalingalar are taken into study among them. They are bounded between the East longitude 77°16'15" and 77°45'40" and the North latitude 09°07'45" and 09°20'23" and covers about 707 km^2 (Fig.1).

Geology and geomorphology: Weathering of rocks primarily controls the major ion chemistry, which plays a dominant role in subsurface geochemical processes. The rock type is made up of weathered and jointed Charnockite in most part and in some part in the east and western side it is made up of Garnetiferous/Granite gneiss. The western portion of the study area is occupied by the Western ghats.

Table 1. Physico-chemical parameters of the groundwater samples.

Parameters	Minimum	Maximum	Average	WHO's Guideline Values (2004)
EC (µS/cm)	290	5200	**1835.5**	1400
pH	7	8.2	7.5	6.5-9.2
TDS (mg/L)	162.3	3512.1	**1161.2**	1000
Bicarbonates (mg/L)	79.3	915	**354.8**	240
Calcium (mg/L)	28	232	93.5	200
Magnesium (mg/L)	7.3	199.4	**63.8**	50
Sodium (mg/L)	12.6	940.7	**234.2**	200
Potassium (mg/L)	0.7	71.1	11.7	12
Sulphate (mg/L)	17.7	218.4	80.8	250
Nitrate (mg/L)	0	403	**93.5**	45
Chloride (mg/L)	31.9	1719.3	**404.8**	250
Fluoride (mg/L)	0.1	1.4	0.7	1.5

Along the foot hills, west of Puliyangudi, Pudur and Vasudevanallur, Bazadas are well developed. Buried pediments occur in small extent in the north of Puliyangudi, in and around Pudur and north of Vasudevanallur. The rest of the area is a pediplain area consisting of shallow pediments and pediments. Inselbergs surrounded by pediments occur in the northeastern side of Puliyangudi. The thickness of the weathered mantle in buried pediment is 27 m in the south of Vasudevanallur and 16 m in Thirumalapuram.

Climate: The study area lies within the tropical monsoon zone. Based on the hydrometeorological features of the basin, year is divided into (1) Monsoon period spanning from June to December and (2) Non-monsoon period spanning from January to May. As the monsoon period brings heavy rainfall, it improves the recharging of groundwater as well as storage of surface water. Hence, the monsoon period is hydrologically significant for water resources analysis. But in the case of non-monsoon period, the rainfall is insignificant (IWS, 2010).

Groundwater sampling: In order to assess water quality of the study area, 40 groundwater samples have been collected during January, 2012. The groundwater sampling locations were selected to cover the entire study area. The locations of groundwater sampling sites were recorded in the field using Geographical Positioning System (GPS). Sampling was carried out using pre-cleaned polypropylene containers, which were rinsed three times with sample water prior to sample collection.

Physico-chemical parameters: The groundwater samples collected were analyzed for TDS, EC, pH, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, NO_3^-, Cl^- and F^- in the laboratory. The results were evaluated in accordance with the drinking water quality standards given by the WHO. To prepare the Piper diagram, the software RockWorks has been used. The Wilcox and USSL Diagrams have been prepared using Microsoft Excel. Location map and Spatial distribution maps were created using ArcGIS 9.1 software.

Results and discussion

An overall assessment of the quality of groundwater samples indicated that 67% of the samples recorded higher Bicarbonate, 47.5% of the samples recorded higher Nitrate, Chloride, Total Dissolved Solids and Electrical Conductivity, 45% of the samples recorded higher Magnesium, 40% of the samples recorded higher Sodium, 25% of the samples recorded higher Potassium and 5% of the samples recorded higher Calcium. The results of the analysis show that the average values of some of the physico-chemical parameters like EC, TDS, HCO_3^-, $Mg2^+$, Na^+, NO_3^- and Cl^- are exceeding the permissible limits (i.e. indicated with bold letters), while some parameters such as pH, Ca^{2+}, K^+, SO_4^{2-} and F^- are not exceeding the permissible limits (Table 1).

Fig. 2. Piper diagram for describing the hydrochemical facies variation.

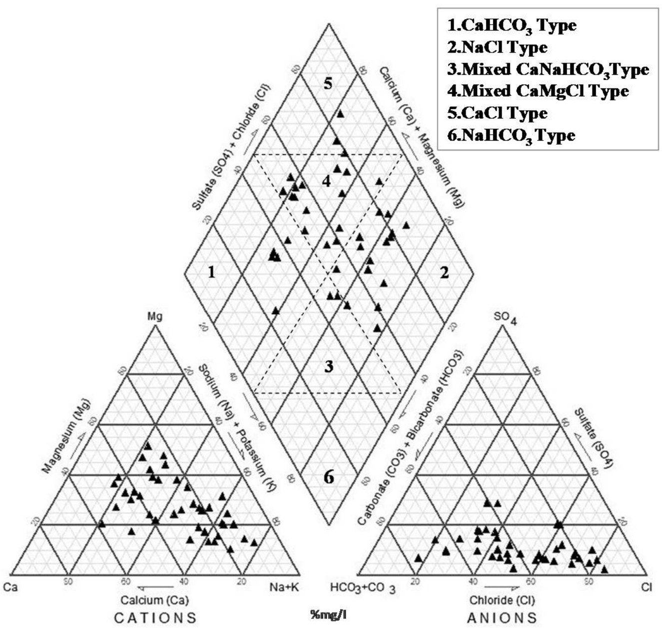


Table 2. Classification of groundwater based on sodium percentage.

Na%	*Water category*	*Sample No.*	*No. of samples*	*% of samples*
<20	Excellent	3,11,12,28	4	10
20-40	Good	1,4,6,7,8,9,10,14,15,16,17,18,22,30,36	15	37.5
40-60	Permissible	2,5,19,25,26,29,31,32,33,35,37,38,39,40	14	35
60-80	Doubtful	13,20,21,23,24,27,34	7	17.5
> 80	Unsuitable	Nil	0	0

Bicarbonate is higher (354.8 mg/L) due to action of CO_2 which chemically reacts upon the minerals present in soil and granitic rock releases HCO_3 into the groundwater environment (Tyagi *et al.,* 2009). Higher Nitrate (93.5 mg/L) indicating sources from plant nutrient leaching and application of nitrate fertilizers (Madison and Brunett, 1984). Chloride is higher (404.8 mg/L) due to industrial, domestic wastages and/or leaching from upper soil layers in dry climates (Srinivasamoorthy *et al.,* 2008). Magnesium is higher (63.8 mg/L), indicating sources from dissolution of magnesium calcite, gypsum and/or dolomite from source rock (Garrels, 1967). The source of Sodium (234.2 mg/L) into the groundwater is due to the weathering of feldspar and due to over exploitation of groundwater (Hem, 1985).

Hydrochemical facies: The evolution of hydrochemical parameters of groundwater can be understood by plotting the concentration of major cations and anions in the Piper diagram (Piper, 1994) (Fig. 2). It shows graphically the nature of the groundwater samples. In the diagram the relative abundance of cations with the % meq/L of Na^{+}+K^{+}, Ca^{2+}, and Mg^{2+} is first plotted on the cation triangle and then the relative abundance of Cl^{-}, SO_4^{2-}, and HCO_3^{-} + CO_3^{2-} is plotted on the anion triangle. The two data points on the cation and anion triangles are then combined into the quadrilateral field that illustrates the overall geochemistry of the groundwater samples. Here it illustrates that most of the water samples are Mixed CaMgCl and NaCl Types. There is no $NaHCO_3$ type of water in the study area.

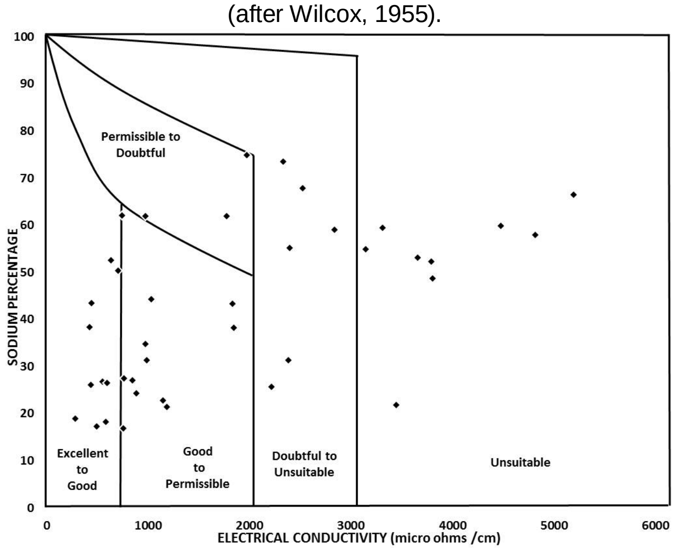
Sodium percentage: Sodium concentration is important in classifying the water for irrigation purposes because sodium concentration can reduce the soil permeability and soil structure (Todd, 1980; Domenico and Schwartz, 1990) and this help little or no plant growth. So sodium is considered as a main factor for determining groundwater suitability for irrigation purposes. Presence of sodium is usually expressed in terms of sodium percentage calculated by the formula:

$$Na\% = \frac{(Na^{+} + K^{+})}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \times 100$$

Based on Na% the value of <60 in groundwater is suitable for irrigation purposes (Table 2). During January 2011, Na% is ranging from 16.74 to 74.84 and only 17.5% of samples represent doubtful for irrigation, 35% of samples show Na% within the permissible limit and the others represent good and excellent for irrigation.

The higher Na% is due to long residence time of water, dissolution of minerals from lithological composition, and the addition of chemical fertilizers by the irrigation waters (Subba Rao *et al.,* 2002; Qiyan and Baoping, 2002). Percent sodium is plotted against conductivity, which is designated as a Wilcox diagram (Wilcox, 1955).

Fig. 3. Plot of sodium percent Vs electrical conductivity (after Wilcox, 1955).



According to Figure 3, the water quality diagram for irrigation and domestic purposes shows that 25% samples are falling under Excellent to good, 30% are Good to permissible, 7.5% are Permissible to doubtful, 15% are Doubtful to unsuitable, and 22.5% are Unsuitable (Fig. 3).

Sodium adsorption ratio: SAR and EC reciprocally can be used to evaluate irrigation water quality. The SAR recommended by the salinity laboratory of the United States Department of Agriculture (Wilcox, 1955) is calculated using the formula:

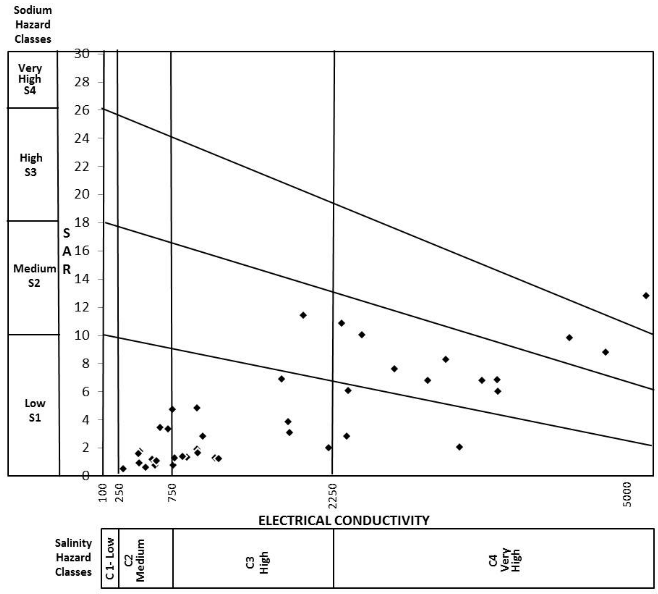
$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{+}+Mg^{+})}{2}}}$$

The classification of groundwater samples from the study area with respect to SAR is represented in Table 3. The SAR values of 65% of the samples are found to be less than 6, and are classified as Excellent for irrigation. SAR is found to be higher in some locations, indicating leaching and dissolution of salts during precipitation infiltrates into the aquifer matrix.

Table 3. Classification of groundwater based on sodium adsorption ratio.

SAR	Water category	Sample No.	No. of samples	% of samples
0 to 6	No problems	1,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,22,23,24,28,29, 30,31,33,36,37	26	65
6 to 9	Increasing problems	2,19,21,25,26,32,35,39,40	9	22.5
> 9	Severe problems	13,20,27,34,38	5	12.5

Fig. 4. US salinity diagram for classification of irrigation waters (after Richards, 1954).



When the SAR and electrical conductivity of water are known, the classification of water for irrigation can be determined by graphically plotting these values on the US salinity diagram (USSL, 1954), (Fig. 4). Based on the USSL diagram, the water quality shows that 37.5% of the samples fall in the C3-S1 (high salinity with low sodium), 25% of the samples fall in the C2-S1 (medium salinity with low sodium), 20% of the samples fall in the C4-S2 (very high salinity with medium sodium), 7.5% of the samples fall in the C4-S1 (very high salinity with low sodium), 5% of the samples fall in the C4-S3 (very high salinity with high sodium), 2.5% of the samples fall in the C3-S2 (high salinity with medium sodium), and 2.5% of the samples fall in the C4-S4 (very high salinity with very high sodium) categories. These groundwater samples show medium to very high salinity hazard with low to very high alkali hazards. But most of the water samples fall in medium to high salinity with low sodium. Based on the USSL diagram, the groundwater samples are satisfactory for irrigation purposes.

Residual sodium carbonate: The excess sum of Carbonate and Bicarbonate in groundwater over the sum of calcium and magnesium also influences the unsuitability for irrigation. This is denoted as Residual Sodium Carbonate (RSC) index which is calculated as:

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

Where, all the concentrations are expressed in meq/L (Ragunath, 1987). The classification of groundwater based on RSC values are summarized in Table 4. According to the US Salinity Laboratory (1954), RSC value less than 1.25 meq/L is good for irrigation, a value between 1.25 and 2.5 meq/L is of doubtful quality and a value more than 2.5 meq/L is unsuitable for irrigation. Hence, continued usage of high RSC waters will affect the yields of crop.

Fig. 5. Spatial distribution maps of sodium percentage and residual sodium carbonate.

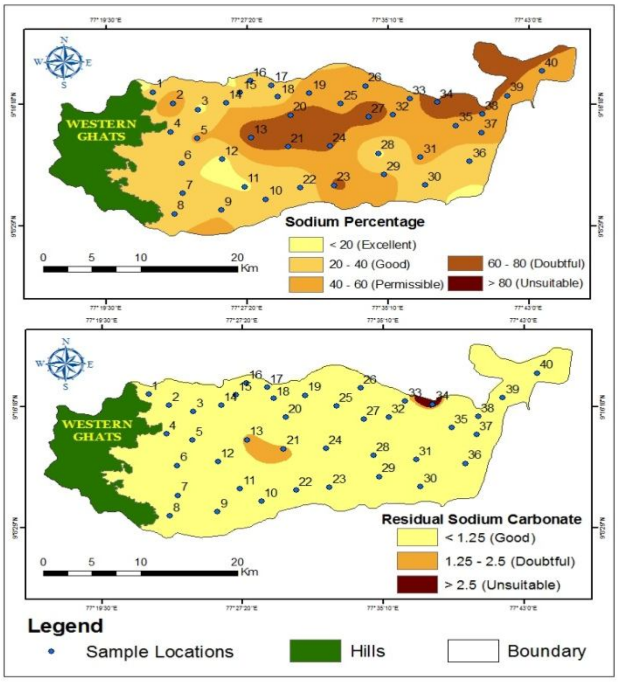
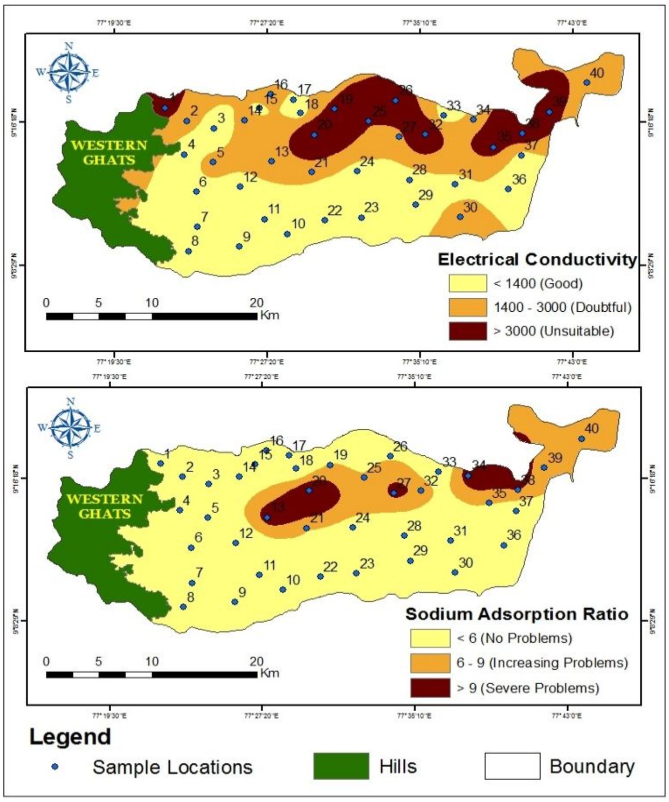


Table 4. Classification of groundwater based on residual sodium carbonate.

RSC	Water category	Sample No.	No. of samples	% of samples
<1.25	Good	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19,20,22,23, 24,25,26,27,28,29,30,31,32,33,35,36,37,38,39,40	37	92.5
1.25-2.5	Doubtful	13, 21	2	5
>2.5	Unsuitable	34	1	2.5

Fig. 6. Spatial distribution maps of electrical conductivity and sodium adsorption ratio.



In the present study, the water samples show RSC values of -22.40 to 4.40 meq/L. 92.5% of the samples have RSC values much less than 1.25 meq/L (safe for irrigation), which revealed that most of the samples are of safe quality categories for irrigation. Further, the value of RSC is negative at 34 sampling sites out of 40, indicating that there is no complete precipitation of calcium and magnesium (Tiwari and Manzoor, 1988). Figures 5 and 6 show that higher concentration of Na%, SAR and RSC were observed in central and north-eastern parts of the study area. EC is higher in north, north-eastern and north-western parts.

Conclusion

The groundwater quality in Kalingalar and Nishabanathi sub-basins has been evaluated for their chemical composition. The order of abundance of chemical concentration is $HCO_3^- > NO_3^- = Cl^- =$ TDS = EC$> Mg^{2+} > Na^+ > K^+ > Ca^{2+}$. The Piper diagram illustrates that most of the water samples are mixed CaMgCl and NaCl types. The study area comprised mainly of Charnockites and Garnetiferous/Granite Gneiss. Mineralogically Charnockites are composed of Quartz, Plagioclase Feldspars and Orthopyroxenes with garnet and biotite as minor constituents. Alteration of Soda Feldspar (Albite) and Potash Feldspars (Orthoclase and Microcline), which are common in the Biotite Gneiss is greatly responsible for the contribution of Na^+ and K^+ ions to groundwater (Subramani *et al.,* 2005). Higher EC values are due to agricultural activities. Based on Na%, 35% of the samples are within the permissible limit, 37.5% are good and 10% are excellent for Irrigation. Totally 82.5% of the samples are suitable for irrigation. The SAR values of 65% of the samples are classified as excellent for irrigation. Based on the USSL diagram, most of the water samples fall in medium to high salinity with low sodium with little danger of exchangeable sodium. So the groundwater samples are satisfactory for irrigation. According to RSC values, 92.5% of the samples are of safe quality categories for irrigation. Overall hydro geochemical analytical study reveals that almost all the groundwater samples collected from the study area are suitable for irrigation purposes. However, some parameters exceed the permissible limit in few locations and thus minimizing its suitability for irrigation purposes.

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