Risk Assessment of Groundwater Quality for Drinking Purposes During COVID-19 Pandemic Period Around Industrial Areas, Perundurai, Erode, Tamil Nadu, India

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Research Article

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Abstract

The present research deals with the Risk assessment of groundwater quality around 15 km radius surrounding SIPCOT industrial estate, Perundurai, Erode district. It is sub-divided into three segments with radius of 5 km each. 79 groundwater samples were collected from domestic and agricultural usage open and bore well points equally distributed (each 4 km distance) over the study area with help of toposheets, during January- 2021 (COVID-19 Pandemic Period). The groundwater samples were tested to determine the physio-chemical parameters using standard testing procedure which include Ca^{+2}, Na^{+}, pH, TA, EC, TDS, K^{+}, TH, Mg^{2+}, $Fe^{2+/3+}$, HCO_3^{-}, F^{-}, NO_3^{2-}, SO_4^{2-} and Cl^{-} for the preparation of spatial distribution maps of each parameter based on WHO standard. Multivariate statistical analysis shown the source of groundwater pollution from secondary leaching of chemical weathering of rocks and minerals and fertilizers used agriculture lands and least percentage of industrials effluents due to the COVID-19 pandemic, not working for all industries during last 6 months. From the Water Quality Index, 18.06 % of the area comes under high and very high risk zone and bivariate plot NO_3 Vs Cl reveals that 17.72 % of the samples are from the bad quality of groundwater. The types of hardness diagram showed 32.91% of the samples fall in hard brackish water as illustrated by the Piper trilinear diagram. The high and very high risk zones, was recommended to concern department to provide the good quality of water supply to the people.

Introduction

Water is an essential for human health. The human body is consisting of more than 70% of water especially blood contains of 83%, muscles and bones contain 75% and 22% of water respectively [Dietary Reference Intakes 2006]. Polluted water can transmit so many diseases is because of the presence of soluble natural substances like Iron, fluoride, nitrate, sulfate etc.[Chetty and Pillay 2019; Nitasha Khatri and Rajitha 2018]. The knowledge of geology, soil profile, aquifer characteristics, source of selected area and collection of the representative samples are the pre-requisite condition of ground water[Selvam 2014].

In the recent decay industrialization period, a large portion of water assets has affected hugely by seepage, leaching and inter mixing of industrial effluents in maximum industrial township and metropolitan urban communities [Girija et al 2007].The effluents have consisting of contamination and toxic colours, may alter the water quality of the region and ultimately causes the health hazards among live-stokes and human being [Pawar et al 2014]. Over the most recent twenty years, the fast development of industrialization and urbanization adversely affects the environment [Verma et al 2013].

The groundwater contaminants have been the subject of many studies in recent times in Tamil Nadu; the industrial effluents have contributed a major source of pollution [Chetty and Pillay 2019; Jeevanadam et al 2006]. The industrial effluents and trade waste of pulp and paper, distillery, fertilizers, electroplating, asbestos, alcohol, detergent, steel, tannery, textile, cane sugar, oils, pesticides and herbicides, radioactive wastes etc. play a significant contribution in pollution of water [Palanisamy and Kavitha 2010]. Water may pollute by many anthropogenic activities like discharge of house hold sewage, disposal of various industrial waste, run off from agricultural fields and many other man made infrastructures and activities [Selvam et al 2017].

Significant studies have been carried out on groundwater quality assessment in this study area, but did not conduct the risk assessment of groundwater quality for drinking purposes using GIS technology and Statistical approach[Vinnarasi et al 2020]. The present study is supposed to generate awareness among the people of the study area about iron, fluoride and chloride related problems due to minor and major elements contamination of water [Nitasha Khatri and Sanjiv Tyagi 2015].The finding of the study will be forwarded to the concerned authorities at district, state and national level for taking up the mitigation measures in iron, fluoride and chloride affected areas of surrounding SIPCOT industrial estate, Erode district [Rao et al 2013]. Moreover, this study is important as there is very little information available about the groundwater quality of 15 km radius of Perundurai SIPCOT area is to provide safe drinking water to the people.

Materials And Methods

Description Of The Study Area

The study area extends 15 km radius around periphery of SIPCOT industrial Estate (Figure 1). The Cauvery, Noyyal and Bhavani are the rivers which are flowing in the area. As a consequence, SIPCOT industrial estate has been established by the government of Tamil Nadu a decade back. SIPCOT consist of 109 industries in which 71 are textile industries 6 chemical industries and 32 other general type industries [Durgadevagi and Annadurai 2016].

The geographical location of the study area lies between 77°24'43.952" E to 77°41'16.701" E longitude and 11°7'35.093" N to 11°23'43.093" N Latitude (Figure 1). It covers an area extent of 706.86 sq.km in which the plain area is 696.88 sq.km, and the hill and forest area is 9.98 sq.km. The domestic and agriculture depends not only deepens on the seasonal rains but greatly depends on groundwater. Since the annual rainfall over the area is the average annual rainfall is 812 mm/year, the agriculture has to depend on groundwater for irrigation. Nearly 65% of the water required for irrigation is served by the bore wells while around 30% is supplied from open wells, surface water sources such as Canals, lakes, tanks accounts only for 5% of the total irrigation requirement [UGSS 2019].

Data Base

For the preparation the study area map, using GIS, Survey of India topo-sheets (58E/7,8,11,12) of scale 1:50,000) were used. 15 km buffer zone is considered for the present study area (Figure 1). It is sub-divided into segments with 5 km each. Spatial variation and zonation maps of various water quality parameters have been developed by means of using GIS Package of ArcGIS version 10.3. The geology map is prepared by digitizing the district resource map (GSI). The soil map is extracted from the district soils map obtained from the Soil Testing lab, Agriculture department, Erode with a scale of 1:250000. The land use/ land cover classes were crosscheck with different field verifications at the time of field validation.

The study area is composed of Archaean Crystalline formations. In the study area not only for the geological formations, while in certain others such as excessive use of agrochemicals, partial to untreated disposal of sewage and effluents has rendered the groundwater contaminated and unfit for direct consumption. WHO has reported that the developing countries like India 80% of the disease in human and about 30% of infant mortality occurs due to water pollution.

Soil is the most significant influencing of the groundwater quality of the region. The different types of soils available in the study area (Figure 2) are brown soil covers 1%, red calcareous soil covers 54% and red non-calcareous soil covers 45%. The calcareous and non-calcareous red soil permeability is moderate to high and brown soil permeability is poor [Kaliraj et al 2014].

Land use/land cover classes are also the mainly contributing factor for the groundwater quality (Figure 3).

Sample Collection And Analysis

Samples were collected from 79 domestic use hand pumps, electric pumps and agricultural open wells equally distributed (each 4km distance) over the study area. Groundwater samples were taken from 7 points around 5km of SIPCOT industrial estate and nearby villages, while 26 sampling points were selected from 5 to 10km radius of SIPCOT (Figure 1). The maximum numbers of sampling points (46 groundwater samples) were selected from 10 to 15km of peripheral radius. The sample containers were made from high-density polyethylene. The samples that were collected in containers were rinsed with bore well samples and dipped in 2ml of HNO_3 for 24 hours and finally cleansed with distilled water. The containers were washed in their respective collected sample before storing the groundwater from the sampling.

The groundwater samples were tested to determine the physio-chemical parameters using standard testing procedure (APHA 2005). The physio-chemical parameters are taken into GIS which has developed the attribute data and prepared the spatial distribution maps for each parameter using inverse distance weighted (IDW) technique [Suresh et al 2010].

Multivariate statistical analysis of groundwater quality, correlation matrix, factor and principal component analysis study was employed with the help of ‘the Statistical Package for the Social Science Software SPSS V.11.0 for Windows’ [IBM SPSS 2013] for the COVID-19 pandemic period. Land use/ land cover map prepared from Landsat 8 Satellite march 2019 (Figure 4).

Water Quality Index (WQI) is the best method to classify the quality of water as per standards and estimate the different parameters which are used for drinking purposes. The results are taken into GIS which has developed the attribute data and prepared the spatial distribution map (Figure 4).

Results And Discussion

In pursuant to the collected groundwater samples (79 numbers) from various parts of the 15 km radius of SIPCOT estate was examined in January 2021 (COVID-19) pandemic period. The addition of TZ+ (cations) and sum of TZ- (anions) equilibrium shows the charge equilibrium inaccuracy proportion [Hemant Pathak and Limaye 2012]. The inaccuracy percentage is amid +1 percent to +10 percent by little exemption as some particles illustrates the unusually elevated concentration occur in the period. Occurrence of inaccuracy in chemical assess of groundwater is also due to the reagent employed, confines of the techniques and the utensil used available of fifth in refined water and so on. The relationship associative among TZ^+ and TZ^- is about 0.5 to 0.8 TDS. The EC proportion various as of 0.4 to 0.8. The rate of mean, minimum, maximum and limiting values with classifications in the study period are given in Table 1.

The pH analysis of groundwater samples from various sampling points of the study is revealed that the values fall between 6.72 to 8.05 (Table 1). The entire study region of groundwater pH values is within the limit of WHO standards. The ranges of EC in the study area vary from 556 μS/cm to 8560 μS/cm for January-2021 COVID-19 pandemic period. The inner area of 5km radius of SIPCOT (Sample well no. 43,52&53), 5-10km (Samples well no. 15,25,33,36,45,49,50,60,70) and 10-15km (Sample well no. 4,13,14,22,23,31,58,66, 68,69,72,75,76) shows very high EC value for this period as seen in Figure 5. Since these wells are located near the discharge the waste water streams of industries, dense residential area and chemical weathering of rock and minerals [Hemant Pathak and Limaye 2012].

Table 1

Results of Groundwater parameters based on the WHO 2017 and Basic statistical analysis

Elements	WHO Standard-2017			Wells exceeding permissible limits out of 79 Samples
	Most desirable	**Maximum allowable**	**Not permissible**	
Electrical Conductivity	<1500µS/cm	-	>1500µS/cm	4,13,14,15,22,23,25,31,33,36,43,45,49,50,52,53,58,60,66,68,69,70,72,75,76 **(25)**
Total Dissolved Solids	<500mg/L	500 to 1500mg/L	>1500mg/L	14,25,31,49,52,58,60,66,69,70,72,76 **(12)**
pH	6.5 to 8.5	-	< 6.5 and >8.5	All samples within Most desirable limits
Calcium (Ca^{2+})	<75mg/L	75 to 200 mg/L	>200 mg/L	14,52,58,60,70,72,76 **(7)**
Magnesium (Mg^{2+})	<50mg/L	50 to 150 mg/L	>150 mg/L	52,72 **(2)**
Sodium (Na^{+})	<200mg/L	-	>200 mg/L	58,60,66,70,72 **(5)**
Potassium (K^{+})	<10mg/L	-	>10mg/L	2,4,5,6,13,14,15,22,24,25,30,31,33,36,38,39,40,42,44,45,48,49,50,52,53,55,56,58,60,61,64,66,67, **(42)**
Iron ($Fe^{2+/3+}$ mg/L	<0.3mg/L		>0.3mg/L	5,6,17,19,20,37,60,70,71,77 **(10)**
Bicarbonate (HCO_3^-)	<300mg/L	300 to 500 mg/L	>500 mg/L	72 **(1)**
Nitrate (NO_3^-)	<45mg/L	-	>45mg/L	All samples within Most desirable limits
Chloride (Cl^-)	<200mg/L	200 to 600 mg/L	>600mg/L	14,49,52,58,60,66,70,72,76 **(9)**
Sulfate (SO_4^{2-})	<400mg/L	-	>400mg/L	52,72 **(2)**
Fluoride (F^-)	<1.5mg/L	-	>1.5mg/L	4,16,17,24,28,29,30,38,43,47,51,55,64,70,72 **(15)**
Total Alkalinity	<500mg/L	-	>500mg/L	72 **(1)**
Total Hardness	<100mg/L	100 to 500 mg/L	>500mg/L	4,13,14,15,22,23,25,31,34,36,43,45,49,50,52,58,60,63,66,68,69,70,72,75,76 **(25)**

The analysis of TDS in the study area reveals that the value is in the ranges from 389mg/L to 5992mg/L for January-2021, COVID-19 pandemic period (Figure 5). It is also found that higher value of TDS of water samples from 5km radius of SIPCOT (Sample well no.52), 5-10km (Samples well no. 25,49,60 and 70) and 10-15km (Sample well no. 14,31, 58,66,69,72,76) as seen in Figure 6. Hence, the analysis of the parameters EC and TDS reflects the intrusion of industries and chemical weathering of rocks and minerals effluent into the groundwater [Manoj et al 2020]. It also causes health issues like kidney stone in humans [Garg et al 2009].

The total alkalinity analysis in the study area reveals that the value is estimated between 84 mg/L and 3020 mg/L for the season as represented in the figures 7 which is well (Sample well no.72) over the permissible limit of WHO. Hence, from the analysis of the parameter, the total alkalinity reflects the soil gases that dissolve in rain, surface water, and groundwater [Durgadevagi and Annadurai 2016].

In the study area, the range of total hardness is 184-2000 mg/L. The inner area of 5km radius of SIPCOT (Sample well no.34, 43 & 52), 5-10 km (Samples well no.15, 25, 36, 45, 49, 50, 60, 63, 66 & 70) and 10-15km (Sample well no.4, 13, 14, 22, 23, 31, 58, 68, 69, 72, 75 & 76) shown very high total hardness in Figure 8 and Table 1 (WHO 2017).

The calcium content analysis of the study area is shown in the Table 1. The influence is that the minimum value of calcium is 46.40mg/L which extends to a maximum of 435.20mg/L. Very high Ca^{2+} value of samples is located within 5km radius of SIPCOT (Sample well no.52) due to industrial effluents. From 5-10km (Samples well no.60 & 70) due to discharge the waste water streams of industries. From 10-15km (Sample well no.14, 58, 72 & 76) due to lineament act as chemical weathering of rocks and addition domestic sewage as seen in Table 1.

The analysis of results in Table 1 reveals that the concentration of Mg is present in the range of 14.40–218.88mg/L from the spatial distribution of magnesium that is shown in Table 1. It is found that nearly 99% of the study area is much good for the concentration of Mg within the most desirable and maximum allowable limit of WHO-2017. The concentration of Na in the region varies from 17 to 1000 mg/L. Table 1shows that 94% of the study area contains the sodium levels within the prescribed limit of WHO standards. And remaining 6% of the study area is under high risk of sodium concentration.

Considering the quality of water in the region, it is found that the concentration of Potassium is ranged from 5 to 400mg/L (Table 1). 15% of the samples contain the potassium levels within the prescribed limit of WHO standards. And remaining 85% of the samples are under high risk of sodium concentration. Although, Na^+ and K^+ ions are naturally found in groundwater, industrial and household waste also add ions to groundwater [Garg et al 2009].The concentration of $Fe^{2+/3+}$ in the region varies from 0 to 2.60mg/L. Table 1shows that 80% of the samples contains the iron levels within the prescribed limit of WHO standards. And remaining 20% of the samples are under high risk of iron concentration. The result shows that the value of NO_3 varies from 5 to 42mg/L for the COVID-19 pandemic period (Table 1). Hence, the region under investigation is least affected by Nitrate content as the consistence of nitrate is below the permissible value of 45mg/L.

The inner area of 5km radius of SIPCOT Sample well no.52 is high concentration of chloride, due to industrial effluents. From 5-10km area is observed the sample well nos. 49, 60 & 70 is above consumption value, due to influence of house hold sewage. From 10-15km (Sample well no. 14,58,66,72&76) show very high Cl^- value for the pandemic period. It is representing percolating as of top most strata due to manufactures and household activities and arid weathers, such addition of Cl^- to the groundwater by mixing with higher chloride water nearby formation and Cl^- leached from fluid inclusion (or) inter-granular salts [Cheong et al 2012] as seen in Table 1.

The result of analysis that is shown in Table 1 reveals that the concentration of SO_4 ranges between 34–450mg/L and from the spatial distribution of sulfates, it is found that 99.88% of the study area is much better for the concentration of SO_4 is within the most desirable limit of WHO-2017.

The study area fluoride content ranges from 0.20 to 2.80 mg/L in groundwater. The fluoride concentration of various sampling points is almost 89% of the groundwater samples in the study area are not affected by fluoride content (less than the prescribed limit of WHO). And only 11.30% of the samples is susceptible to fluoride content that is greater than the permissible limit of drinking water (Sample nos. 4,16,17,24,28,29,30,38,43,47,51,55,64,70,72). The fluoride content of the not permissible samples ranges from 1.6 to 2.80 mg/L (Table 1) in the study region.

Integration Study Of Spatial Maps

The systematic union analysis was carried out on the GIS platform utilizing maps of various cations such as Ca^{2+}, Mg^{+2}, Na^+, K^+ and $Fe^{2+/3+}$ and Anions like HCO_3^-, Cl^-, SO_4^{2-} and F^-. The main cations and anions quality of groundwater is shown by the integrated output maps Figures 9 and 10. Figure 9 demonstrates that 1.55% of the study region has cations levels that are within the most desired limit, whereas 87.49% of the area is underline by maximum allowable class for drinking uses. Furthermore, 10.95 percent of the research region is at high risk of cation concentration.Not permissible class of samples is located within 5km radius of SIPCOT (Sample well no.52) due to industrial effluents. From 5-10km (Samples well no.60 & 70) due to discharge the waste water streams of industries. From 10-15km (Sample well no. 58, 66 & 72) due to lineament act as chemical weathering of rocks and addition domestic sewage as seen in Figure 9.

The integrated anion content concentration of various sampling points is mapped as the spatial distribution in Figure 10 which shows that almost 23.01% of the groundwater in the study area is most desirable class; maximum allowable category is 67.85%. And only 9.14% of the study area is susceptible to anion content that is greater than the permissible limit of drinking water (Sample nos. within 5km radius area as 43, 51 and 52; 5 to 10 km radius area is 24, 28, 55, 60, 64; 10 to 15 km radius area as 4, 14, 29, 38,66, 72). It is representing percolating as of top most strata due to manufactures and household activities and arid weathers, such addition of anions to the groundwater by mixing with higher anions water inter-granular salts.

Piper Trilinear Diagram

The piper (Figure 11) plot shows that 97.47% of the samples in Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} type indicate the predominance of anthropogenic impact [Srinivasamoorthy et al 2011]. The association of Na^+-K^+-HCO_3^- is 94.94% of the samples correspondingly. It is mainly due to feldspar weathering processes/ion exchange processes [Sekaran et al 2019].The plot shows that 62.03% and 30.38% of the samples signify the mixed (CaMgCl and Ca-Cl^-) category respectively. These types indicate the predominance of anthropogenic impact. Few locations indicate $CaHCO_3$ and Na-Cl^- categories. Percolation meteoric water initiates bicarbonate to the groundwater.

The cation triangle plot reveals that the majority of the samples fall in ‘No dominant’ (92.41%).

The anion triangle plot reveals that 56.96% of the samples are represented as ‘No dominant’. The second dominating (40.50%) anion is Cl^- ion next to HCO_3^- in the study area (Figure 11). In general, alkali exceeds alkali earth indicating control of water chemistry by strong acid along with weathering of feldspar enriched rocks and SIPCOT estate industries effluents.

Correlation Analysis

Correlation between the various chemical constituents was conceded out for pandemic period (COVID-19) with respect to open wells and tube wells in order to locate the closely related positive and negative ion from their correlation coefficient. Table 2illustrates that the EC and TDS shows good positive correlation between Na^{+} (r = 0.92), NO_3^{2-} (r = 0.92), Mg^{2+} (r = 0.92), Cl^{-} (r = 0.86), Ca^{2+} (r = 0.92), SO_4^{2-} (r = 0.81), K^{+} (r = 0.79), HCO_3^{-} (r = 0.73) and negative correlation with pH (r=-0.12).

While the Ca^{+2}, Mg^{2+} is positive correlation with Cl^{-} (r = 0.93) reflecting the influencing man-made activities [Thivya et al 2013]. Na^{+}, K^{+} is positive correlation with HCO_3^{-} (r = 0.97) indicates chemical weathering [Prasanna et al 2010] of as illustrated by the Piper trilinear diagram (Figure 11).

Total Hardness showed good positive correlation with Ca^{2+}, Mg^{2+} (r = 1.00), Cl^{-} (r = 0.93), NO_3^{2-} (r = 0.92), SO_4^{2-} (r = 0.90) and showed negative correlation with pH (r= -0.10). Higher values of TH concentration in groundwater samples might be due to maximum salt concentration. T.Alk shows good positive correlation with K^{+} (r = 0.97), HCO_3^{-} (r = 1.00), Na^{+} (r = 0.92), NO_3^{2-} (r = 0.51) and negative correlation with $Fe^{2+/3+}$, pH (r=-0.01, -0.04) influencing of agricultural activities and industrial effluents or sewage infiltration [Cheong et al 2012]. pH is negative relation with other parameters.

Table 2
Inter-elements correlation matrix for groundwater

Correlation Matrix - Marked correlations are significant at p< .05000 N=79															
Variable	Ca	Mg	Na	K	Fe	Cl	HCO_3	SO_4	NO_3	F	pH	EC	TDS	T.Alk	TH
Ca	1.00														
Mg	0.99	1.00													
Na	0.70	0.71	1.00												
K	0.55	0.55	0.90	1.00											
Fe	0.04	0.04	0.10	-0.01	1.00										
Cl^{-}	0.93	0.93	0.66	0.40	0.10	1.00									
HCO_3	0.47	0.47	0.87	0.97	-0.01	0.29	1.00								
SO_4	0.90	0.90	0.61	0.47	0.11	0.80	0.38	1.00							
NO_3	0.92	0.91	0.79	0.56	0.13	0.91	0.51	0.82	1.00						
F	0.14	0.16	0.33	0.35	0.05	0.05	0.41	0.15	0.16	1.00					
pH	-0.10	-0.11	-0.10	-0.10	0.07	-0.15	-0.04	-0.08	-0.08	0.01	1.00				
EC	0.92	0.92	0.92	0.79	0.08	0.86	0.73	0.81	0.92	0.26	-0.12	1.00			
TDS	0.92	0.92	0.92	0.79	0.08	0.86	0.73	0.81	0.92	0.26	-0.12	1.00	1.00		
T.Alk	0.47	0.47	0.87	0.97	-0.01	0.29	1.00	0.38	0.51	0.41	-0.04	0.73	0.73	1.00	
TH	1.00	1.00	0.71	0.55	0.04	0.93	0.47	0.90	0.92	0.15	-0.10	0.93	0.93	0.47	1.00

Cl^{-} and SO_4^{2-} are established to tolerate statistically the important correlation with most of the parameter representatives seal alliance of these factors with each other. So, the parameter, EC, can provide an excellent sign of a numeral with associated factors. Poor correlation subsists among K, HCO_3^{-} and other ions. This indicates the chemical disintegration process that stimulate beside by the release of second stage salt formation. It might be the principal supplier in support of those particles.

Factor Analysis

The factor analysis for the January-2021 (COVID-19 Pandemic Period) was conceded away and the results show complexity in chemical nature of the area. The association of the ion in Factor 1 with the total variance of 63.24% representing high positive loadings on Ca, Mg, Cl^{-}, and SO4 which clearly indicates that these ions observed in the investigated outcome of groundwater is associated with the rock weathering and domestic discharges and industrial effluents. NO_3, EC, TDS, TH indicates that the alkalinity observed in the investigated outcome of groundwater is associated with the huge quantity of chemical fertilizers used in irrigation [Selvakumar et al 2017]. This shows that the EC is managed by this chief ion of calcium, magnesium, chloride and sulphate. This factor can be clarified by the large habitation instance of groundwater, better rock water interaction and superior solvent of minerals [Le et al2017].

Factor 2 stands for Na, K, HCO3 plus T.Alk by 14.98% of total variance (Table 3). This factor indicates that the pollution from agricultural land using fertilizers or due to sodium, potassium and bi-carbonates processes that normally occur on bore well water point in soils segment, where natural substances and O_2 are copious along with secondary dissolution [Selvakumar et al 2017].

Seventy-nine samples of groundwater were taken from principal component analysis and the correlation matrix is demonstrated in Table 4 and Figure20 which signifies the resolved initial PC, its Eigen values and % variance associated in every PC. Scree plot (Figure 12) demonstrates the three-dimension loading plots of factor score [Dudeja et al 2013]. Eigen values superior of one are considered, and the initials of three prime mechanisms are the most chief components that represent 63.24% percent variables in water quality including in the period of study.

Table 3
Factor loading

Variable	Factor 1	Factor 2
Ca	0.954	0.246
Mg	0.952	0.251
Na	0.578	0.769
K	0.344	0.911
Fe	0.114	-0.036
Cl	0.964	0.082
HCO3	0.240	0.958
SO4	0.892	0.170
NO3	0.904	0.307
F	-0.017	0.546
pH	-0.131	-0.017
EC	0.832	0.550
TDS	0.832	0.550
T.Alk	0.240	0.958
TH	0.956	0.249
Expl.Var	7.255	4.478
Prp.Totl	0.484	0.299
Eigenvalue	9.487	2.247
% Total variance	63.244	14.980
Cumulative Eigenvalue	9.487	11.734
Cumulative %	63.244	78.224

Drinking Water Quality Index (Wqi)

The Drinking Water Quality Index (DWQI) spatial distribution map for the period is shown in figure 13which emphasis that the very high risk for drinking in the zones which are closer to the SIPCOT estate where noticed; one in southeastern part (5-10 km radius) and another in southwest corner (10-15 km radius) of the study area.

The quality of groundwater based on TDS and TH diagram is presented in six segments such as soft saline, soft brackish, soft fresh, hard saline, hard brackish and hard fresh water categories respectively [Elumalai et al 2017]. This diagram reveals that 67.09% of the samples fall under 'Hard fresh water' category which is mainly due to the presence of weathering processes/ion exchange processes. Rest of 32.91% of the water samples were fall in 'Hard brackish water' (Figure 14) respectively. Hard brackish groundwater area is the direct influence of the SIPCOT effluents.

In this diagram, Cl^- is plotted in X-axis and NO_3 is plotted in Y-axis. This plot (Figure 15) indicates four different types of hydro-geochemical process type 1 (less than 6.6% of the Cl^- and NO_3), type 3 (6.6–10% of the Cl^- and NO_3), type 2 (10 % to 40 %) and type 4 (More than 40%) in the study. The plot reveals that 82.28% of the groundwater samples fall under type 1; it has a good quality of water. Rests 17.72% of the samples have a bad quality of groundwater. Thus, above data indicates the impact of SIPCOT effluents on groundwater chemistry.

Conclusion

The present research deals with the groundwater quality and hydro geochemical process around 15 km radius of SIPCOT industrial estate in Perundurai, Erode district, Tamil Nadu. Based on the WHO standard, GIS spatial analysis demonstrates that 10.95% of the research region is at high risk of cation concentration. And only 9.14% of the study area is susceptible to anion content that is greater than the permissible limit of drinking water. EC, TDS, TH parameters have observed 10 to 25 samples (11.30 to 46.80% of area) is under high risk.

Drinking Water Quality Index and Bivariate plot TDS Vs TH shows not permissible class of samples is located within 5km radius of SIPCOT (Sample well no.43, 51 and 52) due to industrial effluents. From 5-10km (Samples well no.24, 28, 55, 60, 64, 70) due to discharge the waste water streams of industries.

From 10-15km (Sample well no. 4, 14, 29, 38, 58, 66, 72) due to lineament act as chemical weathering of rocks and addition domestic sewage

The statistical analysis indicates that the groundwater pollution from the agricultural land using fertilizers or secondary salts, anthropogenic influence from SIPCOT plays a major role in determining the groundwater chemistry of the region. It is also represented by the Piper trilinear diagram.

Though the high court ordered all units follow zero liquid discharge (ZLD) system and the Supreme Court upheld it, many units violated the norms and let the untreated effluents in open places, bore wells, wells and rainwater and dumped the sludge's in open places and buried in the earth.Hence, no pollution causing units are permitted hereafter in SIPCOT, the sludge in the earth, tanks be removed, usage of coal and firewood as fuel be banned, type retreading and old battery processing units be closed. They also wanted people's representatives be included in the monitoring committee led by collector to check pollution problem, protected water supply be arranged in 25 villages around the SIPCOT where drinking water was much contaminated, studies be made about TDS in all water courses in SIPCOT and surrounding villages every month and it be made public, relief be given to the families whose members died due to cancer.

Declarations

Ethics approval and consent to participate - Not Applicable

Consent for publication – Not Applicable

Authors Contribution

1. **Manoj Shanmugamoorthy (MS)**

Identified the problem and found out the suitable area for this study, performed various tests and analysis to check the suitability of the water and involved in manuscript preparation.

2. **Anandakumar Subbaiyan (AS)**

Field visit, Water sample collection, interpreted the results and involved in manuscript preparation.

3. **Lakshmanan Elango (LE)**

GIS map preparation, Correlation Matrix for ground water and has been major stand towards the completion of the manuscript.

4. **Sampathkumar Velusamy (SV)**

Supported the study with rainfall and groundwater level data and involved in manuscript preparation.

Funding – Not Applicable

Competing Interests - The authors declare that they have no competing interests.

Availability of Data and Material - The results and analysis of the current study are available with the corresponding author and can be fetched from the same on reasonable request.

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Tables

Table 4 is not available with this version.

Figures

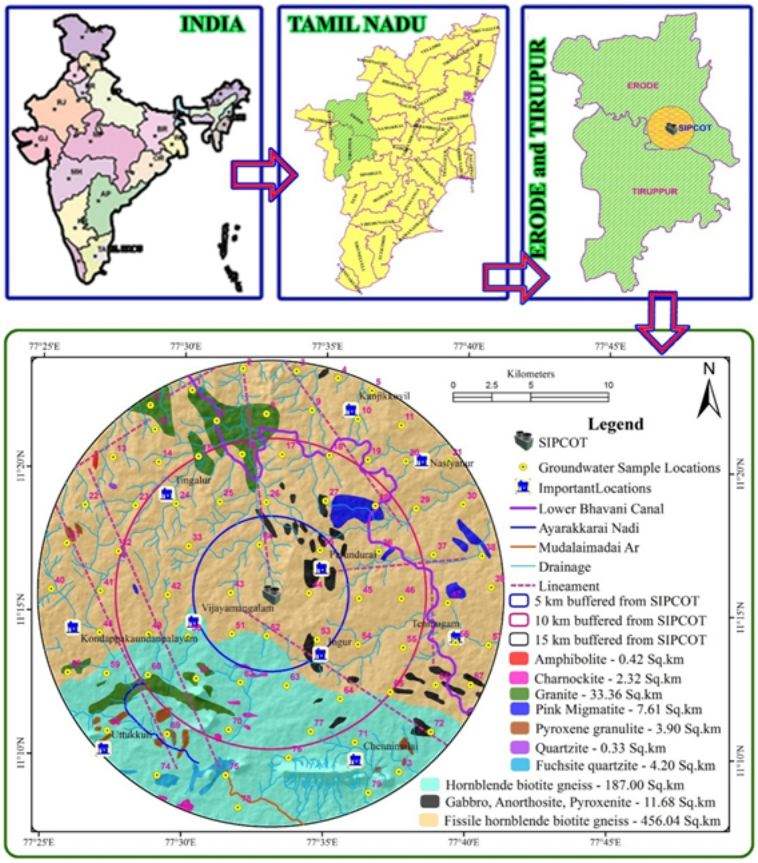

Figure 1

Study area with Geology Map

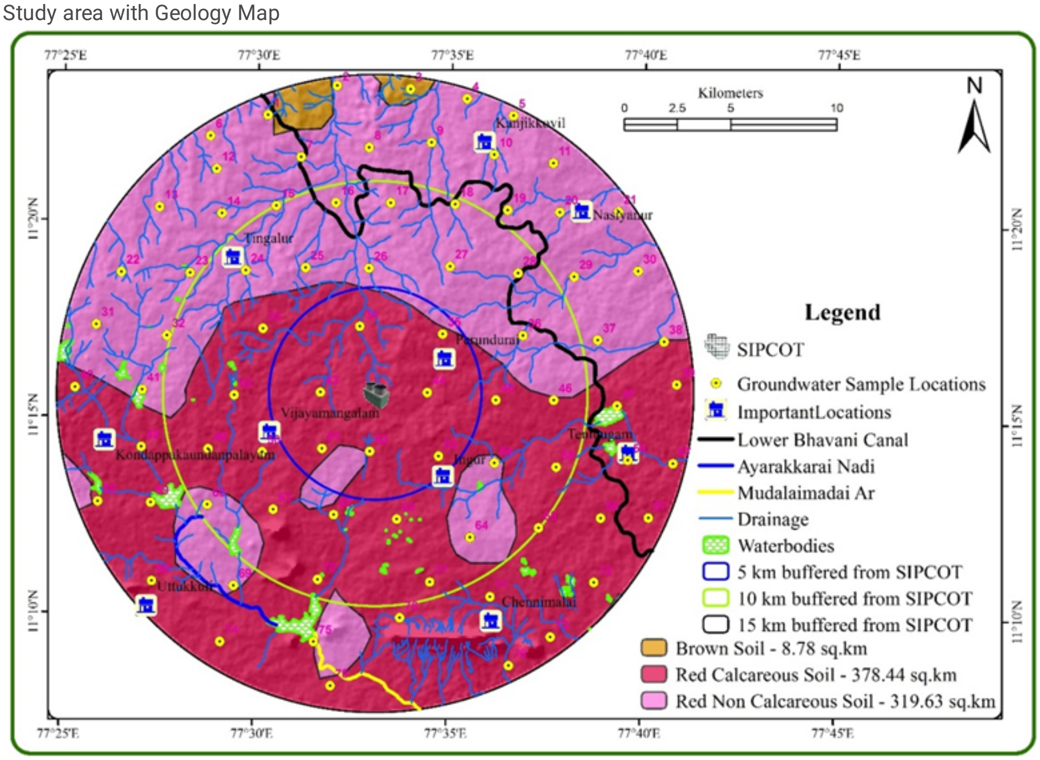

Figure 2

Soil with River and Drainage and sampling points map

Figure 3

Land use/land cover with sampling points map

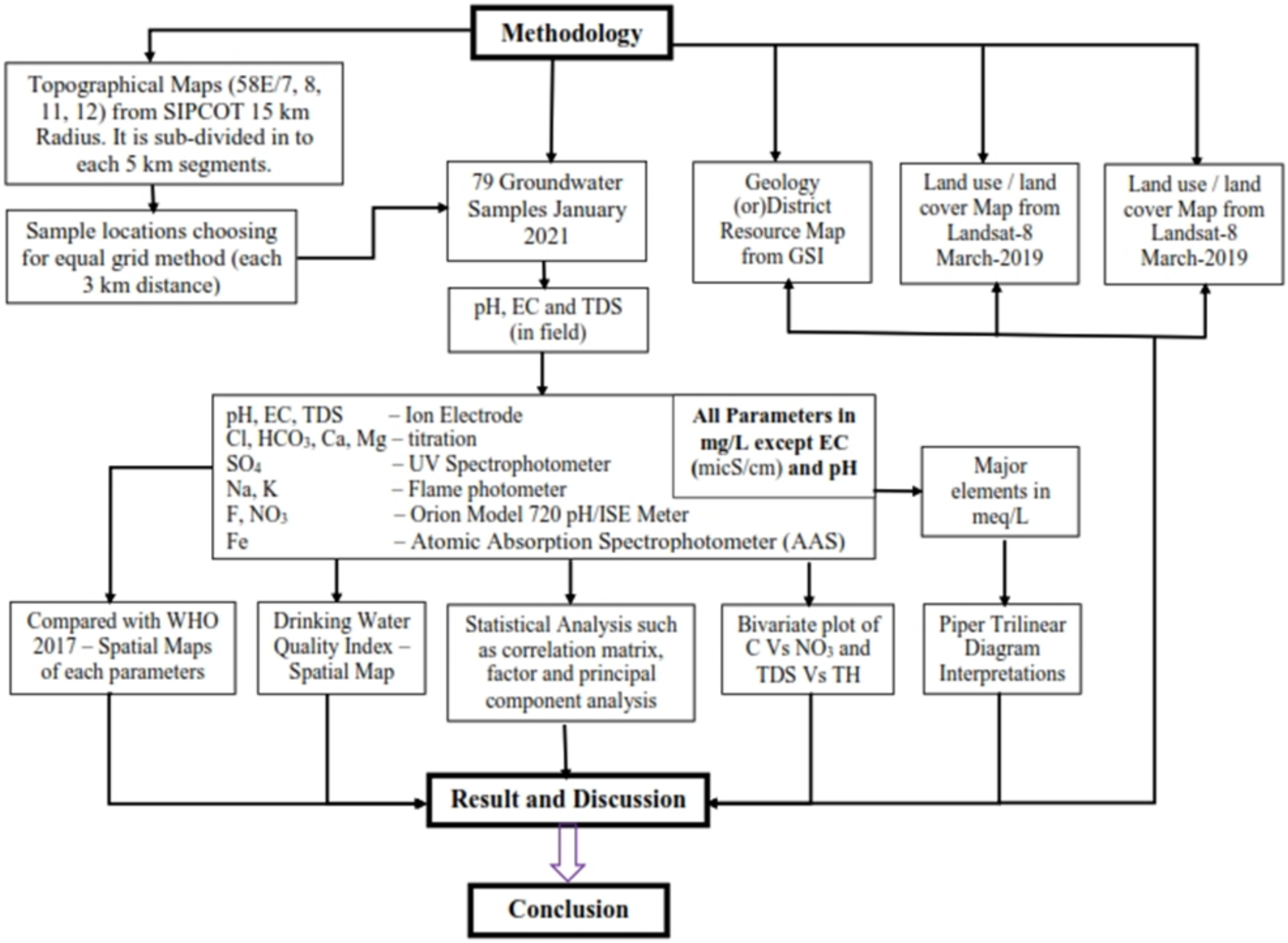

Figure 4

Methodology Flowchart

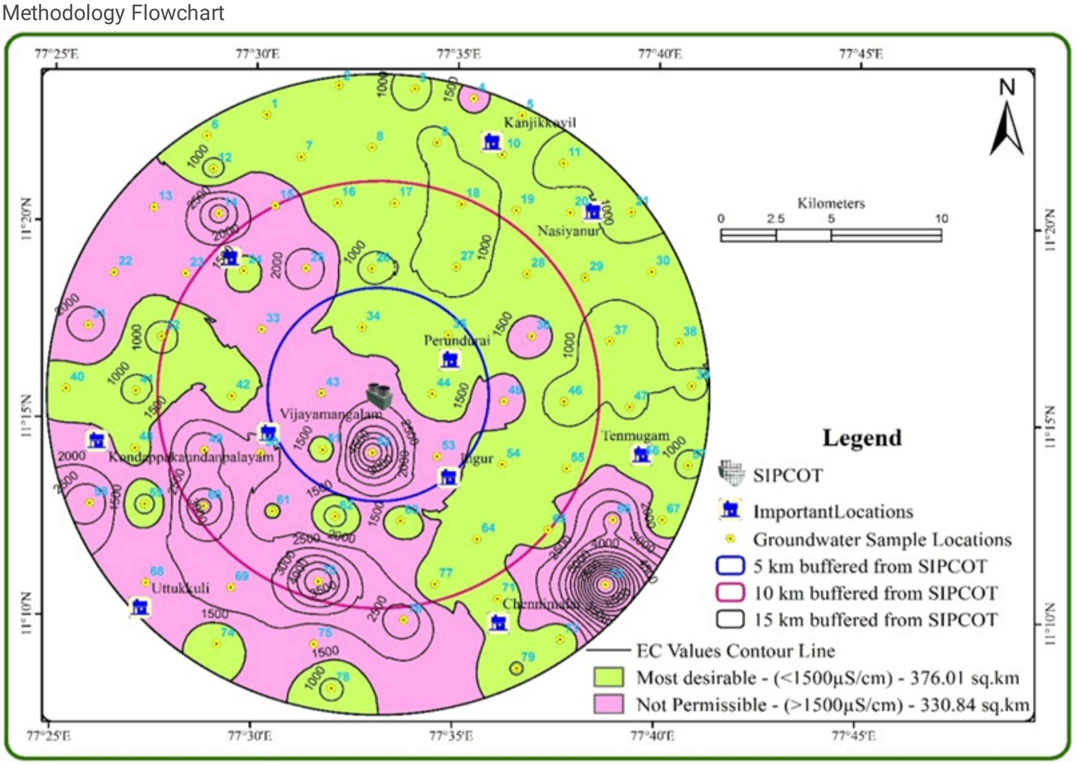

Figure 5

EC Spatial variation of Groundwater

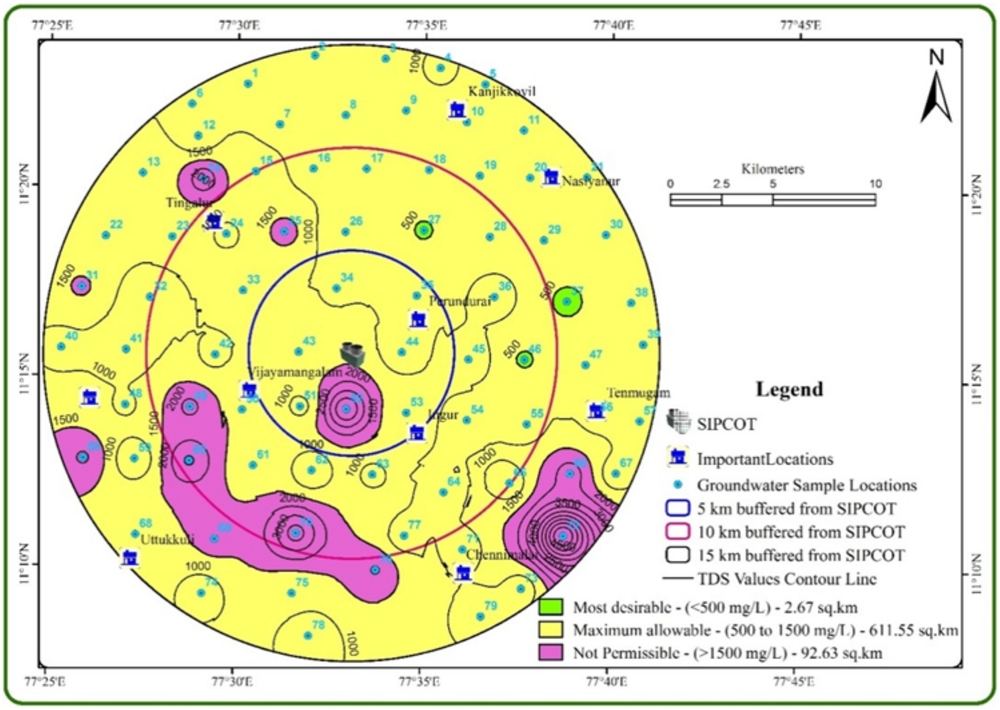

Figure 6

TDS Spatial variation of Groundwater

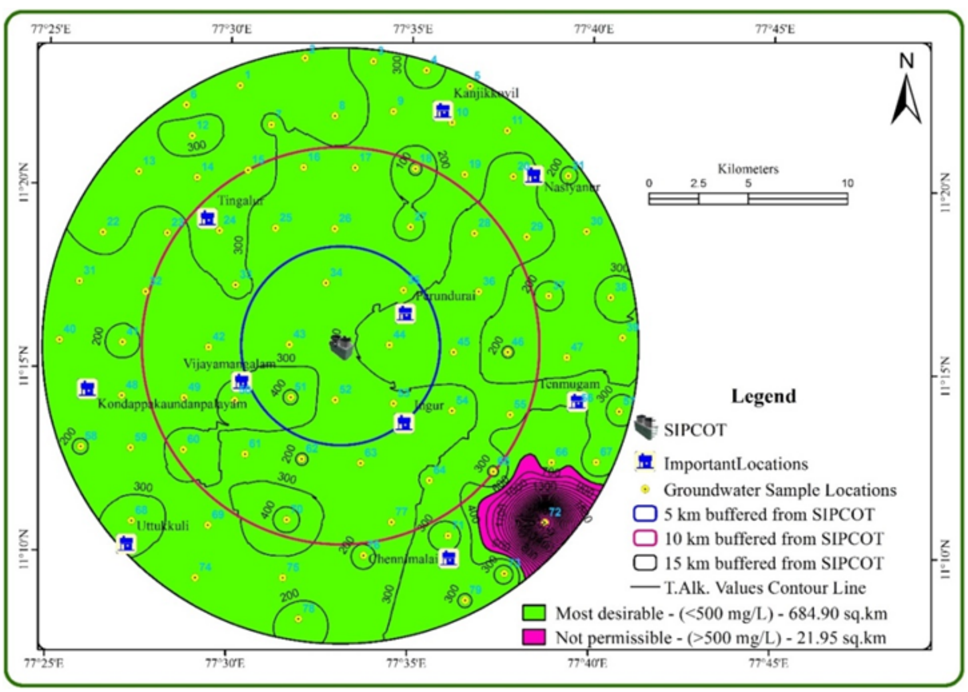

Figure 7

Total Alkalinity Spatial variation of Groundwater

Figure 8

Total Hardness Spatial variation of Groundwater

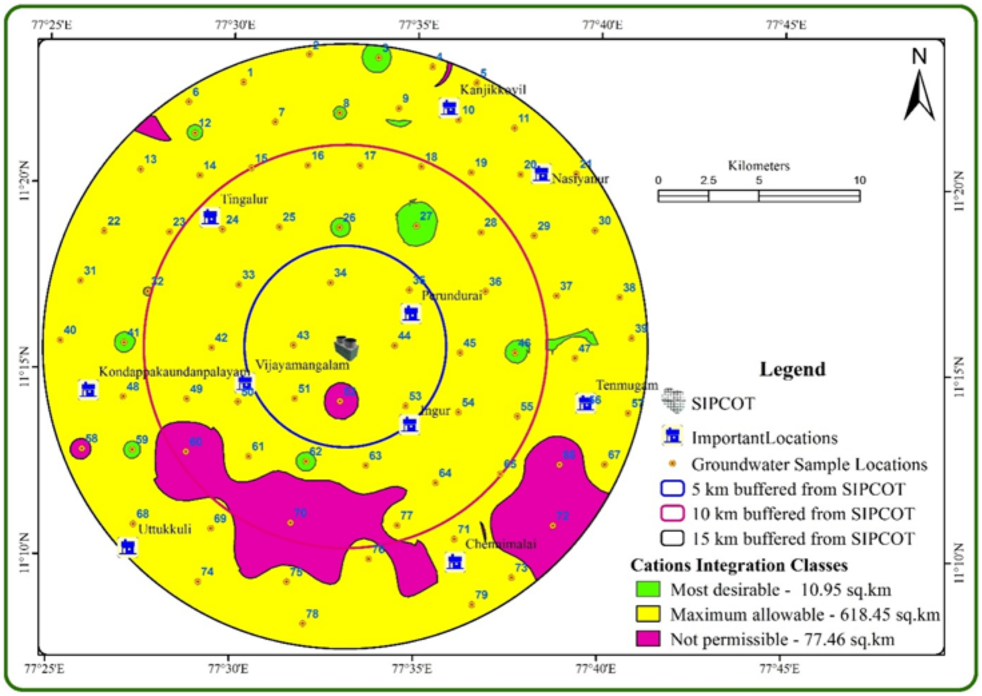

Figure 9

Integration of cations (Ca^{2+}, Mg^{+2}, Na^{+}, K^{+} and Fe^{3+}) Spatial variation

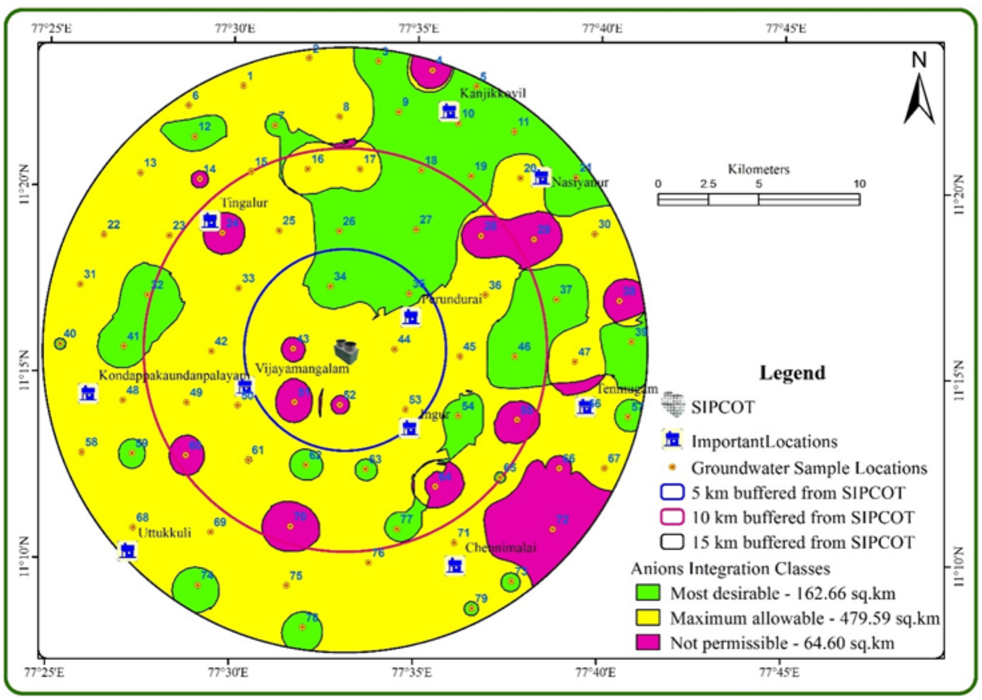

Figure 10

Integration of cations (HCO_3^-, Cl^-, SO_4^{2-} and F^-) spatial variation

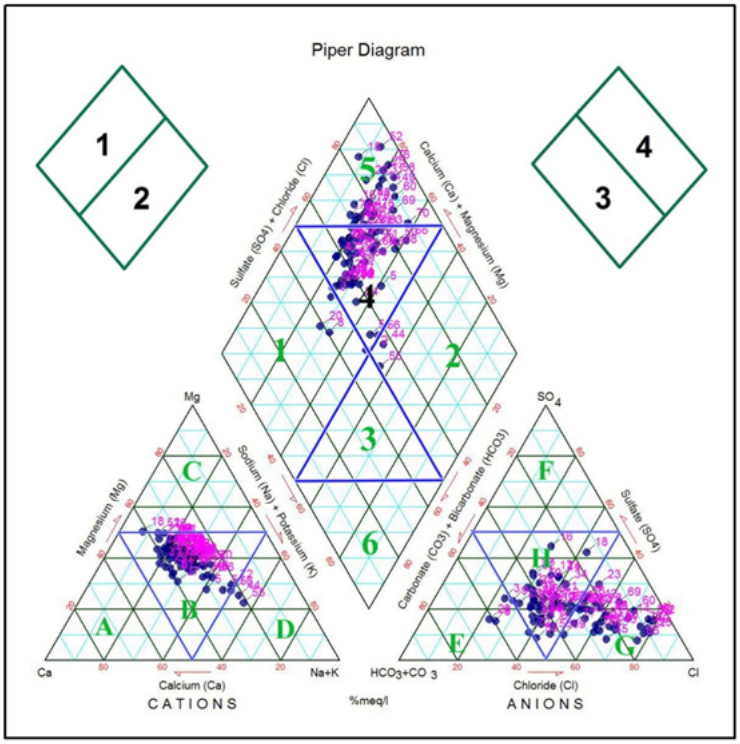

Figure 11

Piper Trilinear Diagram

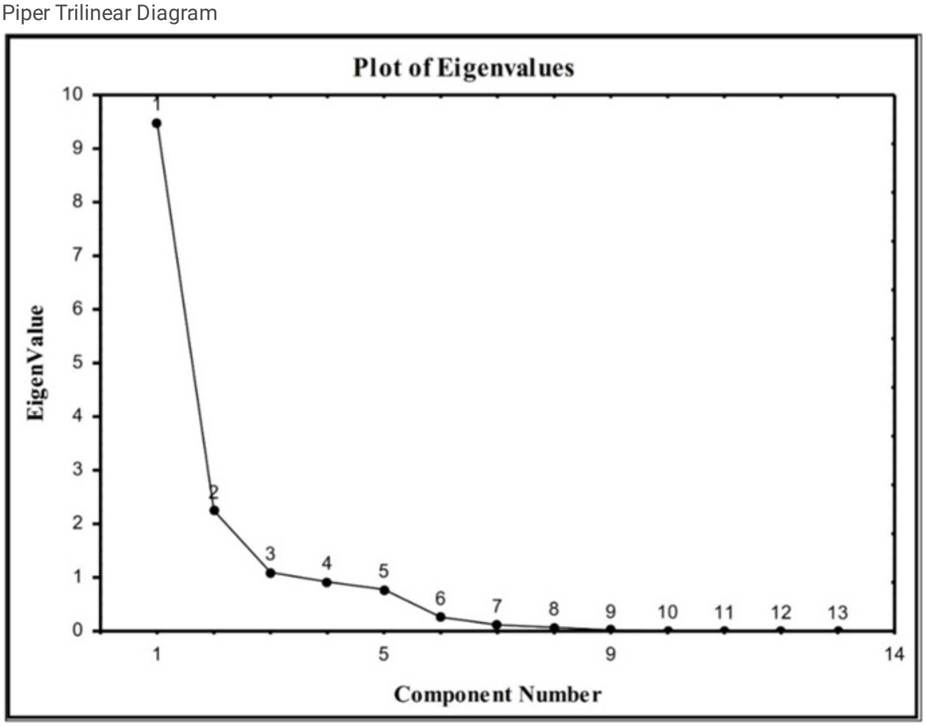

Figure 12

Scree plot of principal components analysis

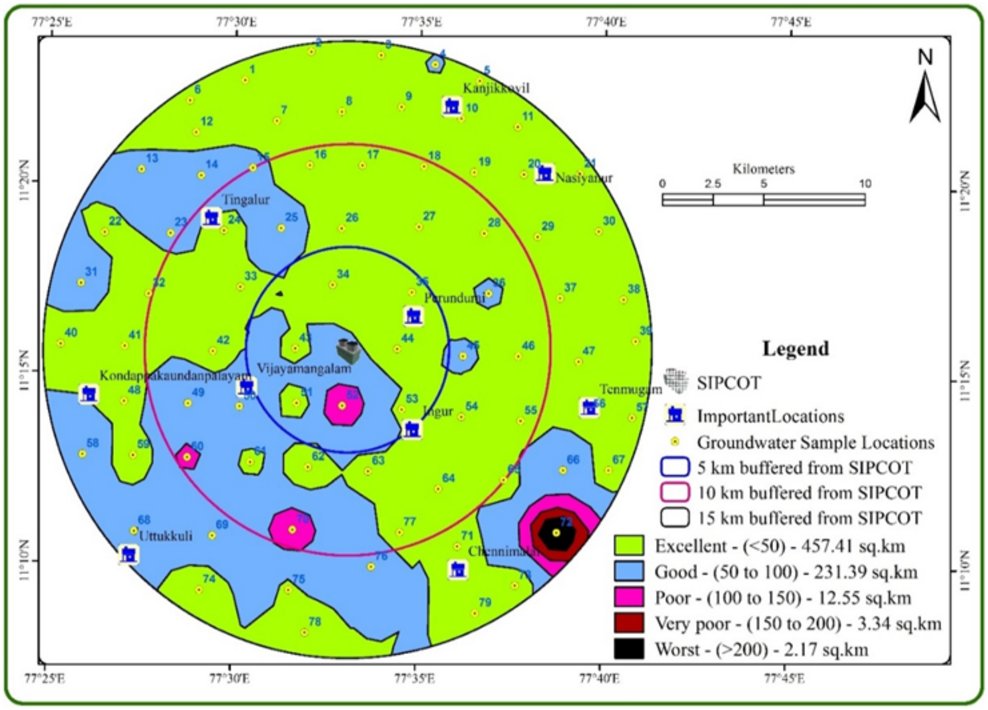

Figure 13

Drinking Water Quality Index (DWQI) Spatial variation of Groundwater

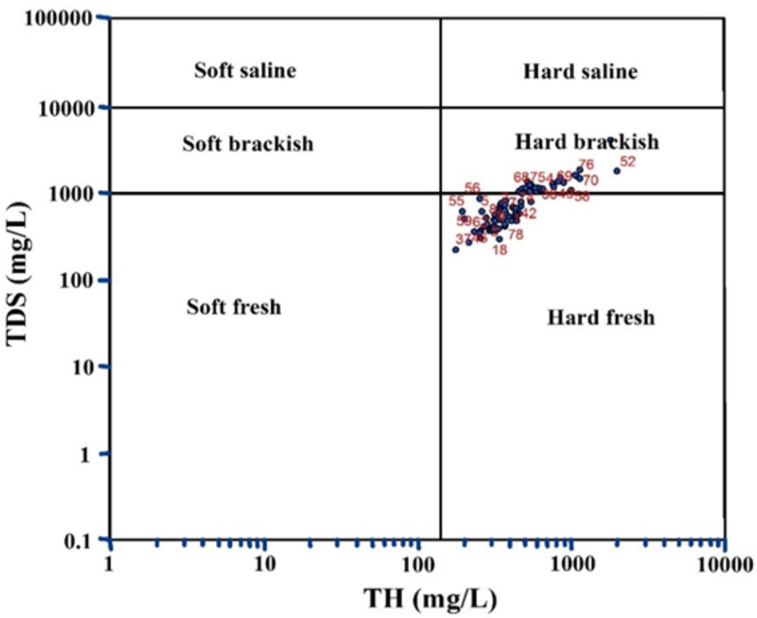

Figure 14

Groundwater quality based on TDS and TH

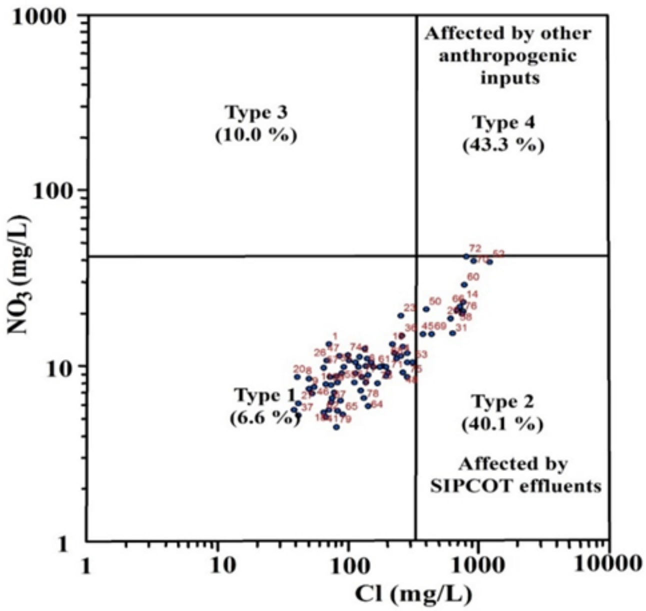

Figure 15

Source identification diagram

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