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Groundwater Quality for Drinking and Irrigation in the District of Tiruvannamalai, Tamil Nadu, India: A Bird's Eye View

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Abstract: Groundwater is a very important natural source of water for the people of Tiruvannamalai due to lack of surface water sources. Excessive usage of fertilizers and geology of region cause the contamination of ground water in this region. 63 locations were identified, and the samples were analyzed using Piper plots, Gibbs diagram, Wilcox plots and Thematic spatial maps. Various quality parameters such as WQI, SAR, Na%, and PI% have been calculated to get a holistic picture of ground water quality in the district.

Keywords: Groundwater, WQI, SAR, Na%, Gibbs diagram, Piper diagram, Wilcox diagram.

1 Introduction

Groundwater accounts for 0.63% of all the fresh water in the hydrosphere. In arid and semi-arid areas ground water contributes to all the drinking and agricultural needs of the people. Over 1.5 billion people in the world are dependent on ground water for their day to day needs [1]. The study area - the district of Tiruvannamalai in Tamil Nadu, India has scanty rainfall and lacks sufficient surface water bodies. This forces the farmers and local population to rely on water drawn from wells/bore wells. With the increasing demand of water for agriculture and industrial purposes the contamination of ground water has become a serious issue. This paper presents a bird's eye view – on the state of ground water taking into account its fitness for drinking and irrigation. Two possible sources of groundwater pollution can be geological processes and anthropogenic activities. 63 samples from across the length and breadth of the study area have been collected and have been subject to physico-chemical analysis. Parameters such as WQI, Na%, SAR, PI% have been calculated for all the samples. The illustrations that find place in this paper have been developed using software applications such as AquaChem 2011.1.40, IBM SPSS 26, MS Excel 2007 and Surfer 15.5.382.

2 Study Areas

Tiruvannamalai district (DMS Lat - 12° 13' 43.0608" N and DMS Long - 79° 3' 59.5584" E) lies in the north-eastern part of Tamil Nadu, India (Figure 1). The district consists of 18 blocks (listed in Table 1). A preliminary geological study revealed the presence of metamorphic and igneous rocks. The rock formations found in the study area include charnockites and igneous rocks. There are no perennial flowing rivers and surface water bodies in this region and there is a rapid increase in the number of borewells being drilled every year. Hence there is a heavy dependence on ground water for all the water needs in this region. A major portion of the land cover is utilized for cultivation of paddy, groundnuts, sugar cane and millets. Farmers are interested in short term crops as quick yields fetch immediate money. This mentality of the farmers has increased the usage of fertilizers and poses the threat of ground water contamination.

3 Materials and Methods

3.1 Sample Collection

The ground water samples (from wells and borewells) were collected from 63 different sites (Figure 1) from the district

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of Tiruvannamalai, Tamil Nadu, India. The land cover was first split into grids using QGIS and a map was prepared.

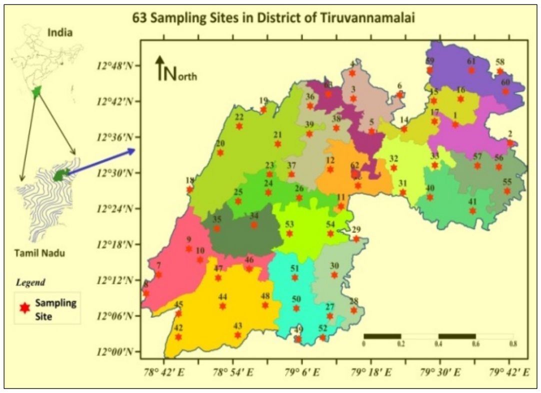

Fig. 1 – Study Area

omitted as they encompassed areas containing forest and mountains. Pre washed laboratory grade polyethylene bottles were used to collect samples from all the sites. In the case of borewells and hand pumps water was purged out for at least 10 minutes before collecting the samples to ensure uniform values of EC, TDS and pH. At most care was taken to prevent any kind of pollution as per the standard protocol recommended by American Public Health Association [2]. A handheld GPS device was used to pin point each sampling site on the map. The sample bottles were neatly labeled and the GPS coordinates were noted down.

Table 1 : Blocks, Locations and physical parameters.

Block	Location	Location ID	Latitude (N)	Longitude (E)	TDS (mg l^{-1})	EC (mScm^{-1})	pH
Anakkavur	Anakkavaur	ANK - 1	12°38'06.08"	79°32'38.21"	67.35	0.879	0.585
	Vengodu	ANK - 2	12°35'00.50”	79°42'10.59"	66.24	0.848	0.607
Arani	Agarapalayam	ARN - 3	12°42'27.55"	79°14'56.16"	81.83	0.819	0.588
	poosimalaikuppam	ARN - 4	12°46'44.40"	79°14'44.14"	72.44	0.821	0.614
	Pudhupattu	ARN - 5	12°36'58.39"	79°18'06.66"	56.03	0.456	0.578
	Randamkorrattar	ARN - 6	12°43'5.54"	79°22'58.46"	68.18	0.654	0.587
Chengam	Naradapattu	CHN - 7	12°12'54.58"	78°41'06.25"	61.10	0.615	0.579
	Neepathurai	CHN - 8	12°09'44.33"	78°38'54.47"	62.17	0.777	0.576
	Pakkaripalayam	CHN - 9	12°17'14.34"	78°46'22.11"	64.16	0.744	0.577
	Pinjur	CHN - 10	12°15'24.41"	78°48'18.19"	60.07	0.574	0.607
Chetpet	Mansurabath	CHT - 11	12°24'22.63"	79°12'47.32"	69.24	0.692	0.566
	Pulivandal	CHT - 12	12°30'34.38"	79°10'55.91"	119.00	0.632	0.565
	Seyanandal	CHT - 13	12°27'51.21"	79°15'44.90"	47.52	0.488	0.570
Cheyyar	Devanathur	CHY - 14	12°37'20.69"	79°23'45.15"	86.84	0.838	0.572
	Murugathanpoondi	CHY - 15	12°42'04.94"	79°28'54.94"	45.65	0.746	0.568
	Nadumbarai	CHY - 16	12°42'24.21"	79°33'35.34"	59.61	0.616	0.575
	Parasur	CHY - 17	12°38'38.17"	79°29'02.15"	68.15	0.698	0.588
Jawadh Hill	Kilayur	JHL - 18	12°27'12.75"	78°46'30.53"	62.74	0.840	0.577
	Nammiyambattu	JHL - 19	12°40'35.59"	78°59'18.00"	64.46	0.783	0.568
	Palamarthur	JHL - 20	12°33'23.55"	78°51'49.09"	59.22	0.853	0.563
	Seangadi	JHL - 21	12°34'50.91"	79°01'49.07"	81.98	0.650	0.542
	Veerappanur	JHL - 22	12°37'49.55"	78°55'06.46"	77.31	0.643	0.574
Kalasapakkam	Kidampalayam	KAL - 23	12°29'43.40"	79°00'22.51"	72.50	0.564	0.555
	Parvathimalai	KAL - 24	12°26'42.89"	79°00'10.33"	64.92	0.505	0.581
	Parvathimalai RF	KAL - 25	12°25'14.23"	78°54'55.38"	51.35	0.364	0.593
	Pillur	KAL - 26	12°25'50.55"	79°05'31.78"	69.07	0.870	0.549
Kilpenathur	Angunam	KIL - 27	12°05’58.21”	79°10’50.79"	62.06	0.860	0.594
	Panniyur	KIL - 28	12°06’56.14”	79°15’00.80"	54.97	0.709	0.569
	Sevarapundi	KIL - 29	12°18’55.10”	79°15’26.54"	77.94	0.841	0.520
	Vedanatham	KIL - 30	12°12’51.31”	79°11’39.18"	69.71	0.765	0.568
Pernamallur	Melnanthiyambadi	PER - 31	12°26'42.64"	79°23'32.77"	54.63	0.660	0.583
	Melpoondi	PER - 32	12°30'50.70"	79°21'57.89"	71.15	0.760	0.550
	Vallam	PER - 33	12°31'16.88"	79°29'05.69"	55.19	0.450	0.562

Polur	Ananthapuram	POL - 36	12°41'14.54"	79°07'25.22"	113.42	0.835	0.556
	Edaipirai	POL - 37	12°29'42.32"	79°04'11.39"	131.43	0.703	0.560
	Illupakkam	POL - 38	12°37'30.87"	79°11'58.18"	54.38	0.719	0.559
	Thurinjikuppam	POL - 39	12°36'32.79"	79°07'17.97"	54.22	0.518	0.579
Thellar	Seeyamangalam	TEL - 40	12°25'54.09"	79°28'15.03"	64.58	0.820	0.582
	Theyyar	TEL - 41	12°23'37.51"	79°35'40.43"	73.06	0.819	0.539
Thandrampet	Beemarapati	THD - 42	12°02' 27.18"	78°44'32.70"	74.38	0.850	0.556
	Kuvilam	THD - 43	12°02'46.38"	78°54'51.39"	74.27	0.792	0.547
	Malamanjanur	THD - 44	12°07' 38.58"	78°52'13.71"	70.70	0.875	0.522
	Melpasar	THD - 45	12°06' 22.15"	78°44'33.54"	49.10	0.632	0.575
	Nedungavadi	THD - 46	12°13'52.46"	78°56'50.23"	54.00	0.654	0.580
	Sathanoor	THD - 47	12°12' 22.88"	78°51'27.46"	47.19	0.649	0.572
	Vakkilapattu	THD - 48	12°07'46.85"	78°59'37.26"	64.87	0.817	0.510
Tiruvannamalai	Devanur	TIR - 49	12°02'05.48"	79°05'25.13"	69.89	0.844	0.544
	Kattompoondi	TIR - 50	12°07'16.08"	79°05'02.03"	76.11	0.662	0.542
	Melathikam	TIR - 51	12°12'25.79"	79°04'46.54"	72.85	0.582	0.525
	Virthuvilanginan	TIR - 52	12°02'23.12"	79°09'38.20"	55.84	0.338	0.613
Thurinjapuram	Karunthuvambadi	TUR - 53	12°19'49.27"	79°03'50.62"	72.35	0.622	0.544
	Mangalam	TUR - 54	12°19'48.33"	79°10'57.77"	86.31	0.715	0.574
Vandavasi	Badhur	VAN - 55	12°26'56.57"	79°41'39.92"	70.49	0.726	0.494
	Vazhur	VAN - 56	12°30'59.93"	79°40'13.52"	77.78	0.856	0.574
	Vengunam	VAN - 57	12°31'12.10"	79°36'30.36"	72.00	0.842	0.546
Vembakkam	Abdullapuram	VEM - 58	12°47'03.42"	79°40'25.24"	62.70	0.772	0.528
	Randam	VEM - 59	12°47'15.45"	79°28'13.28"	73.39	0.905	0.496
	Sodiambakkam	VEM - 60	12°43'39.32"	79°41'22.92"	146.08	0.907	0.562
	Vembakkam	VEM - 61	12°47'12.71"	79°35'27.77"	121.46	0.816	0.533
West Arani	Devikapuram	WAR - 62	12°29'43.73"	79°15'11.49"	77.46	0.846	0.558
	Ramasanikuppam	WAR - 63	12°43'13.15"	79°10'35.56"	106.14	0.890	0.584

The samples were then carefully transported to the laboratory for further analysis.

3.2 Physical Parameters (TDS, EC and pH)

For the present study three major physical parameters namely Total Dissolved Solids (TDS), Concentration of Hydrogen Ion (pH) and Electrical Conductivity (EC) were determined (Table 1). A compact probe type TDS meter was used to measure the Total dissolved solids in the samples. EC and pH were found using a multi-parameter water quality tester (Hanna HI – 9829 USA).

3.3 Chemical Parameters

A total of 9 different chemical parameters were analyzed using different methods as per the standard procedure recommended by the APHA 1999 [2]. To determine concentration of calcium and magnesium traditional titration method was used. Bicarbonate and chloride concentration was determined using acid titration and silver nitrate titration methods respectively. For sulphate analysis spectrophotometry technique was used. Sodium and Potassium were analyzed using a flame photometer. Concentration of Fluoride and Nitrate was determined using ion-chromatography.

3.4 Analytical Methods Used-Water Quality Index (WQI)

WQI is a very important water quality parameter to determine the suitability of water for drinking purposes [3,4]. This parameter gives a holistic picture of the quality of water at large. The calculation of ground water involves four major steps : - a) Assignment of weight (w_i) to each water parameter [5], b) Calculation of Relative Weight (W_i), c) Calculation of the Quality Rating Scale (q_i) and d) Computation of Water Quality Index (WQI). Equations 1, 2 and 3 are used to calculate Relative Weight, Quality Rating Scale and Water Quality Index respectively. Weight to each parameter has been assigned according to the table 2. Relative Weight (W_i) is calculated using equation – 1

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where w_i is the assigned weight of each parameter.

Quality Rating Scale (q_i) is calculated using the equation – 2

$$qi = \frac{C_i}{S_i}\, x\, 100 \quad (2)$$

Where C_i stands for the parameter's concentration and is the standard value prescribed by WHO 2011 [6].

Calculation of Water Quality Index (WQI) [7,8] is done using the equation – 3

$$WQI = \sum_{i=1}^{n} W_i \, x \, q_i \tag{3}$$

3.5 Sodium Percentage (Na %)

Sodium Percentage is essentially used to assess the quality of ground water used for irrigation. Elevated levels of sodium can cause Sodium hazard and displace the magnesium and calcium ions in the soil. This can prevent air and water from entering the soil reducing its permeability and can destroy crops easily [9]. It is calculated using equation 4 [10].

$$Na\% = \frac{(Na^{+} + K^{+}) \, x \, 100}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \tag{4}$$

3.6 Sodium Absorption Ratio (SAR)

Sodium Absorption Ratio is a parameter of great importance in assessing the fitness of ground water for irrigation. When sodium absorbs magnesium and calcium, cation exchanges take place. This parameter indicates the level of exchange that has taken place [11]. Equation 5 is used to calculate SAR.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{5}$$

3.7 Permeability Index (PI %)

Permeability Index Percentage is another such parameter used to assess the suitability of ground water for irrigation [12].

$$PI\% = \frac{(Na^{+} + \sqrt{HCO_3^{-}}) \, x \, 100}{Ca^{2+} + Mg^{2+} + Na^{+}} \tag{6}$$

4 Results and Discussion

All parameters determined in this study were analyzed statistically and the minimum, maximum, mean and standard deviation have been tabulated in table 2. The permissible limit recommended by WHO [6] corresponding to each parameter is also presented for reference in table 2. The illustrations in this paper contain histograms, Piper Digrams, Gibbs plot, Wilcox plot and spatial thematic maps. Software packages such as AquaChem 2011.1.40, IBM SPSS 26, MS Excel 2007 and Surfer 15.5.382 have been used extensively to enhance understanding at a quick glance.

4.1 Total Dissolved Solids (TDS)

TDS refers to the amount of dissolved solids present in the water samples. These dissolved solids could contain sulphates, chlorides, bicarbonates, potassium, sodium, magnesium, calcium etc., in smaller quantities [13]. In the collected samples TDS ranged from 233 to 2488 mg l^{-1} with a mean of 789.98 mg l^{-1}. The histogram in figure 2 shows the frequency distribution of TDS in the samples. A spatial map has been plotted in figure 3 showing the variation of TDS in the study area.

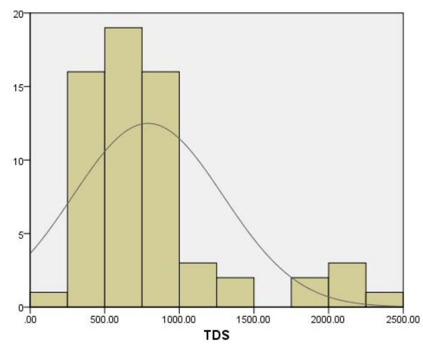

Fig. 2 : Distribution of TDS.

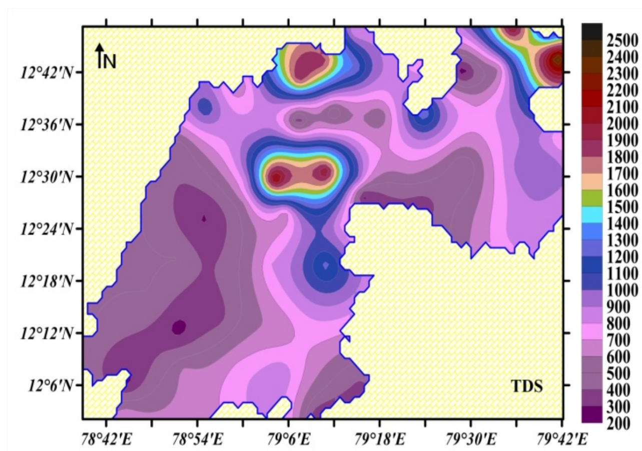

Fig. 3: Spatial variation of TDS in the samples.

4.2 Electrical Conductivity (EC)

Electrical conductivity is an indicator of ionic concentration in the sample and is the measure of salinity. The low and high values of EC in the samples are 1.28 mS cm^{-1} and 96.4 mS cm^{-1} respectively. The mean value of EC was found to be 29.67 mS cm^{-1}. The frequency variation and spatial variation of EC is shown in the histogram and spatial map in figure 4 and figure 5 respectively.

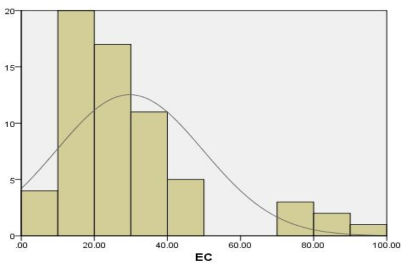

Fig. 4 : Distribution of EC.

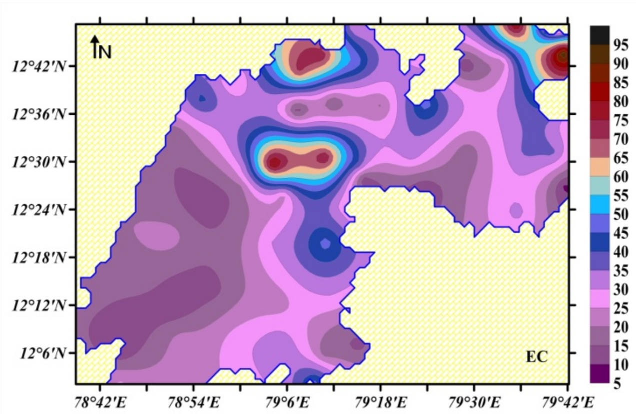

Fig. 5: Spatial variation of EC in the study area.

4.3 Concentration of Hydrogen Ion (pH)

The measure of acidity or alkalinity in the sample can be best determined by measuring the pH of the sample. The range of pH is from 6.75 to 8.67 in the samples and the mean works out to be 8.1. The frequency distribution of samples is presented as a histogram in figure 6 and spatial variation is illustrated thematically in figure 7.

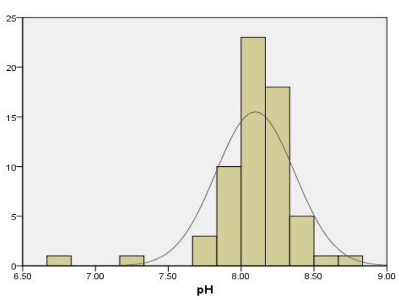

Fig. 6: Distribution of pH.

4.4 Concentration of Cations

Sodium is an important component of water and is highly essential for sound physical health. On analyzing the samples, it was found that the concentration varied from a minimum of 98.23 mgl^{-1} to a maximum of 161.9 mgl^{-1}. The mean concentration was calculated to be 122.80 mgl^{-1}.

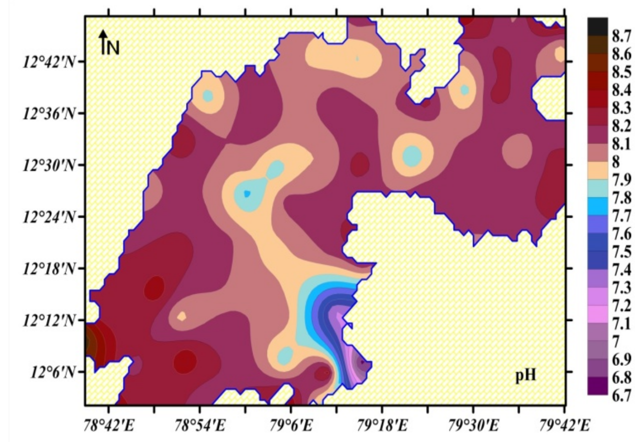

Fig. 7: Spatial variation of pH in the study area.

When its level in water exceeds the WHO permissible level [4] of 200 mgl^{-1} it can cause delirious health effects such as vomiting and hypertension [14,15]. None of the samples exceeded this limit. A histogram in figure 8 has been presented to show the frequency distribution in the samples. Calcium is essential for the physical wellbeing of human beings. The determined concentration of calcium ranged from 90.23 mgl^{-1} to 166.91 mgl^{-1} with an average of 115.81 mgl^{-1}. If the levels of calcium in water exceeded the stipulated level of 75 mgl^{-1} specified by WHO it can lead to osteoporosis, hypertension and kidney stones [6]. All the samples are found to exceed this limit. Figure 9 illustrates the frequency distribution in the samples in the form of a histogram. According to WHO 2011 [6] enzymes in the human body require magnesium for their optimal functioning. On measuring the concentration of magnesium in the samples the minimum and maximum were recorded to be 90.34 mgl^{-1} and 141.92 mgl^{-1} respectively. The mean concentration was calculated to be 111.46 mgl^{-1}. Based on WHO permissible limit of 50 mgl^{-1} all the samples exceeded this limit. A histogram is drawn to show the frequency distribution of magnesium concentration in the samples (figure 10). Potassium concentration in the samples ranged from 14.23 mgl^{-1} to 51.09 mgl^{-1} with a mean of 27.16 mgl^{-1}. The permissible concentration recommended by WHO is 200 mgl^{-1} and all the samples are found to relatively safe [6]. The concentration values were plotted in the form of a histogram in figure 11.

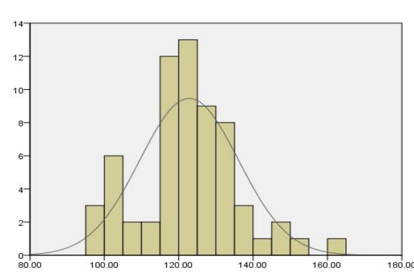

Fig. 8 : Distribution of Na.

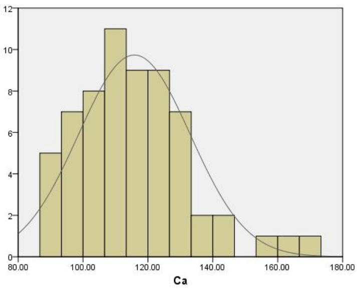

Fig. 9: Distribution of Ca.

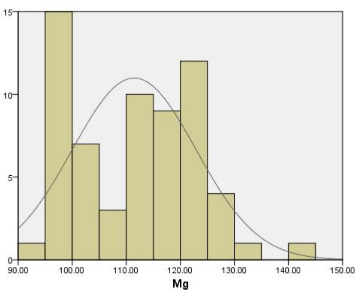

Fig. 10 : Distribution of Mg.

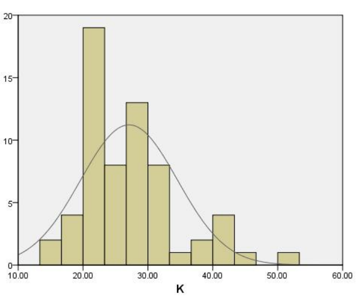

Fig. 11 : Distribution of K.

4.5 Concentration of Anions

Bicarbonates are found in water due to the presence of dissolved carbon dioxide, dissolved salts and some other cations. Higher concentration of bicarbonate in ground water could be due to the mixing of carbonic acid from the weathering of carbonate rocks beneath the earth's surface [16]. The range of bicarbonate concentration in the samples is from 38.25 to 368.45 mgl^{-1} with a mean of 122.52 mgl^{-1}. WHO's permissible limit is < 500 mgl^{-1} [4] and comparing the concentration of the samples with the aforesaid limit all the samples are safe for consumption. Figure 12 shows a histogram of distribution of bicarbonates in the samples. Chloride concentration in the samples was found to range from 166 mgl^{-1} to 487.91 mgl^{-1} with an average of 304.82 mgl^{-1}; the distribution is depicted pictorially in figure 13. According to WHO the concentration of chloride below 250 mgl^{-1} is acceptable [6]. Some samples were found to exceed this limit and may be due to rock types in the study area. In the case of ground water higher concentration of chloride could be due to rock water interaction in regions predominantly having sedimentary rocks [17]. The stipulated limit of nitrate concentration prescribed by WHO is 45 mgl^{-1} [6]. The lowest and highest concentration in the samples was 35.43 mgl^{-1} and 70.21 mgl^{-1} respectively. Mean concentration was worked out to be 51.16 mgl^{-1}. A histogram in figure 14 shows its frequency distribution. Higher concentration in some samples can be attributed to the local geology. Elevated levels of nitrate concentration in groundwater could be due to extensive of usage of nitrogen rich fertilizers in agricultural lands [18]. Sulphate's concentration in the samples ranged between 13.75 mgl^{-1} and 51.2 mgl^{-1} with a mean of 22.83 mgl^{-1}. When its concentration exceeds 250 mgl^{-1} [6] it can cause severe organ damage in the human body and sometimes corrosion of pipes [19]. Some samples were found to exceed this limit. A plot showing the frequency distribution is shown in figure 15. Fluoride in water when is found to be within the WHO [4] prescribed limit of 1.5 mgl^{-1} it can be helpful to the human body; on the contrary when its concentration is extremely low or high can cause different health problems and even dental fluorosis [20,21]. On analyzing the samples some were found to exceed this limit. The concentration in samples ranged from 0.1 mgl^{-1} to 2.26 mgl^{-1} with a mean of 0.35 mgl^{-1}. Figure 16 has been plotted to represent the frequency distribution in the samples.

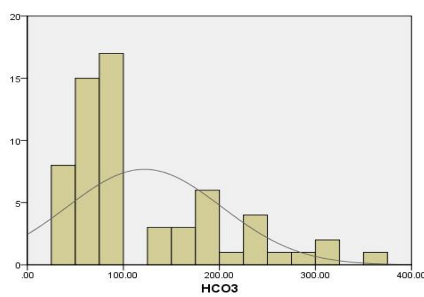

Fig. 12: Distribution of HCO3.

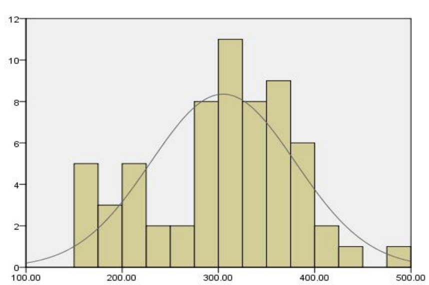

Fig. 13: Distribution of Cl.

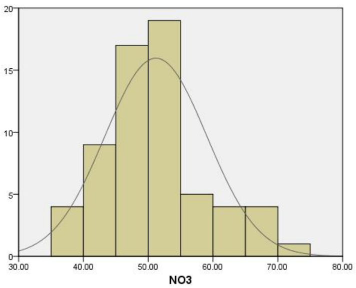

Fig. 14: Distribution of NO3.

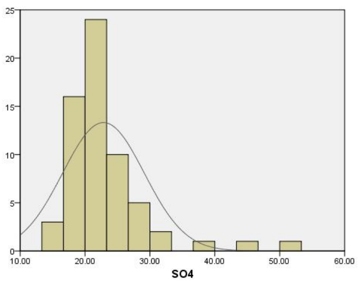

Fig. 15: Distribution of SO4.

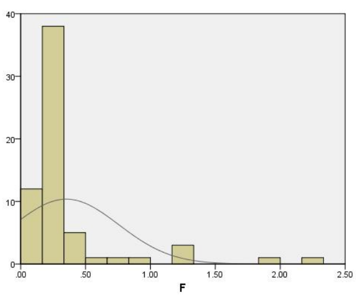

Fig. 16 : Distribution of F.

4.6 Piper Diagram

A piper diagram [22] is often used to study the hydrochemical facies of water and can elicit valuable information on the hydrogeological conditions of a region. It consists of two triangles at the base. The triangle on the left represents cations whereas the triangle on the right represents anions. The concentration of cations and anions in meq/l is plotted in its respective triangle. On the top of the Piper diagram is a diamond shaped area and each point in the triangle is projected on to it to find the point of intersection. The Piper diagram for this study (figure 17) has been plotted using AquaChem 2011.1.40 – scientific software for graphical analysis and modeling of water quality data.

Figure 18 shows the classification scheme and table 3 shows the classification as recommended by Piper. On overlaying the Piper diagram in figure 17 on classification scheme in figure 18 it is found that 70% of the samples were non-carbonates exhibiting hardness that exceeded 50%, whereas 30% of the samples were of the mixed type. In the cations triangle all the samples fell into the category of no dominant type, whereas in the anions triangle 70% of the samples fell into the category of no dominant type and the rest were of sulphate type.

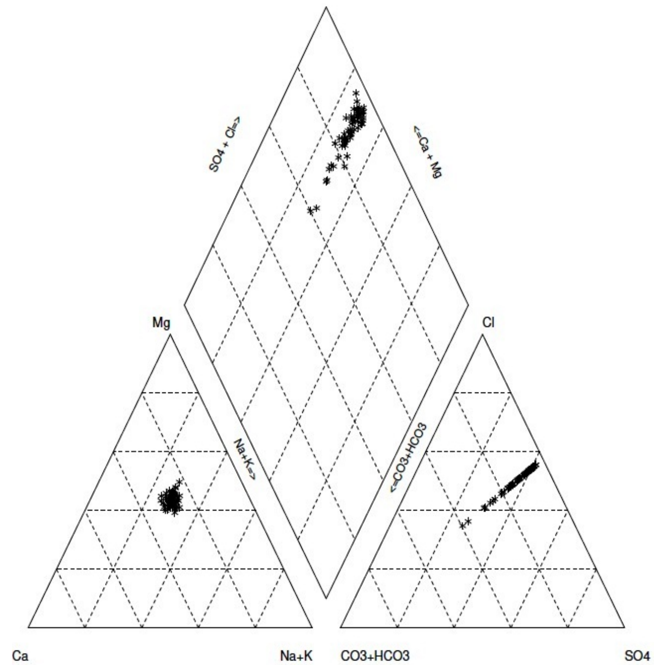

Fig. 17 : Piper Diagram showing samples.

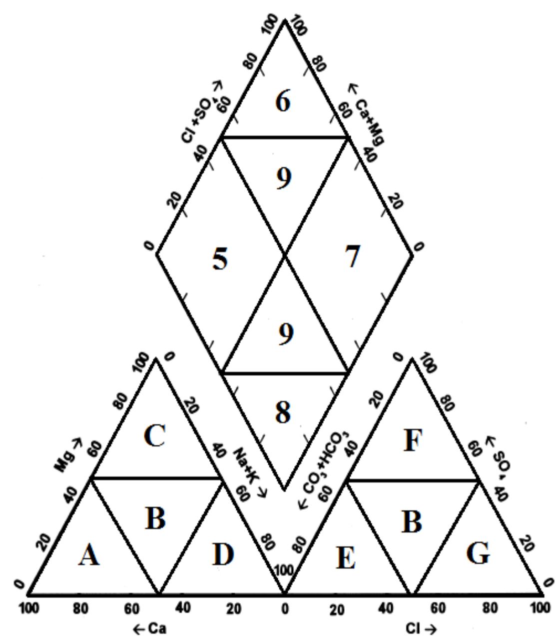

Fig. 18 : Piper's classification scheme.

Table 2 : Physico-chemical Parameters and Assignment of Relative Weights.

Parameter	Unit	Min	Max	Mean	Std Dev	WHO (2011) Permissible Value [6]	Weight	Relative Weight
Chemical Parameters								
Cl^-	mg l^{-1}	166	487.91	304.82	75.20	250	1	0.001
SO_4^{2-}	mg l^{-1}	13.75	51.2	22.83	6.29	250	3	0.002
NO_3^-	mg l^{-1}	35.43	70.21	51.16	7.93	45.00	5	0.003
F^-	mg l^{-1}	0.1	2.26	0.35	0.40	1.50	5	0.003
Na^+	mg l^{-1}	98.23	161.9	122.80	13.28	200.00	3	0.002
K^+	mg l^{-1}	14.23	51.09	27.16	7.50	200.00	1	0.001
Mg^{2+}	mg l^{-1}	90.34	141.92	111.46	11.44	50.00	2	0.001
Ca^{2+}	mg l^{-1}	90.23	166.91	115.81	17.21	75.00	2	0.001
$HCO3^-$	mg l^{-1}	38.25	368.45	122.52	80.10	500.00	3	0.002
Physical Parameters								
pH		6.75	8.67	8.1	0.27	6.5-8.5	4	0.003
TDS	mg l^{-1}	233	2488	789.98	502.81	500	5	0.003
EC	mS cm^{-1}	1.28	96.4	29.67	20.05	1500	4	0.003
							$\Sigma w_i = 38$	**$\Sigma W_i = 0.025$**

Table 3 : Piper's classification of ground water.

Classification	
1	Alkaline earths exceeding alkalies
2	Alkalies exceeding alkaline earths
3	Weak acids exceeding strong acids
4	Strong acids exceeding weak acids
5	Carbonate hardness exceeds 50%
6	Non-carbonate hardness exceeds 50 %
7	Alkalies and strong acids predominated
8	Alkaline earth and weak acids predominated
9	Mixed type
A	Calcium type
B	No dominant type
C	Magnesium type
D	Sodium and potassium type
E	Bicarbonate type
F	Sulphate type
G	Chloride type

4.7 Gibbs Plot

Gibbs plot is a commonly used to study the relationship between ground water and rock type it comes from. According to Gibbs there exist three fields namely precipitation dominance, evaporation dominance and rock-water interaction dominance [23]. There are two Gibbs' plots a) TDS versus Gibbs Ratio 1 (shown in figure 19) and b) TDS versus Gibbs Ratio 2 (shown in figure 20). Gibbs Ratio 1 and Gibbs Ratio 2 are calculated using the equations 6 and 7 respectively and have been presented in table 4 for each sample.

$$Gibbs\ Ratio\ 1\ (anions) = \frac{Cl^-}{(Cl^- + HCO_3^-)} \quad (6)$$

$$Gibbs\ Ratio\ 2\ (cations) = \frac{Na^+ + K^+}{(Na^+ + K^+ + Ca^{2+})} \quad (7)$$

As seen in figure 19 majority of the samples fell into the zone of rock dominance. Figure 20 also reveals the dependence of all ground water samples on the rocks. However a few samples displayed evaporation dominance.

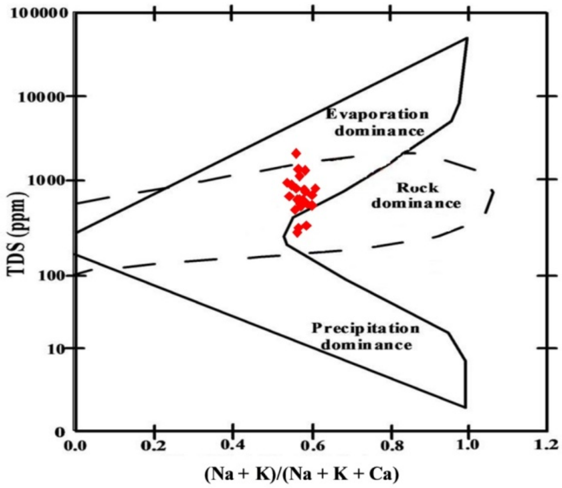

Fig. 19: Gibbs plot 1.

4.8 Water Quality Index

Water quality index has been calculated for all the samples and is presented in table 4. Each sample has been classified for quality as excellent, good, poor, very poor and unsuitable for drinking based on the range as shown in table 5 [6]. Figure 21 shows the spatial variation of WQI in the study area.

4.9 Water Quality for Irrigation Purposes-Sodium Percentage

Sodium percentage for all the samples has been calculated and presented in table 4. Table 5 shows the classification scheme used to assess its quality as excellent, good, permissible, doubtful and unsuitable. The thematic variation map in figure 22 shows the spatial change in sodium percentage. A Wilcox diagram [24] has been plotted with Na% versus EC to assess the quality of water for irrigation purposes (figure 23).

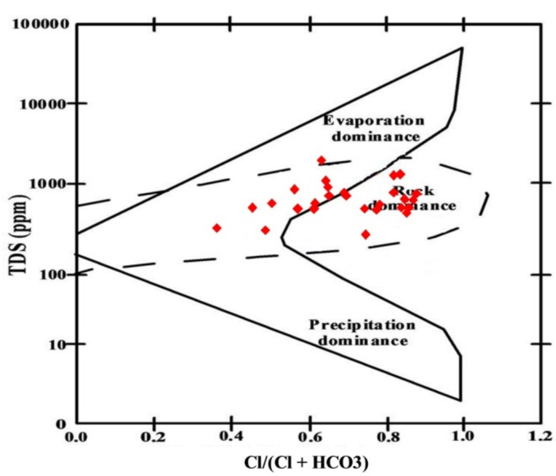

Fig. 20: Gibbs Plot 2.

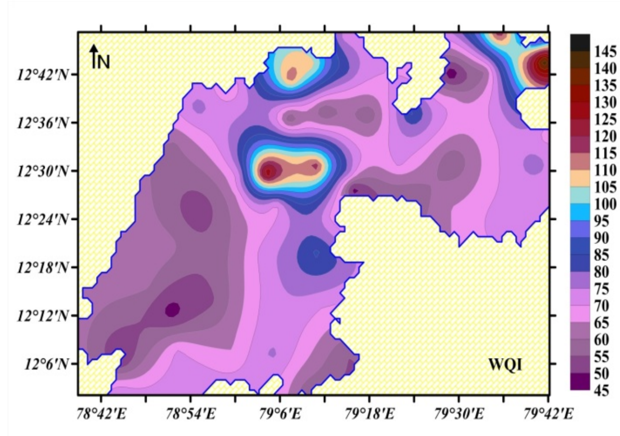

Fig.21: Spatial Variation of WQI.

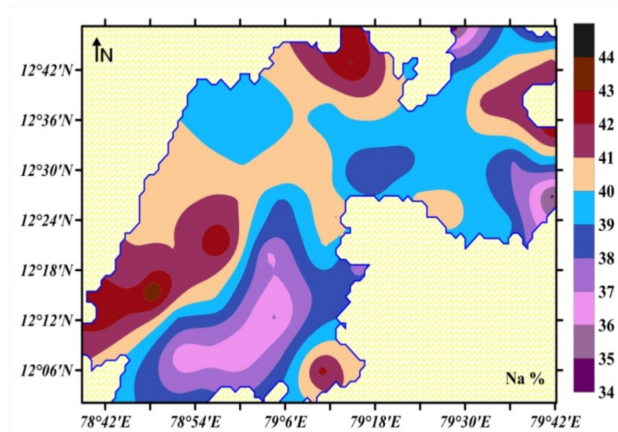

Fig. 22: Spatial variation of Na%.

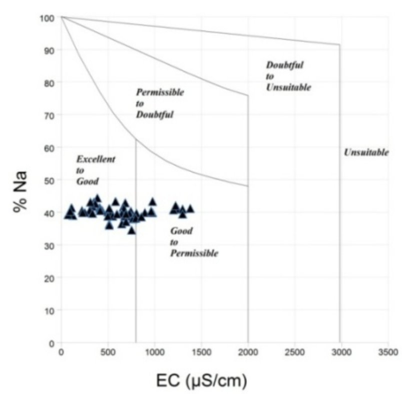

Fig. 23: Wilcox Diagram.

4.10 Sodium Absorption Ratio (SAR)

SAR for the samples is presented in table 4 and the groundwater quality for irrigation is classified according to the scheme mentioned in table 5. Samples were classified as excellent, good, fair and poor. A spatial map is presented in figure 24 showing the variation of SAR in the study area. A plot of SAR versus EC; USSL diagram [25] has been plotted in figure 25. 15% samples fell in the C1-S1 (Low salinity – Low Alkalinity) zone whereas 85% samples fell in C1-S2 (Low salinity – Medium alkalinity) zone.

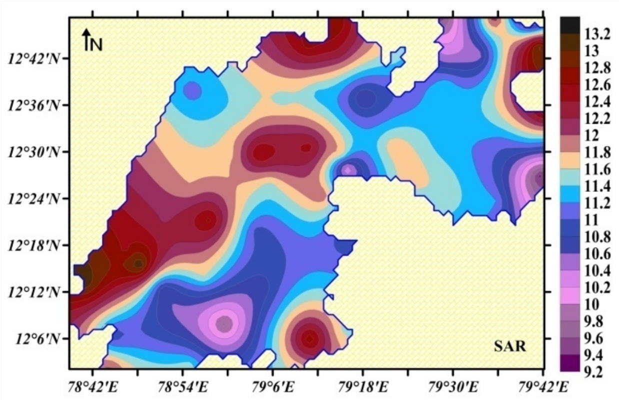

Fig. 24: Spatial variation of SAR.

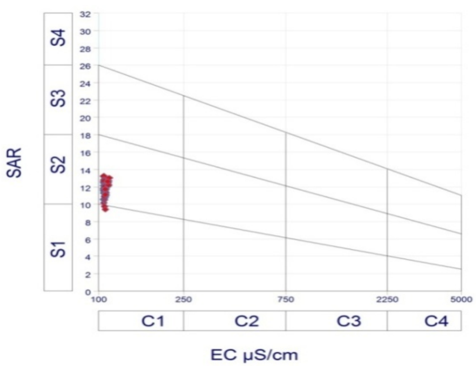

Fig. 25 : USSL diagram.

4.11 Permeability Index Percentage

Table 4 shows the PI% calculated for all the 63 samples. They have been classified as class 1, class 2 and class 3 based on the classification scheme in table 5. A spatial map is presented in figure 26 which depicts the variation of PI% in the study area.

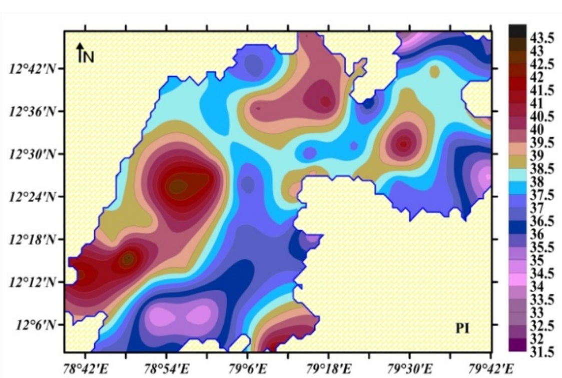

Fig.26 : Spatial variation of PI%.

Table 4: Locations with calculated Water Quality Parameters.

Location ID	WQI	Gibb 1	Gibb 2	Na %	SAR	PI %
ANK - 1	67.35	0.879	0.585	41.47	11.21	38.03
ANK - 2	66.24	0.848	0.607	43.12	12.71	39.99
ARN - 3	81.83	0.819	0.588	43.12	12.28	39.42
ARN - 4	72.44	0.821	0.614	42.73	12.76	40.11
ARN - 5	56.03	0.456	0.578	40.35	10.53	40.86
ARN - 6	68.18	0.654	0.587	39.34	11.57	39.2
CHN - 7	61.1	0.615	0.579	42.93	13.13	42.34
CHN - 8	62.17	0.777	0.576	41.7	12.43	39.96
CHN - 9	64.16	0.744	0.577	41.1	12.56	38.93
CHN - 10	60.07	0.574	0.607	44.16	13.21	43.5
CHT - 11	69.24	0.692	0.566	41.05	11.96	39.33
CHT - 12	119	0.632	0.565	40.73	12.49	38.52
CHT - 13	47.52	0.488	0.57	38.83	10.17	39.14
CHY - 14	86.84	0.838	0.572	39.7	11.03	35.74
CHY - 15	45.65	0.746	0.568	38.95	10.45	37.48
CHY - 16	59.61	0.616	0.575	39.88	10.48	38.71
CHY - 17	68.15	0.698	0.588	39.21	11.37	38.72
JHL - 18	62.74	0.84	0.577	40.34	12.15	37.81
JHL - 19	64.46	0.783	0.568	39.73	11.51	38.14
JHL - 20	59.22	0.853	0.563	40.27	11.66	38.44
JHL - 21	81.98	0.65	0.542	39.1	11.49	37.5
JHL - 22	77.31	0.643	0.574	39.58	11.1	38.07
KAL - 23	72.5	0.564	0.555	40.08	11.73	39.19
KAL - 24	64.92	0.505	0.581	40.94	11.79	42.4
KAL - 25	51.35	0.364	0.593	41.22	11.82	42.98
KAL - 26	69.07	0.87	0.549	38.55	11.51	36.52
KIL - 27	62.06	0.86	0.594	42.44	12.79	39.67
KIL - 28	54.97	0.709	0.569	40.25	11.61	39.73
KIL - 29	77.94	0.841	0.52	37.63	10.86	35
KIL - 30	69.71	0.765	0.568	38.66	11.36	37.17
PER - 31	54.63	0.66	0.583	40.17	11.71	39.06
PER - 32	71.15	0.76	0.55	38.63	11.75	37.31
PER - 33	55.19	0.45	0.562	39.43	11.21	41.49
PUD - 34	57.06	0.83	0.59	42.95	12.68	40.66
PUD - 35	61.85	0.804	0.572	40.95	12.19	38.48
POL - 36	113.42	0.835	0.556	40.45	12.04	36.63
POL - 37	131.43	0.703	0.56	40.76	12.67	37.69
POL - 38	54.38	0.719	0.559	39.72	11.32	39.82
POL - 39	54.22	0.518	0.579	40.02	11.52	40.19
TEL - 40	64.58	0.82	0.582	40.27	11.57	37.18
TEL - 41	73.06	0.819	0.539	39.4	11.23	37.34
THD - 42	74.38	0.85	0.556	39.31	12.03	36.86
THD - 43	74.27	0.792	0.547	38.56	11.47	36.39
THD - 44	70.7	0.875	0.522	36.18	10.71	34.35
THD - 45	49.1	0.632	0.575	39.54	10.83	38.96
THD - 46	54	0.654	0.58	39.73	11.6	39.03
THD - 47	47.19	0.649	0.572	39.12	10.59	38.54
THD - 48	64.87	0.817	0.51	36.32	9.7	34.53
TIR - 49	69.89	0.844	0.544	39.33	11.33	37.43
TIR - 50	76.11	0.662	0.542	37.86	11.13	37.24
TIR - 51	72.85	0.582	0.525	35.84	10.69	36
TIR - 52	55.84	0.338	0.613	40.04	11.7	41.82
TUR - 53	72.35	0.622	0.544	36.8	10.91	37.07
TUR - 54	86.31	0.715	0.574	40.03	11.27	37.47
VAN - 55	70.49	0.726	0.494	34.77	9.32	34.29
VAN - 56	77.78	0.856	0.574	39.46	11.17	36.33
VAN - 57	72	0.842	0.546	37.92	11.08	36.55

VEM - 58	62.7	0.772	0.528	37	9.8	35.95
VEM - 59	73.39	0.905	0.496	34.21	9.39	31.84
VEM - 60	146.08	0.907	0.562	40.89	13.05	35.96
VEM - 61	121.46	0.816	0.533	39.17	12.22	35.55
WAR - 62	77.46	0.846	0.558	38.27	11.73	36.81
WAR - 63	106.14	0.89	0.584	41.8	12.62	37.58

Table 5: Classification of Ground water samples based different parameters.

Parameter	Range	Classification of Quality	No of Samples
Water Quality Index (WQI)	0-25	Excellent	0
	26-50	Good	4
	51-75	Poor	44
	76-100	Very Poor	9
	>=101	Unsuitable for Drinking	6
Sodium Percentage (Na %)	0-20	Excellent	0
	21-40	Good	34
	41-60	Permissible	13
	61-80	Doubtful	0
	>=80	Unsuitable	16
Sodium Absorption Ratio (SAR)	0-10	Excellent	4
	10-18a	Good	59
	18-26	Fair	0
	>26	Poor	0
Permeability Index (PI%)	>75	Class 1	0
	25-75	Class 2	63
	<25	Class 3	0

5 Conclusions

All the 63 samples were analysed for physical and chemical parameters. These parameters were compared against their respective permissible limits recommended by WHO. The type of water was identified using Piper's plot. Gibbs diagram was used to assess the type of water based and the samples were found to have higher rock-water dependence. WQI was calculated to assess ground water quality and its spatial variation map was plotted using Surfer 15.5.382 Na%, SAR and PI% were calculated to assess the fitness of ground water for irrigation purposes. Wilcox plot and USSL plots were drawn to identify the same graphically. Thematic spatial maps have been plotted to graphically analyse the variation of each parameter in the study area. Excessive usage of fertilizers is causing anthropogenic pollution of ground water, thus the usage of NPK fertilizers could be replaced bio-fertilizers and manure.

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