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A Study on Ground Water Quality Analysis in the District of Idukki, Kerala

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ABSTRACT: This study has been done in a district of Kerala, Idukki. Here to check the quality of Ground water, data are taken from where the samples are taken from 12 dug wells of this district. The quality of Ground Water (WG) will be measured in the term of drinking and irrigation purpose along with the changeability of seasons and space. So for that, some parameters and calculations are done like PH, EC, TDS, SAR, TH, % Na, SSP, Potential Salinity, Permeability Index, Mg Hazard, Mg Ratio etc. Otherwise Wilcox and Richard's diagram has been used to know the quality of water for the irrigation purpose. Gibb's diagram has been used and it has been found that the GW chemistry of this region is controlled by the rock dominance. Water Quality Index has been also used which gives positive result for the use of this water. Piper's Trilinear diagram has also been used to know the type of the GW, on the basis of cations and anions, which shows the type of Ground Water like Carbonate hardness (Secondary alkalinity), exceeds 50% (Chemical properties are dominated by alkaline earth and weak acids), Non-carbonate hardness (Secondary salinity), exceeds 50% (Chemical properties are dominated by alkaline earth and strong acids), Mixed types (No cation-anion pairs exceeds 50%). There has been also a try to know the relation between the major ions and their chemistry. The measure and parameters are taken to measure the drinking and irrigation water criteria, all are giving positive result.

KEYWORD: Hydro-chemical faces, Water Quality Index, GW chart USGS, Chemiasoft etc.

- **INTRODUCTION:**

There is growing concern throughout India about the contamination of groundwater as a result of physical and human activities. In India, groundwater resources are being utilized for drinking, irrigation and industrial purposes. It is one of the major sources for drinking, agriculture, industry, as well as to the health of rivers, wetlands, and estuaries throughout the country. Large-scale development of ground-water resource with accompanying declines in ground-water levels and pollution has led to concerns about the future availability of ground water to meet domestic, agricultural and industrial needs[1] (Datta, 2005). So therefore, we should give more attention to groundwater to not spoil their physical as well as chemical properties and to maintain its usability for drinking, irrigation etc purposes. So, for that, we need to always keep an eye on the water quality parameters to know their status and take appropriate measures to maintain its usability in various fields.

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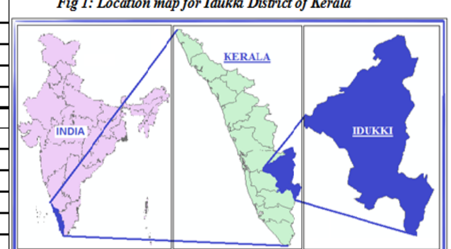
- **STUDY AREA:**

For this study, IDUKKI district of KERALA has been chosen. It lies between North latitudes 09° 16′ 30″ and 10° 21′00″ and East longitudes 76° 38′ 00″ and 77°24′30″. Idukki district is located in the south central part of Kerala and forms part of the eastern border of the State with Tamil Nadu. It is bounded by Ernakulum district in the northwest and west, Kottayam district in the west and Pathanamthitta district in the south as. The name 'Idukki' is derived from the Malayalam word "*Idukku*" indicating narrow gorge. This Idukki district is very famous for hydroelectricity project on Periyar River. Almost 80% of this district is drained by Periyar and its tributaries. More than 50% of the area is under forest cover. The net area sown constitutes about 45% of the total area. More than 80% of the cropped area is under perennial crops[2]. This industrially backward region's people main occupation is agriculture. In these districts, there are 12 dug wells has been found and from that, samples are taken. Table 1 is showing the location of dug wells from where samples have been taken in Idukki district. This has been Shown below—

Table 1: Stations of sampling to measure the water quality in Idukki

ID in Map	SAMPLE STATIONS	LATITUDE (in decimal degree)	LONGITUDE (in decimal degree)
1	*Churuli*	9.917131	76.961066
2	*Elapora*	9.635397	76.978929
3	*Idukki*	9.813808	76.929735
4	*Kaliyar*	9.985341	76.776932
5	*karikunnam*	9.836857	76.713147
6	*koilkadavu*	10.249303	77.159301
7	*munnar*	10.088933	77.059525
8	*Nedumkandun*	9.836261	77.157144
9	*peruvanthanam*	9.557817	76.935498
10	*Vaznitala*	9.887128	76.644159
11	*Marykulam*	9.697271	77.038456
12	*Anakkara*	9.66407	77.165772

Fig 1: Location map for Idukki District of Kerala



- **RESEARCH QUAESTION:**

What is the quality of the ground water in the study area? Are they suitable for drinking purpose or irrigation purpose?

[1] Datta, 2005

[2] Central Ground Water Board report on Idukki, 2013

- **OBJECTIVE:**

Here to show the quality of GW, this paper can be divided into broader 5 sections. The 1st section will describe the quality on the basis of the drinking water criteria and the later one will describe the quality on the basis of irrigation water criteria in the section 3. So, the 1st section of this paper is going to show some spatio-temporal analysis of ground water quality on the basis of some physiochemical parameters of water like hydrogen ions, EC, TH, Ca, Mg, Na, K, HCO3, CL, So4, F, and CO3 etc and compare them with drinking water standard given by WHO (2006), ISI (1995), EU (1998), or BIS (2009) etc, with some suitable techniques, methods and tools like geospatial technique and ms excel. In between two section of this paper as 2nd section, there will be some technical analysis to understand the type of GW. In later section (III), the water quality of this region will be defined on the basis of the irrigation water criteria by using various methods like TH, Salinity Hazard, SAR, % of Na, permeability index, potential salinity, RSC, RSBC, ESR, Mg Hazard, SSP etc and also try to understand this with suitable diagrams like Richard's diagram, Wilcox diagram etc. Here in 4th section also will be attempted to show correlation between the each parameter in order to know-how one parameter is affected by the other one. In the last section by the water quality index, we will try to find out the quality of the ground water of Idukki district of KERALA.

- **DATASOURCE:**

Mainly for this paper the data has been provide by Central Ground Water Board reports of 2013 and 2015.

- **MEHODOLOGY:**

Now, various methodologies will be used in this paper for some particular Objective. These are—

- **SECTION I**

Here at first, there will be a discussion on general parameters of water like PH, TDS, EC etc and then the major ion chemistry will be shown ***Electro neutrality*** (cations & anions and the ionic balance (*E*) or reaction error of ions with a method describing below) with some suitable diagrams and statistical and geostatistical techniques like Raster interpolation, kriging etc by using Arc GIS mapping and excel compare them with the drinking water criteria as provided by WHO, BIS, ISI or UN.

$$E = \frac{\sum Cation - \sum Anion}{\sum Cation + \sum Anions} \times 100$$

- **SECTION II**

PART 1: In this part, the ***Hydro-Chemical faces*** will be shown to know the water quality type on the basis of major anions and cations by ***Piper's Trilinear diagram*** by using an software called "***GW CHART calibration plots: A graphing tool for model analysis***", provided by ***US geological survey***.

PART 2: Then in the second part of this paper, will be shown the ***controlling mechanism of water chemistry by Gibb's Diagram.***

- **SECTION III**

PART 1: In the 4th part of this paper, here will try to find out the G.W of Idukki is how much suitable for agricultural irrigation. And for that various method has been adopted like below—

- *Salinity Index (found on the basis of software cum online calculator called "CHEMIASOFT"),*
- *Chlorinity index*
- $\textbf{Total hardness }(TH) = Ca \times \frac{CaCO3}{Ca} + Mg \times \frac{CaCO3}{Mg}$
- ***Sodium Absorption Rate (SAR)or sodicity Index***
- $= \frac{Na}{\sqrt{(CA+Mg)/2}}$ ***milliequivalent per liter***
- *% of Sodium* $(\%Na) = \frac{(Na+K)100}{Ca+Mg+Na+K}$
- ***Salinity Hazard by using the Richard's diagram for classification of irrigation water and for that, we need SAR and % Na as suggested by Salinity Department of USDA.)***
- *Soluble Sodium Percentage (SSP)*= $\frac{Na}{Na+Ca+Mg} \times 100$
- *Permeability Index (PI)* = $\frac{(Na+\sqrt{HCO3}}{Ca+Mg+Na+K} \times 100$
- *Potential Salinity* = *Cl – (½)*SO4*
- *Magnesium hazard*= $\frac{Mg*100}{Mg+Ca}$
- *Magnesium Ratio (MR)*= *Mg/Ca*
- *Exchangeable sodium rate (ESR)* = $\frac{Na}{Mg+Ca}$

- **SECTION IV**

Now in this part of this paper, the correlation in between the water quality parameters will be shown. That means how they are related to each other and how they are affecting to each other.

- **SECTION V**

In the last sectional part of this paper, the water quality index will be shown, and how they are spatially varying with the seasonal change. Here to find out the quality INDEX of the GW, will use by following the method which has been use earlier by various scholar like "***Prabodha Kumar Meher, Prerna Sharma, Yogendra Prakash Gautam, Ajay Kumar, Kaushala Prasad Mishra***" has used this WQI in their paper in ***"Evaluation of Water Quality of***

Ganges River Using Water Quality Index Tool". This method logy can be describe as below—

"According to its relative importance to overall water quality, each measured parameter was assigned a definite weight (Wa). Parameters having significant influence were assigned higher weight and lower weight to that of the least influencing one. Subsequently, relative weights (Wr) were calculated by using the formula

$$W_r = W_{a_i} \div \sum_{i=1}^{n} W_{ai} \quad \text{(Eq. 1)}$$

(Wr = Relative weight, Wa = assigned weight of each parameter, n = Number of parameters considered for the WQI). Further, quality rating scale (Q) has been calculated for the each parameter by dividing its respective standard values as suggested in the BIS guidelines.

$$Q_i = [C_i \div S_i] \times 100 \quad \text{(Eq. 2)}$$

However, to calculate Q for the DO and pH, different methods were employed. The ideal values (Vi) Of pH (7.0) and DO (14.6) were deducted from the measured values in the samples (Hameed et al., 2010).

$$Q_{i\,pH,DO} = [(C_i - V_i) \div (S_i - V_i)] \times 100 \quad \text{(Eq. 3)}$$

(Qi = Quality rating scale, Ci = measured concentration of each parameter, Si = Drinking water standard values for the each parameter according to BIS). Next, sub indices (SI) have been calculated to compute the WQI.

$$SI_i = W_r \times Q_i$$
$$WQI = \sum SI_i \quad \text{(Eq. 4)}$$

& (Eq. 5)

Finally, the obtained WQI values were categorized as proposed. (Table 6, Yadav et al., 2010)"

RESULT AND DISCUSSION:
<u>Section I</u>

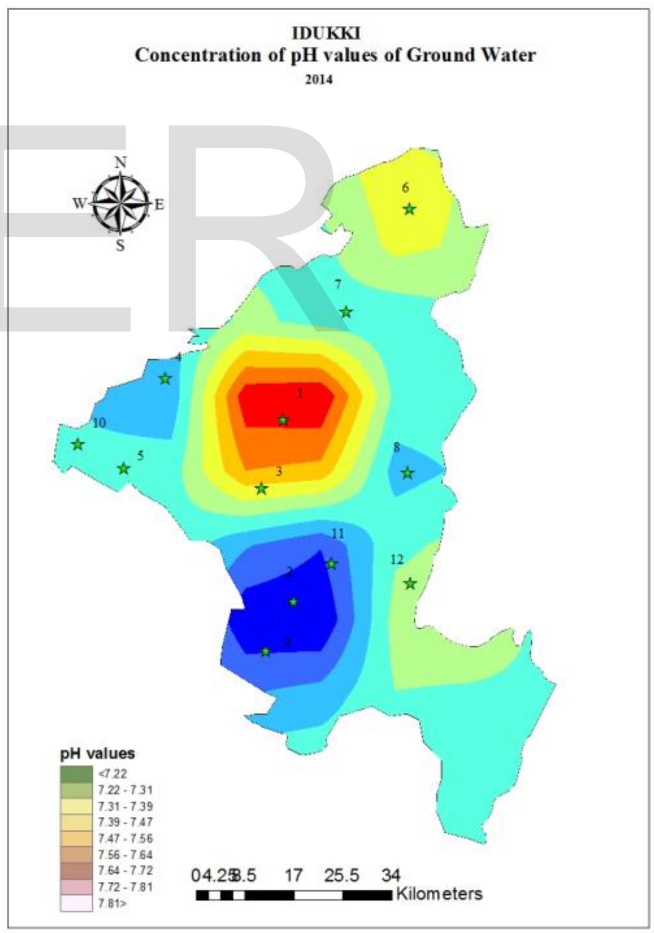
❖ **PHYSICAL PARAMETERS**

There are some non-ionic parameters (pH, EC, TDS,) and the major ions like Ca^{2+}, Mg^{2+}, Na^{+} and K+, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^- etc in the 12 station samples are presented in Tables 2 and 3 respectively.

pH:

This pH is means the activity of hydrogen ion located in the water and also an indication of chemical equilibrium. This pH value is determined by the carbon-di-oxide, carbonate and bicarbonate system of the water. This give rise to pH values to different level according to their solubility with changing temperature and pressure. We can see in table 2, the minimum amount of pH is 6.9 found in elapora and peruvanthanam region and maximum is 8.4 (apr) in churuli region and 7.89 (nov) in koilkadavu. The pH acceptable limit is 6.5-8.5 (according to BIS, 2009). So we can say pH amount of 12 stations are good. Different level of concentration of pH has been seen in different dug well's water. This concentration variation is shown in the fig 2.

Fig 2: pH distribution across different dug wells



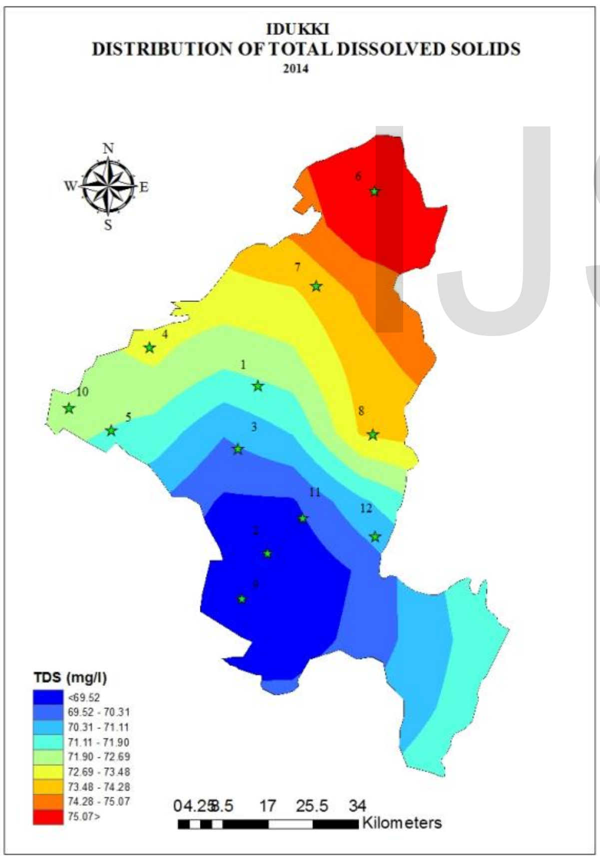
TDS (Total Dissolved Solids):

Dissolved solids means any kind of minerals, salts, metals, cations or anions dissolved in water. So TDS means the total amount of inorganic salts (Ca, Mg, K, Na, HCO_3, CO_3, SO_4 etc) and some amount of organic matter dissolved in water. This TDS is used only to know the amount of dissolved solids in the water but cannot say about the relation between the dissolved solids. So this indicator is used to know the general water quality. Groundwater has been classified according to its TDS content as follows (after Hem, 1970):

Fresh	<1000 ppm
Moderately saline	3000 to 10000 ppm
Very saline	10,000 to 35,000 ppm
Briny	>35,000 ppm

In the Idukki, as the table 2 shows, the TDS range is falling in the range of 24 mg/l to 391 mg/l. The spatial variation of TDS across stations has created a pattern in the district of Idukki; this has been shown in fig 3→

Fig3: distribution of TDS:



Electrical Conductance (EC):

The conductivity of water is affected by the suspended impurities and also depends upon the amount of ions in the water.[3] It is defined at a standard temperature 25° C. The amount of EC % can increase upto 2 or 3 % with increase in temperature of 1° C.[4] the acceptable limit of the EC in water as proposed by BIS 2009 is 750. The EC value of this sample stations is lying between the range of 47 to 340 μS/cm at 25°C with the mean value of 126.5 in November and 140.7 μS/cm in April.

❖ MAJOR ION CHEMESTRY

Concentration of major ions (Ca^{2+}, Mg^{2+}, Na^+ and K^+, $HCO3^-$, Cl^-, $SO4^{2-}$, NO^{3-}) are also generally low (Table 3). Some analysis of this major ion concentration has been done and it is like—

Electro neutrality (ionic balance):
To verify the analytical error of analyzed ion concentration, some scholars like ***Adomako, Bam, Nartey, Akiti, Kaka*** computed electro neutrality (ionic balance) by following equation:

$$E = \frac{\sum Cation - \sum Anion}{\sum Cation + \sum Anions} \times \mathbf{100}$$

Where the sum of major cations and anions are expressed in meq/L and E is the error percent/reaction error/ cationic and anionic balance. The ionic balances for the analyses vary from -0.89% IN Peruvanthanam and 0.19% in Anakkara. ***The reaction error of all groundwater samples was less than the accepted limit of ±10% (Hem, 1975)*** and an added proof of the precision of the data.[5] As we can see, in the table 3, the mean E value is -0.55% in April and -0.50% in November, with the standard deviation of -0.73 and -0.61% in the district of IDUKKI.

Calcium (Ca):
Ca is relatively dominant cations with the range between 3.2mg/l in vazhithala to 29mg/l in nedumkandun. The feldspars, pyroxenes and amphiboles and less common minerals such as apatite and wollastonite present in igneous and metamorphic rocks are the common sources of calcium. As BIS 2009 has fixed its acceptable limit and it should be below 75mg/l, which is obeyed by all sample stations of Idukki.

Magnesium (Mg):
Mg in GW is mainly found due to ferromagnesian minerals like Olivine, Pyroxene, Amphibolites and dark coloured mica among igneous rock. The acceptable limit of Mg in water is 30mg/l (BIS, 2009). In the table 3, we can see the value of Mg lie between 0.97 and 7.3mg/l. The reaction involving solution of magnesium is controlled by the amount of CO2 in groundwater in dissolved state.[6]

Sodium (Na) and Potassium (K):

The concentration of Na in normal water should lie be 200ppm and K 10ppm (BIS, 2009). In the study area the range of maximum and minimum concentration is 4.75ppm and 27ppm. The K concentration ranges from 0.7ppm at vazhithla to 17 ppm at anakkara.

[3] **Dhirendra Mohan Joshi, Alok Kumar, and Namita Agrawal.**
[4] ***USGS***

[5] ***Adomako, Bam, Nartey, Akiti, Kaka, Elixir Agriculture 39 (2011) 4793-4807***
[6] **S. K. Nag, "Quality of ground water in parts of arsa block, purulia district, west bengal.**

Stations	pH		EC in µS/cm at 25°C		TDS (mg/l)	
2014	**Apr**	**Nov**	**Apr**	**Nov**	**Apr**	**Nov**
Churuli	8.44	7.64	105	74	53	37
Elapora	6.97	7.52	176	149	90	76
Idukki	7.63	7.21	64	58	32	29
Kaliyar	7.23	7	198	210	101	107
Karikunnam	7.42	7.19	251	66	128	33
Koilkadavu	7.77	7.89	246	270	126	138
Munnar	7.33	7.29	80	97	40	49
Nedumkandun	7.3	7.75	298	340	153	175
Peruvanthanam	7.03	6.99	59	48	30	24
Vazhithala	7.39	7.33	56	59	28	30
Marykulam	7.16	7.42	64	47	32	24
Anakkara	7.63	7.74	91	100	46	51
mean value	***7.4***	***7.4***	***140.7***	***126.5***	***95***	***79***
Sd	***0.4***	***0.3***	***88.2***	***96.9***	***89***	***78***
min	***6.97***	***6.99***	***56***	***47***	***28***	***24***
max	***8.44***	***7.89***	***298***	***340***	***391***	***306***
median	***7.36***	***7.375***	***98***	***85.5***	***56***	***44***

Bicarbonate and Carbonate (HCO^3 & CO^3):

These are the basically primary anions in GW. These are formed by CO_2 which is released by organic decomposition of soil. These may also come from acid rain, atmospheric CO_2 or solution of carbonate rocks. These ions show the alkaline character of GW. The highest amount of HCO_3 is found in Munnar that is 68 and lowest recorded as 0 at koilkadavu. HCO_3 is the dominant anion among other anions with the mean concentration of 29.2 in April and 31.1 in November. In the case of carbonate, its concentration is very low. In every dug wells, the CO_3 is 0, except churuli (4.8mg/l in April).

Sulphate (SO_4): The concentration of sulphate may be the result of oxidation of sulphide materials. The natural water sulphate concentration acceptable limit is 200ppm (BIS, 2009). Here in the table 3, the SO4 concentration is very low with the mean value of 3.9 ppm with the standard deviation of 4.

Chloride (Cl): This content of GW can be derived from soluble chloride present in rocks, saline intrusion, connate and juvenile water or human made contamination e.g. industrial, domestic etc. The acceptance limit for Cl is 250 mg/l for BIS, 2009. In the study area, every dug well have a well mix of Cl ions in GW, as table 3 says.

Fluoride (F):

The fluoride acceptance limit is 1mg/l as per BIS. In the study area all stations have below 1 mg/l concentration in GW.

Nitrate (NO3):

Except koilkadavu's concentration of nitrate (173mg/l), NO_3 concentration is very low that the mean value become 22.1 with the SD of 48.4 mg/l. "The low NO_3^- in groundwater could mean that there is little or no pollution of the resource or the geology of the area does not contain the anion. Fertilizer and sewage is possible sources nitrate in groundwater"[7].

So after discussing the physical and chemical properties of ground water of Idukki district, table no. 2 is showing the mean, SD, median, maximum and minimum concentration of non ionic parameters across all the 12 dug well station. This table is like below—

Table 2: Non-Ionic parameters determined in ground water samples

Now the major ionic concentration of various stations had been shown in the table 3, with the SD, median, maximum and minimum concentration of non ionic parameters across all the 12 dug well station. This table is like→

Table 3: Concentration of major ions in mg/L determined in the groundwater samples

Stations	Ca		Mg		Na		K		CO3		HCO3		SO4		CL		F		NO3		E	
2014	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	APR	NOV
Churuli	10	5.6	2.9	1.9	5	5	1.2	1.2	4.8	0	37	54	2.4	0.46	5.7	5.7	0.16	0.46	2.8	14	-0.43	-0.69
Elapora	11	12	2.4	1.9	1.9	8.9	3.6	4.7	0	0	46	39	2	1	7.1	4.3	0.13	0.52	0	0.77	-0.49	-0.24
Idukki	4.8	3.2	0.49	0.97	4.7	5.9	12	0.9	0	0	20	37	4.4	4.4	24	18	0.11	0.45	22	10	-0.52	-0.73
Kaliyar	11	12	3.9	4.4	12	13	5.4	6.6	0	0	22	20	2	1	7.1	7.1	0.18	0.44	0.84	3.2	0.01	0.07
Karikunnam	17	14	3.9	0.92	11	4.5	7.1	4.1	0	0	22	12	11	3	26	30	0.15	0.48	27	12	-0.38	-0.42
Koilkadavu	17	18	5.8	7.3	13	19	4.6	5.7	0	0	0	0	1.2	0.37	107	89	0.18	0.78	173	133	-0.75	-0.63
Munnar	5.6	6.4	0.97	0.97	4.8	6.7	3	2.7	0	0	68	66	13	11	26	27	0.33	0.74	11	31	-0.78	-0.78
Nedumkandun	22	29	3.9	4.4	18	27	3.1	3.6	0	0	15	20	1.3	1.5	8.5	11	0.25	0.48	16	12	0.07	0.18
Peruvanthanam	3.2	3.2	1.5	0.97	3.7	3.3	1	0.9	0	0	61	76	4.7	3.8	58	65	0.2	0.43	1.7	1.2	-0.86	-0.89
Vazhithala	4	4.8	0.97	0.49	3.2	4.1	0.7	0.9	0	0	27	12	1.9	0	9.9	11	0.39	0.46	11	9	-0.70	-0.51
Marykulam	3.2	3.2	2.4	0.97	3.5	3.8	2.5	0.9	0	0	15	20	2.1	0.1	7.1	7.1	0.19	0.46	0.06	0.58	-0.35	-0.52
Anakkara	10	14	0.97	0.97	2.7	3.1	1.6	17	0	0	17	17	1	0	8.5	7.1	0.14	0.38	0.14	0	-0.27	0.19
mean value	**9.9**	**10.5**	**2.5**	**2.2**	**7.0**	**8.7**	**3.8**	**4.1**	**0.4**	**0.0**	**29.2**	**31.1**	**3.9**	**2.2**	**24.6**	**23.5**	**0.2**	**0.5**	**22.1**	**18.9**	-0.55	-0.50
sd	**6.2**	**7.7**	**1.6**	**2.1**	**5.2**	**7.4**	**3.2**	**4.5**	**1.4**	**0.0**	**20.1**	**23.6**	**4.0**	**3.2**	**30.0**	**26.8**	**0.1**	**0.1**	**48.4**	**37.0**	-0.73	-0.61
min	**3.2**	**3.2**	**0.49**	**0.49**	**1.9**	**3.1**	**0.7**	**0.9**	**0**	**0**	**0**	**0**	**1**	**0**	**5.7**	**4.3**	**0.11**	**0.38**	**0**	**0**	-0.03	0.28
max	**22**	**29**	**5.8**	**7.3**	**18**	**27**	**12**	**17**	**4.8**	**0**	**68**	**76**	**13**	**11**	**107**	**89**	**0.39**	**0.78**	**173**	**133**	-0.72	-0.59
median	**10**	**9.2**	**2.4**	**0.97**	**4.75**	**5.45**	**3.05**	**3.15**	**0**	**0**	**22**	**20**	**2.05**	**1**	**9.2**	**11**	**0.18**	**0.46**	**6.9**	**9.5**	-0.33	-0.38

Section II

- **Part I: HYDRO-CHEMICAL FACIES:**

To know the hydro-geochemical regime of the study area, the analytical values obtained from the groundwater samples are plotted on Piper (1994) tri-linear diagram**.** This diagram obtains two triangles; left triangle is for cations and right is for anions. One diamond shaped structure will lie between two triangles, where the combined point of anions and cations will be plotted, from which inference is drawn on the basis of hydro-geochemical facies concept. This diagram's various portion indicates distinct zones of cations and anions concentration, which help us to understand and identity of the water composition in different classes. To define composition class, Back and Hanshaw (1965) suggested subdivisions of the Trilinear diagram (Figure 5) to define composition class, based on which the interpretation of distinct facies from the 0 to 10% and 90% to 100% domains on the diamond-shaped cations to anions graph is more helpful than

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[7] ***Adomako, Bam, Nartey, Akiti, Kaka, Elixir Agriculture 39 (2011) 4793-4807***

using equal 25% increments. Here the figure 4 is showing only the general structure of piper's trilinear diagram. The actual plotting of the cations and anions are given below in fig. 5 &6.

Figure 4: Classification diagram for anion and cation facies in the form of major-ion percentages.

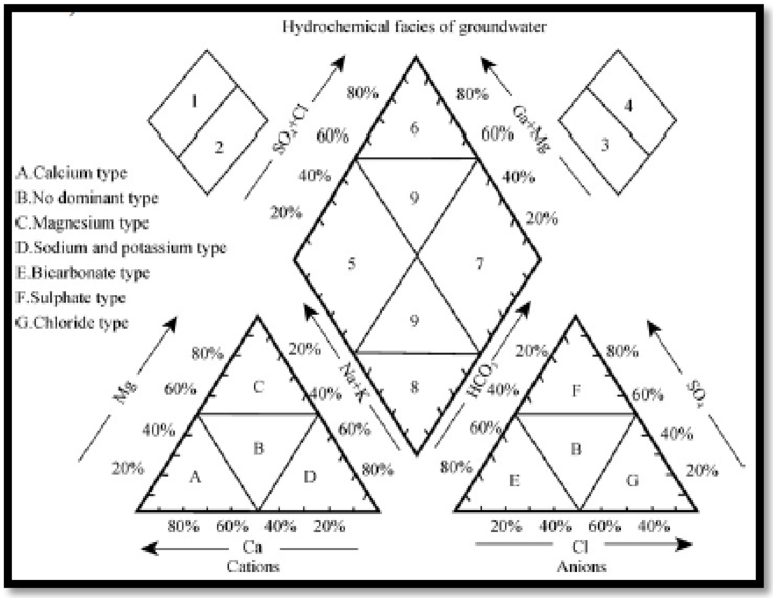


Figure 5: Piper diagram showing groundwater samples from Idukki in NOVEMBER of 2014

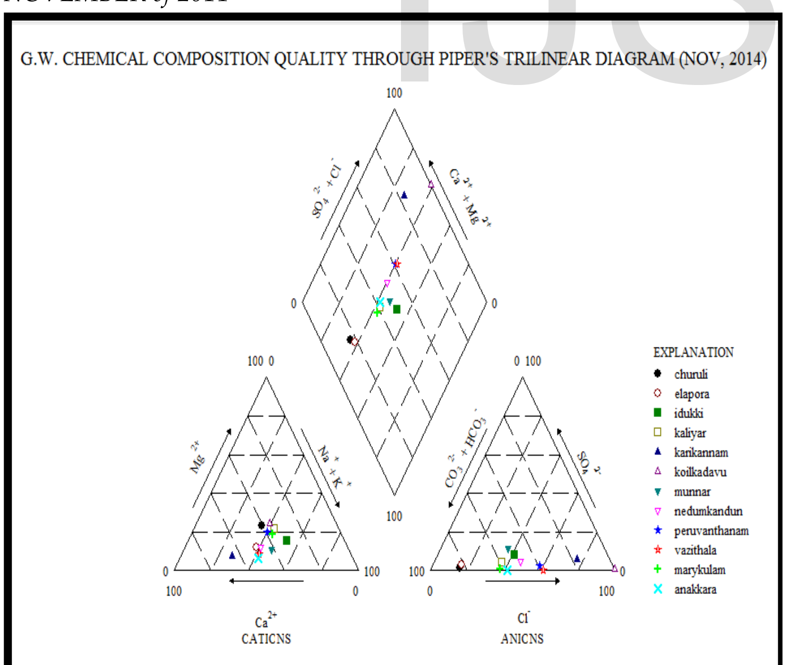
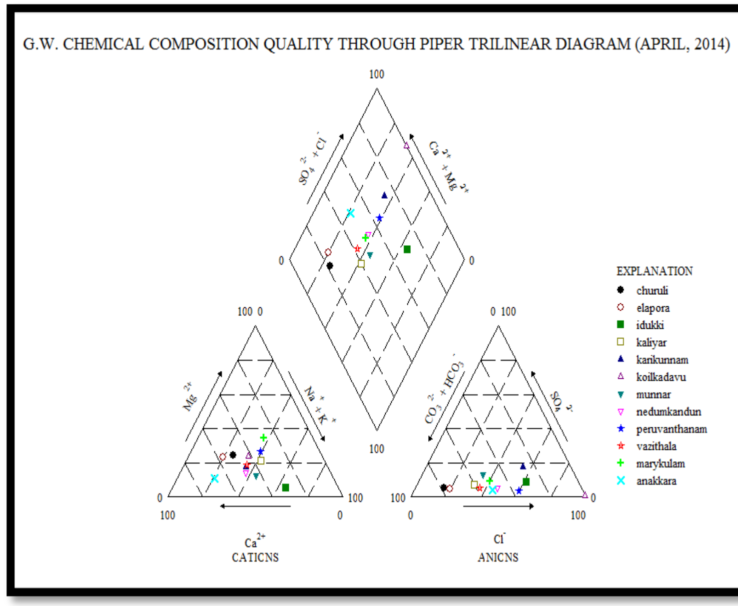


Figure 6: Piper diagram showing groundwater samples from Idukki in APRIL of 2014



The Piper tri-linear graphical representation of chemical data of representative samples from the study area reveal the analogies, dissimilarities and different types of waters in the study area, which are identified and listed in Table 4. This clearly explains the variations or domination of cation and anion concentrations during the season.

In the given figure 6, as we can see, in the month of November, the anions are mostly dominated by HCO^{3-} and CLO^{-} type of GW, but the cations are not derived by any kind of dominant kind of water (mixed) except karikannum, where some amount of Ca^{+} dominant type of GW can be seen and for that reason, the concentration of Ca^{+} is quiet high between other regions of Idukki. In the month of April (figure5), the scene has quietly changed. For anions, very low amount of change can be observed to mixed type water, and for cations Karikannum has shifted to mixed type from Ca^{+} type water and anakkara, elapora has come to Ca^{+} type of water from mixed type.

In the given table no 4, we will see how sample stations are changing its category in different season. In this case H_2O through rainfall plays important role for this variation of chemical properties of GW.

Table 4: Characterization of GW of Idukki district on the basis of Piper-Trilinear diagram

Subdivision of the diamond	**Characteristics of corresponding subdivision of diamond shaped fields**	**Sample stations Id which are falling into particular category**	
		APRIL, 2014	**NOVEMBER, 2014**
1	Alkali earth $(Ca^{2+}+Mg^{2+})$ exceeds alkalis $(Na^{+}+K^{+})$		
2	Alkalis $(Na^{+}+K^{+})$ exceeds alkaline earth $(Ca^{2+}+Mg^{2+})$		
3	Weak acids $(CO_3^{-}+HCO_3^{-})$ exceeds strong acids $(SO_4^{2-}+Cl^{-})$		
4	Strong acids $(SO_4^{2-}+Cl^{-})$ exceeds weak acids $(CO_3^{-}+HCO_3^{-})$		
5	Carbonate hardness (Secondary alkalinity) exceeds 50% (Chemical properties are dominated by alkaline earth and weak acids)	***1,2,4,7,10***	***1,2,4,11,12***
6	Non-carbonate hardness (Secondary salinity) exceeds 50% (Chemical properties are dominated by alkaline earth and strong acids)	***6***	***5,6,***
7	Carbonate alkalinity (Primary salinity) exceeds 50% (Chemical properties are dominated by alkaline earth and weak acids)	***3***	***3***
8	Carbonate a alkalinity (Primary alkalinity) exceeds 50% (Chemical properties are dominated by alkalis and weak acids)		
9	Mixed types (No cation-anion pairs exceeds 50%)	***5,8,9,11,12***	***7,8,9,10,***

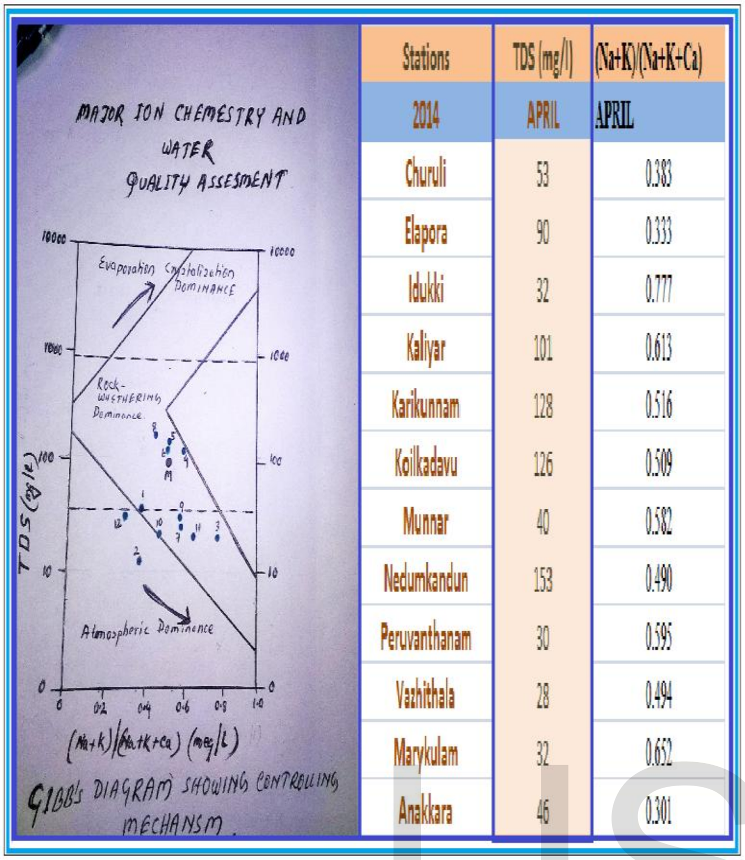
❖ Part 2: MECHANISMS CONTROLLING GROUND WATER CHEMESTRY

Gibbs in 1970 has suggested a diagram by which we could know the GW chemistry and relationship of the chemical composition of the water from their respective aquifers such as chemistry of the rock types, chemistry of precipitated water and rate of evaporation. In this diagram dominant cations are plotted against the values of TDS. Gibbs diagrams, representing the ratio for cations [(Na +K) / (Na + K + Ca)] as a function of TDS is widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation-dominance, rock-dominance and evaporation dominance.[8]

The data has been plotted in the Gibbs diagram and then our samples suggested that the chemical weathering of rock-forming minerals influences the groundwater quality by means of dissolution of rocks through which water is circulating in all water sample station except Anakkara region and Elapora region. This two region is dominated by atmospheric condition like precipitation. It will be clear by the given diagram as proposed by Gibbs—

[8] ***Adomako, Bam, Nartey, Akiti, Kaka,***

Fig.7: Gibbs diagram showing controlling and [(Na +K) / (Na + K + Ca)] values mechanism



Stations	TDS (mg/l)	(Na+K)/(Na+K+Ca)
2014	APRIL	APRIL
Churuli	53	0.383
Elapora	90	0.333
Idukki	32	0.777
Kaliyar	101	0.613
Karikunnam	128	0.516
Koilkadavu	126	0.509
Munnar	40	0.582
Nedumkandun	153	0.490
Peruvanthanam	30	0.595
Vazhithala	28	0.494
Marykulam	32	0.652
Anakkara	46	0.301

Section III

- **SUITIBILITY OF GROUNDWATER FOR IRRIGATION:**

For irrigation purpose water quality is very important. High amount of dissolved ions can affect the physical and chemical properties of plant and soil. The chemical disrupts plant metabolism. Water quality problems in irrigation include indices for salinity, Chlorinity, sodicity and alkalinity.[9]

There are so many indicators to understand the suitability of GW for irrigation purpose. These are like salinity index or hazard as computed with the measured value of EC, Sodicity index or sodium absorption rate, % of Sodium, Soluble sodium percentage, RSBC, RSC, permeability index, Potential salinity (PS), Mg hazard, Exchangeable sodium ratio. These are calculated with some suitable methods which are given in the table 6. So now there interpretation is shown below—

Salinity Index:

By using Chemiasoft, salinity has found and this salinity will be verified on the basis of the classification of Handa, 1969. Like below—

Table 6: Classification of waters based on of EC (Handa, 1969)

EC/µS/cm	Water salinity	Range (No. of sample)	Sample id for location
00-250	Low (Excellent quality)	56-246 (10)	1,2,3,4,6,7,9,10,11,12
251-750	Medium (Good quality)	251-296 (2)	5,8
750-2250	High (Permissible quality)	-	-
2251-6000	Very high	-	-
6001-10000	Extensively high	-	-
10001-20000	Brines weakly conc	-	-
20001-50000	Brines moderately conc.	-	-
50001-100000	Brines highly conc.	-	-
>100000	Brines extremely highly conc.	-	-

So after the above table, on the basis of EC, Handa has classified the salinity of water for its verification. Salinity index of ground water has been calculated on Chemiasoft on the basis of water EC and temperature at 25 deg. C. So after calculation and verification, we can see that the range of the salinity index of the study area is containing good to excellent quality of Ground water for the irrigation purpose.

Total hardness (TH)

In determining the suitability of groundwater for domestic and industrial purposes, hardness is an important criterion as it is involved in making the water hard. Water hardness has no known adverse effects; however, it causes more consumption of detergents at the time of cleaning and some evidence indicates its role in heart disease[10]. The Total Hardness (TH) (Todd, 1980; Hem, 1985; Ragunath, 1987) was determined by the following equation:

$$TH = 2.497\ Ca^{2+} + 4.115\ Mg^{2+}$$

[Where Ca^{2+} and Mg^{2+} concentrations are expressed in meq/L]

In the table 7, Sawyer and McCarty's classification on groundwater based on TH will show the GW water quality for irrigation.

[9] Mills, 2751-2250003

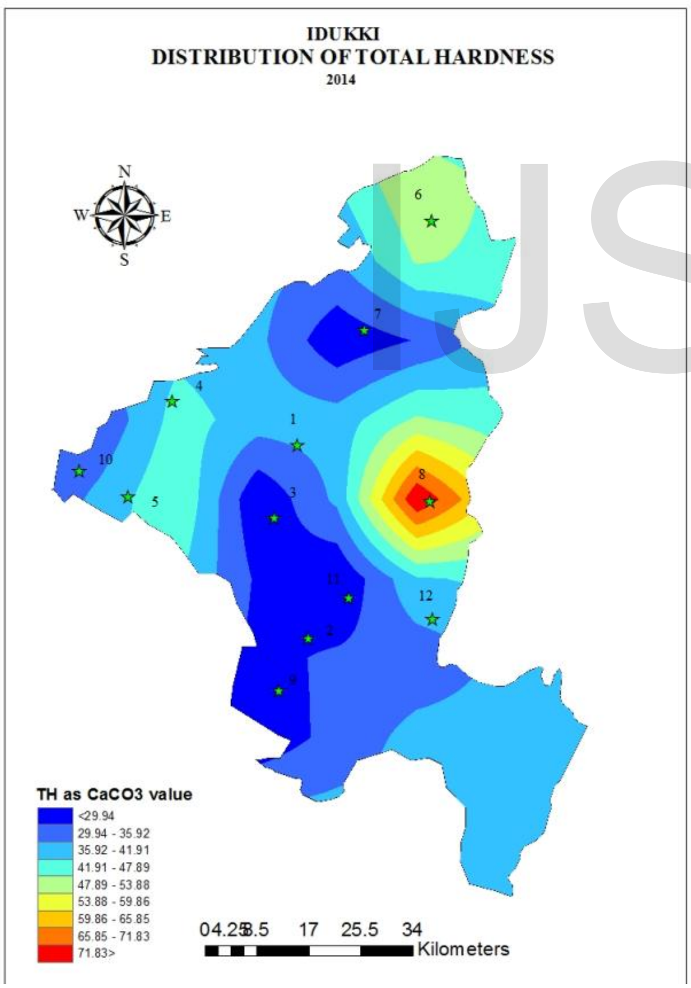
[10] Schroeder, 1960

Table 7: Sawyer and McCarty's classification for groundwater based on hardness

TH as CaCO3 (mg/L)	Water class	Range (No. of samples)	Sample id for location
<75	soft	14-66 (11)	1,2,3,4,5,6,7,9,10,11,12
75-150	Moderately hard	90	8
150-300	Hard	-	-
>300	Very hard	-	-

This classification shows, all samples are fall under soft class except 8[th] station (Nidumkandun), which is falling in the category of moderately hard water. The spatial variation across 12 dug wells in the term of TH can be shown like below by the figure 8→

Figure 8: distribution of Total hardness of GW.



Sodium Absorption Ratio (SAR) or sodicity index:

The salinity laboratory of US department of Agriculture recommends the sodium absorption ratio (SAR) because of its direct relation to the absorption of sodium by soil. This SAR is a relative proportion of Na ions to Mg & Ca in a water sample. It is defined by—

$$SAR = \frac{Na}{\sqrt{(CA+Mg)/2}} \text{ milliequivalent per liter}$$

Generally the high Na deposition may deteriorate the soil characteristic. The excessive sodium content may reduce the soil permeability for which supply of needed water for crops will inhibit. The classification of groundwater samples from the study area with respect to SAR (Todd, 1959) is presented in Table 8. In this table, we can see that all samples are falling in the category of excellent for irrigation purpose.

Table 8: Classification of waters based on SAR values (Todd, 1959; Richards, 1954) and sodium

<u>Hazard classes based on USSL classification</u>

SAR Value	Sodium hazard class	Remark on quality	Range (No. of samples)	Sample id for location
<10	S1	excellent	0.65-7.07 (12)	1,2,34,5,6,7,8,9,10,11, 12
10-18	S2	Good	-	-
19-26	S3	Doubtful/fairy poor	-	-
>26	S4&S5	Unsuitable	-	-

In this table, we can see that all samples are falling in the category of excellent for irrigation purpose.

Salinity hazard:

For the purpose of diagnosis and classification, the total concentrations of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance. Classification of groundwater based on salinity hazard (viz., electrical conductivity) is presented in Table 9.

Table 9: Salinity hazard classes (Adomako, Bam, Nartey, Akiti and Kaka)

EC (µS/cm)	Salinity hazard class	Remark on quality	Range (id No. of samples)
<250	C1	Excellent	56-246 (1,2,3,4,6,7,9,1,0,11,12)
250-750	C2	Good	251-298 (5,8)
750-2250	C3	Doubtful	-
>2250	C4&C5	Unsuitable	-

Except nedumkandun and karikannam is good, all samples are falling in the category of excellent characteristic for irrigation. A more detailed analysis of the suitability of water for irrigation can be made by plotting sodium-absorption ratio and electrical

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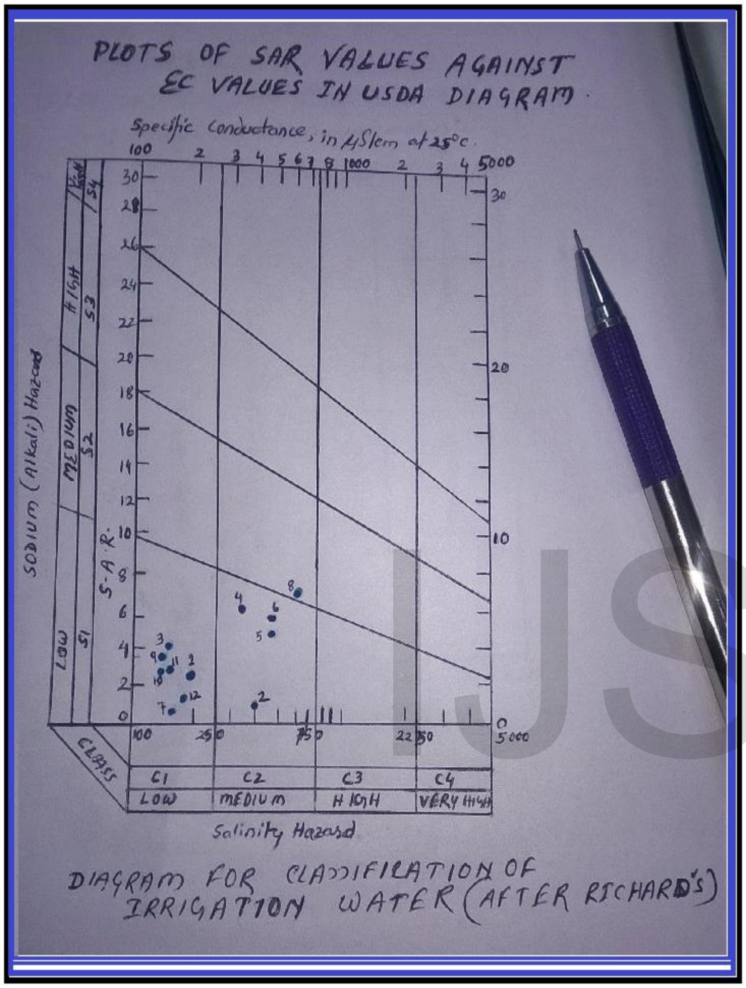
conductivity (Figure) data on US Salinity Laboratory diagram or Richard's diagram (USSL, 1954) like below—

Figure 9: US salinity hazard diagram of water samples (after Richards, 1954)



This diagram has been plotted with the data of SAR and EC from the table 14 and 2 respectively. So as the diagram says us, most of the samples of GW of different places like 1, 3,7,9,10,11 & 12 sample stations are falling in C1S1 category, that means this water have low salinity and low sodium type. The water of sample stations like 2, 4, 5, 6 are falling in the category of C2S1, indicates low sodium with medium salinity and only station 8th water sample is falling in the category of medium salinity with medium sodium means C2S2 category. So at last we can say that, GW samples that fall in C1, are useful for irrigation in most of the crop and in the case of C2 means medium salinity is also useful for irrigation purpose but some amount of leaching is required.

Percent sodium (Na %)

Methods of Wilcox (1995) and Richards (1954) have been used to classify and understand the basic characteristics of the chemical composition of groundwater since the suitability of the groundwater for irrigation depends on the mineralization of water and its effect on plants and soil. Percent sodium can be determined using the following formula:

$$(\%\boldsymbol{Na}) = \frac{(Na+K)100}{Ca+Mg+Na+K}\ (meq/l)$$

Here table 10 is showing the classification of GW samples with respect of % of Na. if the concentration of Na will be high in the water of irrigation, it gets absorbed by the clay particles by displacing the Mg and Ca ions. This kind of exchange process may reduce the permeability of water which can lead to poor internal drainage system. Hence, air and water circulation is restricted under wet conditions and such soils will become usually hard when dries[11].

Table 10: Sodium percent water class (Wilcox, 1955)

Na%	Water class	Range (no. of samples)	Sample id for location
<20	excellent	10.05-17.68 (2 sample)	2, 12
20-40	Good	21.6-39.36 (10 sample)	1,3,4,5,6,7,8,9,10,11
40-60	Permissible	-	-
60-80	Doubtful	-	-
>80	Unsuitable	-	-

In this table we can see except 2 & 12 sample station (excellent water), all sampling stations water is falling in good category water. In the table 11, if we take the classification of water for irrigation by Eaton, in 1950, all stations are falling in the water class of safe as the % of Na is below 60%.

Table 11: Sodium percent water class (Eaton, 1950)

Na%	Water class	Range (no. of samples)	Sample id for location
>60	unsafe	-	-
<60	safe	10.05-39.36 (12 sample)	1,2,3,4,5,6,7,8,9,10,11,12

Wilcox has classified groundwater (1948) for irrigation purposes by correlating the Na % and EC. To understand this relation, he had suggested a suitable diagram. After plotting the data from table 2 &6 for EC & Na % this can be shown like—

[11] Saleh et al., 1999

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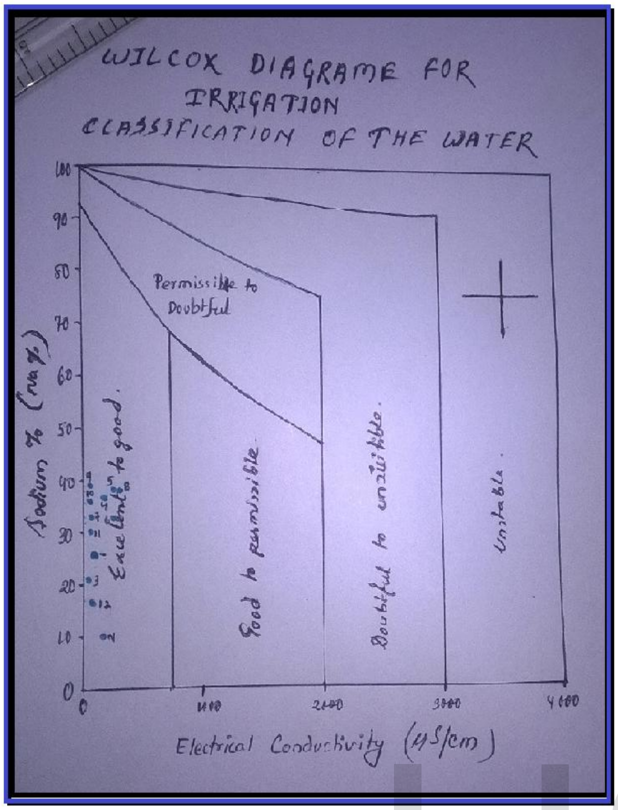
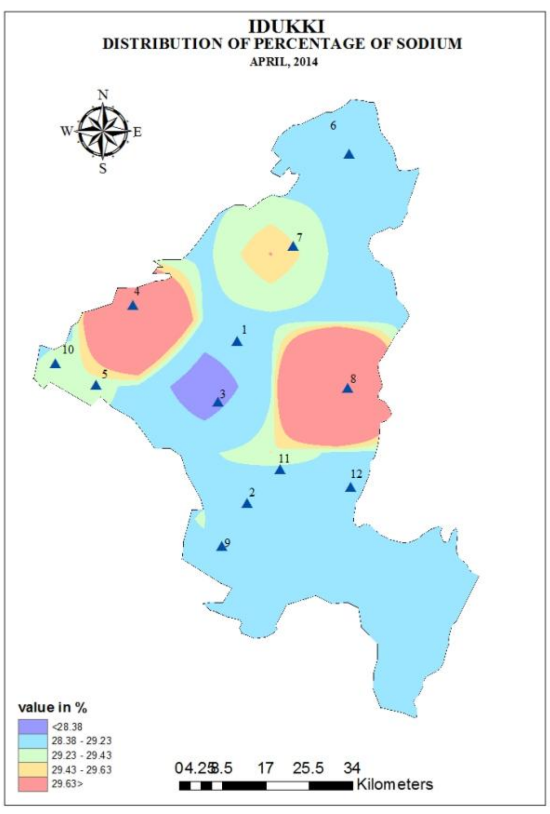
Fig 10: A plot of percentage of sodium vs. conductivity (after Wilcox, 1995).



After plotting the values, we can see values are falling in the category of excellent to good, which indicates the water is suitable for irrigation.

Figure 11: distribution of sodium (%)→



Soluble sodium percentage (SSP)

To measure water quality for agricultural purposes SSP has been calculated. Basically it means among the major cations (Na, Ca, and Mg), how much % has been taken by sodium. For that simply the formula has been used below—

$$\textit{Soluble Sodium Percentage (SSP)} = \frac{Na}{Na+Ca+Mg} \times \mathbf{100}$$

Todd in 1960, has classified water for irrigation into 5 classes, which has been shown below in table 13. Here according to this classification 5 station's water sample are identified as permissible water (3,4,7,8,9) and other 7 stations are falling in the category of good to excellent.

Table 12: Soluble-Sodium Percentage (SSP) (Todd, 1960)

SSP	Water class	Ranges (no. of Samples)	Sample id for location
0-20	excellent	12.45-19.75 (2)	2,12
20-40	Good	27.93-39.17 (5)	1,5,6,10,11
40-60	Permissible	41.0-47.05 (5)	3,4,7,8,9
60-80	Doubtful		
80-100	Unsuitable		

Permeability index (PI)

The permeability of soil is also affected by long time usage of irrigation water with the influence of Na, Mg, Ca & HCO_3 content in the soil. Doneen (1964) and Ragunath (1987) evolved a criterion for assessing the suitability of water for irrigation based on a Permeability Index (PI) and waters can be classified as Class I, Class II, and Class III. Permeability Index (PI) can be written as follows:

$$PI = \frac{(Na+\sqrt{HCO3}}{Ca+Mg+Na+K} \times \mathbf{100}\ (meq/l)$$

The PI of Idukki region is ranged from 0.32 to 1.22 %, which is very low. So after observing the Doneen's chart (Domenico and Schwartz, 1990; WHO, 1989) we can see that all samples will fall in the class of I & II because PI value of every station is less than 20 %.

Potential Salinity (PS)

Doneen (1954, 1962) pointed out that the suitability of water for irrigation is not dependent on the concentrations of soluble salts. Doneen (1962) is of the opinion that the low soluble salts gets precipitated in the soil and accumulated with each successive irrigation, whereas the concentration of highly soluble salts enhance the salinity of the soil. Potential salinity is defined as the chloride concentration plus half of the sulphate concentration:

$$\textit{Potential Salinity} = Cl - (½)*SO4$$

In the study area, the range of potential salinity is 4.50 to 106.40 meq/l. In the area of Koilkadavu region the chloride concentration is very high as table 1 is showing, which results the highest potential salinity in this region (106.40). This chloride of GW may be derived from soluble chloride from rocks, saline intrusion, connate and juvenile water or human made contamination e.g. industrial, domestic etc of this region.

Magnesium hazard (MH)

Basically in every normal case Mg and Ca will always maintain a state of equilibrium. When the water are Na dominated and highly saline and Ca and Mg do not behave equally in the system of soil then Mg deteriorates soil structure particularly. High level of Mg concentration can occur in the presence of exchangeable Na ions. So more amount of Mg concentration affects adversely to the soil quality to alkaline and adverse affect on crop.

Paliwal (1972) introduced an important ratio called index of magnesium hazard. Magnesium index of more than 50% would adversely affect the crop yield as the soil become more alkaline.

$$\underline{\textbf{Magnesium hazard}} = \frac{Mg}{Mg+Ca} * 100$$

So after applying this formula to the study region, we can see that, in every place this index is less than 50%. Its range lies between 8.84% at anakkara region to 42.86% marykulam.

Magnesium ratio (MR)

Magnesium ratio is ratio of Mg and Ca (Mg/Ca), by which table 13 had shown classification like below, where all station's water indicates safe irrigation water.

Table 13: Permissible limits of residual Mg/Ca ratio in irrigation water

Class	remark	Ranges (no. of samples)	Sample id for location
<1.5	safe	0.10-0.75 (12 samples)	1,2,3,4,5,6,7,8,9,10,11,12
1.5-30	Moderate	-	-
>3.0	Unsafe	-	-

Exchangeable sodium ratio (ESR)

Exchangeable sodium ratio (ESR) can be defined as:

$$\underline{ESR} = \frac{Na}{Mg+Ca}$$

Water quality for agricultural purposes in the study area based on ESR values varied from 0.14 to 0.89. It indicates there is an equilibrium state in between Na and Ca & Mg. In this area Na is not dominated, so that the probability of coming Mg Hazard is low in this district of Kerala.

So after all discussion, a table 14 has presented to know the actual values of the parameters→

Table 14: Irrigation water quality parameters for groundwater samples collected in Idukki district of Kerala

Stations ID	1	2	3	4	5	6	7	8	9	10	11	12
TH as CaCO3	38.0	38.0	14.0	44.0	58.0	66.0	18.0	90.0	14.0	14.0	18.0	30.0
SALINITY INDEX	0.1	0.1	0.0	1.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0
SAR (meq/l)	2.8	1.0	4.1	6.2	4.8	5.4	0.7	7.1	3.4	2.9	3.0	1.6
Na%	26.2	10.1	21.4	37.2	28.2	32.2	33.4	38.3	39.4	36.1	30.2	17.7
SSP (meq/l)	27.9	12.4	47.0	44.6	34.5	36.3	42.2	41.0	44.0	39.2	38.5	19.8
Permeabolity index	0.6	0.5	0.4	0.5	0.4	0.3	0.9	0.5	1.2	0.9	0.6	0.4
Potential Salinity (meq/l)	4.5	6.1	21.8	6.1	20.5	106.4	19.5	7.9	55.7	9.0	6.1	8.0
Magnesioum hazerd	22.5	17.9	9.3	26.2	18.7	25.4	14.8	15.1	31.9	19.5	42.9	8.8
ESR	0.4	0.1	0.9	0.8	0.5	0.6	0.7	0.7	0.8	0.6	0.6	0.2
Magnesium ratio	0.3	0.2	0.1	0.4	0.2	0.3	0.2	0.2	0.5	0.2	0.8	0.1

Section IV

- **CORRELATION MATRIX FOR THE MAJOR IONS AND THEIR CHEMESTRY:**

As we know between cations and anions the correlation always being low. Here EC is highly positively related with cations (Na, Ma & Ca). TDS and EC's r value is 1, means perfectly related, because, TDS is being measured on the basis of EC at 25° C. And for that also, TDS has highly significant positive relation with Ca (.9), Mg (.8), and Na (.8). Otherwise we can see good relation among the cations. there is significant relation, because they are inter dependent on each other. Like, if the concentration of Na will be high in the water of irrigation, it gets absorbed by the clay particles by displacing the Mg and Ca ions. Otherwise highly positively related ion chemistry can be seen between Potential salinity and chloride (0.99), MH and MR (0.98) etc. pH and NO_3 has also a positive significant relation (0.7934).

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Here a correlation matrix has been shown below—

	pH	ECi~250C	Ca	Mg	Na	K	CO3	HCO3	SO4	CL	F	NO3	TDSmgl	Sl INDEX	SAR meql	P.index	Na %	Mg hazard	P. sl	Mg ratio
pH	1.0000																			
ECinScm~250C	-0.0310	1.0000																		
Ca	0.1599	0.9590	1.0000																	
Mg	0.1452	0.8419	0.7698	1.0000																
Na	0.0541	0.8699	0.8334	0.7744	1.0000															
K	0.0249	0.2042	0.1335	0.0572	0.2326	1.0000														
CO3	0.7934	-0.1273	0.0051	0.0759	-0.1193	-0.2568	1.0000													
HCO3	-0.2664	-0.4386	-0.4721	-0.5121	-0.4856	-0.3036	0.1225	1.0000												
SO4	-0.1190	-0.0616	-0.1040	-0.1937	-0.0471	0.2415	-0.1203	0.5393	1.0000											
CL	0.0843	0.2050	0.1646	0.4391	0.2557	0.1044	-0.1979	0.1359	0.0541	1.0000										
F	-0.1782	-0.1881	-0.2033	-0.2133	0.0125	-0.4793	-0.1536	0.2815	0.2052	-0.0581	1.0000									
NO3	0.2759	0.4308	0.4196	0.6376	0.4389	0.1980	-0.1257	0.4848	-0.1123	0.8673	-0.0635	1.0000								
TDSmg/l	-0.0332	1.0000	0.9589	0.8418	0.8700	0.2022	-0.1287	0.4383	-0.0649	0.2066	-0.1879	0.4312	1.0000							
Sl INDEX	-0.1664	0.3517	0.2031	0.3894	0.4296	0.1805	-0.1078	0.1760	-0.1553	-0.1428	-0.1034	-0.0649	0.3588	1.0000						
SAR meq/l	0.0310	0.6786	0.6101	0.6701	0.8830	0.3392	-0.1244	0.6047	-0.2578	0.2329	-0.1104	0.3554	0.6794	0.4999	1.0000					
P. index	-0.3240	-0.6082	-0.6532	-0.5160	-0.4302	-0.5297	-0.0347	0.7202	0.2551	0.0156	0.6036	-0.3726	-0.6064	-0.1973	-0.3535	1.0000				
Na %	-0.1242	0.1089	0.0279	0.2430	0.4924	-0.2391	-0.1047	0.0292	0.1204	0.2578	0.6004	0.1257	0.1098	0.2843	0.5353	0.4970	1.0000			
Mg hazard	-0.2424	-0.1230	-0.2750	0.3025	-0.0424	-0.3346	0.0460	0.0242	-0.1766	0.1858	0.0291	0.0533	-0.1220	0.1405	0.1244	0.3158	0.4025	1.0000		
Potential Sl	0.0923	0.2094	0.1717	0.4525	0.2592	0.0886	-0.1902	0.1718	-0.0120	0.9978	-0.0718	0.8759	0.2111	-0.1327	0.2503	-0.0013	0.2501	0.1977	1.0000	
Mg ratio	-0.2600	-0.1859	-0.3254	0.2239	-0.0960	-0.3031	0.0052	0.0579	-0.1833	0.1296	-0.0011	0.0065	-0.1850	0.0838	0.0799	0.2892	0.3462	0.9876	0.1419	1.0000

Section V

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- **WATER QUALITY INDEX OF VARIOUS SAMPLE STATIONS OF IDUKKI:**

The water quality index of these stations are being shown in table no (_). To measure the WQI, we have to follow a method which has been used earlier by various scholars like Yadav et al., 2010. The formulas are—

$$W_r = W_{a_i} \div \sum_{i=1}^{n} W_{ai} \quad \textit{(Eq. 1)}$$

Wr = Relative weight,

$$Q_i = [C_i \div S_i] \times 100 \quad \textit{(Eq. 2)}$$

Qi = Quality rating scale,

$$SI_i = W_r \times Q_i \quad \textit{(Eq.3)}$$

$$WQI = \sum SI_i \quad \textit{(Eq.4)}$$

SI= sub indices *&*

WQI= water quality index

- So after that calculation of this is done like below for each station with **seasonal variation—**

1st step: choosing the parameter for ***WQI*** measurement by ***following Prabodha Kumar Meher, Prerna Sharma, Yogendra Prakash Gautam, Ajay Kumar, Kaushala Prasad Mishra*** scholars—

Stations	pH	EC in µS/cm at 250C		Ca		Mg		Na		SO4		CL			F
2014	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr
Churuli	8.44	7.64	105	74	10	5.6	2.9	1.9	5	5	2.4	0.46	5.7	5.7	0.16
Elapora	6.97	7.52	176	149	11	12	2.4	1.9	1.9	8.9	2	1	7.1	4.3	0.13
Idukki	7.63	7.21	64	58	4.8	3.2	0.49	0.97	4.7	5.9	4.4	4.4	24	18	0.11
Kaliyar	7.23	7	198	210	11	12	3.9	4.4	12	13	2	1	7.1	7.1	0.18
Karikunnam	7.42	7.19	251	66	17	14	3.9	0.92	11	4.5	11	3	26	30	0.15
Koilkadavu	7.77	7.89	246	270	17	18	5.8	7.3	13	19	1.2	0.37	107	89	0.18
Munnar	7.33	7.29	80	97	5.6	6.4	0.97	0.97	4.8	6.7	13	11	26	27	0.33
Nedumkandun	7.3	7.75	298	340	22	29	3.9	4.4	18	27	1.3	1.5	8.5	11	0.25
Peruvanthanam	7.03	6.99	59	48	3.2	3.2	1.5	0.97	3.7	3.3	4.7	3.8	58	65	0.2
Vazhithala	7.39	7.33	56	59	4	4.8	0.97	0.49	3.2	4.1	1.9	0	9.9	11	0.39
Marykulam	7.16	7.42	64	47	3.2	3.2	2.4	0.97	3.5	3.8	2.1	0.1	7.1	7.1	0.19
Anakkara	7.63	7.74	91	100	10	14	0.97	0.97	2.7	3.1	1	0	8.5	7.1	0.14

2nd step: Now in the second step, weight and acceptable limit (BIS, 2009) and relative weight (Wr) has been calculated for both seasons (Apr & Nov) by the equation 1—

Weight	4	4	5	5	2	2	2	2	1	1	4	4	3	3	2	2	4	4
BIS 2009	6.5	6.5	750	750	75	75	30	30	200	200	200	200	250	250	1	1	500	500
Wr Apr	0.1485	0.14815	0.185	0.185	0.074	0.074	0.074	0.074	0.037	0.037	0.148	0.148	0.1111	0.1111	0.074	0.074	0.148	0.148
Wr Nov	0.14815	0.14815	0.185	0.185	0.074	0.074	0.074	0.074	0.037	0.037	0.148	0.148	0.1111	0.1111	0.074	0.074	0.148	0.148

3rd step: In this step, Quality rating scale (Qi) is being calculated for each station and season by the equation 2—

Stations	pH	EC in µS/cm at 250C		Ca		Mg		Na		SO4		CL		F		TDS		
2014	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	APR	NOV
Churuli	129.8	117.5	14.0	9.9	13.3	7.5	9.7	6.3	2.5	2.5	1.2	0.23	2.28	2.28	16	46	10.6	7.4
Elapora	107.2	115.7	23.5	19.9	14.7	16.0	8.0	6.3	0.95	4.45	1	0.5	2.84	1.72	13	52	18	15.2
Idukki	117.4	110.9	8.5	7.7	6.4	4.3	1.6	3.2	2.35	2.95	2.2	2.2	9.6	7.2	11	45	6.4	5.8
Kaliyar	111.2	107.7	26.4	28.0	14.7	16.0	13.0	14.7	6	6.5	1	0.5	2.84	2.84	18	44	20.2	21.4
Karikunnam	114.2	110.6	33.5	8.8	22.7	18.7	13.0	3.1	5.5	2.25	5.5	1.5	10.4	12	15	48	25.6	6.6
Koilkadavu	119.5	121.4	32.8	36.0	22.7	24.0	19.3	24.3	6.5	9.5	0.6	0.185	42.8	35.6	18	78	25.2	27.6
Munnar	112.8	112.2	10.7	12.9	7.5	8.5	3.2	3.2	2.4	3.35	6.5	5.5	10.4	10.8	33	74	8	9.8
Nedumkand	112.3	119.2	39.7	45.3	29.3	38.7	13.0	14.7	9	13.5	0.65	0.75	3.4	4.4	25	48	30.6	35
Peruvantha	108.2	107.5	7.9	6.4	4.3	4.3	5.0	3.2	1.85	1.65	2.35	1.9	23.2	26	20	43	6	4.8
Vazhithala	113.7	112.8	7.5	7.9	5.3	6.4	3.2	1.6	1.6	2.05	0.95	0	3.96	4.4	39	46	5.6	6
Marykulam	110.2	114.2	8.5	6.3	4.3	4.3	8.0	3.2	1.75	1.9	1.05	0.05	2.84	2.84	19	46	6.4	4.8
Anakkara	117.4	119.1	12.1	13.3	13.3	18.7	3.2	3.2	1.35	1.55	0.5	0	3.4	2.84	14	38	9.2	10.2

4th step: In this step, Sub indices (Si) of each stations and season has been calculated by 3rd equation—

2014	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	apr	nov	APR	NOV
Churuli	19.28	17.41	2.59	1.83	0.99	0.55	0.72	0.47	0.09	0.09	0.18	0.03	0.25	0.25	1.18	3.40	1.57	1.10
Elapora	15.89	17.14	4.34	3.68	1.09	1.18	0.59	0.47	0.04	0.16	0.15	0.07	0.32	0.19	0.96	3.85	2.66	2.25
Idukki	17.43	16.43	1.58	1.43	0.47	0.32	0.12	0.24	0.09	0.11	0.33	0.33	1.07	0.80	0.81	3.33	0.95	0.86
Kaliyar	16.52	15.95	4.88	5.18	1.09	1.18	0.96	1.09	0.22	0.24	0.15	0.07	0.32	0.32	1.33	3.26	2.99	3.17
Karikunnam	16.95	16.39	6.19	1.63	1.68	1.38	0.96	0.23	0.20	0.08	0.81	0.22	1.16	1.33	1.11	3.55	3.79	0.98
Koilkadavu	17.75	17.98	6.07	6.66	1.68	1.78	1.43	1.80	0.24	0.35	0.09	0.03	4.76	3.96	1.33	5.77	3.73	4.08
Munnar	16.75	16.62	1.97	2.39	0.55	0.63	0.24	0.24	0.09	0.12	0.96	0.81	1.16	1.20	2.44	5.48	1.18	1.45
Nedumkandun	16.68	17.66	7.35	8.39	2.17	2.86	0.96	1.09	0.33	0.50	0.10	0.11	0.38	0.49	1.85	3.55	4.53	5.18
Peruvanthanam	16.06	15.93	1.46	1.18	0.32	0.32	0.37	0.24	0.07	0.06	0.35	0.28	2.58	2.89	1.48	3.18	0.89	0.71
Vazhithala	16.88	16.71	1.38	1.46	0.39	0.47	0.24	0.12	0.06	0.08	0.14	0.00	0.44	0.49	2.89	3.40	0.83	0.89
Marykulam	16.36	16.91	1.58	1.16	0.32	0.32	0.59	0.24	0.06	0.07	0.16	0.01	0.32	0.32	1.41	3.40	0.95	0.71
Anakkara	17.43	17.64	2.24	2.47	0.99	1.38	0.24	0.24	0.05	0.06	0.07	0.00	0.38	0.32	1.04	2.81	1.36	1.51

Now before going to the last step (5th), here the ***Water Quality Scale*** has been given to get idea about the value of ***Water Quality index***. This scale has been provided by ***Yadav et al., 2010*** like below—

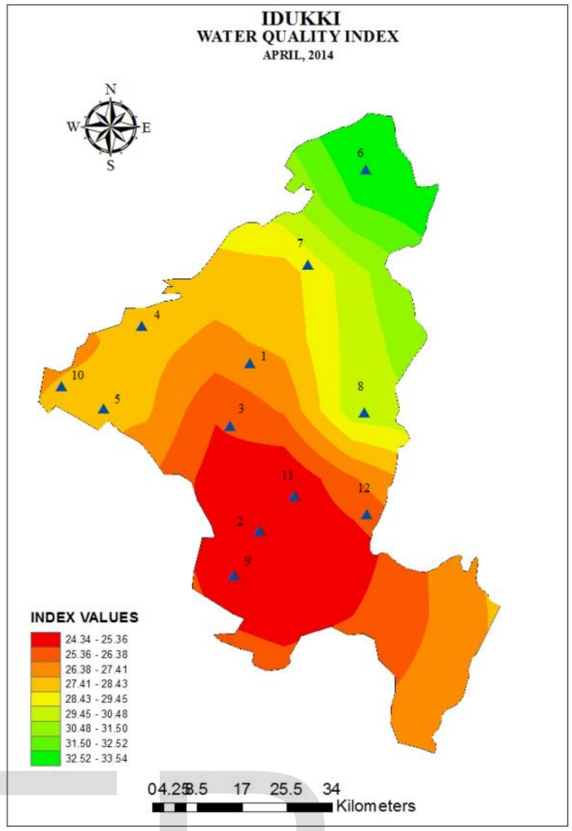
Water Quality Index	Water Quality
0-25	Excellent
25-50	Good
51-75	Poor
76-100	Very poor
Above 100	Unsuitable

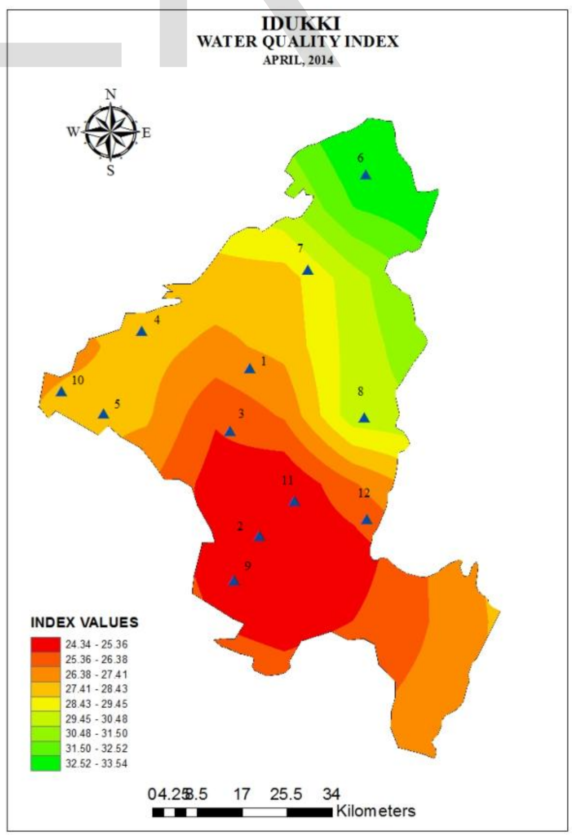
5th step: So, now at the last step, ***WQI*** has been calculated for each stations and seasons by using the equation no. 4 with adding the table which will interpret the ***water quality*** as proposed by ***Yadav***—

	2014	WQI	WQI	Water qualitty (Yadav et al., 2010)	Water qualitty (Yadav et al., 2010)
ID	Station	Apr	Nov	Apr	Nov
1	Churuli	26.85	25.14	Good	Good
2	Elapora	26.03	29.00	good	good
3	Idukki	22.85	23.84	excellent	excellent
4	Kaliyar	28.46	30.46	good	good
5	Karikunnam	32.85	25.79	Good	excellent
6	Koilkadavu	37.07	42.41	Good	Good
7	Munnar	25.34	28.94	excellent	Good
8	Nedumkandun	34.35	39.83	Good	Good
9	Peruvanthanam	23.56	24.79	excellent	excellent
10	Vazhithala	23.25	23.61	excellent	excellent
11	Marykulam	21.73	23.13	excellent	excellent
12	Anakkara	23.80	26.42	excellent	Good

So, we get the WQI with result, and thus all the sections are covered. This WQI, how changing spatially and seasonally and at what intensity some Geostatistical Analysis has been done, with the help of Raster Interpolation and Kriging, and some mapping to get visual idea of changing the WQI spatially like below—

Figure 12: Showing seasonal change in WQI, in IDUKKI





CONCLUSION

So after above brief analysis of Ground Water (GW) quality of the district of Idukki of Kerala, on the basis of various parameters (physical and chemical) of GW and suitable methodologies and then verifying them on the basis of drinking and irrigation water criteria provided by various scholars and institution like Bureau of Indian Standard, we get the results e.g. the water quality of Idukki, which are giving more or less same result. In the case of drinking water criteria, all parameters which are taken like pH, TH, Na, Ca, Mg, CO_3, HCO_3, K etc, all are maintaining their acceptable limit demarked by BIS, in 2009 in every sample stations of Idukki. Which indicates this water is suitable for drinking purpose. When irrigation criteria have come into focus, all diagrams like Gibb, Wilcox or Richard, all are showing that this water is suitable for irrigation. Otherwise, there has been used various methods like SAR, % Na, Permeability index, Salinity Index, TDS, Mg ratio, Mg hazard, Potential Salinity etc and verify the results on the basis of their scale provided by various scholars like Richards, Todd, Eaton, Wilcox etc and get positive result for irrigation of every dug wells GW of Idukki. And at the end, the WQI has been calculated by the method of Yadav, 2010, it also gives the expected result like good to excellent has come. So at last we can say that, the Ground Water quality of Idukki district of Kerala is very good for drinking purpose as well as irrigation purpose. Further as Gibb's diagram shows, Ground Water chemistry of this region is controlled by rock dominance, so finally it can be concluded that, the ground water quality of this region which is good for drinking and irrigation is controlled by the lithology.

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APPENDIX:

Stations	2014	Churuli	Elapora	Iduki	Kaliyar	Karikunnam	Koilkadavu	Munnar	Nedumkandun	Peruvanthanam	Vazhithala	Marykulam	Anakkara
pH	apr	8.44	6.97	7.63	7.23	7.42	7.77	7.33	7.3	7.03	7.39	7.16	7.63
	nov	7.64	7.52	7.21	7	7.19	7.89	7.29	7.75	6.99	7.33	7.42	7.74
EC in µS/cm at 250C	apr	105	176	64	198	251	246	80	298	59	56	64	91
	nov	74	149	58	210	66	270	97	340	48	59	47	100
TH as $CaCO_3$	apr	38	38	14	44	58	66	18	90	14	14	18	30
	nov	22	38	12	48	14	74	20	90	12	14	12	38
Ca	apr	10	11	4.8	11	17	17	5.6	22	3.2	4	3.2	10
	nov	5.6	12	3.2	12	14	18	6.4	29	3.2	4.8	3.2	14
Mg	apr	2.9	2.4	0.49	3.9	3.9	5.8	0.97	3.9	1.5	0.97	2.4	0.97
	nov	1.9	1.9	0.97	4.4	0.92	7.3	0.97	4.4	0.97	0.49	0.97	0.97
Na	apr	5	1.9	4.7	12	11	13	4.8	18	3.7	3.2	3.5	2.7
	nov	5	8.9	5.9	13	4.5	19	6.7	27	3.3	4.1	3.8	3.1
K	apr	1.2	3.6	12	5.4	7.1	4.6	3	3.1	1	0.7	2.5	1.6
	nov	1.2	4.7	0.9	6.6	4.1	5.7	2.7	3.6	0.9	0.9	0.9	17
CO_3	apr	4.8	0	0	0	0	0	0	0	0	0	0	0
	nov	0	0	0	0	0	0	0	0	0	0	0	0
HCO_3	apr	37	46	20	22	22	0	68	15	61	27	15	17
	nov	54	39	37	20	12	0	66	20	76	12	20	17
SO_4	apr	2.4	2	4.4	2	11	1.2	13	1.3	4.7	1.9	2.1	1
	nov	0.46	1	4.4	1	3	0.37	11	1.5	3.8	0	0.1	0
CL	apr	5.7	7.1	24	7.1	26	107	26	8.5	58	9.9	7.1	8.5
	nov	5.7	4.3	18	7.1	30	89	27	11	65	11	7.1	7.1
F	apr	0.16	0.13	0.11	0.18	0.15	0.18	0.33	0.25	0.2	0.39	0.19	0.14
	nov	0.46	0.52	0.45	0.44	0.48	0.78	0.74	0.48	0.43	0.46	0.46	0.38
NO_3	apr	2.8	0	22	0.84	27	173	11	16	1.7	11	0.06	0.14
	nov	14	0.77	10	3.2	12	133	31	12	1.2	9	0.58	0

Data Source: Central ground water board reports on Kerala, Idukki, 2013 & 2011