International Journal of Research in Advent Technology, Vol.7, No.5, May 2019
E-ISSN: 2321-9637
Available online at www.ijrat.org

Hydro-geochemical Evaluation of Groundwater for Its Suitability to Various Uses; A Case Study of a Small Mountainous River Basin in Western Ghats, South India

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Abstract: Groundwater is a major source of water for agricultural and domestic uses and also for other development activities. Therefore, groundwater quality including its, seasonal variations and its suitability for drinking, irrigation and industrial usage are evaluated. In this study, 27 groundwater samples were collected from the basin during the three seasons. The samples were analysed for various physico-chemical parameters and major ions. The analysis shows that most of the samples are acidic in nature. Based on analytical results, Gibbs diagram, Wilcox, piper and WQI were determined for suitability irrigation and drinking use. According to, Gibbs diagram majority of the samples fall in the rock and evaporation dominance controlling the groundwater chemistry, the piper diagram shows that Ca–HCO_3 mixed $CaNaHCO_3$ and NaCl type dominated. The suitability of groundwater for irrigation were determined by analysing SAR, Na %, MHR, PI and the suitability of water for drinking were determined by water quality index. It has been concluded that, the groundwater in the basin is good for drinking as well as and irrigation purposes but mostly not suitable for industrial purposes. Besides this, few of the samples which are found not suitable for irrigation and drinking purposes may be due to anthropogenic intervention.

Key words- Neyyar basin, Gibbs and piper diagram, WQI, SAR, and Permeability index

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1. INTRODUCTION

The water is one of the essential needs for the growing population in the world. Water is needed for industrial, domestic, environmental, recreational, agricultural and other purposes. Due to the growth in population and economic development, the demand for water has increased by 400% between 1940 and 1990, globally [1]. The demand of groundwater resources also has continued to increase in most parts of the world, and many areas experience shortage of freshwater. An estimate by the United Nations reveals that, by the year 2025 two third of humanity will face the shortage of freshwater. Another study indicates that the world population without safe drinking water may rise to 2.3 billion in 2030 unless specific efforts are put in. At present one third of the world population is facing water stress. Many studies have been conducted to manage the human needs to balance with the supply from natural resources and the ability of nature to provide these resources in aneconomic manner. In turn, many countries, especially the developed countries in the world have accelerated rain water harvesting as well as artificial recharge methods in their area and benefited by the same. In developing countries the awareness and adoption has occurred only during the last 10-20 years. Several studies are being carried out in the field of groundwater development and management. Based on the geomorphological indicators and hydrological characteristics delineated from the satellite imageries, they have demarcated the probable recharge and discharge sites. Numerical modelling techniques were employed by different workers with the help of groundwater levels and water quality parameters as the input data [2][3][4][5].Groundwater and solute transport, as well as the flow along fresh-saline boundary conditions were analysed by employing these models. India has only 4% of the run-off compared to the rivers of the world and it is high time to concentrate on micro level studies for the effective conservation and sustainable management of the available water resources.

Thiruvananthapuram district, the southernmost district of Kerala, is one of the fast-developing administrative divisions of the state. At present major part of the water demand for 24 grama panchayats, of the Neyyar river basin is being met from groundwater. The basin is affected by the in-stream as well as flood plain mining practices. The purpose of this study is to: present the use of the WQI as a tracing tool for assessing the suitability for drinking purpose, evaluate the groundwater resources for irrigation purposes, and classify the hydro-geochemical outline of groundwater resource in Neyyar basin, Thiruvananthapuram.

2. MATERIALS AND METHODS

2.1 Study Area

Thiruvananthapuram, formerly known as Travancore, is the capital of the state of Kerala. Thiruvananthapuram district is situated between north latitudes $8^{0}17'$ and $8^{0}54'$ and east longitudes $76^{0}41'$ and $77^{0}17'$. The total area of the district is 2192 sq.km as the district stretches from north to south with the Arabian Sea in the west side; the relative humidity is generally high. It rises up to about 95% during the south-west monsoon. The present study area lies between $77^{o}04'$ – $77^{o}19'$ E longitudes and $08^{o}31'$- $08^{o}52'$N latitudes. The study area mainly drained by Neyyar River, the southernmost river of the Kerala state, has its origin in the Agastya Mala. The average temperature in the study area ranges between 28 to 30 ^{o}C. The basin receives rain during the South-West and North-East monsoons; highland region receives 30 to 40 cm rain annually and experiences a humid tropical climate.

The geological development can be grouped into four units, namely (i) Crystalline rocks of Archaen age (ii) Sedimentary rock of Tertiary age (iii) Laterite capping the crystalline and sedimentaries and (iv) Recent to sub-recent sediments forming the low-lying areas and rivers valleys. The study area mainly consists of crystalline rocks of Archaen age comprising of gneisses and charnockite-Khondalite suite blanketed by fairly thick laterite capping with lenses of graphite, alluvium and soil. The thickness of laterite capping increases from higher altitude to lower altitude [6]. The main rock types in the area are charnockite, khondalite with veins of pegmatite, pyroxene granulite, garnet-biotite gneiss, garnet sillimanite gneiss, calc-granulites and quartzite. Dykes of dolerite and gabbroic composition follow the major structural trends.

2.2 Methodology

The study area base maps were scanned and digitized from the survey of India (SOI) Top sheets No.58H/02, 58H/03 and 58H/06. ArcGIS®10.3 software was used to analyze the spatial data on groundwater quality [7]. A total of 27 ground water sampling spots were fixed in Neyyar river basin and water samples were collected during three seasons (per-monsoon, monsoon and post-monsoon) from Neyyar river basin. The location of sampling spots in Figure 1.

Some parameters like pH, EC, TDS and salinity were measured in situ using field equipments all other water quality parameters were analyzed at the lab as per the standard proposed by the American Public Health Association [8]. The samples for analysis were collected as per the protocol. The water quality guideline values were obtained from World Health Organization [9] and Indian Standard institute [10] for agricultural and domestic purposes.

3. RESULTS AND DISCUSSION

3.1 *Drinking Suitability*

The statistics of minima-maxima of physico-chemical characteristics, major ions concentrations of ground water samples during the three seasons are tabulated in Table 1.

3.1.1 Temperature

The temperature of the water is important because it affects the amount of dissolved oxygen in the water, as the temperature decreases the amount of oxygen dissolved in water increases. The minimum - maximum temperature values were ranged from 26.5-29.9, 26.2-29.4, and 26.5-29.8 during three seasons

Temperature was found to be highest with value of 29.9 ^{o}C at sample 4 during Pre-monsoon and minimal value of 26.2 ^{o}C was observed at sample 24 during monsoon season.

Temperature is also responsible for the reproduction of aquatic animals, also for photosynthesis of plants and development in aquatic organisms, a moderate amount of temperature is essential for all living things to sustain their life in this planet.

3.1.2 pH

The pH of water is extremely significant, which maintain the concentration of hydrogen and hydroxyl ions in water. The standard values of pH for drinking water specified by BIS and WHO is 6.5-8.5. pH obtains intensity of acidity or alkalinity and the concentration of ions in water. The P^H values ranged from 4.77-6.92, 4.83-7.84 and 4.65-7.82 during the three seasons. Higher pH values of 7.84 were found in sample 3 and minimum values of 4.65 were found in sample 1 with an average value of 6.02. pH below 6.5 may causes corrosion in pipes.

The pH values varies from 4.65 -7.84 (Table 1), which clearly shows that the groundwater in the study area is slightly acidic in nature. This may be due to the anthropogenic intervention and other natural occurrences in the study area.

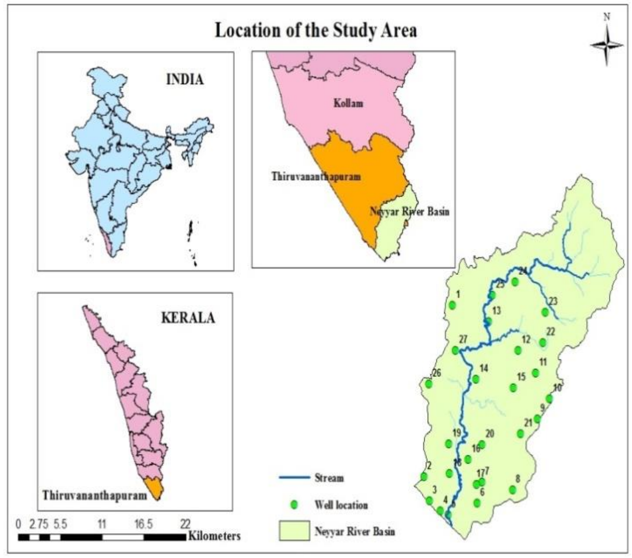

Figure: 1 sampling spot location map

Table: 1 Statics of Minima-Maxima specification on drinking water in study area

Specification	Pre-Monsoon		Monsoon		Post-Monsoon		WHO Standard (2011)	BIS / ISI Standard (2012)
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum		
Temp (^oC)	26.5	29.9	26.5	29.4	26.2	29.8	-	-
pH (on scale)	4.77	6.92	4.83	7.84	4.65	7.82	6.5-8.5	6.5-8.5
EC (µs/Cm)	41.8	1161	48.7	1112	44.5	737	1500	-
TDS (mg/l)	29.6	826	27.9	788	31.5	522	500	500
HCO_3(mg/l)	5.07	213.62	12.06	452.38	5.03	175.92	500	-
Cl^- (mg/l)	5.2	289.32	1.92	248.08	2.08	208.45	250	250
SO_4^{2-} (mg/l)	0.06	2.45	0.11	2.87	0.13	4.62	250	200
Ca^{2+} (mg/l)	1.61	50.05	1.61	95.27	0.81	59.74	75	75
Mg^{2+}(mg/l)	0.47	21.75	0.44	13.94	0.48	17	50	30
Na^+ (mg/l)	2.1	178.2	1.67	290.59	1.99	406.4	200	-
K^+ (mg/l)	0.48	245.1	0.16	130.25	0.45	215.6	12	-
T H (mg/l)	8	178.14	6	288.23	4	182.15	-	200

3.1.3 Electrical Conductivity

Electrical Conductivity is used to measure purity of water and also electric current flow. High electrical conductivity is regarded as pollution indicator.

The most advisable limit of Electrical Conductivity in drinking water is given as 1500 µS/cm (WHO). The

EC of ground water is varying from 41.8-1161 µS/cm with a mean value of 333.19 µS/cm. Higher EC indicates the rehab of salts in the ground water, which depends upon concentration, temperature and types of ions.

3.1.4 Total Dissolved Solids

TDS indicate the amount of inorganic chemicals in water solutions. As per WHO and ISI specifications TDS up to 500 mg/l is maximum limit. In the study area the TDS values varies between 27.9 - 826 mg/l, indicating that most of the groundwater samples lies within the permissible limit, as in Table 2. High level of TDS in drinking water may be irksome to users due to its taste and this could also cause problems in water pipes and household applications.

This high content of TDS in sample may due to contamination from domestic waste and leaching of salts from soil into the groundwater.

Table: 2 Davis and De Wiest (1966)- classification on TDS

TDS(mg/l)	Classification	Sample %
< 500	Desirable for drinking	88.89
500-1,000	Permissible for drinking	11.11
1000-3,000	Irrigation purpose	-
> 3,000	Infirm drinking & irrigation	-

3.1.5 Total Hardness

Hardness is an important parameter in decreasing the toxic effect of poisonous element. Hardness is primarily caused by the dissolved mineral compounds calcium and magnesium although smaller contributions to hardness will also come from some other ions including iron and manganese. The total hardness varies from 4.0-288.23 mg/l with an mean value of 44.58 mg/l. A maximum value of 288.23 mg/l hardness was observed at sample 3 during monsoon season. Increase in hardness of water, may due to the deposition of magnesium and calcium content. Groundwater of the whole study area are within the permissible limit by ISI (2012). According to the classification of of groundwater showed in Table 3, based on total hardness, 80.24% of the total groundwater samples are soft; 14.81% belong to moderately hard and only 4.93 % belong to hard. The analysis indicates that water in the study area is soft to hard. The quality is evaluated by comparing with the specifications of TH and TDS set by the WHO and ISI

Table: 3 Classification on Total Hardness Sawyer and McCarty(1967)

Total Hardness	Classification	% of samples
0-75	Soft	88.24
75-150	Quite hard	14.81
150-300	Hard	4.93
over 300	Very hard	-

3.2.6 Bicarbonate

The value of bicarbonate was observed as 5.03-213.62; 12.06-452.38 and 5.03-175.92 mg/l with a mean value of 53.62 mg/l, from the study area. Sample 3 has maximum (452.38 mg/l) and sample 1 has minimum (5.03 mg/l). The standard limit of bicarbonate is 500mg/l, which indicates that all samples are within the desired limit. Bicarbinate is a main ion except in the groundwater, occuring near the coast. The high concentrarion of bicarbonate in the water points to the dominance of mineral dissolution [11].

3.1.7 Chloride and Sulfates

The chloride concentration serves as an indicator of pollution by sewage and is considered as tracer for groundwater contamination in the drinking water [12]. A high concentration of chlorides affects growth of vegetation and results in metal corrosion. The permissible limit for chloride is 250 mg/l as per ISI and WHO. Water with high chloride content usually has an unpleasant smell and taste while drinking and may be not good for agricultural purposes as well. In the study area, the concentration of chloride is between 5.20-289.32, 1.92-248.08 and 2.02-208.45 mg/l during the three seasons with a mean value of 56.13 mg/l, relatively the higher concentration of chloride is observed from the sample 6, (289.32 mg/l) during pre-monsoon.

Sulfate is one of the major anion appear in natural water. The ISI permissible limit for sulfate (SO_4^{2-})

concentration is 200 while WHO is 250 mg/l. The sulfate concentration of groundwater in the study area ranges between 0.06 and 26.36 mg/l and has a mean value of 1.46 mg/l, which indicates that all samples are within the licit limit.

3.1.8 Sodium and Potassium

The observed value of Sodium (1.67 to 406.4) varies from 2.1-178.2; 1.67-290.59 and 1.99-406.4 mg/l during the three seasons with an average of 48.28 mg/l. According to WHO, maximum permissible limit of sodium is 200 mg/l. A few samples from the study area exceed the permissible limit. The maximum value of 406.4 mg/l sodium was observed at sample 22 during Post-monsoon season. The excess intake of sodium can cause blood pressure and other health problems in human beings. Ground water with high sodium content is not fit for agricultural purpose as well as it affects the water intake by plants.

The Potassium content in Neyyar River fluctuated between 0.48-245.1; 0.16-130.25; 0.45-215.6 throughout the period of sampling. The average value of potassium is 20.13 mg/l with a maximum value of 245.10 mg/l, which indicate the potassium form complexes in studied surroundings.

3.1.9 Calcium and Magnesium

The calcium (Ca^{2+}) and magnesium (Mg^{2+}) in waters are generally used to classify the suitability of water. Calcium and magnesium ions are both common in natural waters and both are essential elements for all organisms. The values of Calcium are between 0.81 - 95.27 mg/l. The permissible limit of calcium for drinking water is 75 mg/l as per ISI and WHO as in table above. This shows that few groundwater samples fall beyond the admissible limit.

Magnesium content in the samples varies from 0.44 - 21.75 mg/l, and the maximum permissible limit of magnesium content in the drinking water is 30 mg/l as per ISI while 50 mg/l according to WHO which shows that all the samples are within the legal limit.

3.2 Evaluation of Irrigation Water Quality with Respect to Different Standards from Graphical Representation

Irrigation plays a dominant role in plant growth as well as crop yield. In order to classify the quality of groundwater for irrigation various determinants such as Na %, SAR, MHR and PI are calculated. Statistical representation of irrigational quality parameters of the groundwater samples are presented in Table 4, 5, 6.

3.2.1 Sodium Percent (Na %)

The sodium in irrigation water is usually denoted as percent of sodium. According to Wilcox in all natural waters Na% is a common parameter to assess its suitability for irrigational purposes. The sodium percent (Na %), was obtained by calculating the relative proportion of cations as in equations 1.

$$Na\% = (Na^{+}+K^{+}) \times 100/[Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}] \quad (1)$$

Where all ions are expressed in meq/l, the Wilcox [13] diagram relating sodium percent and electrical conductivity shows that 82.71% of samples are excellent for irrigation while 16.05 % of samples belong to Permissible level and1.24 % of the samples are Doubtful for irrigation with an average values of 63.27mg/l as in Table.5 (Figure 2).

3.2.2 Permissible Index (PI)

Based on the permissible index (PI), water suitability for classification in irrigation water was developed by Doneen [14]. The PI was calculated by the following equation 2.

$$PI = [Na^{+} + (HCO_3)^{0.5}] \times 100/ [Na^{+}+Ca^{2+}+Mg^{2+}] \quad (2)$$

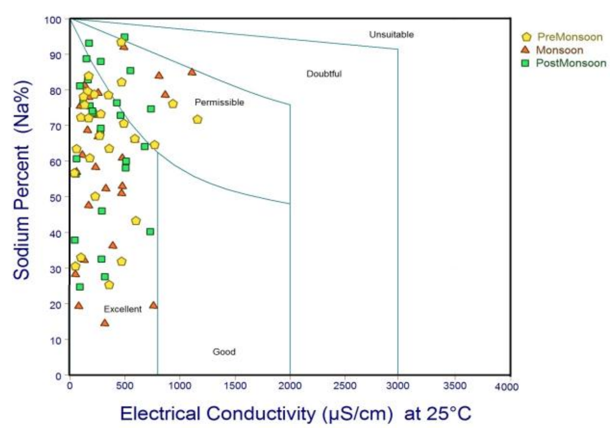

Figure 2: Irrigation Classification (Wilcox 1955)

Table: 4 (Doneen 1964) - Classification based on PI

Classification	PI Values	% Of Samples
Excellent	>75 (Class I)	92.59
Good	25-75(Class II)	7.41
Unsuitable	<25 (Class III)	-

Table: 5 Irrigational quality indices of ground water

Specification	Minimum	Maximum	Average
Na%	14.45	94.91	63.27
PI	56.80	376.7	121.77
SAR	0.25	31.67	3.71
MHR	6.05	92.12	43.04

***All Specification in (mg/l)**

The PI values and other classifications, as per WHO for assessing groundwater for irrigation uses tabulated in Table 4. The PI values in the study area vary from 56.80 to 376.70 in the seasonal periods, with an average of 121.77 (Table 5).

According to the study, about 92.59 % of samples falls under class I and only 7.41 belong to class II during all the seasons which indicate that waters are categorized is good for irrigation.

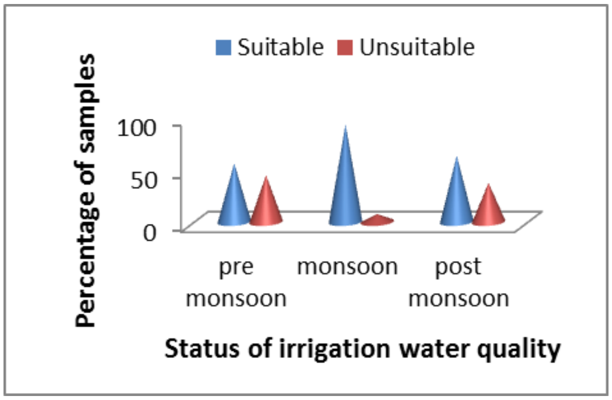

Figure 4: Status of irrigation water quality of groundwater as per MHR

3.2.3 Sodium Adsorption Ratio (SAR)

Sodium adsorption ratio is the most commonly used method to evaluate the effects of exchangeable sodium on the physical condition of the soil [15]. SAR is estimated by the following formula.

SAR= Na/ [(Ca + Mg)/2] $^{0.5}$(3)

Water with high SAR values when used for irrigation may require soil adaptation to prevent damage to the soil, because soil may lose calcium and magnesium due to excess sodium content in the water. So this may reduce the ability of the soil to form stable cluster and loss of soil form. Then the soil becomes compact and impervious creating hindrance to crop production.

The values vary between 0.25 and 31.67 with an average of 3.71. The classified values are tabulated in Table 6. The SAR values of all the samples are found within the range of excellent excluding the sample 21 which is found to be unsuitable for irrigation purpose.

3.2.4 SAR-Conductivity (USSL)

The USSL [16] diagram (Figure 2) considers the united effect based on EC and SAR, plotting EC against SAR, 48.15 % samples of three seasons in groundwater samples lie in the class of C1S1 (low salinity-low sodium type) and 43.21% of the samples belong to C2-S1 type (medium salinity- low sodium) indicate sample is good for irrigation on all type of soil. Few samples from Pre-monsoon (2.40%) fall into the C3-S1class (high salinity with low sodium) while 4.94% of monsoon and pre-monsoon samples lie within the class of C3-S2 and C3-S3 respectively. This can be used for irrigate salt tolerant and semi tolerant crops under favourable drainage condition. High salinity content in water in C4-S4 class, can affect the plant growth, while the medium type pose sodium hazard in fine-consistency soils and special soil administrative method are to be used during irrigation.

Table: 6 (Todd 1959; Richards 1954) - Classification on SAR

Classification	SAR Values	Samples
Excellent	<10	77
Good	10-18	2
Doubtful	18-26	1
Unsuitable	>26	1

3.2.5 Magnesium Hazard

In most waters calcium will be maintaining equilibrium with magnesium. Paliwal [17] developed magnesium hazard ratio for the effect of crop yield.

$$MH= Mg^{2+} \times 100 / (Ca^{2+} + Mg^{2+}) \quad (4)$$

The MHR Values range from 14.91 to 77.29 %, 6.05 to 60.02 % and 7.58 to 92.12 % during all the three seasons with an average of 43.04 as in Table 5. Majority of the samples (70.37 %) during the study period is suitable for irrigation while 29.63 % falls in the unsuitable category with magnesium hazard >50 % (Figure 4) shows during monsoon water is suitable for irrigation. Analysis shows that 29.63 % samples are un-favourable for agricultural yield. Excess amount of Mg^{2+} changes the soil properties and reduce the plant growth.

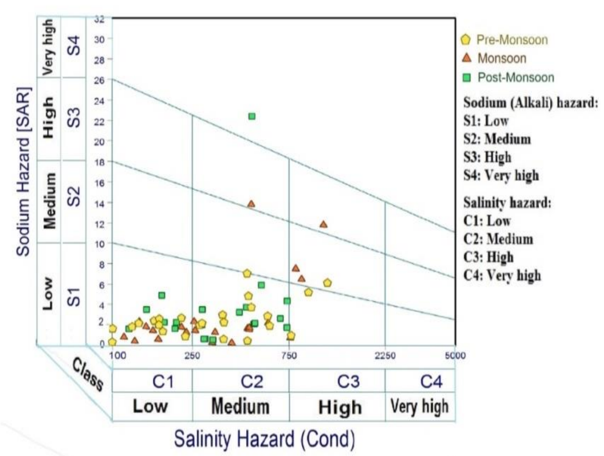

Figure: 3 SAR-Conductivity plot diagram (USSL 1954)

3.3 Piper Diagram

The hydro-chemical development of groundwater can be implied by plotting major cations and anions; the diagrams relive the problems related to geochemical evolution of groundwater. Piper [18] diagram reveals both similitude and dis- similitude amid groundwater samples, which tend together as similar groups. The diamond shaped areas are combination of both cations and anions ion of piper diagram (Figure 5), which clearly explaines the clusters in the area

The groundwater samples shows that in pre-monsoon, monsoon and post-monsoon about 22.22 % of the samples fall in the field I (alkali earth exceeds alkalies); 77.77 % of the samples fall in field 2 (alkalies exceeds alkaline earth) and 30.86 % of the samples fall in field 3 (Weak acids exceeds strong acids); about 69.13 % of the samples fall in the field 4 (Strong acids exceeds weak acids); 18.52% of the samples fall in field 5 Carbonate hardness (Secondary alkalinity) exceeds 50% (Chemical properties are dominated by alkaline earth and weak acids); 50.62% of the samples fall in field 7 Carbonate alkalinity (Primary salinity) exceeds 50% (Chemical properties are dominated by alkaline earth and weak acids) and 14.82 % of the samples fall in the field 9 Mixed types (No cation-anion pairs exceeds 50%) and type 6 Non-carbonate hardness (Secondary salinity) exceeds 50% (Chemical properties are dominated by alkaline earth and strong acids) & type 8 Carbonate alkalinity (Primary alkalinity) exceeds 50% (Chemical properties are dominated by alkalies and weak acids) are absent

The present study indicate that Ca–HCO_3, mixed $CaNaHCO_3$ and NaCl type dominate and the plot shows that all of the samples fall under the subdivision of alkaline earths exceeds alkali metals and weak acidic anions exceed strong acidic anions, the presence of NaCl indicate that there is an ion exchange taken place in this area..

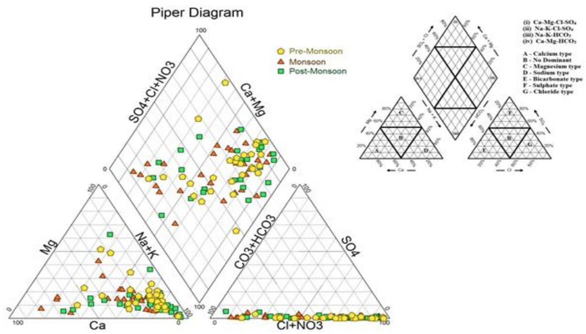

Figure: 5 Piper diagrams

3.4 Controlling Mechanism of Water Chemistry

The groundwater quality for drinking and irrigation purposes was evaluated based on WHO standards. The groundwater quality is remarkably changed by the anthropogenic interventions and other nature occurrences. Gibbs diagram [19] is used to understand relationship of water composition and aquifer lithological feature. The mechanism which control ground water chemistry are based on evaporation dominance, rock dominance and Rainfall dominance which is plotted by hydro-chemical data variation in the ratios of $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ with TDS.

The rock-weathering dominance suggest that the chemical composition of water were mainly controlled by weathering reactions, indicating that the silicate weathering is the dominant process for supply of the calcium ions to the groundwater and there is slight affinity towards the evaporation domain which reflects the precipitation of $CaCO_3$ from solution, leaving Na^+ and Cl^- as the dominant ionic constituents and there must be accepting as reflecting of major influence on the solute composition of stream water (Figure 6).

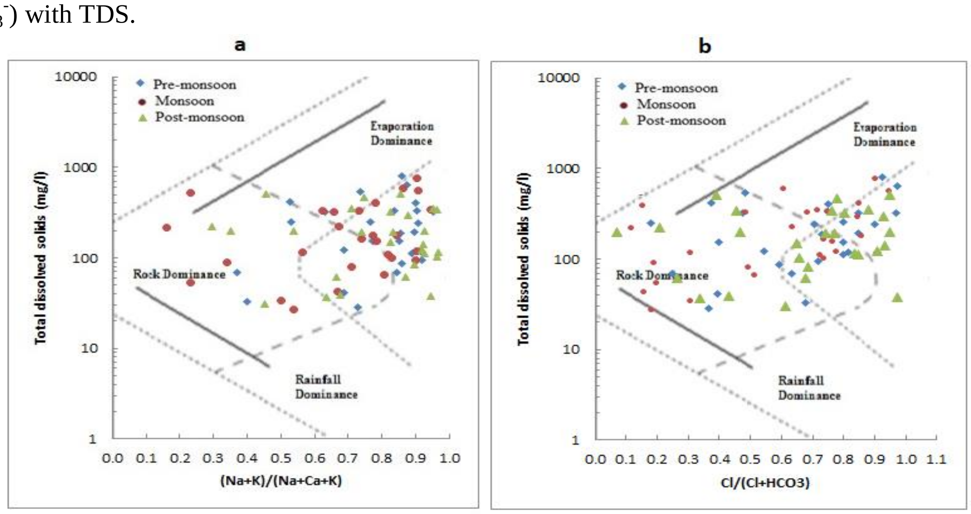

Figure 6: Rock-weathering dominance diagram (Gibbs 1970)

Table: 7 Water quality statics and its purposes

Sl.No:	WQI	Water Quality Status (WQS)	Purposes
1	0-25	Excellent	Drinking, irrigation and industrial
2	26-50	Good	Drinking, irrigation and industrial
3	51-75	Poor	irrigation and industrial
4	76-100	Very Poor	irrigation
5	>100	Unfit for drinking and fish culture	Proper treatment required before use

3.5 Water Quality Index

The overall water qualities of Neyyar basin groundwater was obtained for creating the water quality index (WQI). WQI has been obtained by using the standards index for drinking recommended by the WHO, ISI. The weighted arithmetic index method [20] [21] has been used for the calculation of WQI of the water body tabulated in Table 8 and water quality statics and its classification tabulated in Table 7.

$$WQI= \Sigma Q_nW_n/ \Sigma W_n \qquad (5)$$

Where Q_n is the quality rating of n^{th} water quality parameter, W_n is the unit weight of nth water quality parameter. The quality rating Q_n is calculated using the equation

$$Q_n=100[(V_n-V_i)/ (V_s-V_i)] \qquad (6)$$

Where V_n is the actual amount of nth parameter present, V_i is the ideal value of the parameter [V_i=0, except for (P^H V_i=7) and Do (V_i=14.6mg/l)], V_s is the standard permissible value for the n^{th} water quality parameter.

$$K = [1/ \Sigma 1/ V_n=1, 2, 3\ldots n] \qquad (8)$$

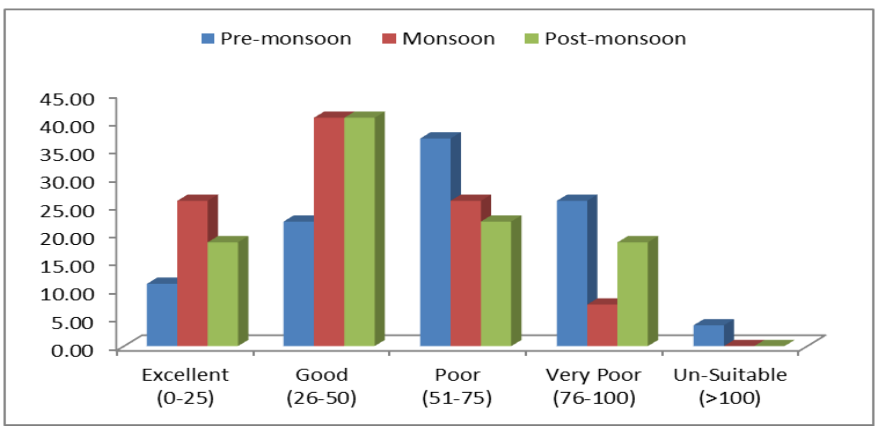

Figure 7: Variation of WQI during different seasons

3.6 WQI Analysis

The chemistry of groundwater is often used as a tool for astute the drinking and irrigation water quality. WQI is an essential for identifying the water quality and sustainability of drinking water.

A total of 27 site samples were analyzed for WQI of all the threeseasons' samples. Among these, 18.52 % of samples showed excellent, 34.57% of the samples under good category, 28.40 % of the samples show

Poor, 17.29 % of the samples fell under very poor and only1.23% of the water, unsuitable for drinking purpose.

This may be due to rock water interaction influencing silicate weathering and the high content of Electrical Conductivity, chloride, sodium, calcium and ion exchange interaction which may also cause anthropogenic activity clearly suggest that rock-weathering interaction process is the main source for degrading the water quality in the study area.

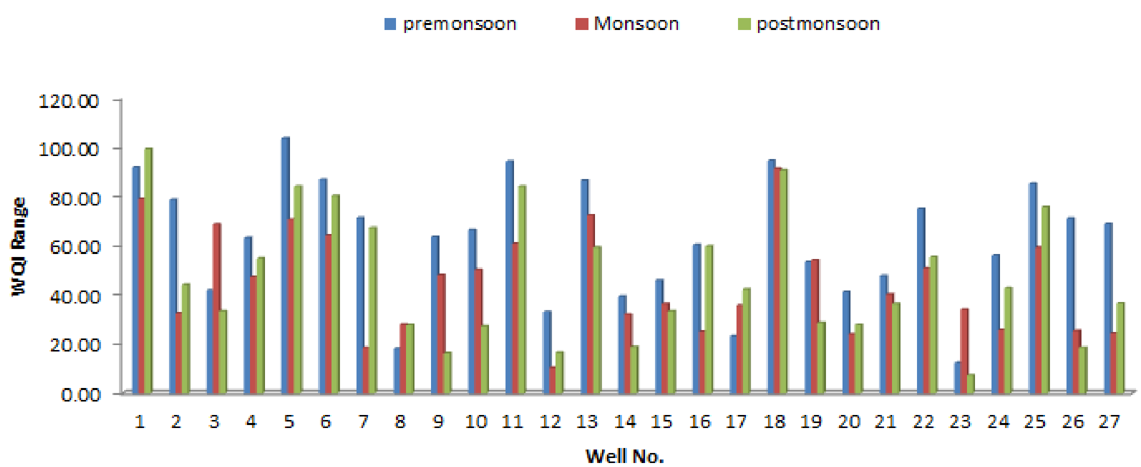

Figure 8: WQI Values graph of studied samples

Table: 8 Relative weights(W_n) of the Specifications used for WQI calculation

Sl.No	Specifications	Standards(S_n)	Recommended Agency	Unit Weight(W_n)
1	P^H	6.5-8.5	ISI/WHO	0.618174
2	E C	300	ISI	0.017515
3	TDS	500	ISI/WHO	0.010509
4	Total Alkalinity	120	ISI	0.043787
5	Total Hardness	300	ISI	0.017515
6	Calcium	75	ISI/WHO	0.07006
7	Magnesium	30	ISI	0.175149
8	Chloride	250	ISI/WHO	0.021018
9	Sulphate	200	ISI	0.026272
		$\Sigma W_{n=}$		1

***All Specification are in (mg/l) except pH and EC(µs/cm)**

3.7 Water Quality for Industrial Purpose

The quality requirements for industrial water range may differ and almost every industrial has its own standards. Industries regularly agonize from the unenviable effects of corrosion, which is caused by chemical reaction on metals and damages on over Layer crust is due to unwanted deposition of $CaCO_3$ on metal surface, which are alsodue to thepoor water quality. The following criteria have been used forchecking the bio-fouling of crust and corrosive properties of the water [22] [23]

a. water with HCO_3 more than 500 mg/l or SO_4 more than 150 mg/l may cause bio-fouling of crust.

b. water with pH <7 or TDS more than 1000 mg/l or Cl more than 400 mg/l may cause corrosion.

About 3.7% of the sample exceeds the limit of 500 mg/l in HCO_3 in monsoon season. Such water samples can damage crust on metal surfaces and hence notsuggested for industries. The groundwater is not free from corrosion, since most of the pH is less than 7. However the concentration of TDS and Cl is not exceeds the limit of 1000 mg/l and 500 mg/l respectively, in any of the seasons.

4. CONCLUSIONS

Groundwater is an imperative source for agricultural and domestic purposes and also for other development activities. The current study is done on open wells and study area is always under pressure due to growing populace and extra urge for fresh water. The piper diagram shows that Ca–HCO_3 mixed $CaNaHCO_3$ and NaCl are dominated water type. pH values from analysed data shows that, groundwater is slightly acidic in nature, as reported by many in lateritic terrain. The aptness of water for irrigation is assessed based on Na%, PI and SAR, shows that most of the sample suitable for irrigation, but few samples are beyond the licit limits. It has been concluded that, water from the study area is fit for drinking and agriculture, asideelect samples which are exceeding the limits may due to anthropogenic intervention and those samples were reluctant for agriculture. Based on the Gibbs diagram, evaporationand rock-waterinteraction are two main responsible processes for changing the chemical composition of groundwater. Based on WQI, majority of the groundwater samples are suitable for drinking and irrigation, but not recommended for industrial purposes, due to low pH. The silicate weathering, anthropogenic interventions and urbanization are the main factors influencing groundwater quality in the study area. Pre-treatment on sewage before draining into adjoining rivers / irrigation channels is the primary solution to preserve and improve the groundwater quality. To improve the quality of water, the Government and other organization should provide the virtuous support to design, water harvesting and artificial recharge methods and it should be implemented to overcome fresh water scarcity and to benefit future generation.

5. ACKNOWLEDGMENT

The authors are thankful to Kerala State Council for Science, Technology and Environment (KSCSTE) for funding and the Executive Director, Centre for Water Resources Development and Management (CWRDM) for providing necessary facilities and support to carry out the study.

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