Evaluation of Groundwater quality and suitability for irrigation using hydro-chemical process in Bhavani taluk, Erode District, Tamilnadu, India

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Abstract

In most regions of the present study area, Bhavani Taluk, groundwater quality is deteriorating at an alarming rate as a result of anthropogenic activities, however, little attention was given to groundwater quality and management. This research examines the quality of groundwater in Bhavani Taluk, Tamilnadu and compares its suitability for irrigation. The Bhavani region of Erode District, Tamilnadu is the most cultivated, with a considerable use of fertilizers and pesticides. Groundwater quality for irrigation purposes was assessed during the pre-monsoon season by collecting samples from 53 different locations. Physico-chemical parameters such as pH, EC, TDS, HCO_3^- , CO_3^{2-} , Cl^- , SO_4^{2-} , NO_3^- , Ca^{2+} , Mg^{2+} , Na^+ and K^+ were measured in these groundwater samples. Irrigation quality measures such as salinity hazard, sodium hazard expressed as SAR, percentage of sodium (% Na), and permeability index (PI) were calculated to evaluate groundwater quality for agricultural irrigation. Based on the classification of Electrical conductivity (EC) most of the groundwater samples are falling under the permissible limit. As per the USSL diagram, the large majority of groundwater samples fall within the category of C3-S1 and the water is suitable for irrigation. Piper trilinear diagram interpretations were made to know the chemical type of the groundwaters. The piper diagram indicates that 50% of the groundwater sample were belongs to Mg^{2+} , Ca^{2+} , HCO_3^- , and Cl^- . The groundwater samples fall under Class I category according to Doneen's Classifications.

Introduction

Water is the essential resource for the human life, functioning as an elixir for survival as well as for the economic development and for environmental sustainability (Abdul Bari and Vennila 2014; Benneyworth et al. 2016). The demand on natural resources is increasing as a result of rapid industrialization and a growing human population, and their conservation is one of mankind's primary issues. Groundwater is essential to the survival of both plant and animals all over the planet. India is one of the world's largest consumers of groundwater, primarily for drinking and agriculture (Shah 2009). The use of surface water (rivers, lakes, and ponds) and subsurface water (groundwater) for irrigation is widespread around the world (Sunil Kumar Srivastava 2019; Bian et al. 2018). In addition, due to a scarcity of surface water resources, the groundwater is essential in Indian agriculture, particularly in the semi-arid regions (Sreedevi et al. 2018). Rock–water interactions, crop production, geochemical settings, industrial emissions, precipitation, topography, weathering nature, evaporation mechanism, and anthropogenic activities all influence groundwater fitness for different purposes (Aravindasamy et al. 2019). Around 50% of the irrigated area depends on the groundwater, drinking water accounts for 65% of groundwater resources, while irrigation accounts for 20% (Vasanthavigar et al. 2012, Saeid et al. 2018). Water availability for irrigation necessitates knowledge of both quantity and quality; yet, the latter has been overlooked, particularly in developing countries. Groundwater becomes contaminated as a result of a variety of pollutants such as pesticide and other chemical product use in the household, agriculture, and industry (Nag and Lahiri 2012). As a result, assessing the irrigation groundwater quality is fundamental for long-term agricultural activities (Sappa et al. 2014). Various researchers in the national and international level

have been carried out to study on the quality of groundwater and its pollution and hydrogeochemical process (Abdul Bari et al. 2016; Khan and Jhariya 2017; Abd El-Aziz 2017; Zhang et al. 2018; Li et al. 2018). The water quality, soil circumstances and drainage characteristics are the factors that influences suitability of water for irrigation (Venkateswaran and Vediappan 2013). The overall amount of salts available, as well as the ratio of sodium to other cations, and a few other characteristics all influence the quality of irrigation water [Kant et al. 2015]. In the Guntur District of Andhra Pradesh, South India, the feasibility of groundwater for irrigation was investigated by measuring groundwater quality (Nagaraju et al. 2014). The concentration and composition of dissolved ions (Cations and Anions in the forms Ca^{2+} , Mg^{2+} , Na^+ , K^+ , CO_3^{2-} and HCO_3^-), which is primarily governed by subsurface lithology, nature of geochemical reactions, salt solubility, and various anthropogenic activities, determines the quality of irrigation water (Singh et al. 2018; Tamma et al. 2015). In the Italian region of Aosta Valley, The hydro-geochemical mechanisms that determine groundwater formulation and its suitability for consumption and agriculture were investigated by Tiwari et al. 2017. In the Bogra district of Bangladesh, Islam and Shamsad (2009) examined the performance of irrigated water and found the components required for plant growth as well as the permissible concentration levels. The numerous geochemical processes (redox reaction, membrane separation, penetration, and adsorption) that occur in the groundwater aquifer affect the hydro-geochemistry of the groundwater (Drever 1997; Hem 1991). According to the above various researches, determining the water quality is fundamentally important for evaluating the effectiveness of crops in most every place, especially where irrigation systems focus on groundwater. Because of the surface water supplies are not available, residents of the area depend on groundwater resources for all of their needs, including household, agricultural, and industrial (Abdul Bari et al. 2015). The irrigational water quality assessment in the north region of Erode district, Bhavani taluk has not carried out so far. As a result, the current study intends to make an attempt on determining the suitability of groundwater for irrigation in Bhavani taluk of Erode District, India with an objective of the study involving evaluating the irrigation water quality parameters, Irrigation water quality classification and grading based on the USA salinity diagram

Description of Study area

Environmental Conditions and location

The research was carried out in the Bhavani taluk, Erode district which is situated in the dry climate region of Tamilnadu, India. It is situated between the latitude N 11°33'4" and longitude E 77°38'0" with a total area of 1492.13 km² (Fig.1) in which reserved forest covering an area of 850.13km² falls in the Survey of India (SOI) Toposheets on 8E05, 58E06, 58E09, 58E10, 58E11. As per the India Meteorological Department (IMD), the climate represents the dry weather conditions expect during the rainy season with the hot summer ranges between 36⁰ C to 41⁰ C and the mild winter ranges between 25⁰ C to 27⁰ C (Abdul Bari et al. 2016). The study area receives the low rainfall in the post monsoon period and the high rainfall (>220mm) in the North-East monsoon with an average annual rainfall of ~786mm (CGWB 2008). Turmeric is the most prevalent crop grown in the research region, followed by banana and mango. The

study area's groundwater source is mostly used for irrigation purposes as most of the peoples depend on the income come over their agricultural lands. The geography of the study area is almost elevated, with occasional undulations and hills in the northern part of the district with an elevation of 1200m and above. The slope of the study area is generally from the West (~420m) to East (~150m). Geologically the area is covered by the Metamorphosed Gneissic rocks of Archean age, with some part of the research area contains the Charnockite and the Peninsular Gneiss (Bari and Vennila 2013)

Sampling and Analysis

A total of 53 groundwater samples were collected (Tube wells and dug wells) using pre-cleaned polyethylene bottles that were entirely filled with no air bubbles and carefully sealed after sampling. Global positioning system (GPS) was used to record the sample locations. Some field and laboratory tests and analyses were conducted to determine the physiochemical features of the groundwater in the area. Total dissolved solids (TDS), hydrogen ion concentrations (pH), electrical conductivity (EC) are measured using the In-situ Portable units and concentrations of a few major and trace ions were measured as given in the Table 1. The sampling was carried out according to the American Public Health Association's Standard Methods (APHA 2012).

The major cations and anions concentration were converted from mg/L to meq/L to calculate the irrigation quality indices. The statistical value of the hydrogeochemical parameters is presented in the Table 2. The accuracy of the analytical results of the measured cations (Ca²⁺, Mg²⁺, Na⁺, K⁺) and the anions (Cl⁻, F⁻,NO₃⁻, SO₄²⁻, CO₃²⁻, HCO₃⁻) which was taken in meq/l was verified using Ionic Balance mass error equation: Eq.1 (Domenico and Schwartz 1998) and he computed ionic balance error was determined to be within 10% of the maximum limit.

$$Ionic\ Balance\ Error\ (IBM) = \frac{(\sum cations - \sum anions)}{(\sum cations + \sum anions)} \times 100 \text{ ----- Equation 1}$$

Results And Discussion

Assessment of Groundwater Quality for Irrigational suitability

The irrigation activity in the study area, Bhavani taluk, Erode District, India is mainly depending on the groundwater due to shortage of the surface water and the rainfall round the year. Because to anthropogenic pollution of groundwater and the presence of natural minerals in aquifers, the quality of groundwater has deteriorated (Gupta and Misra 2018). The assessment of pollutant levels of physical and chemical characteristics in water is necessary for effective detection of groundwater pollution. The groundwater suitability for the irrigationis mainly calculated using the Electrical Conductivity(EC),Sodium Hazard in terms of Sodium Adsorption Ratio (SAR), Sodium Percentage (Na %) and Permeability Index (PI) (Karanth1987; Ragunath 1987). Wilcox Diagram, Doneen Plot and USSL diagram were plotted to assess the irrigation quality and Piper Trilinear diagram is also prepared for hydrochemical analysis. The

analytical data of these indices are given in the Table 2. The order of the dominance of the cation and anions from the datas obtained are $K^+ < Mg^{2+} < Ca^{2+} < Na^+$ and $F^- < NO_3^- < SO_4^{2-} < Cl^- < HCO_3^-$ respectively

Hydrochemical properties of the Groundwater:

The anthropogenic pollution of groundwater and the presence of natural materials in estuaries, the quality of groundwater has deteriorated (Gupta and Misra 2018), hence the determination of the physicochemical characteristics of water is of much importance for the accurate detection of the pollution in the groundwater. The statistical results of the hydrochemical analysis of the 53 groundwater samples is presented in Table 2. The acidic or the alkaline nature of the solution would be found out by pH, Water's inherent taste is generally changed to a bitter taste by the pH (WHO 2017). The pH value of the groundwater samples varies between 7.2 to 8.12 with an average of 7.4, indicating that the groundwater in the study area is naturally alkaline. All of the groundwater samples taken for irrigation purposes are below the safe limit (Ayers and Westcat1994). The calcium content of the groundwater in the study region varies between 18mg/l to 210mg/l with a mean value of 67.32 mg/l. Magnesium ranges between 12mg/l to 110mg/l with an average value of 44mg/l. The concentration of sodium ranges from 12 to 327 mg/l, with a mean of 121.10 mg/l. The potassium ion concentration in groundwater varies between 2 and 76 mg/l, with a mean of 15.32 mg/l. Chlorine levels in the study area range from 20 to 458 mg/l, with a mean of 123.20 mg/l. The average nitrate concentration in this area's groundwater is 47.32 mg/l, with a range of 1 to 172 mg/l. Sulphate concentrations in the study area range from 0 to 201 mg/l, with an average of 82.62 mg/l. Fluoride levels in the study area range from 0.01 to 1.6 mg/l, with a mean of 0589 mg/l.

Salinity and Alkalinity Hazard

The important parameter in the agriculture water is the assessment of the Salinity Hazard, because irrigation water with a high salt concentration causes the soil to become salinity, which has a negative impact on plant salt absorption efficiency (Saleh et al. 1999). The salinity hazard is measured with the values of Electrical Conductivity (EC) and Total Dissolved solids (TDS). Electrical conductivity (EC) or Specific conductance, indicating a measure of the total ion concentration in natural water (Hem 1991; Hounslow 1995). EC values ranges from 358 μ S/cm to 2420 μ S/cm with the mean value of 1242.42 μ S/cm (Fig.2). The geochemical process and anthropogenic activities are both primarily responsible for the increased concentration of EC (Subba Rao et al. 2017). As per table 3, according to Wilcox's classification (Wilcox 1955), none of the water samples are suitable for irrigation and almost 62% of the samples falls in the permissible range. Richards (1954) divided the suitability of groundwater for irrigation into four categories (Table 4), based on this classification 20% of the groundwater samples falls in very high saline region. About 62% of the samples falls in the high saline and 18% in the medium saline category for irrigation purposes. Plants can be adversely affected by high saline levels, which can be harmful (Sreedevi et al. 2019). TDS is mainly composed of inorganic salts, and a TDS concentration in water greater than 500 mg/l can cause gastrointestinal irritation (Seth et al. 2015). The total dissolved solids (TDS) of the collected samples varying from 198mg/l to 1342mg/l with an average value of

742.52mg/l (Fig.2). As per the table 3, 74% of the groundwater samples in the study region represents the slightly saline water (450 to 2000mg/l) category, 24% of the samples representing No Saline category and only 2% of the samples in severe saline category for irrigation purpose.

Sodium Adsorption Ratio (SAR):

The sodium adsorption ratio (SAR) is the expression of the Sodium hazards. Continuous irrigation with groundwater with a high SAR might lead to deterioration in the soil's physical composition (Subba Rao 2008; Karanth 1987). Excess Na^+ accumulations used in water for irrigation have the unfavourable impact of lowering permeability of the soil by altering soil characteristics due to particle congestion (Kelley 1951). Hence the Na^+ concentrations to be considered for assessment of the water's suitability for irrigation (Towfiqul et al. 2017). The SAR value is calculated using the following formula (Richards 1954) Equation 2:

$$SAR = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \quad \text{----- Equation 2}$$

All values are expressed in terms of meql/litre.

According to the SAR classification based on Richards (1954) as given in the Table 3, 45% and 32% samples of the study area are found to be excellent and Good for irrigation purposes respectively and 23% of the samples are not suitable for irrigations.

The USSL diagram was plotted using the values of SAR and EC (Karnath 1987; USSL 1954) which distinguishes the different categories of the irrigation water in terms of sodium or alkaline hazard and salinity hazard (Fig.3). The SAR and the EC values are used to plot the United States Salinity Laboratory (USSL) graphical representation (Fig.4, Table 5), and found that 57% of samples falls in C3-S1 (High Salinity and Low Alkalinity) and 19% of Samples falls in C2-S1 (Medium Salinity and Low Alkalinity) Category and 7% and 6% of the samples falls in the C3-S2 (High Salinity and Medium Alkalinity) and C4-S2 (Very high salinity and medium alkalinity) respectively.

Kelly's Ratio (KR):

Kelly's ratio (KR) is another measurement used to assess the irrigation quality of groundwater (Kelly 1963). Since Ca^{2+} and Mg^{2+} maintain their steady state in most of the waters, this parameter is calculated using Na^+ to them. KR is calculated using the equation 3

$$KR = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \quad \text{----- Equation 3}$$

Where the ionic concentrations are expressed in meq/l.

The water with the value of $KR < 1$ is considered as suitable for irrigation whereas if it is above 1 ($KR > 1$), the water is not suitable for irrigation. From the Table 3, It was determined that 85 percent of the groundwater samples in the study region, Bhavani taluk, are appropriate for irrigation, whereas 15% are not.

Percentage of Sodium (Na^+ %):

The commonly used parameter for the evaluation of the suitability of the water for irrigation is the percentage of the sodium content. The sodium hazard is caused due to the higher concentrations of Na^+ (Wilcox 1955). Because sodium reacts with soil and affects its permeability, the amount of sodium in irrigation water is crucial in determining its quality. (Purushothman et al. 2012; Raju et al. 2009). Excess Na^+ in water has the unfavourable impact of lowering soil permeability, altering soil characteristics, and perhaps stunting plant growth (Nishanthiny et al. 2010; Obiefuna and Sheriff 2011). The hardness of the soil is also increasing due to the sodium availability in the groundwater (Varol and Davraz 2015). The $Na\%$ is also referred as Soluble sodium percentage and the correlation of sodium with the Ca^{2+} and Mg^{2+} is calculated using the Equation 4 (Wilcox 1948).

$$\% Na = \left(\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \right) \times 100 \text{ (All Values in meq/L)} \quad \text{----- Equation 4}$$

As per the Table 3, the results based on the % Na shows that the percentage of sodium in the study region varies from 2% (Unsuitable for Irrigations) to 49% (within the permissible limit for irrigations). According to the Table 3 and Fig. 5, based on the Eaton Classification, 77% of the groundwater samples is safe for suitability of irrigation and 23% of the groundwater samples is unsafe for irrigations. Irrigation water should have a maximum Na^+ level of 60%, according to Indian Standards (BIS 2003). Na^+ accumulations may occur if the percent Na exceeds 60, causing the soil's physical qualities to deteriorate (Ramesh and Elango 2012).

In evaluating the suitability of groundwater for irrigation, Wilcox (1955) has used the relation between Sodium Percentage ($Na\%$) and specific Conductance (EC) to design the Wilcox graph, in which the five different zones are divided to classify the irrigation water classes. (Fig.6). The Wilcox diagram plot shows that 25% and 36% of the groundwater samples fall into the Excellent and Good categories, respectively, while 19% of the samples were within permissible limits, ten samples were questionable, and only a few samples were in the inappropriate category. Hence the groundwater in the study region according to this classification is suitable for irrigation.

Permeability Index (PI):

The suitability of the groundwater for the irrigation is assessed on the basis of the PI values. The long period of the water for the irrigations results in the reduction of the soil permeability due to the deposition of the ions (Ehya and Saeedi 2018). The PI values has been evaluated by using the calcium, magnesium, sodium and bicarbonates given by the equation 5 (Ragunath 1987).

$$PI = \left(\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \right) \times 100 \text{ ----- Equation 5}$$

Here the concentrations are expressed in meq/L.

The permeability index (PI) was classified by Doneen (1964) into three classes: Class I, Class II, and Class III, respectively (Fig.7). The 100% permeability which is suitable for the irrigation is considered as the Class I, the 7% of the maximum permeability which is slightly suitable for irrigations is considered as the Class II and the water with 25% of the permeability which is unsuitable for irrigation is considered as the Class III classifications. Based on the values obtained in the PI, 85% of groundwater samples in the study region is suitable for the irrigation and 11% of these samples is slightly suitable for irrigations and only 3% of the samples are unfit for irrigation (Table 3).

Magnesium Hazard (MH):

A parameter termed Magnesium Hazard is a method for determining groundwater suitable for irrigation (Szaboles and Darab 1964). In groundwater the magnesium and calcium maintain the state of equilibrium. It is expressed in equation 6. The ionic concentrations are given in meq/l.

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \text{----- Equation 6}$$

If the magnesium level in the water is greater than 50% than the water is suitable for irrigation (Palliwal 1972, Nagaraju et al. 2014). From the Table 3, it is found that almost all the samples are not suited for irrigation. Due to higher level of magnesium in the water, the quality gets affects and leads to alkaline nature of the soil and reducing the yield of the crops. (Rao et al. 2012).

Hydrochemistry of the Groundwater

Piper-Trilinear Diagram

Groundwater geochemistry is influenced by two factors: geochemical reactions and mixing of nearby samples. Groundwater flow patterns and chemical histories can be determined via hydrogeochemical facies analysis (Chung et al. 2015). The quality of groundwater as well as various geochemical evolution paths have been represented using major ion chemistry data shown on a Piper trilinear diagram (Piper 1944) [Fig5]. The piper trilinear diagram is made up of two triangle fields (where the major cation and anions' percentage epm values are plotted) and a central diamond-shaped field (where cations and anions are projected for the display of water's general characteristics) (Guler et al. 2002). The number of sub-areas in the cations, anions triangles, and centre diamond field represents the particular geochemistry of groundwater samples. The diagram assisted in the classification of groundwater and the

assessment of groundwater geochemistry. From the Piper diagram (Fig.8), the 42 % of the groundwater samples (n= 22) fall in the field of mixed Ca^{2+} - Mg^{2+} - Cl^- and Ca^+ - HCO_3^- types of hydrochemical facies respectively and few samples(~6%) falls in Mixed Ca^{2+} - Na^+ - HCO_3^- and rest fall in the Ca^+ - Cl^- (~10%) types of hydrochemical facies.

Conclusion

In this research the suitability of the groundwater in Bhavani taluk, Erode district was evaluated to demarcate the feasible zone for the irrigation purpose. The geochemistry of the groundwater reveals that most of the samples falls in the alkaline nature($\text{pH}>7.0$) of groundwater. $\text{K}^+ < \text{Mg}^{2+} < \text{Ca}^{2+} < \text{Na}^+$ was the order of the cation concentration in the groundwater samples, while $\text{F}^- < \text{NO}_3^- < \text{SO}_4^{2-} < \text{Cl}^- < \text{HCO}_3^-$ was the order of the anion concentrations. 74% of the groundwater samples falls in the slightly saline region based on the salinity hazard except for few locations which comes under no saline region. Comparing to the alkalinity the salinity is little higher in the study region. The different irrigation water quality parameters like electrical conductivity (EC), Salinity Hazard (SH), Sodium Adsorption ratio (SAR), Sodium Percentage (% Na), Kelly' Ratio, Magnesium Hazard (MH) were assessed for the 53 groundwater samples. As per the obtained results SAR, Kelly ratio, % Na determines that only few samples are unsuitable for irrigation whereas the magnesium hazard shows that all the samples are unsuitable for irrigation due to increased magnesium content in the groundwater. The interpretation of the piper trilinear diagram was made to found out the chemical types of groundwater and it reveals that the most of the samples falls in the category of mixed Ca^{2+} - Mg^{2+} - Cl^- , Ca^{2+} - Na^+ - HCO_3^- Ca^+ - Cl^- , Ca^+ - HCO_3^- types of hydrochemical facies representing the temporary hard water and permanently hard water types. The groundwater samples falls in the Class I category (~85%) as per the classification of Doneen's Permeability Index and the water is suitable for irrigation. The wilcox diagram shows that nearly 80% of the samples are suitable for irrigation purpose and only few samples (20%) of the groundwater is unsuitable for irrigation. The U.S .Salinity diagram (USSL) shows that ~57% and 11% falls un C3-S1(High Salinity with Low Alkalinity) and C4-S1 Category (Very High salinity with low alkalinity). The increases in salinity affects the crop growth in the soil, hence proper drainage is necessary in the areas of high salinity to have the satisfactory growth of the soil. The study's overall findings point to a worrying scenario in terms of groundwater quality, which may necessitate appropriate corrective actions. Artificial recharge techniques may be developed to lower increased chemical concentrations in groundwater, or alternatively, suitable crops may be introduced to maintain current groundwater quality.

Declarations

Authors' contributions

Jabar Abdul Bari: conceptualization, supervision, investigation, methodology, writing - original draft, writing - review & editing; Karthikeyan Perumal: data curation, formal analysis; software; data analysis; investigation; software. Subagunasekar Muthuramalingam: software; data analysis; investigation.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

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Tables

Table 1 Method of Analysis for the Groundwater Samples

Parameters	Methods
pH, Electrical Conductivity (EC) and Total Dissolve Solids (TDS)	Portable field units
Carbonates (CO_3^{2-}) and Bicarbonates (HCO_3^-)	Potentiometric method
Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Total Hardness (TH)	Titration methods
Sodium (Na^+) and Potassium (K^+)	Flame Photometer method
Chlorine (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^{2-}) and Fluoride (F^-)	Spectrophotometer

Table 2 Statistical Summary of Hydro-geochemical Parameters

Parameters	Units	Minimum	Maximum	Mean
pH	No unit	7.2	8.12	7.4
EC	$\mu\text{s}/\text{cm}$	358	2420	1242.42
TDS	mg/l	198	1342	742.52
TH	mg/l	104	780	347.24
Ca^{2+}	mg/l	18	210	67.32
Mg^{2+}	mg/l	12	110	44
K^+	mg/l	2	76	15.320
Na^+	mg/l	12	327	121.10
Cl^-	mg/l	20	458	123.20
NO_3^-	mg/l	1	172	47.32
SO_4^{2-}	mg/l	0	201	82.62
F^-	mg/l	0.01	1.6	0.589
HCO_3^{2-}	mg/l	158	756	432.12

Table 3 Classification of groundwater quality for suitability of Irrigation purpose

Parameters	Range	Classifications of Water	No. of Samples
EC (Wilcox 1955)	< 250	Excellent	-
	250 - 750	Good	10
	750- 2000	Permissible	33
	2000-3000	Doubtful	9
	>3000	Unsuitable	1
SAR (Richards 1954)	<10	Excellent	24
	10-18	Good	17
	18-26	Doubtful	5
	>26	Unsuitable	7
Na % (Wilcox 1955)	<20	Excellent	2
	20- 40	Good	15
	40-60	Permissible	26
	60-80	Doubtful	9
	>80	Unsuitable	1
Na % (Eaton 1950)	<60	Safe	41
	>60	Unsafe	12
TDS in mg/l (Ayers and Westcott 1985; UCCC 1974)	<450	No Saline	13
	450 - 2000	Slightly Saline	39
	> 2000	Severe Saline	1
Permeability (Doneen 1964)		Class I	45
		Class II	6
		Class III	2
Kellys Ratio (KR)	<1	Suitable	45
	>1	Unsuitable	8

Table 4 Irrigation water Classification based on EC (Richards 1954)

EC ($\mu\text{S}/\text{cm}$)	Water Category	% of the Samples
<250 $\mu\text{S}/\text{cm}$	Low Saline	-
250 $\mu\text{S}/\text{cm}$ -750 $\mu\text{S}/\text{cm}$	Medium Saline	18
750 $\mu\text{S}/\text{cm}$ -2250 $\mu\text{S}/\text{cm}$	High saline	62
>2250 $\mu\text{S}/\text{cm}$	Very High saline	20

Table 5 Irrigation water categories based on USSL Classification

Type of Water	Category of water	% of Samples
C2S1	Medium Salinity with Low alkalinity	19
C3S1	High Salinity with Low Alkalinity	57
C4S1	Very High salinity with low alkalinity	11
C3S2	High Salinity with medium alkalinity	7
C4S2	Very high salinity with medium alkalinity	6

Figures

Figure 1
Location map of the study area with sampling points

Figure 2

Concentration of TDS and Electrical Conductivity (EC)

Figure 3

USSL diagram of groundwater samples in study area, Bhavani taluk

Figure 4

Classification of groundwater based on Salinity (SAR and EC) in study area

Figure 5

Classification of Groundwater to the % Na in the groundwater samples

Figure 6

Wilcox diagram of the groundwater samples in study area, Bhavani taluk

**Classification of Irrigation Water for
Soils of Medium Permeability (Doneen)
Pre-Monsoon**

Figure 7

Permeability Index diagram classification of groundwater in study area, Bhavani taluk

Figure 8

Piper's trilinear plot of the major ions of groundwater in the study area, Bhavani taluk