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Evaluation of ground water suitability for irrigation in Vansda taluka of Navsari district of South Gujarat

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Abstract
The ground water quality of Vansda taluka has been assessed to see the suitability of ground water for irrigation applications. Groundwater samples were collected before and after monsoon in the year 2020-2021 for various water quality characteristics from ten villages of Vansda taluka of Navsari district by using GPS system. The suitability of ground water for irrigation purpose was evaluated based on salinity, Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Magnesium Hazard (MH), Sodium percent (%Na), permeability index (PI) and Irrigation water quality index (IWQI). In general, the ground water of Vansda taluka is safe for irrigation purpose. Overall in Vansda taluka, 70% and 45% surveyed water samples were found falling in no restriction to medium restriction category of irrigation during before and after monsoon respectively.

Keywords: Groundwater, IWQI, RSC, SAR, MH

1. Introduction

Ground water plays a very important role in agriculture, for both watering of crops and for irrigation of dry season crops. Groundwater quality is considered of great importance with rapid industrialization. Deterioration in groundwater quality has an adverse impact on plant growth. Soil becomes saline and the permeability of soil decreases if the inferior water is used continuously without proper drainage for irrigation purpose. The quality of crop and yield are affected by irrigation water quality (Shyamala *et al.* 2008) [18]. Determination of water quality is the most important aspect to determine its suitability to grow crops. Mapping of groundwater quality become one of the best approaches which provide the information about the suitability of the water for irrigation purpose. Water is one of the most important inputs required for crop production. India accounts for 2.2% of the global land and 4% of the world's water resources and accommodates 16% of the world's population (Ramesh and Elango, 2011) [16]. Water Quality Index (WQI) is a very useful and efficient method to evaluate the suitability of water quality and for communicating the information on overall quality. The quality of the irrigation water has to be evaluated to avoid or, at least, to minimize impacts on agriculture. The integration of the geographic information system (GIS) platform to the assessment procedure not only allows the decision maker to create parameter maps for easy visual interpretation.

2. Location and Methodology

Gujarat is situated on the west coast of India and lies between 20001' and 24000' North latitude and 68004' and 74004' East longitude. Navsari district is located between 20007' and 21000' North latitude and 72043' and 73000' East longitude. Groundwater samples were collected by using GPS system before and after monsoon in the year 2020-2021 for various water quality characteristics from ten villages of Vansda taluka of Navsari district, AES-III of South Gujarat heavy rainfall zone. The samples were collected in prewashed polyethylene narrow mouth bottles (three times rinsed with same water to be sampled). Locations (longitude and latitude) of sampling point were measured by using a global positioning system (GPS). Details of sampling locations and name of villages are presented in Table 1.

Table 1: Sampling sites along with the coordinates

Sr. No.	Sample location		Longitude	Latitude
	Taluka / Village			
1	Vansda	Gargpur-1	20 43.307	73 20.238
2		Gargpur-2	20 59.561	72 57.717
3		Lachhakadi-1	20 42.356	73 20.370
4		Lachhakadi-2	20 42.319	73 20.106
5		Pipalkhed-1	20 40.529	73 16.751
6		Pipalkhed-2	20 40.597	73 16.985
7		Khanpur-1	20 36.190	73 14.657
8		Khanpur-2	20 36.035	73 15.190
9		Vanarasi-1	20 45.787	73 20.181
10		Vanarasi-2	20 45.671	73 20.693
11		Navtal-1	20 45.614	73 25.983
12		Navtal-2	20 45.612	73 25.701
13		Mahuvas-1	20 45.869	73 24.887
14		Mahuvas-2	20 46.108	73 24.391
15		Bhinar-1	20 49.133	73 19.851
16		Bhinar-2	20 49.024	73 19.715
17		Sindhai-1	20 50.949	73 19.532
18		Sindhai-1	20 50.547	73 19.803
19		Kamboya-1	20 47.118	73 14.692
20		Kamboya-2	20 46.487	73 14.378

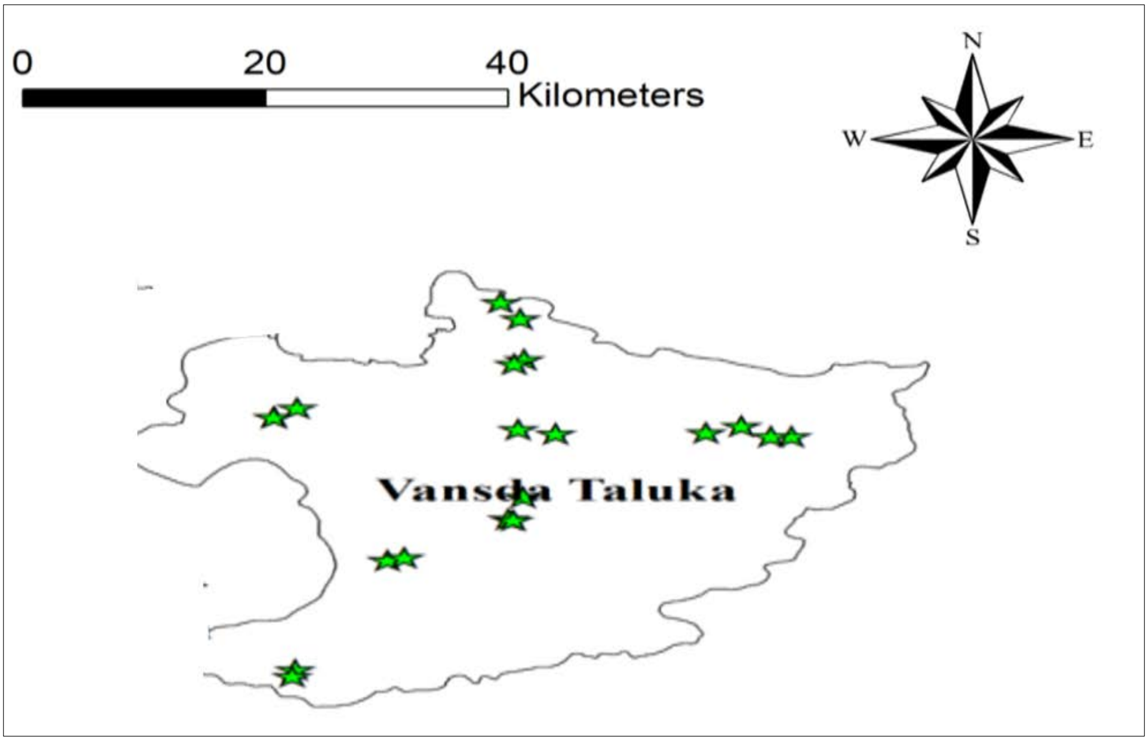

Fig 1: Location map of the sampling sites

Chemical Parameters of the Samples

The analysis of various chemical parameters was carried out as per the methods described in APHA (1998) [1]. EC and pH were measured using conductivity meter and pH meter. Sulphate (SO_4^{2-}), Nitrate (NO_3^-), Fluoride (F^-) and B content were determined by colorimetric method. Chloride (Cl^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), calcium (Ca^{2+}) & magnesium (Mg^{2+}) content were measured by the titration method, while Na^+ and K^+ were estimated by the flame photometer method.

Evaluation of Irrigation Water Quality

Concentrations of different parameters and irrigation indexes like soluble sodium percentage (SSP), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium hazard (MH), permeability index (PI), and Irrigation water quality index (IWQI) were calculated to assess groundwater quality.

Sodium Hazard (SH).

It was assessed by evaluating soluble sodium percentage and sodium absorption ratio.

Soluble Sodium Percentage (SSP)

SSP was calculated by employing the equation given by Todd (1995) [20].

$$SSP = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100. \quad (1)$$

(Ionic concentration was presented in me/l).

Alkalinity Hazard

Alkaline hazard is expressed as sodium adsorption ratio (SAR) was calculated using the equation given by Raghunath (1987) [14].

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (2)$$

Where the ionic concentration was presented in me/l.

Bicarbonate Hazard

Bicarbonate hazard is expressed as residual sodium carbonate (RSC) and was evaluated employing the following equation of Eaton (1950) [4].

$$RSC = \left(HCO_3^- + CO_3^{2-}\right) - \left(Ca^{2+} + Mg^{2+}\right) \quad (3)$$

Where the ionic concentration was presented in me/l.

Estimation of Irrigation Water Quality Index (IWQI)

The EC, Na^+, Cl^-, HCO_3^- and SAR parameters suggested by (Meireles *et al.*, 2010) [12] have been used to calculate the IWQI. In the first step, values of the accumulation weights (wi) suggested by (Meireles *et al.*, 2010) [12] have been defined based on their relative significance to the irrigation water quality. Its normalized values and their total are equal one as shown in Table 2. Based on different parameters recommended by (Ayers and Westcot, 1994) [2], Qi value was estimated in the second step as shown in Table 3. It represents non-dimensional number with the higher value indicating a better water quality and vice versa. Qi value was calculated using the following equation:

$$Q_i = q_{imax} - \left\{\frac{\left[\left(x_{ij} - x_{inf}\right) * q_{iamp}\right]}{x_{amp}}\right\} \quad (5)$$

where qi max is a maximal value of qi for the class, xij is the observed value of chemical parameters, xinf is the minimal limit of the class to each parameter belongs; qi amp is class amplitude; and xamp is upper limit of the last class of each parameter. Finley Irrigation water quality index (IWQI) has been calculated according to the following equation:

$$IWQI = \sum_{i=1}^{n} Qi * wi \quad (6)$$

Where IWQI is the non-dimensional irrigation water quality index ranging from 0 to 100; Qi is the quality measurement of the parameter, (ith) a number from (0 to 100) is a function of its concentration; and wi is the normalized weight of the parameter. Meireles *et al.* 2010 [12], have divided the values of IWQI for the suitability of the irrigation water class into five dimensionless parameterclasses based on the proposed groundwater quality index determined by the existing groundwater quality index as shown in Table 4.

GIS Database Generation and Analysis

The results of the chemical analysis of the water samples were transferred to the GIS environment to create a water quality database in the study area, and the spatial distribution map for pH and EC has been generated using the Arc GIS 10.1 software.

3. Result and discussion

3.1 Physicochemical parameters

The different analysis parameters data of before and after monsoon water samplings are summarized in table 5.1 and 5.2. The pH values in Vansda taluka ranged from 6.91 to 7.58 with an average value of 7.32 and 7.21 to 8.52 with an average value of 7.60 during before and after monsoon respectively (Table 5.1). It is commonly observed that groundwater that is uncontaminated shows pH value in the range of 6.00–9.00 (Hitchon *et al.* 1999) [7]. The mean values of pH suggest that groundwater shows significant variation in pH during different sampling periods. The range values indicate that in the study area 100% groundwater samples during pre-monsoon as well as post-monsoon season were neutral to alkaline in reaction. All the groundwater samples belonged to the safe limit for irrigation purpose (Ayers and Westcat, 1998) [2].

Electrical conductivity (EC) represents the measure of the dissolved ions and salinity. High EC in water samples could be due to leaching or dissolution of the aquifer material or mixing of saline sources or a combination of these processes (Hem 1991; Hounslow 1995) [6, 8]. The ground water samples of the surveyed district area showed EC in the range of 0.24-1.44 dS/m with an average value of 0.58 dS/m during before monsoon and 0.48-2.25 dS/m with an average value of 1.12 dS/m during after monsoon. (Table 5.1). The increase in average value of EC after monsoon can be attributed to contribution of salts from unsaturated zone, which dissolve in the infiltrating water that ultimately reach the water table.

The average value of Sodium (me/l) concentration in the study area is 2.51 me/l and 3.40 me/l before and after monsoon respectively. The common sources of Na^+ in this region are weathering of minerals. Among other major cations, calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions are important constituents, which control the water hardness. Calcium is present in groundwater due to its easy solubility and abundance in most rock. Ca^{2+}+ Mg^{2+} ranged with a mean value of 4.42 me/l and 8.70 me/l during before and after monsoon respectively respectively (Table 5.1). Both Ca^{2+} and Mg^{2+} are derived from the silicate rocks as well as dolomitic deposits.

Chloride (Cl^-) in groundwater of this region ranged from 1.20-8.20 me/l with an average value of 3.04 me/l during monsoon and 1.40-37.00 me/l with an average value of 12.46 me/l during before and after monsoon respectively. Fluoride (F^-) in groundwater of this region ranged from 0.10 to 0.43 mg/l with a mean value of 0.27 mg/l during before monsoon and from 0.00 to 1.31 mg/l with a mean value of 0.12 mg/l during after monsoon period. Sulphate (SO_4^{2-}) in groundwater of this region ranged from 0.00 to 45.02 mg/l with a mean value of 13.49 mg/l during before monsoon and from 0.00 to 34.78 mg/l with a mean value of 9.42 mg/l during after monsoon (Table 5.2).

The Nitrate (NO_3^-) in groundwater of Vansda taluka ranged from 0.00 to 21.16 mg/l with an average value of 5.27 mg/l and 3.65-66.42 mg/l with an average value of 20.69 mg/l respectively during before and after monsoon (Table 5.2).

Suitability for irrigation

The suitability of groundwater for irrigation is mainly evaluated using electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), percent of sodium (Na%) and irrigation water quality index (IWQI).The suitability of groundwater for irrigation based on EC is classified into four groups (Richards 1954) [17]. It was found that about 80.00% of the samples fall in high salinity category (0.75-2.25 dS/m) during after monsoon in Vansda taluka. (Table 5.4).

Sodium Adsorption Ratio (SAR)

High concentration of Na^+ in irrigation water affects the soil permeability and the texture. This makes the soil hard to plough and unsuitable for seedling emergence (Trivedy and Goel 1984) [21]. This effect is monitored by sodium/alkali hazard, which is expressed as the SAR. This ratio is computed from the relative proportion of Na^+ concentration to Ca^{2+} and Mg^{2+} concentrations in a given water sample. The Sodium Adsorption Ratio shows the impact of relative cation fixation on sodium build up in the soil, consequently, continuous use of water with high SAR may cause a prolonged dent to soil. Due to the formation of stable aggregates, the soil structure is affected. Permeability of soil is reduced and in turn, crop yield is decreased. When the concentration of Na^+ ions is high in irrigation water, Na^+ replaces Ca^{2+} and Mg^{2+} ions absorbed onto the clay material. This exchange mechanism reduces the permeability of soil matter and eventually results in soil with poor internal drainage (Karanth 1987) [9].

Based on the content of soluble cations in the water samples, the index of sodicity hazard SAR was computed. The pre-monsoon season SAR was found ranged from 0.62 to 2.86 with a mean value of 1.66 while in the case of post monsoon season SAR was found ranged from 0.32 to 4.30 with a mean value of 1.74. The similar results were also reported by Ghodke *et al*. (2016) [5]. Majority of the water samples of studied taluka area fall in low alkali hazard class (S_1) during both before and after monsoon (Table 5.3). Similar results were observed by Khodapana *et al.,* 2006 [10].

Percent Sodium

According to Nagarju *et al*. (2006) [13], the percentage of soluble sodium is an important parameter in classifying irrigation water in terms of soil permeability. Sodium ion present in irrigation water tends to be exchanged by Mg^{2+} and Ca^{2+} ions present in clay particles. This exchange process reduces the permeability of soil and causes poor internal drainage and hardening of soil, which further adversely affects the soil quality & seedling emergence. (Tijani, 1994) [19]. Sodium combines with inorganic carbon (HCO_3^- and CO_3^{2-}) to form alkaline soils and combines with Cl^- to form saline soils. Both these soils are not favorable for plant growth. This effect is commonly indicated by Na% (Wilcox 1948) [22]. Excessive soil salinity and alkalinity are harmful for plant growth and crop productivity. The classification of irrigation water based on soluble sodium percentage (SSP) is given by Todd. He classified the irrigation water quality into 5 categories (excellent, good, permissible, doubtful, and unsuitable). Na% value of up to 60 in groundwater is considered as acceptable for agricultural purposes (Ramakrishna 1998) [15]. Na % in groundwater of this study area showed a wide range of variation. It was found that most of the samples fall in good class (60.00% and 35.00%) in Vansda taluka during before and after monsoon respectively (table 5.5). High Na% in water coupled with high EC decreases the osmotic activity of plants and thus, limits the absorption of water and nutrients from the soil.

Residual Sodium Carbonate (RSC)

In addition to SAR and Na%, the excess CO_3^{2-} and HCO_3^- in groundwater over the sum of Ca^{2+} and Mg^{2+} ions also influences the suitability of groundwater for irrigation. This is defined as residual sodium carbonate (RSC). Water with a carbonate concentration larger than the calcium and magnesium concentration is recognized by the term "residual sodium carbonate". If the sodium in clayey soil is higher, it causes swelling and reduces infiltration capacity. The water samples containing excess of CO_3^{2-} and HCO_3^- precipitate $CaCO_3$ in soil from solution and increase Na^+ concentration in water. This results in soil dispersion and limits nutrient uptake by plants. This also reduces water infiltration into the soil surface and further down the soil profile, thus limiting aeration and leading to reduced crop growth. Water with RSC less than 1.25 is suitable for irrigation, whereas marginally suitable up to 2.50 and not suitable for irrigation above 2.50 (Lloyd and Heathcote 1985) [11]. The RSC in groundwater of Vansda ranged from 0.00 to 3.80 me/l with an average value of 1.50 me/l and 0.00 to 2.20 me/l with an average value of 1.10 me/l respectively during before and after monsoon (Table 5.3). Majority of the samples falls under safe category in Vansda taluka. The higher mean value of RSC was found during before monsoon than after monsoon, the reason behind might be dilution salts present in the ground water due to high rainfall during monsoon season in the study area, similar results were also reported by Ghodke *et al.* (2016) [5]. In the natural water system, magnesium and calcium maintain a state of equilibrium. High value of any one of the cations can increase soil pH and reduces infiltration capacity of soil, which adversely influences the crop yield.

Chloride hazard

Cl^- is essential to plants in very low amounts, but high concentrations may cause toxicity to sensitive crops. The mean of Cl^- concentration is high in post-monsoon and high concentration of Cl^- is not absorbed by soil and therefore, water moves in the transpiration stream of the plant and accumulates in the leaves. It causes the leaf burn or drying of leaf tissue in crops, and it occurs when the absorption of Cl^- concentration exceeds the tolerance limits of the crop (Ayers and Wescot 1985). In these areas, management consideration is required for the prevention of Cl^- hazard. After monsoon, 55% of water samples were observed under medium to high chloride hazard condition. (Table 5.5). Crops such as potato (Solanum tuberosum), sorghum (Sorghum bicolor), corn (Zea mays), tomato (Solanum lycopersicum), sugar-beet (Beta vugaris), barley (Hordeom vulgare), asparagus (Asparagus officinaly), and cauliflower (Brassica oleracea var.botrytis) are susceptible to medium-to-high Cl^- hazard zones (Ayers and Wescot 1985).

Irrigation water quality index (IWQI)

The Irrigation water quality index (IWQI) has been calculated according to the following equation:

$$IWQI = \sum_{i=1}^{n} Qi * wi$$

Where IWQI is the non-dimensional irrigation water quality index ranging from 0 to 100; Qi is the quality measurement of the parameter, (ith) a number from (0 to 100) is a function of its concentration; and wi is the normalized weight of the parameter. Meireles *et al.* 2010 [12], have divided the values of IWQI for the suitability of the irrigation water class into five dimensionless parameter classes based on the proposed groundwater quality index determined by the existing groundwater quality index. The classes were defined based on salinity hazard problems, soil water infiltration reduction, and toxicity to plants as suggested by (Bernardo, 1995) [3].

The analysis of IWQI shows that the suitability of groundwater for irrigation in the studied area is divided into five classifications of water use restrictions. Based on IWQI, 25%, of groundwater fall in the low-restricted restriction categories in Vansda taluka and could be used for irrigation directly without any processing as well as before monsoon, the 30.00% & 20.00% of the studied samples fall in the moderate and highly restricted for use classification respectively, which means they can be used in soils with high permeability without compact layers, requiring moderate leaching of salts to ensure no harm to plants. While after monsoon, 30.00%, of ground water fall in high restriction category in study area.

Conclusion

The percentage of surveyed samples were found falling in no restriction to medium restriction category of irrigation water of Vansda (70% and 45%) during before and after monsoon, respectively. The pH of water samples in the study area was neutral to alkaline in nature. All the water samples were classified as high-salinity water (C_3) groups and low-sodium water (S_1) groups. During the post-monsoon season pH, EC, SAR and RSC values of the groundwater were found to decrease due to the dilution of groundwater during monsoon season. Due to the presence of salinity hazards in the groundwater, it will be better to use the surface water for irrigation purposes. If there is less availability of surface water, irrigation with groundwater should be done after ensuring well drainage facilities in the field. In addition to this, good soil water management strategies will help in maintaining adequate saltwater balance for appropriate crop growth. Pre-dominance of cations such as magnesium and calcium in the groundwater indicated pollution to anthropogenic activities. Thus, the study reveals that most of the groundwater samples have exceeded their permissible limits in the irrigation water. High salinity and chloride hazards may reduce the crop production and growth; which may require careful management and special type of irrigation practices to avoid crop failures. The overall results of the study indicate alarming situation with reference to groundwater quality and it may need suitable remedial measures. To reduce the higher chemical concentrations in the groundwater artificial recharge techniques maybe worked out or alternatively suitable crops may be adopted to sustain the present groundwater quality.

Table 2: Weights for the IWQI parameters according to Meireles *et al.*, 2010 [12]

Parameter	Weight (wi)
EC	0.211
Na^{+1}	0.204
HCO_3^-	0.202
Cl^-	0.194
SAR	0.189
Total	1.0

Table 3: Limiting values of (qi) calculations (Ayers and Westcot, 1994) [2].

HCO_3^{-1}	Cl^-	Na^+	SAR	EC (µS/cm)	*Qi*
(meq/l)			$(meq/l)^{1/2}$		
1 ≤ HCO3 < 1.5	1 ≤ Cl< 4	2 ≤ Na < 3	2 ≤ SAR < 3	200 ≤ EC< 750	85-100
1.5 ≤ HCO3< 4.5	4 ≤ Cl< 7	3 ≤ Na < 6	3 ≤ SAR < 6	750 ≤ EC < 1500	60-85
4.5≤HCO3< 8.5	7 ≤ Cl< 10	6 ≤ Na < 9	6 ≤ SAR< 12	1500 ≤ EC< 3000	35-60
HCO3< 1 or HCO3 ≥ 8.5	1 <Cl ≥ 10	Na < 2 or Na ≥ 9	2 ≤ SAR ≥ 12	EC < 200 or EC ≥ 3000	0-35

Table 4: Irrigation Water Quality Index Characteristics (Meireles *et al*. 2010) [12].

Recommendation		***Water use restrictions***	***IWQI***
Plant	***Soil***		
No toxicity risk for most plants”	May be used for the majority of soils with low probability of causing salinity and sodicity problems. Leaching recommended within irrigation practices”.	No restriction (NR)	85-100
Avoid salt sensitive plants	Recommended for use in irrigated soils with light texture or moderate permeability. Salt leaching recommended. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay	Low restriction (LR)	70-85
Plants with moderate tolerance to salts may be grown	May be used in soils with moderate to high permeability values, moderate leaching of salts suggested.	Moderate restriction (MR)	55-70
Should be used for the irrigation of plants with moderate to high tolerance to salts with special salinity control practices.	May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 µS cm-***1*** and SAR above 7.0	High restriction (HR)	40 - 55
Only plants with high salt tolerance, except for waters with extremely low values of Na+, Cl- and HCO***3-***	Should be avoided for irrigation under normal conditions. May be used occasionally in special cases, Water with low salt levels and high SAR require gypsum application. In high saline water, soils must have high permeability.	Severe restriction (SR)	0-40

Table 5: Statistics of Groundwater Chemistry of Vansda taluka

Sample no.	Before monsoon				After monsoon			
	pH	EC (dS/m)	Ca+ Mg (me/l)	Na (meq/lit)	pH	EC (dS/m)	Ca+ Mg (me/l)	Na (meq/lit)
1	7.12	1.13	7.00	5.13	7.21	1.38	6.80	5.57
2	7.05	0.64	5.40	1.56	7.46	1.50	12.20	5.07
3	7.14	0.47	4.40	2.31	7.91	0.97	12.80	1.58
4	7.42	0.43	3.60	2.52	7.59	0.58	9.40	2.62
5	7.21	0.45	4.00	1.05	8.32	0.48	3.40	3.89
6	7.41	0.33	2.80	2.80	7.96	0.83	2.40	4.02
7	7.23	0.54	3.80	3.14	7.45	0.56	4.60	4.59
8	7.41	0.37	2.40	2.10	7.84	1.27	4.80	2.08
9	6.91	0.59	3.20	1.29	7.21	2.25	10.00	3.41
10	7.12	0.61	4.00	2.20	7.31	0.68	17.20	12.60
11	7.58	0.24	1.60	0.70	7.46	0.98	6.20	0.66
12	7.43	0.45	3.60	1.62	7.27	0.77	8.80	1.06
13	7.56	0.35	2.80	0.74	7.54	1.14	7.00	0.61
14	7.57	0.38	3.60	1.56	7.26	2.16	10.20	1.58
15	7.05	1.44	10.20	5.06	7.71	1.45	5.00	4.60
16	7.53	0.68	5.60	4.78	7.31	1.28	13.20	3.31
17	7.34	1.04	9.00	3.55	7.91	0.93	11.20	3.39
18	7.49	0.68	5.00	4.52	7.49	1.32	7.40	4.06
19	7.44	0.42	3.80	1.84	7.30	0.98	12.00	1.34
20	7.41	0.35	2.60	1.74	8.52	0.82	9.40	2.04
Mean	7.32	0.58	4.42	2.51	7.60	1.12	8.70	3.40
Max.	7.58	1.44	10.20	5.13	8.52	2.25	17.20	12.60
Min.	6.91	0.24	1.60	0.70	7.21	0.48	2.40	0.61
Std. dev.	0.20	0.30	2.16	1.42	0.37	0.48	3.78	2.63

Table 6: Statistics of different anions of Groundwater of Vansda taluka

Sample no.	Before monsoon				After monsoon			
	Cl^- (me/l)	F^- (ppm)	SO_4^{2-} (ppm)	NO_3^- (ppm)	Cl^- (me/l)	F^- (ppm)	SO_4^{2-} (ppm)	NO_3^- (ppm)
1	8.20	0.314	13.97	4.01	37.00	0.00	19.87	9.12
2	3.00	0.360	19.87	13.50	7.40	0.13	29.81	7.66
3	1.20	0.152	0.00	16.42	29.60	0.14	13.35	26.64
4	2.00	0.260	34.16	0.00	10.20	0.18	4.97	38.32
5	1.80	0.307	0.00	0.00	1.40	0.00	11.80	4.74
6	1.80	0.233	7.76	0.00	27.80	0.01	0.62	3.65
7	2.60	0.196	13.66	0.00	4.60	0.03	0.00	28.47
8	1.60	0.255	30.74	6.93	30.60	0.06	2.17	39.05
9	2.40	0.350	4.04	10.22	3.00	0.21	3.11	14.60
10	2.60	0.415	0.00	0.00	7.20	0.32	0.00	5.84
11	1.40	0.217	0.00	14.23	7.40	0.17	4.97	25.91
12	2.40	0.145	19.56	1.82	8.60	0.06	1.86	10.22
13	2.40	0.365	1.55	10.22	11.20	0.26	6.21	22.63
14	2.40	0.140	18.01	0.00	11.40	0.17	4.04	12.77
15	6.20	0.103	45.02	0.00	18.20	0.19	34.78	66.42
16	4.20	0.393	4.35	21.17	16.20	0.37	8.07	22.99
17	5.20	0.195	27.01	2.92	4.60	0.10	26.08	31.39
18	4.00	0.432	24.84	0.00	4.20	0.02	11.49	14.96
19	3.00	0.227	5.28	0.00	3.40	0.00	1.55	12.77
20	2.40	0.265	0.00	4.01	5.20	0.07	3.73	15.69
Mean	3.04	0.27	13.49	5.27	12.46	0.12	9.42	20.69
Max.	8.20	0.43	45.02	21.16	37.00	1.31	34.78	66.42
Min.	1.20	0.10	0.00	0.00	1.40	0.00	0.00	3.65
Std. dev.	1.75	0.10	13.48	6.68	10.63	0.11	10.39	15.19

Table 6: SSP, SAR, MH and PI of groundwater of Vansda taluka

Sample no.	Before monsoon					After monsoon				
	SSP (%)	SAR	MH	PI	RSC	SSP (%)	SAR	MH	PI	RSC
1	42.47	2.74	57.14	54.0	1.5	45.03	3.02	32.35	63.1	0.6
2	22.43	0.95	51.85	44.6	1.4	29.39	2.05	47.54	35.1	1.6
3	34.45	1.56	54.55	59.3	2.4	11.20	0.63	90.63	21.8	0.1
4	41.22	1.88	66.67	61.8	0.4	21.81	1.21	78.72	32.3	1.2
5	20.85	0.74	50.00	42.5	1.3	53.44	2.98	23.53	80.1	0.8
6	50.13	2.37	21.43	67.9	3.8	62.67	3.67	50.00	93.0	1.6
7	45.34	2.27	52.63	62.3	1.6	49.98	3.02	56.52	76.1	1.4
8	46.76	1.92	16.67	71.0	1.4	30.28	1.34	75.00	64.0	0.8
9	28.82	1.02	50.00	58.6	1.8	25.49	1.53	64.00	45.7	2.2
10	35.49	1.55	50.00	58.3	2.0	42.29	4.30	95.35	46.2	0.1
11	30.52	0.78	12.50	69.3	1.4	9.77	0.38	80.65	34.9	1.8
12	31.09	1.21	38.89	56.7	1.4	10.84	0.51	88.64	28.3	0.6
13	20.93	0.62	21.43	42.7	2.7	8.06	0.32	65.71	38.0	0.3
14	30.30	1.16	44.44	49.6	1.0	13.46	0.70	76.47	32.4	0.0
15	33.22	2.24	68.63	51.0	0.8	48.00	2.91	68.00	78.5	1.4
16	46.12	2.86	78.57	61.6	0.3	20.06	1.29	89.39	36.7	0.7
17	28.35	1.67	71.11	43.0	0.0	23.30	1.43	53.57	45.6	0.6
18	47.72	2.86	68.00	64.4	1.0	35.69	2.11	75.68	62.2	2.2
19	32.65	1.33	42.11	52.0	2.9	10.13	0.55	81.67	37.7	2.0
20	40.20	1.53	30.77	63.1	0.9	17.92	0.94	82.98	47.1	2.0
Mean	35.45	1.66	47.37	56.69	1.5	28.44	1.74	68.82	49.94	1.10
Max.	50.13	2.86	78.57	71.01	3.8	62.67	4.30	95.35	92.98	2.20
Min.	20.85	0.62	12.50	42.46	0.0	8.06	0.32	23.53	21.77	0.00
Std. dev.	9.13	0.71	19.04	8.96	0.9	16.79	1.20	19.67	20.04	0.73

Table 7: Suitability of groundwater for irrigation based on salinity hazard

Conductivity (dS/m)	Water class	Percentage of samples (Vansda taluka)		Inference
		Before monsoon	After monsoon	
0-0.25	Low salinity	5.00	0.00	• Can be used for most soil for most crops • Little likelihood of salinity
0.25 to < 0.75	Medium salinity	80.00	20.00	• Can be used with moderate leaching • Moderate salt tolerant crops should be grown
0.75 -2.25	High salinity	15.00	80.00	• Cannot be used where drainage is restricted • Salt tolerant plant and additional manage-ment practices should be followed
>2.25	Very high salinity	0.00	0.00	• Not suitable for irrigation • Can be used occasionally with leaching • Salt tolerant crop should be grown with additional management practices

Table 8: Classification of groundwater on the basis of percent sodium and chloride hazard.

Percent sodium				Chloride hazard			
Na%	Class	Before monsoon	After monsoon	Cl^- (me/l)	Class	Before monsoon	After monsoon
<20	Excellent	0.00	35.00	0-4	Low	75.00	15.00
20-40	Good	60.00	35.00	4-7	Medium	20.00	20.00
40-60	Permissible	40.00	25.00	7-12	High	5.00	35.00
60-80	Doughtful	0.00	5.00	12-20	Doughtful	0.00	10.00
>80	Unsuitable	0.00	0.00	>20	Unsuitable	0.00	20.00

Table 9: Classification of groundwater on the basis of bicarbonate hazard.

RSC (me/l)	Class	Percentage of samples (Vansda taluka)		Inference
		Before monsoon	After monsoon	
<1.25	Safe	100.00	70.00	Probably safe for most purpose
1.25-2.5	Marginal	0.00	25.00	Marginal can be used on light textured soil with adequate leaching and application of gypsum
>2.5	Unsuitable	0.00	5.00	Not suitable for irrigation purposes

Table 10: Classification of groundwater on the basis of IWQI.

Value (me/l)	Class	Percentage of samples (Vansda taluka)	
		Before monsoon	After monsoon
0-40	Severe restriction (SR)	10.00	25.00
40-55	High restriction (HR)	20.00	30.00
55-70	Moderate restriction (MR)	30.00	25.00
70-85	Low restriction (LR)	25.00	20.00
>85	No restriction (NR)	15.00	0.00

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