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Analysis of Water Quality of Selected Irrigation Water Sources in Gandevi Taluka of Navsari District of South Gujarat, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Groundwater quality was evaluated for irrigation purpose by collecting the groundwater samples from 20 different locations during pre-monsoon and post-monsoon seasons. These groundwater samples were analyzed for physico-chemical parameters like pH, EC, TDS, major cations, and anions. Furthermore, irrigation quality indices like salinity hazard, chloride hazard, magnesium hazard, carbonate and bicarbonate hazard and sodium hazard were calculated using the analytical results. The average SAR, Na⁺ ion, PI, MH and IWQI varied from 6.34 to 2.53, 14.13 to 5.44 me/l, 68.31 to 56.76 me/l, 73.16 to 76.72 %, and 44.24 to 31.25 me/l, during pre-monsoon and post-

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monsoon seasons respectively. Based on the EC, more than 50% of the samples are falling under high salinity category in both seasons. Overall in Gandevi taluka, based on IWQI, 40 % and 45 % surveyed water samples were found falling in severe restriction category of irrigation during before and after monsoon respectively. The study revealed that most of the water samples are exceeding the critical levels of irrigation water quality and it may require careful management to grow suitable crops in the study area. In addition, the study also points out that usage of such a high TDS groundwater for irrigation may cause soil salinity.

Keywords: Groundwater; IWQI; RSC; SAR; MH and water quality.

1. INTRODUCTION

“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 approach which provide the information about the suitability of the water for irrigation purpose. 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” [1]. “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” [2]. “Determination of water quality is the most important aspect to determine its suitability to grow crops. Mapping groundwater quality has become one of the best approaches to provide the information about water's suitability 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” [3]. 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.

2. 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 2021-2022 for various water quality characteristics from ten villages of Gandevi 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.

2.1 Chemical Parameters of the Samples

The analysis of various chemical parameters was carried out as per the methods described in APHA [4]. EC and pH were measured using conductivity meter and pH meter. Sulphate (SO_4^{2-}), nitrate (NO_3^-), fluoride (F^-) and boron (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 sodium ion (Na^+) and potassium ion (K^+) were estimated by the flame photometer method.

2.2 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 [5].

2.3 Sodium Hazard (SH)

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

Table 1. Sampling sites along with the coordinates

Sr. No.	Sample location Taluka / Village	Longitude	Latitude
1	Ancheli-1	20 50.677	72 56.735
2	Ancheli-2	20 50.766	72 56.877
3	Amalsad-1	20 49.373	72 57.046
4	Amalsad-2	20 48.350	72 57.204
5	Undach-1	20 45.224	72 59.337
6	Undach-2	20 45.199	72 59.325
7	Kalamtha-1	20 46.786	72 56.537
8	Kalamtha-2	20 46.904	72 56.452
9	Devsar-1	20 46.891	72 58.764
10	Devsar-2	20 47.012	72.59.030
11	Nandarkha-1	20 46.340	73 00.445
12	Nandarkha-2	20 46.101	73 00.644
13	Gandeva-1	20 52.054	73 04.686
14	Gandeva-2	20 52.244	73 04.723
15	Vadsangal-1	20 49.394	73 00.652
16	Vadsangal-2	20 49.207	73 00.778
17	Pathri-1	20 50.456	73 00.223
18	Pathri-2	20 50.480	73 00.497
19	Sonwadi-1	20 51.166	72 58.563
20	Sonwadi-2	20 51.174	72 58.342

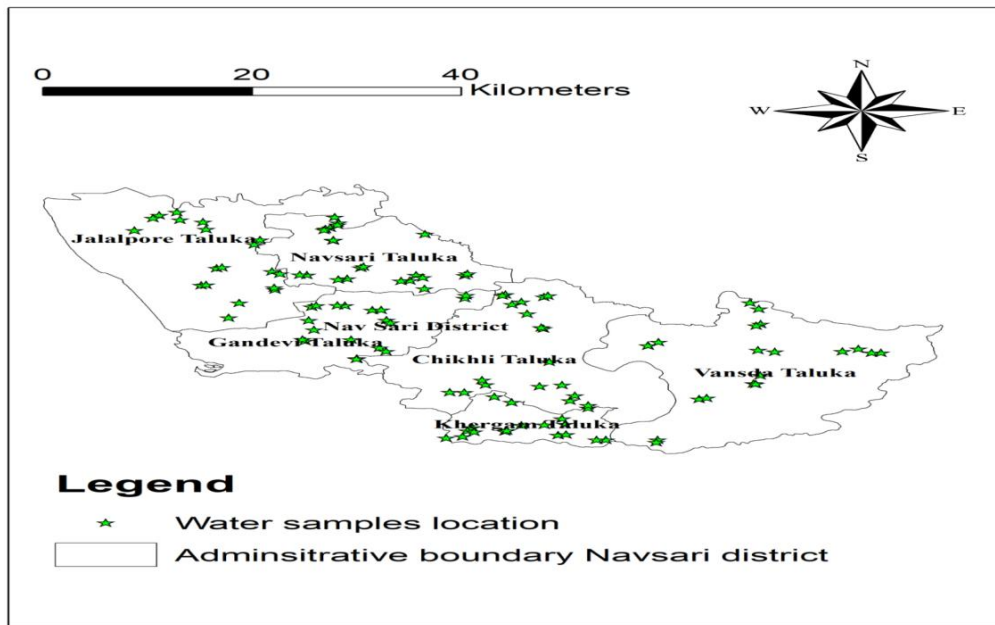


Fig. 1. Location map of the sampling sites

2.4 Soluble Sodium Percentage (SSP)

SSP was calculated by employing the equation given by Todd [6].

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

2.5 Alkalinity Hazard

Alkaline hazard is expressed as sodium adsorption ratio (SAR) was calculated using the equation given by Raghunath [7].

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

2.6 Bicarbonate Hazard

Bicarbonate hazard is expressed as residual sodium carbonate (RSC) and was evaluated employing the equation of Eaton [8] $RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{+2} + Mg^{+2})$

2.7 Estimation of Irrigation Water Quality Index (IWQI)

The EC, Na⁺, Cl⁻, HCO₃⁻ and SAR parameters suggested by Meireles et al. [9] have been used to calculate the IWQI. In the first step, values of the accumulation weights (wi) suggested by Meireles et al. [9] 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 [10], 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:

$$Q_i = \frac{q_{i\max} - [(x_{ij} - x_{inf}) * q_{iamp}]}{x_{amp}}$$

where $q_{i\max}$ is a maximal value of q_i for the class, x_{ij} is the observed value of chemical parameters,

x_{inf} is the minimal limit of the class to each parameter belongs; q_i amp is class amplitude; and x_{amp} is upper limit of the last class of each parameter. Finley Irrigation water quality index (IWQI) has been calculated according to the following equation:

$$IWQI = \sum_{i=1}^n Q_i * w_i$$

Where IWQI is the non-dimensional irrigation water quality index ranging from 0 to 100; Q_i is the quality measurement of the parameter, (i^{th}) a number from (0 to 100) is a function of its concentration; and w_i is the normalized weight of the parameter. Meireles et al. 2010, 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 as shown in Table 4.

2.8 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.

Table 2. Weights for the IWQI parameters according to Meireles et al. [9]

Parameter	Weight (wi)
EC	0.211
Na ⁺	0.204
HCO ₃ ⁻	0.202
Cl ⁻	0.194
SAR	0.189
Total	1.0

Table 3. Limiting values of (Qi) calculations [10]

HCO ₃ ⁻	Cl ⁻ (me/l)	Na ⁺	SAR (me/l) ^{1/2}	EC (µS/cm)	Qi
1 ≤ HCO ₃ < 1.5	1 ≤ Cl < 4	2 ≤ Na < 3	2 ≤ SAR < 3	200 ≤ EC < 750	85-100
1.5 ≤ HCO ₃ < 4.5	4 ≤ Cl < 7	3 ≤ Na < 6	3 ≤ SAR < 6	750 ≤ EC < 1500	60-85
4.5 ≤ HCO ₃ < 8.5	7 ≤ Cl < 10	6 ≤ Na < 9	6 ≤ SAR < 12	1500 ≤ EC < 3000	35-60
HCO ₃ < 1 or HCO ₃ ≥ 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 [9]

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 $\mu\text{S cm}^{-1}$ and SAR above 7.0	High restriction (HR)	40 -55
Only plants with high salt -	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

3. RESULT AND DISCUSSION

3.1 Physicochemical Parameters

The different analyzed parameters data of water samplings are summarized in Table 5(a) and 5(b).

The pH values in Gandevi taluka ranged from 7.33 to 8.98 with an average value of 8.29 and 8.02 to 9.00 with an average value of 8.60 during before and after monsoon respectively. (Table 5(a)). It is commonly observed that groundwater that is uncontaminated shows pH value in the range of 6.00–9.00 [11]. “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 alkaline in reaction. The acceptable level of irrigation water pH ranges between 6.5 and 8.4. Therefore, most of the pH values of the studied area are not within the acceptable limits for irrigation purposes” [10].

“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” [12]. The ground water samples of the surveyed district area showed EC in the range of 0.42-7.90 dS/m with an average value of 2.63 dS/m during before monsoon and 0.88-8.53 dS/m with an average value of 2.37 dS/m during after monsoon. (Table 5b). 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 concentration in the study area is 14.13 me/l and 5.44 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 11.36 me/l and 9.80 me/l during before and after monsoon respectively (Table 5.a). Both Ca^{2+} and Mg^{2+} are derived from the silicate rocks as well as dolomitic deposits.

Table 5 (a) Statistics of groundwater chemistry of Gandevi taluka

Sample no.	Before monsoon				After monsoon			
	pH	EC (dS/m)	Ca+ Mg (me/l)	Na (me/l)	pH	EC (dS/m)	Ca+ Mg (me/l)	Na (me/l)
1	8.41	1.06	9.80	8.78	8.43	1.79	14.00	5.16
2	8.49	0.42	3.00	1.30	8.62	3.27	24.40	2.67
3	8.64	2.60	5.40	18.19	8.30	2.52	8.00	3.08
4	8.83	2.20	7.20	23.82	8.91	2.71	4.00	4.11
5	8.02	1.06	5.80	4.67	8.52	1.70	10.00	3.20
6	7.89	1.30	9.00	7.27	8.02	1.80	7.60	1.31
7	8.62	6.80	35.80	34.02	8.85	8.42	11.60	13.42
8	8.71	7.80	42.80	35.31	8.63	0.88	5.00	3.25
9	7.79	7.90	19.40	34.17	8.20	8.53	20.20	17.94
10	7.63	4.60	19.20	11.44	8.19	6.20	19.40	16.85
11	8.49	3.70	12.80	19.04	8.61	5.90	11.60	3.17
12	8.35	4.20	12.00	23.93	8.88	3.51	4.00	14.86
13	8.98	1.20	2.60	15.36	9.00	1.82	2.00	2.41
14	8.93	0.91	2.00	10.57	8.91	1.20	3.20	0.73
15	8.10	1.62	8.40	8.00	8.58	1.84	12.20	1.96
16	8.17	1.07	8.60	4.17	8.65	1.35	9.40	4.89
17	8.61	0.61	1.80	3.83	8.65	1.15	6.00	1.68
18	8.26	1.55	6.00	8.76	8.79	1.69	6.60	2.47
19	7.33	0.98	9.00	3.56	8.58	1.69	11.80	4.75
20	7.45	0.97	6.60	6.46	8.71	1.20	5.00	0.84
Mean	8.29	2.63	11.36	14.13	8.60	2.96	9.80	5.44
Max.	8.98	7.90	42.80	35.31	9.00	8.53	24.40	17.94
Min.	7.33	0.42	1.80	1.30	8.02	0.88	2.00	0.73
Std. dev.	0.48	2.41	10.77	10.93	0.27	2.37	6.06	5.50

Table 5 (b) Statistics of different anions of groundwater of Gandevi 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	3.4	0.003	54.96	40.87	15.8	0.05	22.36	27.37
2	2.6	0.000	0.00	23.36	28.6	0.38	18.32	20.80
3	8.0	0.000	124.20	13.50	6.0	0.28	4.97	23.72
4	5.4	0.345	66.45	40.14	24.8	0.00	55.89	20.80
5	10.0	0.000	51.85	13.87	7.2	0.00	13.66	39.05
6	4.2	0.007	58.68	24.45	3.4	0.04	0.00	22.63
7	26.8	0.000	177.61	10.58	74.8	0.38	63.03	15.33
8	28.0	0.195	186.30	29.20	4.6	0.00	46.58	20.07
9	35.4	0.171	109.61	10.95	60.8	0.00	155.87	54.38
10	22.6	0.124	126.37	25.55	77.2	0.00	131.03	82.84
11	20.0	0.184	127.31	14.23	56.2	0.00	69.24	22.26
12	22.0	0.021	193.13	36.49	22.4	0.00	82.59	45.25
13	4.8	0.252	41.61	24.09	8.4	0.15	47.51	27.01
14	3.0	0.271	6.21	24.45	4.0	0.33	14.59	20.44
15	8.0	0.184	146.56	19.34	78.8	0.00	74.83	33.21
16	5.0	0.208	121.10	31.39	10.6	0.08	66.76	40.51
17	3.0	0.196	0.00	17.15	2.0	0.00	20.18	136.13
18	5.4	0.000	58.37	19.34	10.2	0.00	35.09	125.54
19	3.4	0.000	39.12	29.20	13.6	0.08	42.54	29.93
20	4.6	0.079	29.19	33.21	6.2	0.00	28.57	16.79
Mean	11.28	0.11	85.93	24.07	25.78	0.09	49.68	41.20
Max.	35.40	0.34	193.13	40.87	78.80	0.38	155.87	136.13
Min.	2.60	0.00	0.00	10.58	2.00	0.00	0.00	15.33
Std. dev.	10.33	0.11	61.88	9.31	27.30	0.14	40.28	34.51

Table 5(c). SSP, SAR, MH and PI of groundwater of Gandevi taluka

Sample no.	Before monsoon					After monsoon				
	SSP (%)	SAR	MH	PI	RSC	SSP (%)	SAR	MH	PI	RSC
1	47.31	3.97	71.43	58.8	0.0	27.05	1.95	91.43	36.0	0.0
2	30.34	1.06	46.67	63.1	0.0	9.98	0.77	92.62	18.5	0.0
3	77.15	11.07	74.07	87.5	1.6	27.99	1.54	37.50	52.7	1.2
4	77.35	12.56	86.11	84.7	0.0	53.45	2.91	70.00	90.4	7.4
5	44.71	2.74	68.97	63.7	0.0	24.29	1.43	78.00	41.2	0.0
6	44.80	3.43	82.22	55.7	0.0	15.04	0.67	76.32	39.8	0.0
7	49.85	8.04	86.59	53.1	0.0	55.68	5.57	87.93	67.4	1.4
8	46.40	7.63	95.79	48.8	0.0	39.42	2.06	60.00	61.7	0.0
9	63.82	10.97	85.57	67.1	0.0	47.12	5.64	76.24	51.6	0.0
10	37.96	3.69	68.75	44.3	0.0	46.80	5.41	77.32	50.4	0.0
11	59.90	7.53	89.06	66.4	0.0	21.87	1.31	91.38	39.1	0.0
12	66.67	9.77	83.33	72.8	0.0	78.83	10.51	75.00	94.2	5.4
13	85.53	13.47	61.54	99.2	6.4	54.76	2.41	60.00	116.3	6.2
14	84.10	10.57	30.00	103.6	5.0	19.01	0.58	81.25	94.1	6.2
15	48.83	3.90	78.57	61.0	0.0	13.97	0.79	90.16	23.8	0.0
16	32.76	2.01	86.05	47.5	0.0	34.28	2.25	87.23	45.9	0.0
17	68.05	4.03	33.33	107.8	4.4	22.36	0.97	66.67	56.3	2.0
18	59.38	5.06	73.33	70.3	0.0	27.33	1.36	81.82	57.6	1.8
19	28.54	1.68	80.00	44.7	0.0	28.84	1.96	69.49	39.2	0.0
20	49.68	3.56	81.82	66.2	0.0	14.85	0.53	84.00	59.1	2.8
Mean	55.16	6.34	73.16	68.31	0.87	33.15	2.53	76.72	56.76	1.72
Max.	85.53	13.47	95.79	107.75	6.40	78.83	10.51	92.62	116.33	7.40
Min.	28.54	1.06	30.00	44.34	0.00	9.98	0.53	37.50	18.46	0.00
Std. dev.	17.36	3.92	17.91	19.13	1.96	17.92	2.48	13.58	25.08	2.51

Table 5(d). Suitability of groundwater for irrigation based on salinity hazard

Conductivity (dS/m)	Water class	Percentage of samples (Gandevi taluka)		Inference
		Before monsoon	After monsoon	
0-0.25	Low salinity	0.00	0.00	(i) Can be used for most soil for most crops (ii) Little likelihood of salinity
0.25 to < 0.75	Medium salinity	10.00	0.00	(i) Can be used with moderate leaching (ii) Moderate salt tolerant crops should be grown
0.75 -2.25	High salinity	55.00	60.00	(i) Cannot be used where drainage is restricted (ii) Salt tolerant plant and additional management practices should be followed
>2.25	Very high salinity	35.00	40.00	(i) Not suitable for irrigation (ii) Can be used occasionally with leaching (iii) Salt tolerant crop should be grown with additional management practices

Table 5(e). Classification of groundwater on the basis of percent sodium and chloride hazard

Percentage sodium				Chloride hazard			
Na%	Class	Before monsoon	After monsoon	Cl ⁻ (me/l)	Class	Before monsoon	After monsoon
<20	Excellent	0.00	25.00	0-4	Low	25.00	10.00
20-40	Good	20.00	45.00	4-7	Medium	30.00	20.00
40-60	Permissible	45.00	25.00	7-12	High	15.00	20.00
60-80	Doughtful	25.00	5.00	12-20	Doughtful	5.00	10.00
>80	Unsuitable	10.00	0.00	>20	Unsuitable	25.00	40.00

Table 5 (f). Classification of groundwater on the basis of bicarbonate hazard

RSC (me/l)	Class	Percentage of samples (Gandevi taluka)		Inference
		Before monsoon	After monsoon	
<1.25	Safe	80.00	60.00	Probably safe for most purpose
1.25-2.5	Marginal	5.00	15.00	Marginal can be used on light textured soil with adequate leaching and application of gypsum
>2.5	Unsuitable	15.00	25.00	Not suitable for irrigation purposes

Table 5 (g). Classification of groundwater on the basis of IWQI

Value (me/l)	Class	Percentage of samples (Gandevi taluka)	
		Before monsoon	After monsoon
0-40	Severe restriction (SR)	40	45
40-55	High restriction (HR)	10	40
55-70	Moderate restriction (MR)	25	10
70-85	Low restriction (LR)	25	5
>85	No restriction (NR)	0	0

Chloride (Cl⁻) in groundwater of this region ranged from 2.60-35.40 me/l with an average value of 11.28 me/l and 2.00-78.80 me/l with an average value of 25.78 me/l during before and after monsoon respectively. Fluoride (F⁻) in groundwater of this region ranged from 0.00-0.34 mg/l with a mean value of 0.11 mg/l during before monsoon and from 0.00 to 0.38 mg/l with a mean value of 0.09 mg/l during after monsoon period. Sulphate (SO₄²⁻) in groundwater of this region ranged from 0.00 to 193.13 mg/l with a mean value of 85.93 mg/l during before monsoon and from 0.00 to 155.87 mg/l with a mean value of 49.68 mg/l during after monsoon (Table 5.b).

The Nitrate (NO₃⁻) in groundwater of Gandevi taluka ranged from 10.58 to 40.87 mg/l with an average value of 24.07 mg/l and 15.33 to 136.13 mg/l with an average value of 41.20 mg/l respectively during before and after monsoon (Table 5.b).

3.2 Suitability for Irrigation

The suitability of groundwater for irrigation is mainly evaluated using electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), percentage of sodium (Na%) and irrigation water quality index (IWQI). The suitability of groundwater for irrigation based on EC is classified into four groups [13]. It was found that about 60.00% of the samples fall in high salinity category (0.75-2.25 dS/m) during after monsoon in Gandevi taluka. (Table 5.d).

3.3 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” [14]. “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 Ca²⁺ and Mg²⁺ 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 Ca²⁺ and Mg²⁺ ions absorbed onto the clay material. This exchange mechanism reduces the permeability of soil matter and eventually results in soil with poor internal drainage” [15].

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 1.06 to 13.47 with a mean value of 6.34 while in the case of post monsoon season SAR was found ranged from 0.53 to 10.51 with a mean value of 2.53. The similar results were also reported by Ghodke et al. [16]. Majority of the water samples of studied taluka area fall in low alkali hazard class (S₁) during both before and after monsoon (Table 5.c). Similar results were observed by Khodapana et al., in 2006 [17].

3.4 Percentage Sodium

According to Nagarju et al. [18], “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 Mg²⁺ and Ca²⁺ 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” [19]. “Sodium combines with inorganic carbon (HCO₃⁻ and CO₃²⁻) 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%” [20]. “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 [6]. 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 [21]. Na % in groundwater of this study area showed a wide range of variation. It was found that 45 % of the samples fall in permissible and good class in Gandevi taluka during before and after monsoon respectively (Table 5.e). 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.

3.5 Residual Sodium Carbonate (RSC)

In addition to SAR and Na%, the excess of 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). 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 [22]. The RSC in groundwater of Gandevi ranged from 0.00 to 6.40 me/l with an average value of 0.87 me/l and 0.00 to 7.40 me/l with an average value of 1.72 me/l respectively during before and after monsoon (Table 5.c). Majority of the samples falls under safe category in Gandevi taluka. The higher mean value of RSC was found during after monsoon than before 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. [16]. 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.

3.6 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, 70 % of water samples were observed high chloride hazard to unsuitable condition. (Table 5.e). “Crops such as sorghum (*Sorghum bicolor*), corn (*Zea mays*), tomato (*Solanum lycopersicum*), sugar-beet (*Beta vulgaris*), barley (*Hordeum vulgare*), asparagus (*Asparagus officinalis*), and cauliflower (*Brassica oleracea var.botrytis*) are susceptible to medium-to-high Cl^- hazard zones” (Ayers and Wescot 1985).

3.7 Irrigation water quality index (IWQI)

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

$$\text{IWQI} = \sum_{i=1}^n Q_i * w_i$$

Where IWQI is the non-dimensional irrigation water quality index ranging from 0 to 100; Q_i is the quality measurement of the parameter, (ith) a number from (0 to 100) is a function of its concentration; and w_i is the normalized weight of the parameter. Meireles et al. (2010), 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 [23].

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, 40 % and 45 % surveyed water samples were found falling in severe restriction category during before and after monsoon, respectively in Gandevi taluka and couldnot be used for irrigation without processing, while 35 % & 50 % of the studied samples fall in the moderate and highly restricted for use classification during before and after monsoon, 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..

4. CONCLUSION

Overall in Gandevi taluka, based on IWQI, 40 % and 45 % surveyed water samples were found falling in severe restriction category of irrigation during before and after monsoon respectively. The study found that the majority of the water samples above the critical levels of irrigation water quality, implying that growing suitable crops in the study area may necessitate cautious management. Furthermore, the study warns that using such high TDS groundwater for irrigation may result in soil salinity. The pH of water samples in the study area was alkaline in nature. Majority of the water samples were classified as high-salinity water (C₃) groups and low-sodium water (S₁) 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 as compared to pre-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. As a result, the investigation showed that the majority of the groundwater samples exceeded their permissible levels in irrigation water. Crop production and growth may be reduced by high salinity and chloride hazards necessitating careful management and particular irrigation measures to avoid crop failure. The study's overall findings indicate a alarming situation in terms of groundwater quality, which may necessitate appropriate corrective measures. Artificial recharge techniques may be developed to reduce increased chemical concentrations in groundwater, or suitable crops may be introduced to maintain current groundwater quality.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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