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The Assessment of the Suitability of Ground Water for Irrigation Purpose of Amravati district

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Abstract: *Groundwater is the most preferred source of water in various user sectors in India due to its near-universal availability, dependability, and low capital cost. The rapid expansion of anthropogenic activities has become a significant contributor to pollutant dispersion in the subsurface environment, and the deterioration of groundwater quality is a common occurrence. Despite differences in the degree of economic development and environmental protection in various regions, the protection of drinking-water sources should be the primary focus for human health. The grade of irrigation groundwater available to irrigation has a significant impact on crops as well as yields. Therefore, there is a need to better understand irrigation water quality. The present study mainly focuses on the assessment of the suitability of groundwater of 15 groundwater samples collected from Amravati district, Maharashtra, India. The groundwater sample datasets of the post-monsoon (2025) season. Water quality indices, namely sodium adsorption ratio (SAR), residual sodium carbonate (RSC or RA), Kelly's ratio (KR), permeability index (PI), total dissolved solids (TDS), and total hardness, have been calculated for separate groundwater samples. All the sample fall in category of safe for irrigation purposes. Only one sample AD1 showing high value for Kelly's ratio (KR=2.54), indicates excess sodium hazard.*

Keywords: Dependability, Anthropogenic, Deterioration, Sodium, Adsorption, Residual, Carbonate, Kelly's ratio, Permeability, Hardness, Hazard.

I. INTRODUCTION

Groundwater is considered one of the major sources of irrigation in India, especially in the arid rural areas, where agriculture is the main source of income for the population. The increase in population needs for increasing food, drought, and climate change have a direct impact on agricultural land; crops, and irrigation at the same time. Around 275 million or about 20% of arable land in the world is irrigated, with irrigated agriculture accounting for 40% of all crop production (1)

The quality of groundwater is affected by many factors, such as physico-chemical characteristics of soil, weathering of rocks, and rainfall, etc. (28). Groundwater quality assessment of different quality parameters has been carried out by various researchers (14). The groundwater quality assessment for drinking and irrigation purposes in the Vindhyan region has been carried out by a few researchers (35).

Assessment of groundwater quality, particularly for irrigation purposes, is based on a series of physicochemical parameters developed over time. The first indicators were developed in the 1950s–1960s with fundamental work such as that by (9, 10) who introduced the sodium adsorption ratio (SAR) and Percentage of Sodium (Na%), respectively, in order to prevent the negative effects of excess sodium on soil structure. Kelly's Ratio (KR), proposed in 1963, and Permeability Index (PI) by (11) were then used to refine the analysis of sodium–calcium–magnesium interactions on soil permeability. The Residual Sodium Carbonate (RSC), introduced by (22) and its variant RSBC, were developed to assess the effects of carbonates and bicarbonates on calcium and magnesium precipitation, indirectly affecting soil salinity and structure. The Magnesium Hazard Ratio (MHR) has been proposed more recently to assess the potential toxic effect of excess magnesium on permeability and plant growth (31). At the same time, integrated approaches have emerged.

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Potential Salinity (PS), proposed by Doneen in the 1960s, considers the combined effects of chlorides and sulfates on the quality of water used for irrigation (11). More recently, synthetic indices such as the Irrigation Groundwater Quality Index (IWQI) and the Groundwater Pollution Index (GPI) have been developed since the 2000s to summarize several physicochemical parameters in a global indicator (13). The Groundwater Pollution Index (GPI) and the irrigation water quality index (IWQI) have emerged as major tools in the monitoring and management of water resources.

II. STUDY AREA

Amravati district, located in the Vidarbha region of Maharashtra, is characterized by an agro-based economy and a rapidly growing urban population. The district is largely dependent on groundwater for irrigation, drinking, and industrial processes. The research focused on multiple sampling sites across rural and urban areas, ensuring a comprehensive analysis of the region's groundwater (3). Wardha River forms the eastern boundary of the district (12). For administrative suitability, the district is divided into 13 talukas, namely, Amravati, Warud, Morshi, Chandur Railway, Tiwsa, Nandgaon, Bhatkuli, Daryapur, Anjangaon, Dharni, Achalpur, Chikhaldara, and Chandur Bazar. It has a total population of 4,014,939 (12)

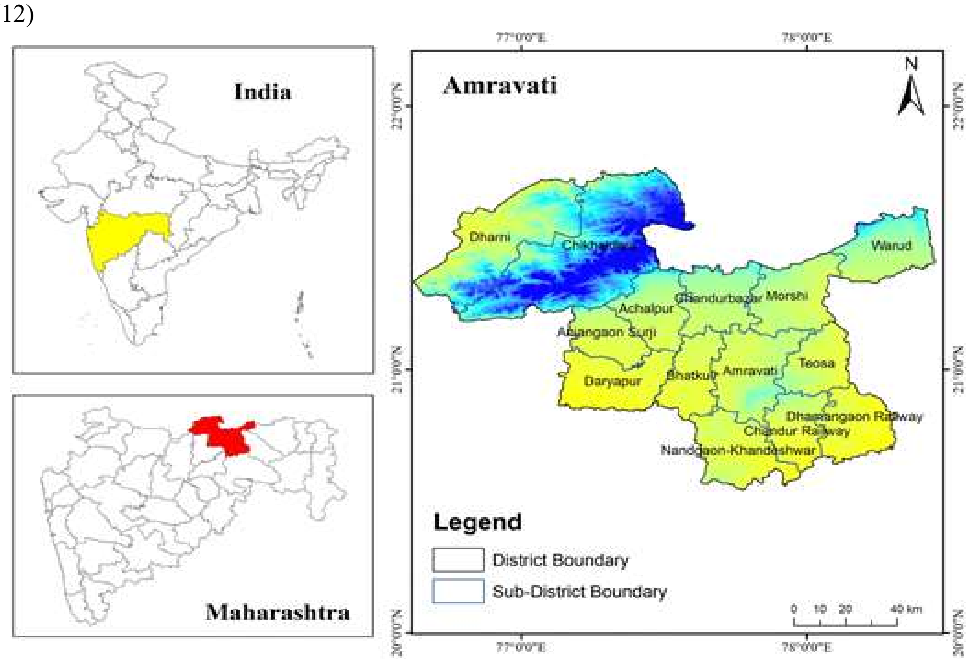

Fig.1 Location map of the water sampling sites in the study area

III.MATERIALS AND METHODS

Sample Collection

Groundwater samples were collected from 19 different locations across Amravati, including wells, boreholes, and hand pumps. The samples were collected during the post-monsoon seasons to account for seasonal variations in water quality. A total of 19 groundwater samples were collected from dug wells and hand pumps from various locations of the study area during the post-monsoon season in August (2025). Major ions were analyzed, such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), and calcium. mentioned in table no. 1. Calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), bicarbonate (HCO3), chloride (Cl), and sulphate (SO4) as per the standard protocol prescribed by APHA (1995). Measured for electrical conductivity (EC), PH and total dissolved solids (TDS) by digital meters, and used the volumetric titration method to determine Calcium (Ca), magnesium (Mg), bicarbonate (HCO3), and chloride (Cl). The flame photometer method is used to measure the concentrations of sodium (Na), potassium (K), and

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sulfate (SO4) ions, which were also measured by a spectrophotometer. Using physicochemical analyses calculated water quality secondary parameters for irrigation such as total hardness (TH), sodium adsorption ratio (SAR), percent sodium (%Na), residual sodium carbonate (RSC), residual sodium bicarbonate (RSBC), Kelleys Ratio (KR), permeability index (PI), Magnesium Adsorption Ratio (MAR).), mention in table no 10

1. Electrical conductivity

Electrical conductivity is a function of temperature, type, and concentration of various ions (9). Classification of irrigation water based on electrical conductivity is presented in Table 3. A solution offers some resistance to the passage of electric current through it, depending on the concentration and type of ions present. The higher the salt content lower the resistance to the flow of current. The resistance(R) is defined by Ohm's law as the ratio of the electrical potential in volts (E) and the strength of the current in amperes (I) (28,31,32)

$$EC = K\ (1/R) \times \frac{1}{R}$$

Electrical conductivity of conductance is the reciprocal of resistance. 1/R=1/ohm=mhos
(reverse of ohm) (at present ohms/cm is expressed in terms of dS/m).

2. Hardness

Hardness in a Water Sample refers to the concentration of dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in water. Hard water does not form soap lather easily and may cause scale formation in pipes and boilers. Acceptable limit: 200 mg/L and Permissible limit: 600 mg/L (if no alternative source available). The most common laboratory method is the EDTA Titration Method. (41,42)

3. Sodium Percentage (Na%)

If the proportion of sodium is high in groundwater for irrigation purpose, it can destroy soil structure (Table 4). A simple method for evaluating the changes of high sodium is the Sodium Adsorption Ratio (SAR), and the sodium percentage (soluble sodium percentage, SSP) is calculated as follows: ((31)

$$Na\,\% = \frac{Na}{Ca + Mg + Na} \times 100$$

4. Permeability index (PI)

Another modified criterion has evolved based on the solubility of salts and the reaction occurring in the soil solution from cation exchange for estimating the quality of agricultural waters (14). Soil permeability is affected by long-term use of irrigation water and is influenced by (a) Total dissolved solids, (b) sodium contents, and (c) bicarbonate content. To incorporate the first three items Doreen had empirically developed a term called, 'Permeability Index' after conducting a series of experiments for which he had used a large number of irrigation waters varying in ionic relationships and concentration (Doneen, 1964) PI is classified under Class I (>75% permeability), Class II (25-75% permeability) and Class III (<75% permeability) orders

The permeability index is given by the following formula:

$$PI = \frac{Na + \sqrt{HNO_3}}{Ca + Mg + Na} \times 100$$

Where, the ions are expressed in meq/l.

5. Kelly's ratio (KR)

Kelly's Ratio was devised by Kelly and is measured considering sodium ion concentration against calcium and magnesium ion concentrations (Kelly WP 1940). Waters with a KI value

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$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

Where, concentrations of all ions have been expressed in meq/l. (17)

6. Sodium adsorption ratio (SAR)

It is a parameter used to measure the sodium hazard of irrigation water. It indicates the relative concentration of sodium (Na^+) ions compared to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in water. Sodium Adsorption Ratio (SAR) is the ratio that expresses the amount of sodium relative to calcium and magnesium in water.It is important in soil science and irrigation water quality because high sodium water can damage soil structure.

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

7. Magnesium Percentage (Mg%)

Magnesium Percentage (Mg%) is a parameter used to evaluate the quality of water for irrigation. It shows the proportion of magnesium ions (Mg^{2+}) relative to calcium (Ca^{2+}) and magnesium (Mg^{2+}) in water. Magnesium percentage indicates the amount of magnesium present compared to total alkaline earth metals (Ca^{2+} + Mg^{2+}) in a water sample. High magnesium in irrigation water can negatively affect soil quality and crop yield. Magnesium % is calculated by formula;

$$Mg\% = \frac{Mg}{Ca + Mg} \times 100$$

IV. RESULTS AND DISCUSSION

To assess the overall irrigational water quality of the samples collected, eight computed water quality parameters have been considered; namely, Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Permeability Index (PI), Residual Sodium Carbonate (RSC), Kelly's Ratio, and Magnesium Adsorption Ratio (MAR). Electrical conductivity (EC), Total Hardness (TH), Sodium Percentage (Na%)

Total hardness (TH)

Magnesium is harmful when its concentration in water exceeds the allowable limit of 200 mg/l. Metal ions with bivalent valence and pH also play a key role in increasing sedimentation when heated, which leads to corrosion of water pipes (3,26,32). Total hardness is the sum of calcium and magnesium concentrations. (32,33,34). The degree of hardness is classed as (1) soft: 0-75 mg/L, (2) moderate: 75-150 mg/L, (3) hard: 150- 300 mg/L, and very hard > 300 mg/L. In the present study, the results showed that the total hardness (TH) concentrations varied between 67 to 402 mg/L, where all water samples fall in the soft to hard category (150-300) and (>300 mg/l), respectively. This indicates that it is suitable for agriculture.

Sodium adsorption ratio (SAR)

Sodium adsorption ratio is a measure of the salinity of the soil determined through quantitative chemical analysis of water in contact with it (23). An excess of HCO3 and CO3 - - ions in water react with Na+ in soil, resulting in a sodium hazard. SAR values are plotted against EC values over the salinity diagram to categorize analyzed water samples according to their irrigational suitability quotient (18,20,23). In the present study, the SAR values range from 0.77 to 2.04 me/l in the post-monsoon. EC range: 0.387 – 1.027 dS/m, mostly C2 (medium salinity) and some C3 (high salinity) SAR range: 0.45 – 2.04 all fall in S1 (low sodium hazard). Most samples fall in C2–S1 and C3–S1 classes (as shown in fig 2), meaning: Low sodium hazard, Medium to moderately high salinity, generally suitable for irrigation with moderate leaching and proper drainage.

Among the studied samples, Sample 1 (2.04) shows the highest SAR value, followed by Sample 4 (1.87) and Sample 12 (1.86); however, these values are still within the excellent category for irrigation water. On the other hand, Sample 9

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(0.45), Sample 13 (0.54), and Sample 2 (0.61) exhibit very low SAR values, indicating a strong dominance of calcium and magnesium ions over sodium ions, which is beneficial for maintaining soil structure and permeability.

Permeability index (PI)

In this study, the Permeability Index was calculated for 19 irrigation water samples to assess their influence on soil permeability. PI values ranged from 6.0% to 38.1%. Among these, Sample 1 (31.8%), Sample 4 (29.2%), Sample 6 (31.3%), Sample 8 (37.6%), and Sample 11 (38.1%) fell within Class II, indicating moderately suitable water for irrigation. These samples are not expected to cause serious permeability problems and can be safely used for agriculture with normal soil management practices.

The remaining samples, including Sample 2 (6.5%), Sample 3 (12.0%), Sample 5 (12.3%), Sample 7 (12.6%), Sample 9 (6.0%), Sample 10 (17.6%), Sample 12 (23.0%), Sample 13 (8.8%), Sample 14 (15.1%), Sample 15 (24.7%), Sample 16 (16.0%), Sample 17 (17.3%), Sample 18 (18.7%), and Sample 19 (14.7%), fall under Class III, indicating low permeability index values. Such water may adversely affect soil permeability and infiltration if used continuously for irrigation, which could ultimately reduce soil productivity and crop yield.

Another modified criterion has evolved based on the solubility of salts and the reaction occurring in the soil solution from cation exchange for estimating the quality of agricultural waters (14). Soil permeability is affected by long-term use of irrigation water and is influenced by (a) total dissolved solids, (b) sodium contents, and (c) bicarbonate content. To incorporate these factors, Doneen empirically developed the Permeability Index after conducting experiments on various irrigation waters with differing ionic relationships and concentrations (8). Overall, the PI assessment indicates that only a few water samples fall within the moderately suitable category, while the majority belong to Class III, suggesting potential permeability issues in soils irrigated with these water sources. Therefore, proper soil management practices, adequate drainage, and periodic monitoring of soil and water quality are recommended to minimize negative effects on soil structure and maintain sustainable agricultural productivity.

Kelly's ratio

In the present study, Kelly's Ratio was calculated for 19 irrigation water samples to assess their suitability for agricultural use. The calculated KR values range from 0.08 to 0.76. All the analyzed samples show KR values less than 1, indicating that the concentration of calcium and magnesium ions is higher than that of sodium ions in the water. This suggests that the irrigation water does not pose a significant sodium hazard and is generally suitable for irrigation purposes.

Among the analyzed samples, Sample 1 (0.76) and Sample 11 (0.52) exhibit comparatively higher KR values, but they remain below the critical limit of 1, indicating that the water is within the acceptable range for irrigation. On the other hand, samples such as Sample 9 (0.08), Sample 2 (0.12), and Sample 13 (0.12) show very low KR values, reflecting a dominance of calcium and magnesium ions over sodium, which is beneficial for maintaining soil structure and permeability.

In the study area, Kellys Ratio ranges from 0.27 to 2.16 with a mean value of 1.12, in this study, 12 water samples showed KR values less than one (KR > 1) are suitable for irrigation, 17 samples fall in the marginal category, and one water samples with KR values more than one (KR > 1) are unsuitable for irrigation purposes in Table 1.Overall, the Kelly's Ratio values of all 19 water samples indicate good irrigation water quality with respect to sodium hazard. Therefore, the studied water sources can be considered suitable for irrigation without causing harmful effects on soil structure or agricultural productivity, although continuous monitoring is recommended for sustainable water and soil management.

Magnesium adsorption ratio (MAR)

In the above present study, the Magnesium Percentage was calculated for 19 irrigation water samples to assess their suitability for agricultural use. The Mg% values range from 25.6% to 53.1%. Among the analyzed samples, most of the samples show Mg% values less than 50, indicating that the irrigation water is generally suitable for agricultural purposes and does not pose a significant magnesium hazard to soil structure.

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However, Sample 5 (53.1%) shows a Magnesium Percentage slightly higher than the permissible limit of 50, suggesting an excess of magnesium in this water sample. Continuous use of such water for irrigation may lead to increased soil alkalinity, reduced soil permeability, and potential adverse effects on crop yield. The remaining samples fall within the acceptable limit, indicating that these water samples are safe for irrigation with respect to magnesium hazard.
MAR categorized water into two broad classes – water having MAR 50 is considered unsuitable. Because MAR values should preferably be greater than 50 to be rendered unsuitable for irrigational purpose and hence in the present study, where MAR values range between 25.6 to 53.1 me/l in post monsoon. The MAR, based on which it can be concluded that almost all water samples are suitable for irrigation. Overall, the Magnesium Percentage analysis indicates that almost all the studied water samples are suitable for irrigation, except for one sample showing slightly higher magnesium content. Therefore, the irrigation water in the Amravati District (Maharashtra) is generally appropriate for agricultural use, although periodic monitoring of water and soil quality is recommended to ensure sustainable agricultural practices. Indicating a strong dominance of calcium and magnesium ions over sodium ions, which is beneficial for maintaining soil structure and permeability.

Table.1 Methods used for analysis of water quality parameters

S. No.	Parameters	Methods
1	pH	pH meter
2	Electrical Conductivity	Conductivity meter
3	Total Hardness	EDTA titration method
4	Total Dissolved Solid	Water quality analyser instrument
5	Chloride	Argentometric titration method
6	Calcium and Magnesium Titration method	Calcium and Magnesium Titration method
7	Sodium, Calcium and Potassium	Flame photometer

Table.2 Standards of water quality by WHO and BIS for drinking purpose

S. No.	Water quality parameters	WHO (1991)		BIS(1991)	
		Max. Desirable	Max. Permissible	Max. Desirable	Max. Permissible
1	pH	7	8.5	6.5	8.5
2	EC	-	1400	-	-
3	TH (mg/l)	100	500	300	600
4	TDS (mg/l)	500	1500	500	1000
5	Ca (mg/l)	75	200	75	200
6	Mg (mg/l)	30	150	30	100
7	Na (mg/l)	-	200	-	200
8	K (mg/l)	-	12	-	-
9	Cl (mg/l)	200	600	250	1000

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10	SO4 (mg/l)	200	400	150	400
11	Turbidity (NTU)			1	5

Table.3 Calcification of irrigation water based on electrical conductivity

S. No.	Type of water	Classification	Electrical Conductivity (μ/cm)
1	Low Sodium	Excellent	100-250
2	Medium	Good	250-750
3	Saline	Permissible	750-2000
4	Highly Saline	Doubtful	2000-3000
5	Very Highly Saline	Unsuitable	> 3000

Table.4 Classification of water based on Sodium Adsorption Ratio (SAR)

S. No.	Type of water	Classification	SAR Value
1	Low Sodium	Excellent	< 10
2	Medium	Good	10 - 18
3	Highly Saline	Doubtful	18 - 26
4	Very Highly Saline	Unsuitable	> 26

Table.5 Classification of water based on Sodium Percentage (Na%):

Sr. no.	Sodium Percentage (Na%)	Water Classification	Suitability for Irrigation
1	< 20	Excellent	Suitable for all types of crops and soils
2	20 – 40	Good	Suitable for irrigation
3	40 – 60	Permissible	Moderate sodium hazard
4	60 – 80	Doubtful	Not suitable for many soils
5	> 80	Unsuitable	Harmful for irrigation

Table 6 Classification of water based on the Permeability Index (PI),

Permeability Index PI %	Class	Water Quality for Irrigation
> 75%	Class I	Good / Suitable
25 – 75%	Class II	Moderate / Marginally suitable

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< 25%	Class III	Unsuitable

Table 7 Analysis of Conductivity and Total Solids

SAMPLE	pH	Conductivity (Ʊ) (µS/cm)	Total Solids(mg/l)
AD1	7.2	485	352
AD2	7.4	523	399
AD3	7.8	387	294
AD4	7.2	1027	609
AD5	8	561	341
AD6	8	834	499
AD7	8.2	672	376
AD8	7.9	543	456
AD9	8	393	260
AD10	8	590	349
AD11	7.6	450	254
AD12	7.3	547	390
AD13	7.9	400	213
AD14	7	560	600
AD15	7.4	590	561
AD16	7.6	671	518
AD17	7	609	505
AD18	7	512	500
AD19	7.1	620	594

Table 8 Analysis of physico chemical parameters

SAMPLE	Alkalinity (mg/l)	Hardness (mg/l)	Dissolved Oxygen (mg/l)	Chemical Oxygen Demand (mg/l)	Biological Oxygen Biological Oxygen Demand (mg/l)
AD1	70	67	7.6	25	6
AD2	87	226	7.9	21	6
AD3	98	234	7.2	23	4
AD4	76	402	6.9	27	7
AD5	167	209	7.2	22	4
AD6	165	211	7.7	20	5
AD7	77	248	8	19	6
AD8	94	101	7	20	6
AD9	150	312	7.9	20	5
AD10	141	269	7.6	22	7
AD11	83	98	8	24	5
AD12	77	181	8.1	19	6
AD13	68	248	8	20	8
AD14	79	276	8	23	6
AD15	105	261	7.9	19	6
AD16	118	222	7.9	20	6
AD17	170	249	7.2	20	5
AD18	99	259	7.7	29	5
AD19	140	266	8	22	6

Table 9 Analysis of Ionic Concentration

SAMPLE	Sulphate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Bicarbonate (mg/l)
AD1	32	52	5	2.2	66	48	19	145
AD2	8	17	16	1.5	35	187	39	210
AD3	21	33	32	2.7	59	156	78	325
AD4	121	57	36	2.3	88	120	29	180
AD5	30	29	41	2.5	40	96	66	400
AD6	56	32	33	1.3	60	87	20	275
AD7	19	21	10	1.6	38	93	43	360

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AD8	70	60	36	2.1	55	66	35	150
AD9	23	43	17	2.5	30	209	78	220
AD10	11	38	22	2.2	54	89	50	310
AD11	43	30	16	1.5	67	77	21	195
AD12	54	43	10	1.1	81	98	34	430
AD13	22	32	29	2.1	28	129	47	280
AD14	17	27	18	2.1	35	75	34	340
AD15	34	21	16	1.2	42	69	31	260
AD16	37	30	21	1.8	34	69	27	380
AD17	39	28	15	2.1	37	72	28	200
AD18	37	27	19	2.1	39	71	27	450
AD19	42	28	18	2.7	33	73	30	300

Table 10 Specific analysis of parameters, KR, SAR, Na%, MAR, PI

SAMPLE	Kellys ratio	Sodium Absorption Ratio (SAR)	Sodium Percentage (Na%) Sodium Percentage (Na%)	Magnesium Percentage (Mg%)	Permeability Index (PI%)
AD1	0.76	2.04	42.0	39.5	31.8
AD2	0.12	0.61	10.8	25.6	6.5
AD3	0.18	0.97	15.3	45.2	12.0
AD4	0.46	1.87	31.4	28.5	29.2
AD5	0.17	0.77	14.5	53.1	12.3
AD6	0.44	1.51	30.3	27.5	31.3
AD7	0.20	0.82	16.8	43.3	12.6
AD8	0.39	1.36	27.9	46.7	37.6
AD9	0.08	0.45	7.2	38.1	6.0
AD10	0.27	1.14	21.5	48.1	17.6

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AD11	0.52	1.74	34.3	31.1	38.1
AD12	0.46	1.86	31.4	36.4	23.0
AD13	0.12	0.54	10.6	37.5	8.8
AD14	0.23	0.84	18.9	42.8	15.1
AD15	0.31	1.06	23.4	42.6	24.7
AD16	0.26	0.88	20.7	39.2	16.0
AD17	0.27	0.94	21.5	39.0	17.3
AD18	0.30	1.00	22.8	38.5	18.7
AD19	0.23	0.82	19.0	40.4	14.7

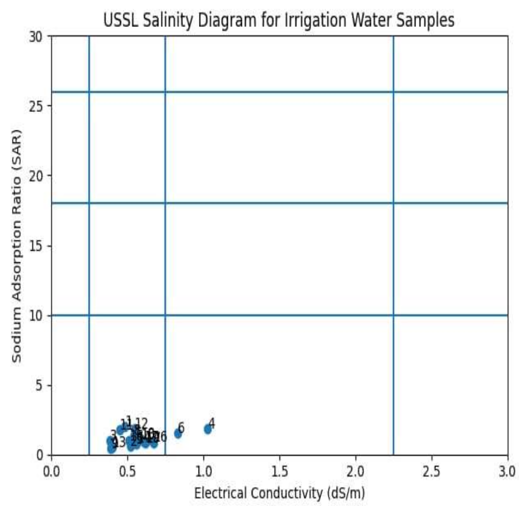

Fig. 2 Salinity diagram for sample

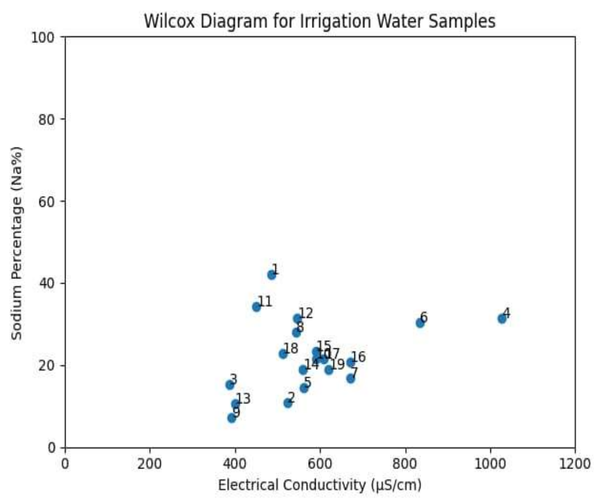

Fig. 3 Wilcox diagram for pre monsoon samples

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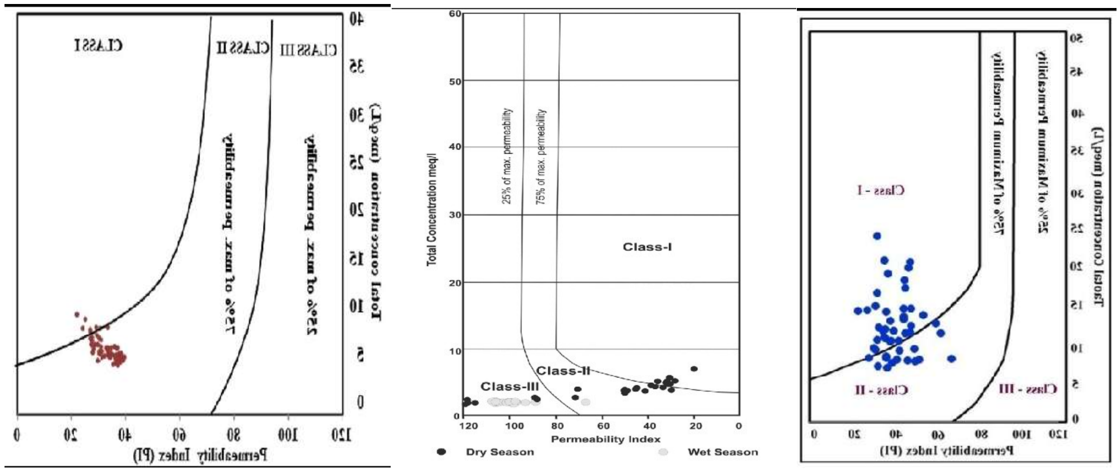

Fig. 4 Doneen's Chart for Permeability Index value of samples

The permeability index (PI) proposed by Doneen was calculated to evaluate the effect of irrigation water on soil permeability. The PI values range from 16.4% to 64.6%. Most of the samples fall under Class II, indicating that the groundwater is suitable for irrigation and will not adversely affect soil permeability, while a few samples fall in Class III, suggesting limited suitability.

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