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Comparison of contemporary and traditional indexing techniques for determining if groundwater is suitable for irrigation

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Research Article

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Abstract

Irrigation water quality (IWQ) may be assessed using a number of water quality indicators, however they have some drawbacks. Using a logical subindex that is sufficiently adaptable and updated to indicate irrigation water appropriateness, this research tried to create a new Overall Irrigation Water Quality Index (Overall IWQIndex). The danger class, a modified rating system for each hazard class's characteristics, and other water parameters that have impacted the soil and plants were all taken into account, along with the maximum proven desirable and permitted value of the parameters. The suggested Overall IWQIndex, a few IWQ factors, and several diagram-based statistical techniques were used to assess the IWQ of forty calcite-type groundwater samples. After a comprehensive correlation analysis of the research data, the appropriateness for IWQ was eventually established. The postmonsoon and premonsoon samples fell into the "good" and "excellent" categories, respectively, according to the findings. In conclusion, the research created an indexing model that provides precise information on the appropriateness of irrigation water and is simple to calculate and rationalise.

KEYWORDS

salinity, water chemistry, irrigation water quality, danger class, and water quality indexes

1 | INTRODUCTION

The main elements that control groundwater geochemistry are human-caused activities like industrialisation, agriculture, urbanisation, and overuse of groundwater resources, as well as natural processes like aquifer lithology, flow route, water-rock interactions, and residence time in the saturated and unsaturated zones (Islam & Mostafa, 2022; Malakar et al., 2019). When surface water is unavailable or affected by surface pollution, groundwater is the primary and generally safe supply for sustainable irrigation practices. The quantity and types of different dissolved solutes have a significant impact on the quality of irrigation water. To assess the appropriateness of irrigation water for preserving the soil environment and improving crop output, a number of irrigation water quality (IWQ) metrics and indexing techniques were developed based on these solutes. The sole irrigation supply in the current research area, a heavily irrigated region of southeast Bangladesh, is groundwater, however the water's quality is unacceptable. According to some studies (Islam & Mostafa, 2021a; Mondal et al., 2010; Zahid, 2015), regular geochemical variation, excessive water exploitation, massive arsenic contamination, the groundwater's interface with saltwater, and the deposition of agrochemicals on the soil are the usual causes of groundwater degradation in this area. In coastal regions where salinity is a major issue, IWQ was measured extensively (Ahmed et al., 2018; Islam & Mostafa, 2021b; Islam et al., 2017a, 2017b, 2017c, 2017d; Mirza et al., 2012).

However, the primary quality problems include the upper Ganges River basin region, calcium-

hardness, and excessive trace metal loading in groundwater (Islam & Mostafa, 2021c). Therefore, a thorough assessment of the water quality is essential for surface irrigation in the research region. The research created an Overall Irrigation Water Quality Index (Overall IWQIndex) and a number of traditional diagram-based statistical techniques for this aim. Because the opposite effect of water on soil and plants relies on the physical and chemical characteristics of soil, the local climate, the kind of irrigation technique, land management, and crop diversification, determining the IWQ is an extremely difficult process. It is difficult to fully evaluate the water's quality using a single index model. Arslan, 2017; Ashraf et al., 2011; Ayers & Westcot, 1985; Bauder et al., 2011; Bozdag, 2016; Hussain et al., 2012; Islam & Mostafa, 2021d; Meireles et al., 2010; Simsek & Gunduz, 2007; Zaman et al., 2018). For example, in order to assess the IWQ of the Simav Plain in Turkey, Simsek and Gunduz (2007) identified a geographical information system (GIS)-based IWQ index by combining five predictable geochemical hazards (salinity hazard, permeability hazard, ion toxicity, trace metal toxicity, and miscellaneous). Additionally, Meireles et al. (2010) proposed a novel approach for evaluating IWQ based on certain water factors. Additionally, Ashraf et al. (2011) used GIS to create an IWQ index for computing residual sodium carbonate (RSC), saturated sodium percentage (SSP), and sodium adsorption ratio (SAR) along with other characteristics. In order to evaluate groundwater suitability for agriculture in Argentina's Wet Pampa Plain, Romanelli et al. (2012) combined water geochemistry, topographical features, and additional parameters like electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), hydraulic conductivity, aquifer size, percent sodium (Na%), SSP, SAR, and RSC. Bozdag (2016) used an analytic hierarchy process (AHP) in conjunction with GIS to assess the adequacy of irrigation water in central Anatolia, Turkey. The many approaches to measuring water quality in irrigated agriculture are somewhat appropriate, but none of them are totally sufficient since crops and agricultural conditions vary greatly. In the meanwhile, such approaches have a small number of parameters and make use of outdated and conventional grading, scoring, and weighting factors for the characteristics and danger classifications that were employed. In the process of developing that indexing system, it also noticed a significant contradiction and developed an uneven operation. An indexing model that took into account the maximum number of water characteristics with a total of six danger classifications was presented in this research. Additionally, the weight factor of each danger class and adjusted rating values of water parameters are used. The suggested indexing model would examine sufficient data on the appropriateness of different water types for each irrigation technique. The methods described in this study have been refined to provide more useful steps for evaluating and controlling irrigated farming's risks connected to water quality. In order to complete the assessment of irrigation water appropriateness and support the relative acceptability of the groundwater samples in the research region, certain conventional measures were used with this projected model. The study's objective was to evaluate traditional and modern water quality indexing techniques for groundwater irrigation in Bangladesh's Ganges River basin. The study's findings aid in evaluating how irrigation water affects soil and crops and in selecting suitable substitutes that might improve local agricultural productivity.

2 | BACKGROUND OF THE STUDY– DRAWBACK OF EXISTING IWQI METHODS

Hussain and colleagues (2018), among others. Some are solely used for irrigation water suitability, whereas the Canadian WQI is used for all applications. Certain index models that are now in use just employ the weight and rating factor; they do not take into account the value of the water quality indicators. Others were only applied to a small number of carefully chosen water quality criteria. As of yet, no single approach has been developed that takes into account the values of the water quality parameters, the recognised acceptable range of parameters, and

different ratings with parameter and danger class score values. For instance, Meireles et al. (2010) employed a small number of parameters but did not include rating or weight factors in their techniques, whereas Simsek and Gunduz (2007) only used scoring of parameters and weight factor of danger class without any concentration of parameters. Furthermore, it was noted that these models displayed various irrigation water indexing values and statuses for the same data. For example, one model indicated that a water sample's water quality status was "good," but the model also indicated that it was "poor." However, a number of studies (Ayers & Westcot, 1985; Islam & Mostafa, 2021d; Simsek & Gunduz, 2007) regarded the lower rating value of parameters as 1, which is incorrect because the rejected category of the parameters at the lowest-scoring point can have an impact on the overall index value. In rejection ranges, zero should be the lowest value of the parameter's score. Furthermore, according to new study findings, the acceptable and allowed ranges of water quality parameters for irrigation are very retroactive and non-uniform. For this reason, it should adjust the score of certain parameter ranges and include a uniform pattern. This work consistently attempts to address these peculiar issues. Table 1 lists the many accepted index techniques along with their drawbacks. The table shows that there are differences in the water categorisation assessment procedures among these methodologies. Each approach only partly satisfies the requirements of a comprehensive and well-fitting indexing equation. Therefore, the uncertainty of water quality indexing motivates us to create a model that takes into account maximum parameters and danger classifications with

TABLE 1 Indexing methods of irrigation water quality assessment and their limitations

Name of index	Final equation	Limitations
Canadian WQI (2001)	Canadian water quality index, $WQI = \frac{100}{\sqrt[5]{\sum_{i=1}^n F_i^2 + F_2 + F_2 h_i}}$	- No. of parameters are not specified (at least four parameters) - No subindex used - Hazards are not classified - No scoring, rating and weight factors are used - Water is classified into only three categories
Simsek and Gunduz index (2007)	Simsek irrigation water quality index, SIWQI = $\sum_{i=1}^5 G_i$	Only nine geochemical parameters are used
Meireles index (2010)	Meireles water quality index, MWQI = $\sum_{i=1}^n q_i w_i$	Maia and Rodrigues (2012)
ssain et al. (2018)	Index of aquifer water quality, Water is classified into only three categories	- No parameters value are used - Only five parameters are used - No. of parameters is specified

- No subindex used
- Hazards are not classified
- No scoring and rating used
- Only nine parameters are used
- No. of parameters is not specified
- Parameters are taken directly as subindex
- Hazards are not classified
- No scoring, rating and weights factors used
- Water is classified into only four categories
- Only 12 parameters are used

IAWQ = $\frac{1}{n} \sum (W_{ri} \times Y_{ri})$ No. of parameters is not specified

- Parameters are directly taken as subindex
- Hazards are not classified
- No scoring and rating value is used

3 | STEPS TO DEVELOP OVERALL IWQINDEX

Every water quality index model is developed using four phases. While the selection of the hazard class, the score and weight of the class, and the rating value of each parameter are employed in the development of an irrigation WQI, the selection of parameters, their weighting, subindexing computation, and aggregation of subindex are crucial processes for all WQIs. These methods are covered in depth here.

3.1 | Selection of hazard class and scoring

The dangers may be roughly divided into six classes: (i) salinity hazard; (ii) sodicity issue; (iii) water penetration rate/permeability of the soil; (iv) crop toxicity from ions and trace metals; (v) changes in soil structure; and (vi) other impacts on plants. Important elements in the index computation are the rating value of parameters and the score of danger classes. Based on the significance of each hazard class in the index model, the suggested model assigned a score ranging from 1 to 6 (Table 2). With a score of 6 ($s = 6$), the salinity hazard is regarded as the most significant concern in the IWQ assessment. However, the impacts of the miscellaneous danger class on plants are regarded as the least important component and have a score of 1 ($s = 1$). The other four hazard classes have ratings of 5, 4, 3, and 2 for sodicity danger, soil water penetration rate, crop toxicity, and shifting soil structure, respectively. The FAO recommendations for agricultural water quality (Ayers & Westcot, 1985; Bauder et al., 2011; Fipps, 2003; Hoffman, 2010; Hussain et al., 2010; Zaman et al., 2018) were updated to create Table 2.

3.2 | Selection of parameters

The six danger classifications take into account 27 IWQ characteristics (Tables 2 and 3). In order to determine the index value that damaged plants and resulted in salty soil conditions, salinity hazard determined by EC and/or TDS (both are employed if correlation matrix, $r < 0.95$) has provided the highest score. Due to their varying detrimental effects, several factors are often taken into account for various kinds of dangers. For instance, SAR, SSP, and %Na of water may concurrently change the soil's sodicity, water permeability, soil structure, and other characteristics. Because of this, they are used as operational parameters in the danger classes' subindex computation (Table 2). However, the danger class of agricultural toxicity is very adaptable in

TABLE 2 The scoring and weight value of hazard classes and included parameters in each class

Name of hazard class	Scoring value (s_x)	Weight value (W_i)	No. parameters (N)	Included parameters
1. Salinity hazard	6	0.286	2	EC, TDS
2. Sodicity hazard	5	0.238	3	Na%, SSP and SAR
3. Permeability/infiltration rate	4	0.190	4	Na%, SSP, SAR and PI
4. Ions and metal toxicity to crop	3	0.143	9	Na ⁺ , Cl ⁻ , B, K, Fe, Mn, As, Cu and Zn
5. Soil structural change	2	0.095	3	Na%, SSP and SAR
6. Miscellaneous effect to crop	1	0.048	5-12	pH, Ca, Mg, NO ₃ ⁻ , SO ₄ ²⁻ , HCO ₃ ⁻ , TH, RSBC, RSC and MAR
		$\sum W_i = 1$		

Abbreviations: EC stands for electrical conductivity; MAR for magnesium adsorption ratio; Na% for sodium percentage; RSBC for residual sodium bicarbonate; RSC for residual sodium carbonate; SAR for sodium adsorption ratio; SSP for saturated sodium percentage; TDS for total dissolved solids; and TH for total hardness. selecting the criteria for water quality. Any elements related to crop toxicity for irrigation water may be added or removed if necessary. The suggested model took into account a few common elements, including Na⁺, Cl⁻, B, K, Fe, Mn, As, Cu, and Zn, which are hazardous to plants if they are present in greater amounts in soil and water. Other trace elements, such as Pb, Hg, Cd, Se, Sb, Co, Cr, and so on, are very dangerous but are not present in sufficient amounts everywhere. These metals may be included in this danger class by anyone. The other water quality metrics, such as pH, Ca, Mg, and NO₃⁻, were placed in another flexible danger class called miscellaneous (Islam & Mostafa, 2022e). To create a subindex value, rescaling or normalising is thus required. The following procedures are used to create the subindex and final index: Step 1: Counting parameter values, acceptable parameter ranges, and other associated factors in the same equation at the same time is very difficult. This stage involves calculating the subindex value of danger classes using Equation (1), which includes rating scores, weight factors, and three different kinds of parameter values at once. $s_x = \frac{C_{max} - C_i}{C_{max} - C_{min}}$ where s_x is the subindex value, C_{max} is the maximum value, C_{min} is the minimum value, and C_i is the measured value. s_x ranges from 0 to 1. For instance, if $C_{max} = 100$, $C_{min} = 0$, and $C_i = 50$, then $s_x = \frac{100 - 50}{100 - 0} = 0.5$. Step 2: The total IWQIndex is determined by multiplying the weight factors (W_i) of each class by the sum of the subindex values of the six danger classes. According to Table 2, $\sum W_i$ is equal to 1. For instance, the weight value produced is 0.238 if the sodicity hazard score is five (5). Every parameter in every class has a rating value (r) of 3-0 (Table 3). The highest value of the excellent range was indicated by the parameter value at rating 3, although rating 0. Overall IWQIndex = $\sum S_i \times W_i$. $i=1$

3.3 | Weight factors of hazard class and rating of parameters

Conversely, the weight value of each class was calculated by dividing each score value by 21 (the total score). S_i is the subindex of the i th hazard class; s_x is the hazard class's scoring value; N is the number of parameters in each class (Table 2); r_i is the parameter's rating value (Table 3); C_{max} is the parameter's maximum value (at $r = 1$); C_{min} is the parameter's minimum value (at $r = 3$); and C_i is the parameter's measured value. Step 2: The total IWQIndex is determined by multiplying the weight factors (W_i) of each class by the sum of the subindex values of the six danger classes. According to Table 2, $\sum W_i$ is equal to 1. For instance, the weight value produced is 0.238 if the sodicity hazard score is five (5). Every parameter in every class has a rating value (r) of 3-0 (Table 3). The highest value of the excellent range was indicated by the parameter value at rating 3, although rating 0. Overall IWQIndex = $\sum S_i \times W_i$. $i=1$

3.4 | Subindex and final index calculation

The purpose of this phase is to create a standard scale for the water quality metrics (Abbasi & Abbasi, 2011). IWQ parameters have diverse scales and units, but most WQI parameters can only be mixed when they have comparable common scales. It is crucial to classify the water quality status for irrigation appropriateness after the total index value of the water samples has been determined. The water samples are divided into six groups based on significant r values (0-3)

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(Table 3). These values are obtained by applying various rating factors (r) (at a minimum and maximum level) to each danger class parameter without altering their scoring or weighting. Suitability range fraction values are rounded to the closest whole number. Areas classified as "rejection" quality and unsuitable for use in agricultural businesses have Overall IWQIndex scores of less than 3.5. Soil might be harmed by such waters.

TABLE 3 Classification of irrigation water quality parameters with the rating value

Parameter	Rating value, r	Degree of restriction on use	Parameter	Rating value, r	Degree of restriction on use
EC ($\mu\text{S/cm}$)			Mn (mg/L)		
<700	3	Excellent	<0.5	3	Excellent
700-1500	2	Good	0.5-2	2	Good
>1500-3000	1	Faire	>2-20	1	Faire
>3000	0	Rejection	>20	0	Rejection
TDS (mg/L)			Cu (mg/L)		
<450	3	Excellent	<2	3	Excellent
450-900	2	Good	2-5	2	Good
>900-2000	1	Faire	>5-30	1	Faire
>2000	0	Rejection	>30	0	Rejection
%Na and SSP (%)			Zn (mg/L)		
<20	3	Excellent	<3	3	Excellent
>20-40	2	Permissible	3-7	2	Good
>40-80	1	Doubtful	>7-35	1	Faire
>80	0	Unsuitable/Rejection	>35	0	Rejection
SAR (meq/L) ^{1/2}			As (mg/L)		
<10	3	Excellent	0-0.01	3	Suitable
10-18	2	Good	>0.01-0.025	2	Marginal
>18-30	1	Faire	>0.025-0.05	1	Poor
>30	0	Rejection	>0.05	0	Rejection
RSC (meq/L)			pH		
<0.5	3	Excellent	>7-7.5	3	Excellent
0.5-2	2	Suitable	>7.5-8	2	Good
>2-3	1	Marginal	6.5-7; >8-8.5	1	Faire
<3	0	Rejection	6.5 > pH > 8.5	0	Rejection

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RSBC (meq/L)			Ca (mg/L)		
<1	3	Excellent	>50-75	3	Excellent
1-5	2	Suitable	>75-150	2	Good
>5-15	1	Marginal	50 > Ca > 150	1	Faire
>15	0	Rejection	>400	0	Rejection
PI (%)			Mg (mg/L)		
>90	3	Excellent	>10-20	3	Excellent
90-75	2	Good	>20-30	2	Good
	1	Faire	10 < Mg > 60	1	Faire
<75-30					

Parameter	Rating value, r		Degree of restriction on use		Parameter
Na (mg/L)	CO_3 (mg/L)		Degree of restriction on use		
<50	3	Suitable	<1	3	Suitable
50-150	2	Marginal	1-3	2	Marginal
>150-400	1	Poor	>3-15	1	Faire
>400	0	Rejection	>15	0	Rejection
Cl ⁻ (mg/L)	HCO_3 (mg/L)				
<30	3	Suitable	<50	3	Suitable
30-150	2	Marginal	50-150	2	Marginal
150-300	1	Poor	>150-600	1	Faire
>300	0	Rejection	>600	0	Rejection
B (mg/L)			NO_3^- (mg/L)		
<0.5	3	Suitable	<2	3	Excellent
0.5-1	2	Marginal	2-5	2	Good
>1-2	1	Poor	>5-30	1	Faire
>2	0	Rejection	>30	0	Rejection
K (mg/L)	SO_4 (mg/L)				
<2	3	Excellent	<10	3	Excellent
2-5	2	Good	10-50	2	Good
>5-35	1	Faire	>50-200	1	Faire
>35	0	Rejection	>200	0	Rejection
Fe (mg/L)	PO_4 (mg/L)				
<2.5	3	Excellent	<0.5	3	Excellent
2.5-5	2	Good	0.5-5.0	2	Good
>5-30	1	Faire	>5-20	1	Faire
>30	0	Rejection	>20	0	Rejection

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Abbreviations: EC stands for electrical conductivity; MAR for magnesium adsorption ratio; Na% for sodium percentage; RSBC for residual sodium bicarbonate; RSC for residual sodium carbonate; SAR for sodium adsorption ratio; SSP for saturated sodium percentage; TDS for total dissolved solids; and TH for total hardness.

TABLE 4 Irrigation water classification

Overall IWQ _{Index} value	Category
<3.5	Rejection to <6 Poor respectively.
6 to <12	Fair
12 to <23	Moderate
23 to <35	Good 3.6 Util
≥35	Excellent

that might be used to limited crops in a fair to moderate manner. Conversely, a score of 23 or more is regarded as "good" or "excellent." The index's computed minimum and maximum values are 0 and 60 at the ratings of $r = 0$ and $r = 3$, which significantly reduce quality and cause production loss. The related waters show "poor" suitability for irrigation techniques when the computed index value falls between 3.5 and 6. Values between 6 and 23 are seen as indicative of waterways. This suggested approach seems to overcome the shortcomings of the earlier index techniques. This proposed model has been updated and improved in five ways: it takes into account the more verified desirable and permissible value of parameters, such as the maximum hazard class; it uses a modified rating system of parameters in each class; it classifies water into maximum categories; and it takes into account a wide range of parameters that impact both crops and soil. This technique may be effectively used for surface water suitability in irrigation as well as groundwater. Agricultural sectors typically utilise four kinds of groundwater: mixed (Ca-Mg-Na-Cl-HCO₃-SO₄), calcite (Ca-HCO₃), sodic (Na-Cl), and calcite-dolomite (Ca-Mg-HCO₃). This approach also evaluates the appropriateness of different water types in an irrigation system. that might be used to limited crops in a fair to moderate manner. Conversely, a score of 23 or more is regarded as "good" or "excellent." The index's computed minimum and maximum values are 0 and 60 at the ratings of $r = 0$ and $r = 3$, which significantly reduce quality and cause production loss. The related waters show "poor" suitability for irrigation techniques when the computed index value falls between 3.5 and 6. Values between 6 and 23 are seen as indicative of waterways. This suggested approach seems to overcome the shortcomings of the earlier index techniques. This proposed model has been updated and improved in five ways: it takes into account the more verified desirable and permissible value of parameters, such as the maximum hazard class; it uses a modified rating system of parameters in each class; it classifies water into maximum categories; and it takes into account a wide range of parameters that impact both crops and soil. This technique may be effectively used

for surface water suitability in irrigation as well as groundwater. Agricultural sectors typically utilise four kinds of groundwater: mixed (Ca-Mg-Na-Cl-HCO₃-SO₄), calcite (Ca-HCO₃), sodic (Na-Cl), and calcite-dolomite (Ca-Mg-HCO₃). This approach also evaluates the appropriateness of different water types in an irrigation system.

4 | SAMPLE ANALYSIS

S were measured right away. A UV spectrophotometer was used to quantify anions such Cl⁻, SO₄²⁻, NO₃⁻, and PO₄³⁻. The titrimetric method was used to analyse Ca²⁺, Mg²⁺, CO₃²⁻, and HCO₃⁻ in water samples. The flame photometric technique was used to determine potassium (K⁺) and sodium (Na⁺). The Atomic Absorption Spectrophotometer (Perkin-Elmer, Model 3110) was used to determine the trace elements. For both the premonsoon (PRM) and postmonsoon (POM) periods, a total of forty groundwater sampling sites were chosen from the Ganges River basin region in Bangladesh's middle

western zone (Figure 1). Water samples ranging in depth from 22 to 125 meters (shallow to semideep aquifer) were taken haphazardly from the authorised pump well. Samples were gathered and stored for chemical and trace metal analysis in accordance with the standard procedure (US-APHA, 2005). Using a portable multimeter, the TD, EC, and pH

4.1 | Water characteristics

Table 5 displays the statistical records of the physical, geochemical, and trace metal properties of groundwater samples from the PRM and POM eras. The findings indicated that Ca^{2+} , Mg^{2+} , and HCO_3^- are the most significant cations and anions in the samples. $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$ are the respective cationic and anionic concentrations seen in water samples. The other parameters fall within normal limits of irrigation appropriateness, with the exception of Ca, HCO_3^- , total hardness, Mn, and Fe (Islam & Mostafa, 2021d). Piper's and Chadha's diagrams are plotted to determine the water type of samples (Chadha, 1999; Piper, 1944). For both periods, the water types were controlled using Piper's diagram of anions HCO_3^- , Cl^- , and SO_4^{2-} and cations Ca^{2+} , Mg^{2+} , Na^+ , and K^+ (Figure 2a). Maximum water samples are identified as Ca and HCO_3^- type and water class as Ca- HCO_3^- based on the figurative zone in Piper's diagram. However, throughout the PRM era, a small percentage of samples were found in no dominating type zone. These samples may be classified as Ca-Mg- HCO_3^- type in an unequal manner. The line plot of $[\text{HCO}_3^- (\text{Cl} + \text{SO}_4 + \text{NO}_3 + \text{PO}_4)]$ vs. $[(\text{Ca} + \text{Mg}) (\text{Na} + \text{K})]$ from Chadha's arrangement diagram (Figure 2b) revealed a strong positive correlation ($R^2 = 0.690$ in the PRM and $R^2 = 0.971$ in the POM), indicating the prevalence of Ca- HCO_3^- facies and exposing the earth metals (Ca^{2+} and Mg^{2+}) suggestively exceed the alkali metals ($\text{Na} + \text{K}^+$) and the strong conjugate base (HCO_3^-) rule over a weak conjugate base (Cl^- , SO_4^{2-} , NO_3^- , and PO_4^{3-}). Therefore, both representations show the 4 3 4

Ca- HCO_3^- type of groundwater class in the study area.

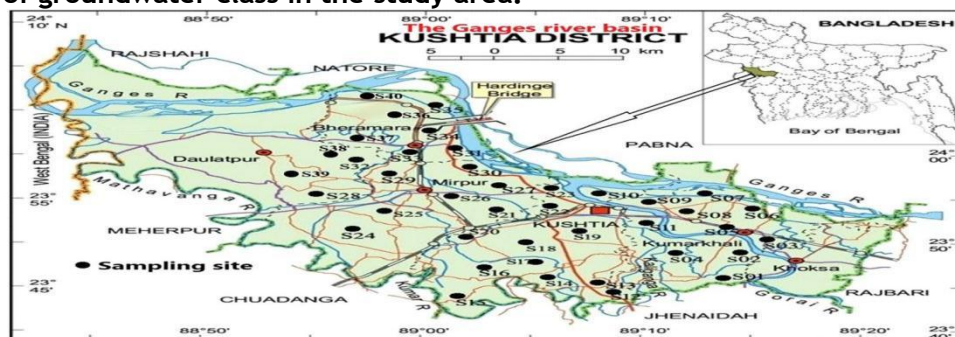


FIGURE 1 Location map of groundwater sampling areas

TABLE 5 Statistics of physicochemical parameters in groundwater during the PRM and POM with their different irrigation water standards

Parameter ^a	Premonsoon, PRM (n = 40)				Postmonsoon, POM (n = 40)				Irrigation water standards		
	Mean	Min.	Max.	±SD	Mean	Min.	Max.	±SD	DPHE (2009)	UCCC (1974)	FAO (1985)
pH	7.02	6.65	7.80	0.218	7.83	7.0	8.91	0.404	6.5-8.5	6.5-8.4	6.5-8.5
EC	669.95	366	1035	172.5	956.8	662	1708	206.1	1000	700-3000	3000
TDS	413.15	219	675	113.21	601.5	450.5	1109	156.2	-	450-2000	2000
Ca	95.	56.6	151.	22.4	114.	67.2	187.	26.87	75	-	400

	64	4	6	4	8						
Mg	32.62	13.0	63.8	12.31	28.96	14.0	52.6	9.438	30-35	-	60
Na	14.12	5.10	71.6	11.68	11.56	3.90	51.6	8.7303	200	70-300	900
K	1.27	0.30	2.90	0.717	1.013	0.20	2.90	0.682	12	-	2
B	0.202	0.001	1.20	0.314	0.223	0.001	1.25	0.343	<1.0	0.7-3	2
Cl ⁻	31.19	12.0	562	9.292	27.09	12.9	41.8	7.604	150-600	140-350	1000
HCO ₃ ⁻	418.6	271.5	703	110.81	448.78	248.5	817	124.45	-	90-500	600
SO ₄ ²⁻	4.14	0.80	14.3	3.805	5.64	0.80	18.317	3.641	10	-	10
NO ₃ ⁻											
PO ₄ ³⁻	1.05	0.46	3.61	0.05	1.15	0.39	4.12	0.06	5	1-5	10

Recommended limit^b

										Long-term use	Short-term use
Fe	7.18	0.60	14.71	2.57		8.11	3.50	17.34	3.12	5	20
Mn	2.66	0.86	6.08	0.59		3.11	1.56	5.43	0.61	0.2	10
Cu	0.91	0.03	3.11	0.99		0.88	BDL	4.44	1.11	0.2	5
Zn	1.44	0.99	6.44	1.87		2.01	1.17	7.65	2.43	2	10
As	0.05	BDL	0.067	0.01		0.050	BDL	0.061	0.01	0.01	0.05

Abbreviation: BDL, below detection limit.

^aAll parameters unit are in mg/L except EC in $\mu\text{S}/\text{cm}$, and pH.

^bAyers and Westcot (1985); Crook (1991).

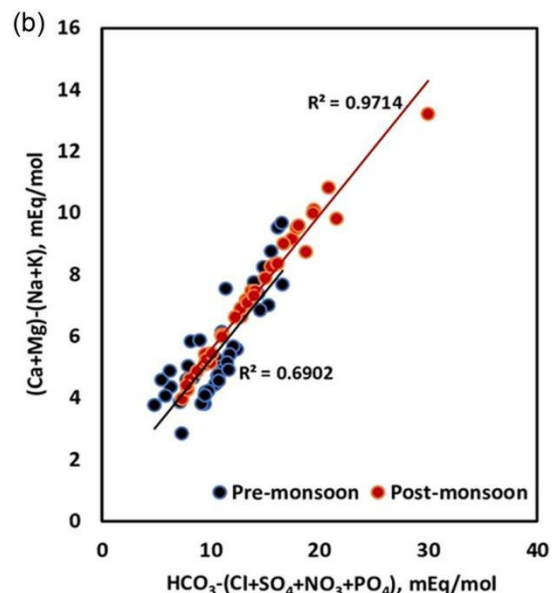
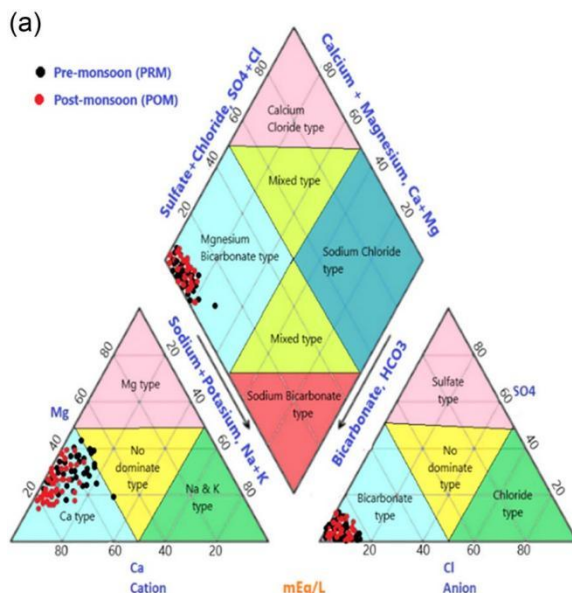


FIGURE 2 (a) Piper's and (b) Chadha's diagram for the evaluation of water type.

4.2 | IWQ and crop yield

The study area's soil is very fertile, and the residents' primary source of income is farming and agricultural production. 104,520 of the 160,800 hectares of land in this region are suitable for cultivation (BBS, 2019). The research area's entire groundwater-irrigated land area is 75,714 hectares. Three crops are grown on around 80% of arable land annually. The research area's key crop production figures are shown in Table 6. Approximately 60–70% of the study area's arable land is irrigated by groundwater, and the quality of that water has a significant impact on crop productivity over an extended period of time. The primary characteristics of the groundwater samples include high salinity (mean EC is 813.4 $\mu\text{S}/\text{cm}$) and higher amounts of several hazardous metals, particularly in shallow aquifer water (water depth < 100 m). If the soil and climate conditions are the same, the deposition of metal salts on topsoil will provide a salinity danger for crops if the overall salinity of irrigation water is greater. The use of high salinity water for irrigation is hampered by soil, crop, climate, and cultural conditions that encourage the buildup of soluble salts in the root zone. Similarly, the use of high salinity water for irrigation is favoured by elements that encourage the periodic leaching of salts from the root zone. Under ideal circumstances, semitolerant crops like wheat have been grown on coarse-textured soils using groundwater with a salinity of more than 800 $\mu\text{S}/\text{cm}$ with very minor yield decreases (Manchanda, 1976; Paliwal, 1972; Tura & Tolossa, 2020). The presence of hazardous substances like boron or heavy metals like Fe, Mn, Pb, As, Cd, Co, and so on in certain water samples causes another issue. Many plants may be toxically affected by an excessive amount of boron in the irrigation water. Similarly, if present in excess in irrigation water, several other ions, such as Cl^- , Na^+ , Ca^{2+} , and so on, may be harmful to some crops. Thus, both gross crop productivity and the soil ecosystem may be impacted by the highly mineralised water.

4.2.1 | Using Overall IWQ_{Index}

The suggested index technique is computed using the evaluated geochemical parameters and computed IWQ parameters, including SAR, Na%, SSP, RSC, RSBC, MAR, and permeability index (PI) (Tables 2 and 5). The research area's calcite type ($\text{Ca}-\text{HCO}_3$) groundwater index values are 34.57 and 29.65 during the PRM and POM sampling seasons, respectively, according to the Overall IWQ_{Index} technique. The results showed that the samples from both seasons are in the "good" category according to the water categorisation (Table 4). However, compared to the POM season, the PRM season's IWQ is comparatively higher and almost in the "excellent" range. Heavy rainfall percolation, increased water-rock interaction, and more mineral dissolution occurred during the wet season. These factors cause the groundwater in the study region to become heavily mineralised following the rainy season (POM period), which raises the EC and TDS values and lowers the Overall IWQ_{Index} value. Additionally, groundwater is less suitable for irrigation because to the increased levels of Ca, Mg, and HCO_3^- during the POM season (Table 5). In the next subsection, these conclusions would be supported by a number of statistical and diagram-based methods.

4.2.2 | Using IWQ parameters

A number of formulae for measuring IWQ parameters were developed between 1950 and 2000. Sodium adsorption ratio, SAR (Richards, 1954); potential soil salinity, PSS (Doneen, 1964); Kelly's ratio, KR (Kelley, 1963); PI (Doneen, 1964); Na%, SSP and MAR (Todd, 1980); RSBC (Gupta, 1983); RSC (Raghunath, 1987); and TH (Hem, 1995). These characteristics are measured using a few geochemical components, including Na^+ , K^+ , Ca^{2+} , Mg^{2+} , CO_3^{2-} , and HCO_3^- in the mEq/L unit (with the exception of TH in mg/L). The FAO and other regulatory agencies recolonise the particular standard value of these criteria. Table 7 displays the statistical findings of the groundwater samples as well as the computed values of those parameters in accordance with this standard.

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The kind and amount of dissolved minerals or nutrients have a major impact on the IWQ. The majority of these minerals come from the water phase from the natural dissolution of rocks and soil/sediment

Rice 100,192 3.365 337,150
 Jute 33,535 13.171 (bales) 563,754 (bales)

Vegetables	12,378	2.453	30,363
Onion	10,119	4.074	41,230
White	10,440	3.541	36,968
Tobacco	14,467	3.285	47,525
Maize	7467	4.281	31,967
Oil seed	5123	1.431	7335
Sugarcane	3505	14.970	52,470

and a small amount originates from the leaching of household and industrial effluent. greater values of Ca²⁺, Mg²⁺, and HCO₃⁻, extremely low CO₂⁻ concentration, low pH, greater EC/TDS value, and lower Na⁺, Cl⁻, and SO₄²⁻ were noted as the primary characteristics of the current irrigation water chemistry. Additionally, Ca-HCO₃ was identified as the water type. The all-detected IWQ parameters would regulate those water properties. The greatest contribution to any index calculation for irrigation water appropriateness is salinity danger, which has the highest score. The EC and TDS of soil and irrigation water are often used to measure it. The examined samples' water chemistry revealed that heavy

TABLE 7 Destructive statistics of irrigation water quality parameters of groundwater samples during the PRM and POM

Indices	Premonsoon, PRM (n = 40)					Postmonsoon, POM (n = 40)				
	Average	Min.	Max.	±SD	% of sample	Average	Min.	Max	±SD	% of sample
EC	670	366	1035	172.5	Good-55 Fair-45	956.8	662	1708	206.1	Good-7.5 Fair-92.5
TDS	413.2	219	675	113.2	Excellent-65 Good-35	601.5	450.5	1109	156.2	Good-100
TH	362.22	122	562	93.52	Hard-5 Very hard-95	404.7	225	615	94.03	Very hard-100
PSS	1.222	0.675	2.163	0.352	Excellent to good-100	1.079	0.499	1.976	0.309	Excellent to good-100
Na%	7.40	3.31	30.97	4.85	Excellent-100	5.67	2.50	22.03	3.42	Excellent-97.5 Good-2.5
SAR	0.32	0.12	1.67	0.26	Excellent-100	0.25	0.09	1.13	0.18	Excellent-100

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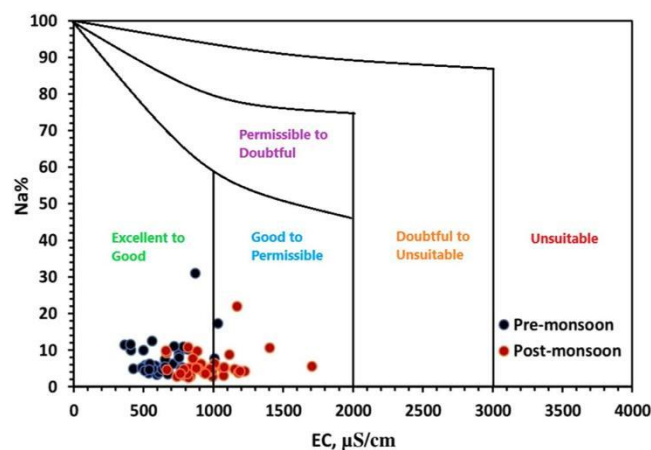
SSP	7.76	3.50	31.4	4.91	Excellent- 97.5 Permissibl e-2.5	5.94	2.64	22.6	3.50	Excellent- 97.5 Permissibl e-2.5
RSBC	2.09	-0.48	5.32	1.32	Safe- 97.5 Marginal -2.5	1.63	-0.75	4.22	1.28	Safe -100
RSC	-0.75	-1.67	-0.3	0.73	Safe-100	-0.63	-1.11	-0.2	0.70	Safe-100
PI	51.16	36.91	71.2	8.02	Excellen t-2.5 Fair- 97.5	51.29	38.63	73.8	7.17	Fair- 100
MAR	35.67	19.70	51.6	7.70	Suitable- 97.5 Unsuitabl e-2.5	29.49	20.06	41.1	5.78	Suitable-100
KR	0.08	0.03	0.45	0.07	Suitable-100	0.06	0.03	0.28	0.04	Suitable-100
Mg:Ca	0.346	0.147	0.64	0.12	No infiltration problem	0.26	0.15	0.42	0.07	No infiltration problem
Na:Ca	0.148	0.053	0.74	0.11	No infiltration problem	0.10	0.04	0.41	0.06	No infiltration problem

In order to determine the salinity danger in groundwater, mineralisation takes place and increased EC and TDS levels (particularly during POM season) were noted (Table 5). According to Hoffman (2010) and Zaman et al. (2018), saline soils often have a pH of less than 8.5, are relatively low in Na, and mostly include Ca, Mg, and Na salt of Cl⁻, SO₄²⁻, CO₃²⁻, HCO₃⁻, NO₃⁻, and PO₄³⁻. The salinity danger in the topsoil may be accelerated by the research area's absolute calcite type (Ca-HCO₃) water, which has a low Na content and high TH. This risk arises when salt builds up in the crop root zone to a level that reduces production because the plants' roots cannot absorb enough water to stay hydrated in salty soil. Crop development is hampered by decreased water intake (Ayers & Westcot, 1985). In general, the level of the water table, method of irrigation (sprinkler or surface), local climate, soil structure, rooting depth, and soil leaching capacity all influence the potentiality of salt danger. The research area's soil is composed of alluvial coarse sand and gravel, and it has a high rate of water infiltration, which contributes to the salinity threat. Sodicity, permeability, and shifting soil structure are the six hazard classifications that are most influenced by the values of Na%, SSP, SAR, and PI. These metrics show the total Na-hazard in the soil, which hardens the soil, lowers the soil's rate of infiltration, limits plants' capacity to adsorb water in the root zone, and makes the soil salty (with Cl⁻) and alkaline (with HCO₃⁻/CO₃²⁻). The concentrations of Na⁺ and Cl⁻ in the samples are much lower than those of Ca²⁺ and Mg²⁺, which results in the lower values of the aforementioned parameters. Some Ca²⁺ and Mg²⁺ may be bound by the greater concentration of HCO₃⁻ ions in samples, decreasing their availability to mitigate the dangerous effects of Na⁺ ions in the soil. Higher

Ca^{2+} and Mg^{2+} concentrations in the study area's irrigation water likely to mitigate the negative impacts of Na^{+} and encourage healthy soil aggregates. The very desirable $\text{Na}\%$, SSP, SAR, and PI values are shown in Table 5. Therefore, the research area's groundwater is in a very excellent situation with regard to the Na-hazard. However, the $\text{Mg}:\text{Ca}$ and $\text{Na}:\text{Ca}$ ratios are important indicators of IWQ.

Water is very dangerous for irrigation if the $\text{Mg}:\text{Ca}$ and $\text{Na}:\text{Ca}$ values are more than 4 and 3, respectively (Ayers & Westcot, 1985). Groundwater in the research region exhibits very low $\text{Mg}:\text{Ca}$ and $\text{Na}:\text{Ca}$ ratios compared to appropriate limits, indicating little risk of soil infiltration issues. Excess Na^{+} in water promotes soil dispersion and structural disintegration when the $\text{Na}:\text{Ca}$ ratio is greater than 3. Infiltration issues will mostly arise from such a high ratio because there is not enough Ca^{2+} or Mg^{2+} to counteract the diffusing impact of Na^{+} . These issues are particularly prevalent in the nation's coastal regions, where Na-salinity poses a major risk to the agricultural industry. The excess concentration of HCO_3^{-} over Ca^{2+} is denoted by RSBC. According to Gupta and Gupta (1998), water with RSBC <5, 5-15, and <15mEq/L are classified as innocuous, minor, and dangerous, respectively. According to Table 5, the RSBC values in the PRM season varied from -0.483 to 5.32 with an average of 2.09, whereas in the POM season, they ranged from 0.751 to 4.22 with an average of 1.63. The findings demonstrated that the water samples were safe to use for irrigation. The research area's groundwater contains extra HCO_3^{-} , as shown by the negative RSBC values. Rather, KR showed that the Ca^{2+} , Mg^{2+} , and Na^{+} ions in the samples were in balance. The additional concentration of Na^{+} in the water is seen when the KR is greater than 1. As anticipated, the samples' KR value was much less than 1, indicating a strong balance between the Ca^{2+} , Mg^{2+} , and Na^{+} concentrations in the water samples. Another indicator, MAR, showed a lower value, indicating that Mg^{2+} was lower than Ca^{2+} . This was a highly positive indication for IWQ (Table 5). The technique used for diagrams The Wilcox diagram and PI diagram were two diagram-based techniques utilised in the research to assess whether water was suitable for irrigation. This research placed the EC and SAR values of forty groundwater samples in Richards' (1954) US salinity danger diagram. For irrigation events, it was shown that over 80% of samples for the PRM period fell into the C2S1 classes (C2 denotes medium salinity danger and S1 denotes lowest sodicity hazard). Additionally, almost all samples during the POM period belong to the C3S1 class (C3 denotes high salinity danger) (Figure 3). This result shows that all soil types, with the exception of the Na^{+} danger, were carried by the groundwaters in the research region. The groundwater's excessive salinity, particularly in

FIGURE 3 US salinity hazard diagram for irrigation water quality POM seasons, maybe the cause of the higher concentration of divalent alkaline earth cations, that is, the high salinity was not the cause of Na-salt, whereas the higher Ca^{2+} and Mg^{2+} concentrations were affected. The results of this salinity danger graphic were validated by the EC, TDS, and SAR values found in water samples throughout both seasons. Furthermore, the suggested Overall IWQ Index values of the POM are lower than the PRM period that validated the results of the US salinity hazard diagram because of the fluctuating salinity conditions. Based on the aforementioned talks, it was considered that the relative values of EC (which creates a salinity danger) and Na^{+} ion concentration (which creates



a sodicity hazard) typically determine whether water is suitable for irrigation. As a result, all of the PRM season samples fell into the cluster of excellent to good classes when the Na% values were plotted against the EC on Wilcox's diagram (Wilcox, 1955) (Figure 4). However, 25% of the POM season samples were in the good to permitted class, and around 75% of the samples were in the outstanding to good class. Wilcox's figure indicated that the total EC value of samples was parallel to Na% readings, much as the US salinity danger diagram. This showed that the EC is independent of the water samples' Na% content. Once again, the results of the suggested Overall IWQIndex for the research region are supported by the diagram's findings. The quantity of Na⁺, Ca²⁺, Mg²⁺, and HCO⁻ in irrigation water and soil directly affects the rate of water infiltration or soil permeability. Soil permeability is seriously threatened by the excess Na⁺ ion in water. Doneen (1964) employs a metric based on the PI to assess whether groundwater is suitable for irrigation. On Doreen's graphic, the PI parameter of forty samples was plotted against the water samples' total ionic content at mEq/L (Figure 5). Three categories of water were used to describe the

FIGURE 4 Wilcox diagram for the suitability of groundwater for irrigation purposes

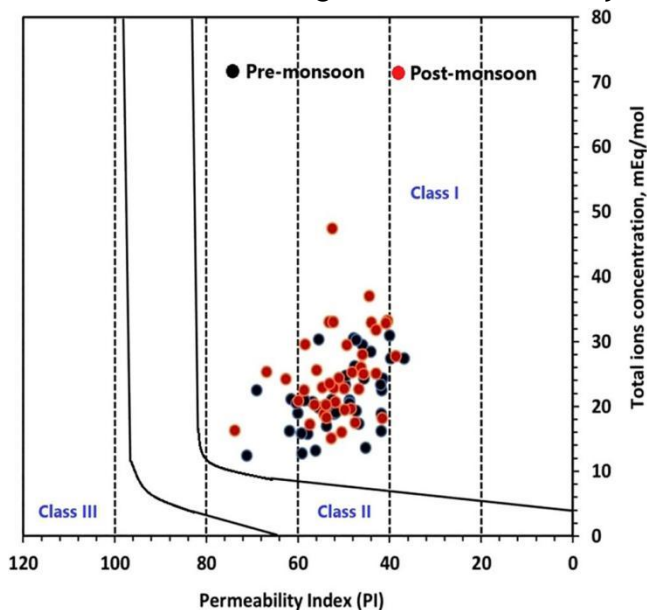


FIGURE 5 Permeability index diagram of the study area's groundwater samples

quality according to the diagram: class Class II water class was mostly appropriate for irrigation, class III water class was inappropriate for irrigation applications, and class I water class demonstrated good water quality for irrigation with reference to low PIs and low to extremely high ion concentration (Doneen, 1964). The groundwater samples' PI values range from 36.91% to 71.27%, with an average of 51.16 for the PRM period (Table 3). Additionally, the POM period had very identical findings. In addition to the PI diagram, all of the samples fall under class I, indicating that the groundwater in the study region was of the highest quality for irrigation and had no issues with water infiltration. The PI diagram result is supported by the subindex value for the permeability hazard class under the Overall IWQIndex, which was produced at a reasonable level. Due to climate change, rainfall percolation, and an unbalanced recharge/discharge ratio in the research region, the study found a significant difference between the PRM and POM seasons in IWQ (BBS, 2019). The POM season was shown to have greater levels of EC, TDS, TH, and several ionic components than the PRM season. This might be because of the mineralisation of water during surface runoff, infiltration, and percolation of precipitation

(Helal et al., 2011). Geochemical processes such rainfall percolation and infiltration, evapotranspiration, ion exchange, and soil/sediment dissolution are usually responsible for the wide variability in conductivity values ($\pm$ SD: 172.5–206.1) (Saha et al., 2008). Thus, there is a significant variance in IWQ due to seasonal oscillations. Bangladesh has investigated the IWQ in fourteen zones (Islam & Mostafa, 2021c). According to the findings of those studies, the irrigation water in coastal areas like the District of Sathkhira (Mirza et al., 2012), Borguna (Islam et al., 2016), Lakshipur (Bhuiyan et al., 2016), Khulna (Didar-ul et al., 2017), and others are highly sodicity affected and unsuitable for irrigation. There is a little salinity issue with another irrigation water in the country's northern and east-northern areas (Islam & Mostafa, 2021c). However, the current investigation found that the irrigation water in the study zone is in excellent condition, with the exception of EC and a transient Ca-hardness issue.

5 | CONCLUSION

The IWQ in the Ganges River basin regions of Bangladesh was evaluated by taking into account a number of geochemical and IWQ characteristics of groundwater for both the PRM and POM eras. In order to simply assess irrigation water appropriateness, the research presented a new Overall IIWQIndex employing the appropriate subindex and aggregated equations, which incorporated the maximum number and kinds of water characteristics. Irrigation water was divided into six categories using the Overall IWQIndex model: rejection (<3.5), poor (3.5 to <6), fair (6 to <12), moderate (12 to <23), good (23 to <35), and excellent (>35). In order to determine their classes for irrigation, this model assessed the calcite type (Ca-HCO₃) of the water in the research region. According to the calculated data, the index values for the PRM and POM sample seasons were 34.57 and 29.65, respectively. Compared to samples from the POM that fell into the "good" category, the samples from the PRM season are of higher quality and are almost in the "excellent" category. Because the samples had greater concentrations of bicarbonate and alkaline earth metal ions, the research found that the average EC and TDS values were much higher than those of the other equivalent geographic region of the nation. The appropriateness for irrigation was assessed using a few diagram-based methods, and the results were compared to the Overall IIWQIndex. According to the US salinity danger map, the groundwater type throughout the PRM and POM seasons was C2S1 and C3S1, respectively. The PI diagram showed that every sample was in the class 1 group for both seasons, while the Wilcox diagram shows that 80% of samples fit into the excellent to good category. These three diagrams' results roughly matched those of the suggested index approach. Even a farm manager or nontechnical decision-maker may use the suggested indexing strategy as a straightforward analytical tool. It is simple to calculate, justify, and provide useful information on irrigation water appropriateness.

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