



Evaluation of the suitability of groundwater for irrigational purposes using irrigation water quality indices and geographical information systems (GIS) at Patna (Bihar), India

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Received: 31 December 2021 / Accepted: 24 March 2022 / Published online: 13 April 2022

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Abstract

Patna, the state capital of Bihar, is primarily reliant on groundwater to meet its daily requirements, and overexploitation has placed significant strain on the quality and quantity of groundwater resources. Regular monitoring of groundwater quality for drinking and irrigational purposes can be useful to detect any undesirable change in its ionic composition. Therefore, the study has been put forward with an objective to monitor the current status of groundwater and give a comprehensive account of spatial and seasonal variation in its physico-chemical characteristics and irrigational suitability using GIS-based approach. Sixty groundwater samples were collected seasonally (pre-monsoon, monsoon and post-monsoon) from 20 (twenty) different locations of Patna, Bihar in 2019–2020 and analyzed for physico-chemical characteristics using standard procedures. All the parameters were compared with the Bureau of Indian Standards 2012. Significant spatial variation was observed in pH, electrical conductivity, total dissolved solids, Mg^{2+} , Na^+ , HCO_3^- , and Cl^- between sampling sites, whereas ANOVA revealed significant seasonal differences in pH ($p=0.000$), Ca^{2+} ($p=0.000$), Mg^{2+} ($p=0.000$) and Na^+ ($p=0.028$). The suitability of groundwater for irrigation was evaluated with the help of sodium adsorption ratio, percent sodium, residual sodium bicarbonate, magnesium hazard, Permeability Index and potential salinity. Based on different irrigational indices, all groundwater samples were found to be suitable for irrigation purposes. USSL diagram has classified nearly 75% of overall groundwater samples features medium salinity with low sodium hazard, while Doneen's plot reveals 98.3% of samples are characterized with maximum permeability.

Keywords Groundwater · GIS · Spatial variation · Seasonal variation · Irrigational suitability · Physico-chemical parameters

Introduction

Groundwater is among those daily and vital necessities on which urban and rural inhabitants are highly dependent, especially in developing countries like India (Gaikwad et al., 2020; Shaikh et al., 2020). In India, approximately 89% of the groundwater is used for irrigation, 9% for domestic use, and 2% for irrigation purposes (CGWB, 2016). Out of India's 1.35 billion population, approximately 80% rely on groundwater for drinking and irrigation (Kumari & Rai, 2020). According to a national sample survey, 30.5% of

households get water from hand pumps, 10.7% from tube wells, and 34.7% based on piped water (NSS, 2018). Over-exploitation of groundwater has been a serious concern, especially in India, as it is the leading country in the world with respect to annual groundwater extraction (Fienen & Arshad, 2016). Furthermore, population explosion, extensive use of fertilizers, dumping of wastes in the surface water bodies, leaching of domestic and industrial wastes are other practices that contribute to the degradation of groundwater resources (Bhatt et al., 2021; Kumar et al., 2021; Panneerselvam et al., 2020). With the increasing population size of Patna, the extraction of groundwater may increase by 20–30% by the year 2025, which is currently 290 MCM per year (CGWB, 2015). Degradation in the quality of water, lowering of the water table by more than 20 feet as reported by Central Ground Water Board, as well as the scarcity of potable and safe drinking water have come up as emerging

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issues, primarily concerning public health (Nabi et al., 2019; Zerbo et al., 2020). In India, agriculture is one of the most critical sectors of the economy. Good water quality is required for irrigation purposes to prevent damage to sensitive crops (Barua et al., 2021; Kurdi et al., 2013) and sustain current agricultural production. Therefore, groundwater quality monitoring must be done regularly (Khan et al., 2020; Suleiman et al., 2020). Several researchers have conducted studies on groundwater quality assessment based on different irrigational indices in foreign countries (Aziane et al., 2020; Ben Moussa et al., 2021; Eldaw et al., 2021; Gabr et al., 2021; Hekmatnia et al., 2021) and India (Thankachan et al., 2020; Al Maliki et al., 2020; Srivastava, 2019; Prabhakaran & Seetharaman, 2020; Kadam et al., 2021). As per the literature review, no prior study on the assessment of groundwater quality based on irrigation indices in Patna has been conducted that the present authors are aware of. With respect to recent groundwater research in the nearby regions, some studies have been conducted in other districts of Bihar, such as Nalanda (Saha et al., 2010), Bhagalpur (Verma et al., 2018), Bhojpur (Kumar et al., 2021; Kumari, 2017; Maity et al., 2020), Jehanabad (Bhatt et al., 2021) as well as in adjacent states, such as Uttar Pradesh and West Bengal (Ahmad & Mazhar, 2020; Barua et al., 2021; Bishwakarma et al., 2022; Madhav et al., 2018; Nijesh et al., 2021; Sarkar et al., 2022; Verma et al., 2021). However, most of the studies conducted in Bihar were confined to a particular season, and limited irrigation indices were estimated. Adding to these, limited approaches were made to examine spatio-temporal changes physico-chemical parameters. No such work has been reported that discusses irrigation suitability of groundwater in the study area. Therefore, the present study aims to evaluate the suitability of groundwater for irrigation purposes and map various physico-chemical parameters and irrigation indices using the geographic information system (GIS) at Patna. The study being the pioneer in this respect may contribute stakeholders to plan a sustainable development and conservation strategy of groundwater resources.

Materials and methods

Study area

The present study is carried out in and around Patna, situated in South Bihar alluvial plains (latitude 25° 13' and 25° 45' N; longitude 84° 43' and 86° 44' E) with an area of 3172 km² (Fig. 1). Patna is shaped like a saucer, with a gentle slope from north to south. The railway line effectively divides the town's topographic features. The area south of the railway line is nearly flat, and rainfall often accumulates for most of the year on a vast area of urban land (Patna Master Plan

2031, 2016). This district experiences a subtropical climate with hot summer, and cold winter, and temperature vary from 30 to 43 °C during summer and 5–21.4 °C during winter. The mean annual rainfall is around 1076 mm and relative humidity reaches approximately 100% during summer. Land use distribution map of Patna indicates that majority of the land is under residential usage (47.5%), followed by agriculture-related (17.66%), public and semi-public (10.18%) transportation (5.90%), commercial (4.46%), mix use (3.37%), flood plain (3.35%), open space (3.07%) industrial (1.05%), airport (1.05%), water body (1.01%), brick kiln (0.70%), and forest (0.64%) (Patna Master Plan 2031, 2016).

Methodology of sample collection and analysis

In the present study, 60 groundwater samples were collected seasonally from 20 different sampling sites during 2019–2020. Sampling was done following the procedure prescribed by (APHA, 2012). Groundwater samples were collected after 10–15 min of pumping and filtering through 0.45 pore-size membrane filters in one-liter acid-washed HDPE (High-Density Polyethylene) bottles. All the samples were stored and transported to the laboratory in an icebox. Samples were analyzed for physico-chemical parameters, namely pH, electrical conductivity (EC), total dissolved solids (TDS), Ca²⁺, Mg²⁺, Na⁺, K⁺, HCO₃⁻, Cl⁻, and compared with (BIS, 2012) standards. Physical parameters, such as pH and electrical conductivity, were measured in situ with a portable kit. Bicarbonate ion was also determined on site using acid titration method. Analysis of remaining parameters was carried out in the laboratory. All of the analytical procedures were carried out in accordance with established protocols (APHA, 2012). Major cations, such as Ca²⁺ and Mg²⁺, were estimated using EDTA titrimetric method, whereas Na⁺ and K⁺ ions were evaluated with the help of flame photometer. TDS was measured using the gravimetric method, while chloride ion was determined by the argentometric method. The appropriateness of groundwater for irrigation is assessed by different irrigation water quality indices, including sodium adsorption ratio (SAR), percent sodium (% Na), residual sodium bicarbonate (RSBC), magnesium hazard (MH), permeability index (PI), potential salinity (PS), and Kelly's ratio (KR). It is computed using the following equations (Eqs. 1–6). In addition, the US Salinity Laboratory's diagram, the Wilcox diagram, and Doneen's chart were created to investigate the combined effects of EC, SAR, Na⁺, and salinity:

$$\text{SAR} = \text{Na}^+ / (\text{Ca}^{2+} + \text{Mg}^{2+} / 2)^{1/2} \text{ (Richards, 1954),} \quad (1)$$

$$\text{Na\%} = [(\text{Na}^+ + \text{K}^+) / (\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+} + \text{Mg}^{2+})] \times 100 \text{ (Wilcox, 1955),} \quad (2)$$

$$RSBC = HCO_3^- - Ca^{2+} \text{ (Gupta, 1983),} \tag{3}$$

$$PI = [(Na^+ + HCO_3^-)/(Ca^{2+} + Mg^{2+} + Na^+) \times 100] \text{ (Doneen, 1964),} \tag{4}$$

$$MR = [(Mg^{2+})/(Ca^{2+} \times Mg^{2+})] \times 100 \text{ (Raghunath, 1987),} \tag{5}$$

$$PS = Cl^- + 1/2SO_4^{2-} \text{ (Doneen, 1962).} \tag{6}$$

Spatial analysis of different irrigation indices was carried out with the help of ArcGIS software (ver 10.5) using inverse distance weighed (IDW) interpolation technique. The IDW method determines a value for each grid node by checking at neighboring data points within a user-defined search radius (Gnanachandrasamy et al., 2015). The interpolation method uses all of the data points, and the node value is determined by averaging the weighted total of all the points. IDW has the benefit of being intuitive and efficient, and being sensitive to outliers (Gunarathna et al., 2016).

Table 1 Statistical summary of the physico-chemical parameters used for the study

Parameters	Min	Max	Mean	Median	Std. deviation
pH	7	8.1	7.38	7.4	0.24
EC	300	1700	726.67	600	296.8
Ca ²⁺	17.63	165.93	66.59	63.7	32.93
Mg ²⁺	3	81.81	29.15	24.4	16.39
HCO ₃ ⁻	228	456	307.15	296	46.13
TDS	236	1195	462.7	354	231.79
Na ⁺	43	236	69.99	62	30.04
K ⁺	3.1	126	9.43	7.1	15.58
Cl ⁻	7	169	50.53	30	45.05

Unit in mg/L, except EC (µS/cm) and pH

Results and discussion

Physico-chemical analysis

The statistical summary of the physico-chemical parameters has been represented in Table 1.

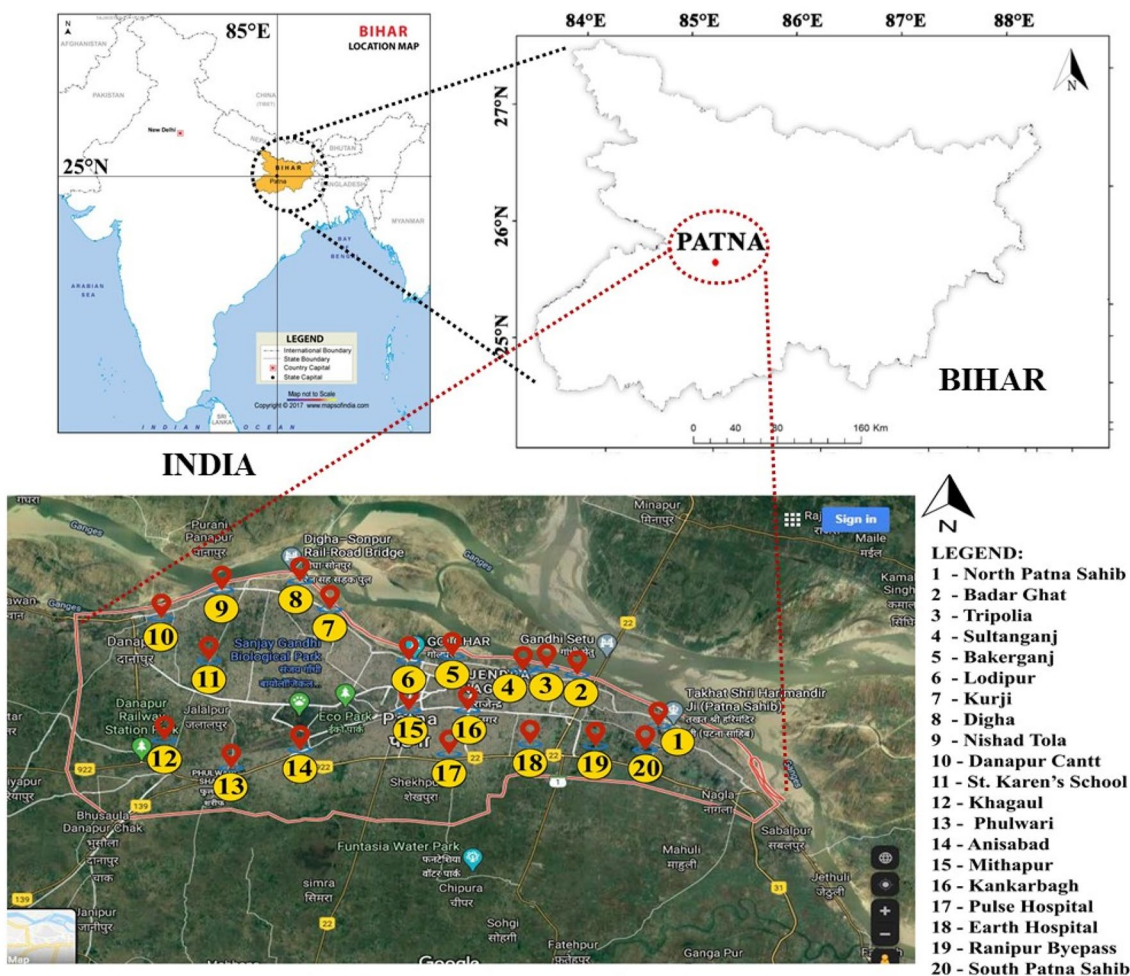


Fig. 1 Map showing study area with 20 sampling locations

pH

The spatial distribution map of pH in the study area indicates all of the water samples were within the desirable limits (6.5–8.5) of BIS, 2012 standards (Fig. 2a). Significant spatial variation in pH was observed ($F = 4.060$, $p = 0.000$) and confirmed by Tukey's multiple comparisons, which showed differences in pH between most sites. Box and Whisker plots for pH showed that pre-monsoon groundwater is more alkaline than monsoon and post-monsoon with negatively skewed values in pre-monsoon and post-monsoon only (Fig. 3a). Analysis of variance (ANOVA) reflected that the pH of groundwater varied significantly between seasons ($F = 8.410702$, $p = 0.0006$) and Tukey's multiple comparisons showed differences in pH between pre-monsoon and monsoon ($p = 0.000$). The pH values rendered groundwater slightly alkaline to alkaline, which can be ascribed to greater concentrations of bicarbonate ions generated by rainwater infiltrating through the soil. Furthermore, weathering of rocks, as well as their subsequent interactions with groundwater, might influence the pH of the study area (Ram et al., 2021; Singh et al., 2015; Tirkey et al., 2017).

Electrical conductivity (EC)

Figure 2b represents the spatial distribution of EC in the study area, and a high concentration of EC was observed in the eastern portion and a small portion in the south part of the area. Results of ANOVA suggest significant spatial variation in EC values ($F = 14.309$, $p = 0.000$), and Tukey's multiple comparisons showed differences in EC between a majority of sites. Increased dissolved salts in water resulted in the rise of EC, which might be from natural (increase in dissolution rate of minerals) or artificial (domestic and agricultural wastes) processes (John & Das, 2020; Rusydi, 2018). Figure 3b is the Box and Whisker plot for EC for all seasons, and it is observed that the concentration of EC was maximum in post-monsoon; positively skewed values were noted only during monsoon and post-monsoon. However, no significant seasonal differences were observed in EC ($F = 0.727309$, $p = 0.4876374$).

Total dissolved solid (TDS)

The spatial distribution map showed that TDS in most water samples from the eastern site was above the desirable limit of 500 mg/L as prescribed by BIS (2012) (Fig. 2c). Spatial variation in TDS was significant ($F = 37.378$, $p = 0.000$), and Tukey's multiple comparisons revealed significant differences between the majority of sampling sites. The value of TDS varies significantly at different geological areas depending upon the dissolubility of minerals (WHO, 2017). The highest TDS values were observed in post-monsoon,

but significant seasonal variations were not observed ($F = 0.134368$; $p = 0.8745443$). Box and Whisker plot revealed that TDS concentration appeared to be positively skewed, displayed high variations, and outliers were present in all seasons (Fig. 3c). Higher TDS values, particularly on the eastern side, can be ascribed to the area's defective drainage system, as water and sewage pipelines lie nearby in many colonies, creating the possibility of contamination of groundwater resources (Patna Master Plan 2031, 2016; Fuentes-Rivas et al., 2020).

Calcium ion (Ca^{2+})

The spatial variation map of Ca^{2+} ion showed that higher concentrations of Ca^{2+} were observed in the major portion of the eastern side and small patches on the western side (Fig. 2d). However, there were no significant differences in the concentration of calcium ions at all sampling sites ($F = 1.240$, $p = 0.276$). The concentration of Ca^{2+} ion appeared to be positively skewed, displayed high variations and deviation from the mean in all seasons. In contrast, maximum concentration was observed in the pre-monsoon season (Fig. 3d). In the present study, 45% of pre-monsoon samples and 30% of the post-monsoon samples were beyond the desirable limit. Because of its great solubility and availability in most rocks, the presence of calcium ion is a common phenomenon in groundwater (Ali & Ali 2018; Sharma et al., 2017). Higher Ca^{2+} ion concentration in the pre-monsoon might be related to weathering of limestone and sedimentary rocks and minerals (Gaikwad et al., 2020; Ibrahim & Lyons, 2017). Significant seasonal difference in Ca^{2+} ion was observed ($F = 18.16614$, $p = 0.0000007$) and Tukey's multiple comparisons showed differences in Ca^{2+} ion between pre-monsoon and monsoon ($p = 0.000$), monsoon and post-monsoon ($p = 0.001$) respectively.

Magnesium ion (Mg^{2+})

The spatial distribution map for Mg^{2+} ion revealed that the values of Mg^{2+} obtained in this study are higher than the desirable limit of 30 mg/l set by BIS (2012) at the majority of sites except for western and small patches of the southern, eastern side (Fig. 2e). The result of ANOVA suggests significant spatial variation ($F = 2.365$; $p = 0.011$), and Tukey's multiple comparisons revealed significant differences between the majority of sampling sites. Box and Whisker plot showed the highest Mg^{2+} ion during post-monsoon and positively skewed during monsoon and post-monsoon, whereas negatively skewed in pre-monsoon (Fig. 3e). The seasonal variation of Mg^{2+} ion was statistically significant ($F = 7.890248$; $p = 0.000$) and Tukey's multiple comparisons showed significant differences between pre-monsoon and monsoon ($p = 0.003$); pre-monsoon and post-monsoon

Fig. 2 Spatial map of physico-chemical parameters **a** pH, **b** EC, **c** TDS, **d** Ca²⁺ ion, **e** Mg²⁺ ion, **f** Na⁺ ion, **g** K⁺ ion, **h** bicarbonate ion, **i** Cl⁻ ion

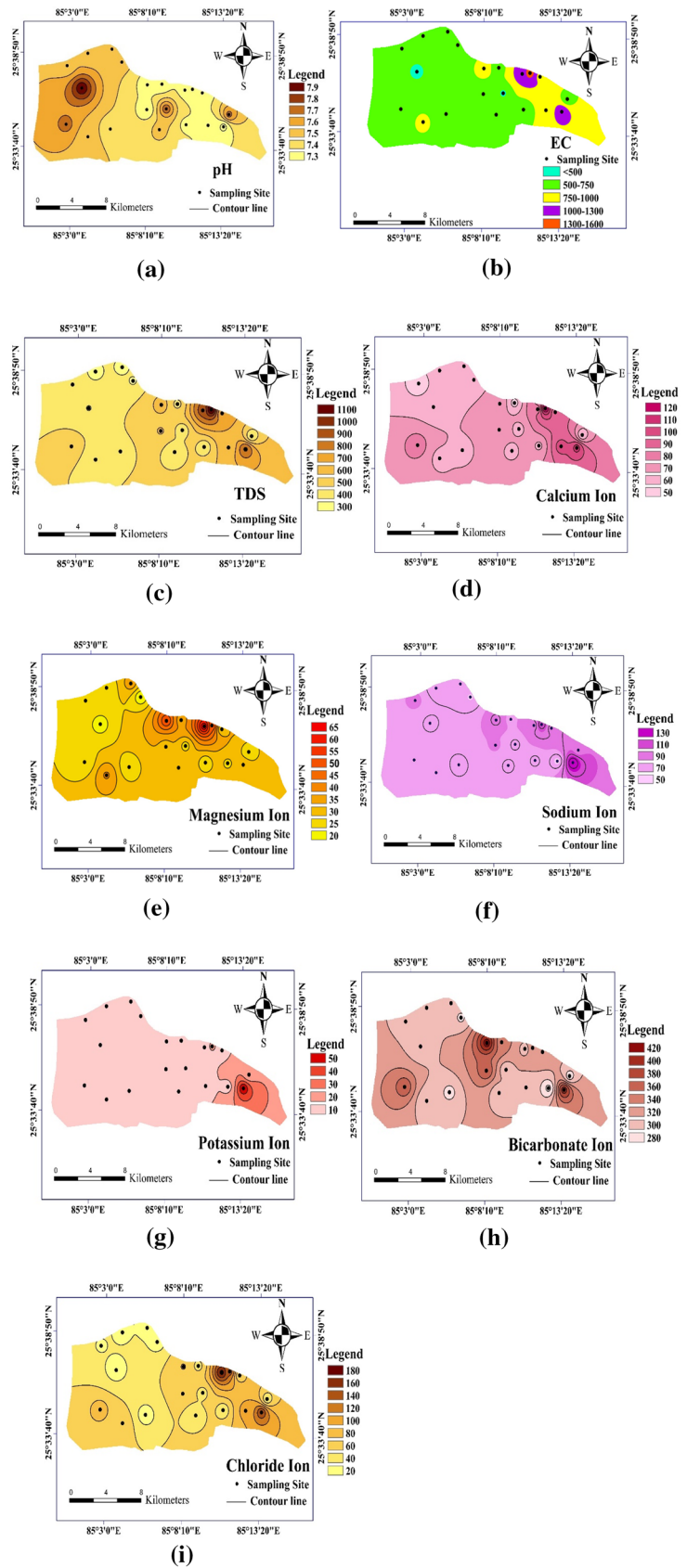
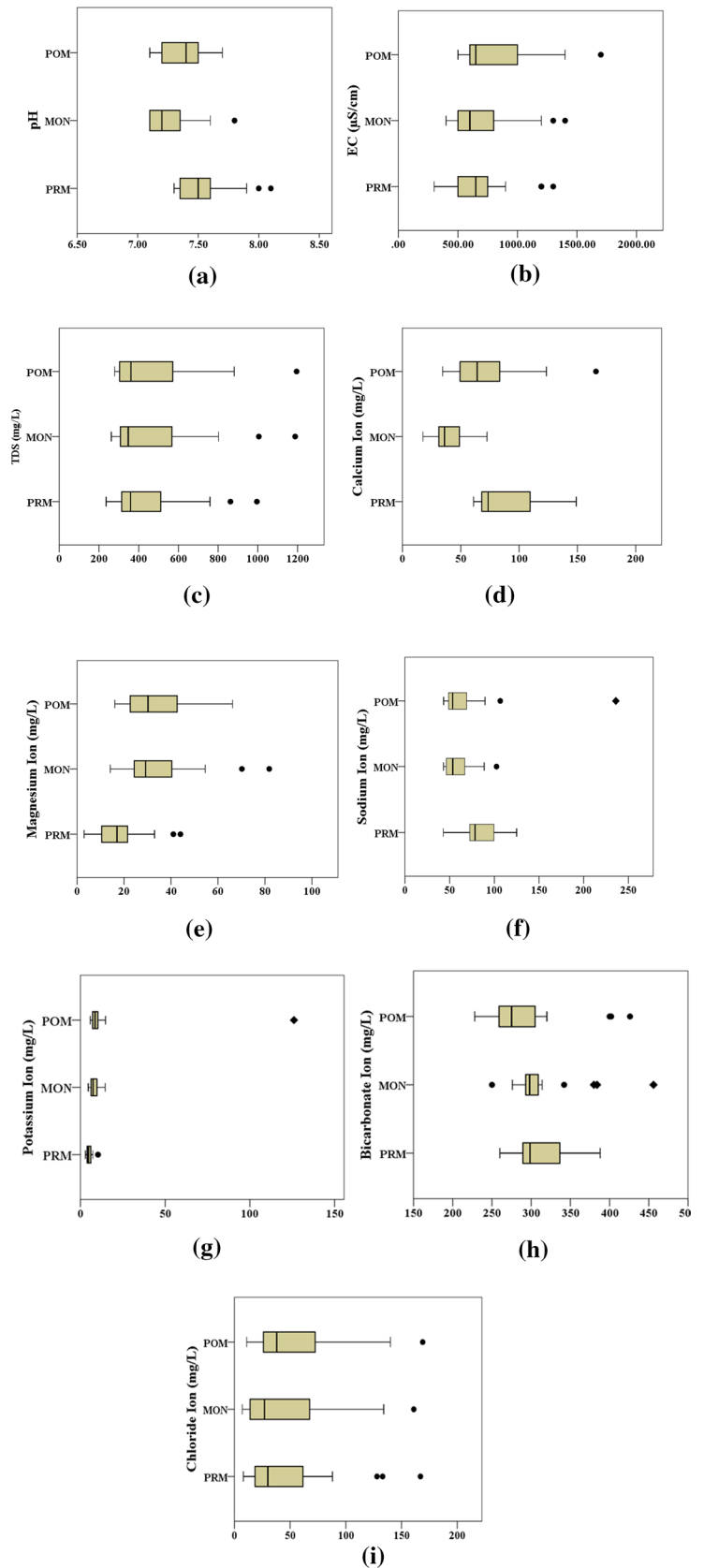


Fig. 3 Box plots showing seasonal variation in the physico-chemical parameters **a** pH, **b** EC, **c** TDS, **d** Ca²⁺ ion, **e** Mg²⁺ ion, **f** Na⁺ ion, **g** K⁺ ion, **h** bicarbonate ion, **i** Cl⁻ ion



($p=0.004$), respectively. Dissolution of silicate and dolomite rocks by weathering and reverse ion exchange processes might be the reason behind higher Mg^{2+} ion concentration in the groundwater (Bouderbala, 2017; Gaikwad et al., 2020; Panneerselvam et al., 2020; Sharma et al., 2017; Srinivasamoorthy et al., 2014; Yasser et al., 2021).

Sodium ion (Na^+)

The concentrations of Na^+ ion obtained in this study are within the prescribed limit of 200 mg/L as set by BIS (2012) standards (Fig. 2f). Significant spatial variation in Na^+ ion was observed ($F=1.985$; $p=0.034$), and Tukey's multiple comparisons revealed differences between Kurji and South Patna Sahib ($p=0.029$), Ranipur Bypass, and South Patna Sahib ($p=0.020$). Higher Na^+ ion concentration was observed in eastern and some patches of north-eastern region which might be due to anthropogenic activities, such as seepage of sewage and domestic wastes by the old and faulty drainage system, prevalent in these regions (Balamurugan et al., 2020; Patna Master Plan 2031, 2016; Selvakumar et al., 2017). The concentration of Na^+ ion appears to be positively skewed, displayed high variations and deviation from the mean in all seasons. An extreme outlier was found during post-monsoon and outliers were observed in monsoon and post-monsoon season (Fig. 3f). Seasonal variation in Na^+ ion was statistically significant ($F=3.791297$; $p=0.028$) and significant differences were observed between pre-monsoon and monsoon seasons ($p=0.023$).

Potassium ion (K^+)

Spatial variation in K^+ ion revealed that the majority of sampling sites were within the prescribed limit of BIS (2012) except eastern areas (Fig. 2g) and significant spatial variation was not observed ($F=0.928$, $p=0.555$). The concentration of K^+ ion appears to be positively skewed, displayed high variations, extreme outliers, and maximum concentration was observed in the post-monsoon season. (Fig. 3g). High K^+ ion values are primarily associated with the seepage of agricultural and domestic wastes in the groundwater (Marghade, 2020; Onwuka et al., 2021). ANOVA shows that K^+ ion did not differ significantly with seasons ($F=2.147568$; $p=0.1261223$).

Bicarbonate ion (HCO_3^-)

The spatial distribution map of bicarbonate ion revealed that the entire study area was beyond the desirable limit of 200 mg/L as set by BIS (2012). A higher bicarbonate ion concentration was observed in central and small stretches of the eastern and western areas (Fig. 2h). ANOVA revealed significant spatial variation in bicarbonate ion values

($F=7.434$, $p=0.000$), and Tukey's multiple comparisons confirmed that most sites exhibited bicarbonate ion concentration differences. Mineral dissolution is a major contributor of bicarbonate ions (Bhunja et al., 2018). Carbonate and silicate weathering in the presence of soil carbon dioxide (gas) might be the reason behind elevated levels of bicarbonate ions in the entire study area (Naidu et al., 2021; Narasimha & Sudarshan, 2017; Roy et al., 2018; Shaikh et al., 2020). Box and Whisker plot showed that bicarbonate ion was highest during pre-monsoon (Fig. 3h), and significant seasonal variations were not observed ($F=1.06183$; $p=0.3525624$). The bicarbonate ion concentration appears to be positively skewed, displaying high variations, outliers and extreme outliers in post-monsoon and monsoon seasons.

Chloride ion (Cl^-)

The spatial distribution map showed that Cl^- values obtained in this study are within the prescribed limit of 250 mg/l (BIS 2012). The concentration of Cl^- ion was marginally higher in the eastern part (Fig. 2i). Higher Cl^- ion values in groundwater are considered a sign of surface contamination (Prasanna et al., 2011) and might be due to the high concentration of animal wastes or industrial wastes (Gupta et al., 2019; Kannan & Mani, 2021). Verma et al., (2021) reported that leaching of infiltrate from sewerage facilities is a major cause of chloride contamination. It can be corroborated with the inefficient sewage system found in these regions (Patna Master Plan 2031, 2016). The spatial variation was significant ($F=74.423$; $p=0.000$), and Tukey's multiple comparisons showed differences in Cl^- ion between the majority of sites. Box and Whisker plot revealed that concentration of Cl^- ion appears to be positively skewed, displayed high variations and extreme outliers were present in all seasons with highest values in post-monsoon (Fig. 3i). Seasonal differences in Cl^- ion concentration were not observed ($F=0.103996$, $p=0.9013991$).

Suitability for irrigation purposes

Apart from drinking and domestic purposes, groundwater is mostly used for irrigation. Groundwater may contain excessive chemical pollutants derived from environmental and anthropogenic activities. Hence, knowledge about the quality of water used in irrigation is essential for improving crop yield and avoiding the deterioration of soil health (Alam et al., 2021). Sodium absorption ratio (SAR), % Na, residual sodium bicarbonate (RSBC), Permeability Index (PI), magnesium ratio (MR), potential salinity (PS), and Kelly Index (KI) were calculated to determine the quality of water for irrigation use. The USSL, Wilcox, and Doneen diagrams have also been used to classify water for irrigation purposes.

Electrical conductivity

Electrical conductivity is valuable for measuring the salinity hazard to crops induced by irrigation. It is thus extensively used to determine the appropriateness of groundwater for irrigation purposes (Kumari & Rai, 2020). Excessive salinity reduces plant osmotic activity and interferes with groundwater and soil nutrient absorption (Lanjwani et al., 2020; Zorb et al., 2019). The classification of groundwater based on EC value (Ayers & Westcott, 1985) and the percentage of samples belonging to each category are shown in Table 2. During pre-monsoon and monsoon, 50% of the groundwater

samples were classified as excellent, compared to 45% in the post-monsoon. The remaining samples were evaluated as "good" for irrigation.

Total dissolved solids

TDS is the measure of bulk salinity in water. The total salt content makes it more difficult for growing plants to absorb water from the soil. The additional energy required by the plant to overcome the pull of the salt on the water in the soil around its roots reduces plant performance, resulting in stunted growth, lower yields, and, in extreme cases, plant

Table 2 Irrigation water quality parameters of groundwater samples at Patna in the year 2019–2020

SL. no	Parameters	Class	Range			% of samples			
			PRM	MON	POM	PRM	MON	POM	
1	EC (microsimens/cm) (Ayers & Westcott, 1985)		300–1300	400–1400	500–1700				
		< 700	Excellent				50	50	45
		700–3000	Good				50	50	55
		> 3000	Fair				0	0	0
2	TDS (mg/L) (Ayers & Westcott, 1985)		236–995	262–1188	279–1195				
		< 450	Suitable				65	65	65
		450–2000	slight to moderate				35	35	35
		> 2000	Severe				0	0	0
3	% Na (Wilcox, 1955)		21.85–48.5	24.7–51.4	22.16–61.91				
		< 20	Excellent				0	0	0
		20–40	Good				50	85	90
		40–60	Permissible				50	15	5
		60–80	Doubtful				0	0	5
		> 80	Unsuitable				0	0	0
4	MR (Raghunath, 1987)		6.68–37.26	30.85–80.39	24.30–72.35				
		< 50	Suitable				100	30	60
		> 50	Unsuitable				0	70	40
5	RSBC (Gupta, 1983)		-5.06	1.35–6.03	-7.03				
		< 5	Satisfactory				100	95	100
		05–10	Marginal				0	5	0
		> 10	Unsatisfactory				0	0	0
6	SAR (Richards, 1954)		0.71–1.93	0.84–1.8	0.74–3.56				
		< 10	Excellent				100	100	100
		10–18	Good				0	0	0
		18–26	Doubtful				0	0	0
		> 26	Unsuitable				0	0	0
7	PS (Doneen, 1962)		0.51–5.62	0.51–5.69	0.77–5.76				
		< 5	Excellent to good				95	85	90
		05–10	Good to injurious				5	15	10
		> 10	Injurious to unsatisfactory				0	0	0

EC electrical conductivity, TDS total dissolved solid, MR magnesium ratio, RSBC residual sodium bicarbonate, SAR sodium absorption ratio, PS potential Salinity

death (Zhang, 2017). Ayers and Westcott (1985) classified groundwater suitability based on TDS values (Table 2). 65% of the samples during the three seasons were good, whereas the remaining samples were categorized as 'slight to moderate' for irrigation. Based on TDS values, groundwater in the study area is suitable for irrigation.

Sodium absorption ratio (SAR)

Sodium absorption ratio (SAR) is used to know water quality for irrigation use because a higher value of SAR causes sodium hazard. According to Richards (1954), high sodium concentration in water can reduce soil permeability by cation-exchange processes between water and soil (Alam et al., 2021; Chaudhary & Sateeshkumar, 2018). Based on SAR values (Richards, 1954) classified irrigation suitability as excellent (0–10), good (10–18), doubtful (18–26), and unsuitable (> 26). SAR values in this study ranged from 0.71 to 3.56 meq/L (Table 2), which falls into the 'excellent' category for irrigation, as illustrated by the spatial distribution map (Fig. 7a). Recently, similar findings were observed by Verma et al., (2018), Maity et al., (2020) and Kumar et al., (2021) for different regions of Indo-Gangetic plains.

The USSL diagram was employed to categorize irrigational water quality based on the value of SAR and EC to predict the extent of sodium and salinity hazard. In this study, the diagram revealed that the majority (~ 75%) of the water samples fall in the field C2S1 (medium salinity with low sodium), while the rest (~ 25%) samples fall in C3S1 (high salinity with low sodium) during all seasons (Fig. 4). Diagram revealed a low sodium hazard, but the salinity hazard varied between medium and high. Hence, water with

moderate to high salinity and low sodium can irrigate any soil with little risk of exchangeable sodium (Rishi et al., 2019). Bhatt et al., (2021) reported high salinity hazard with low sodium hazard and very high salinity with low sodium hazard in 21% and 3% of the groundwater samples, respectively, in the neighboring district of Jehanabad.

The Wilcox diagram has been used to check the suitability of irrigational water quality based on the value of Na% and EC to predict the extent of sodium hazard (Wilcox, 1955). Water with high sodium ions causes absorption of Na⁺ by soil particles displacing Ca²⁺ and Mg²⁺ (Chaudhary & Sateeshkumar, 2018), which ultimately reduces soil permeability in wet conditions (Yang et al., 2020). High sodium ions in water can react with carbonate/bicarbonate and chloride ions, rendering soil alkaline and saline and limiting irrigation appropriateness (Kumar & Balamurugan, 2019). Na% values of groundwater varied from 28.1 to 61.9 meq/l during the study period (Table 2). The diagram revealed 78.3% of all water samples fall in excellent to good category, while only one sample seems doubtful for irrigation (Fig. 5).

Residual sodium bicarbonate (RSBC)

When the calcium ion concentration in groundwater is less than that of bicarbonate ion, the additional bicarbonate ion combines with Na⁺ ion to form residual sodium bicarbonate (Shukla & Saxena, 2020). Higher sodium bicarbonate concentration is detrimental to soil physical properties as they tend to accelerate the decomposition of organic materials (Panneerselvam et al., 2020). Value of RSBC calculated for different sites during the study period varied from 1.35 to 6.03 meq/l and revealed that

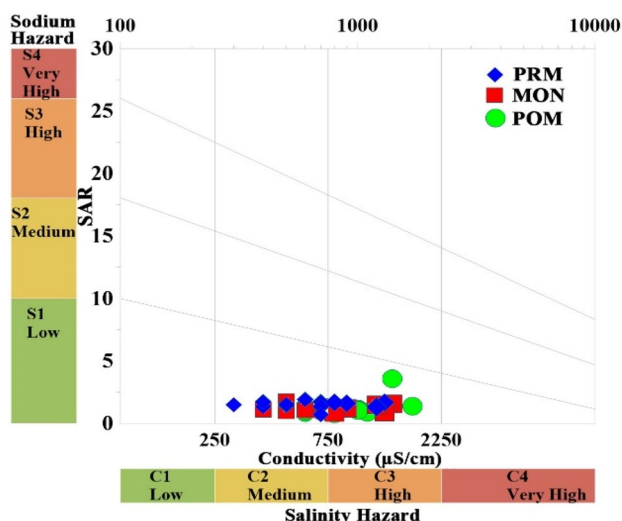


Fig. 4 USSL diagram for classification of irrigation water quality based on the value of SAR and EC

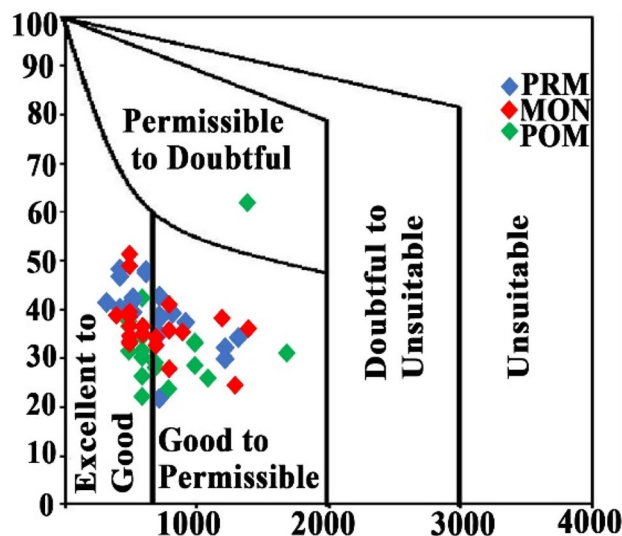


Fig. 5 Wilcox diagram for classification of irrigation water quality based on the value of % Na and EC

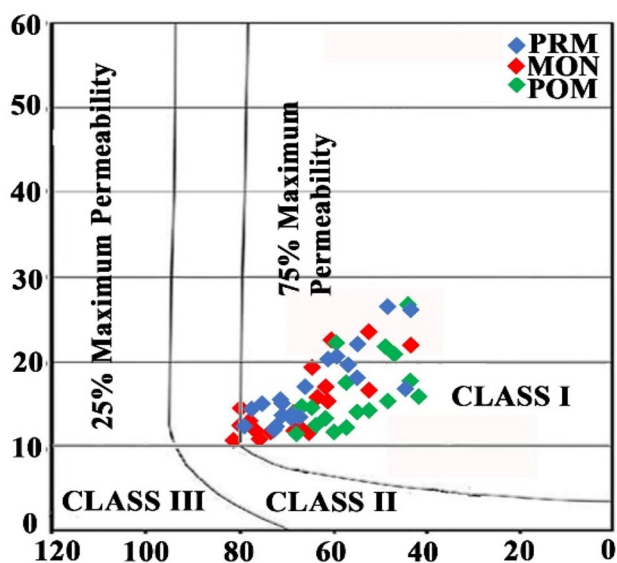


Fig. 6 Doneen's plot based on total ion concentration and permeability index

all water samples, excluding 5% sample collected during monsoon, were satisfactory for irrigation usage (Table 2). The spatial variation map indicated that groundwater is acceptable for irrigation based on RSBC values (Fig. 7b). The spatial variation map showed that groundwater is satisfactory for irrigation based on RSBC values (Fig. 7b). A previous study conducted by Bhatt et al., (2021) in the adjacent district of Jehanabad reported 27.6% of the samples as marginally suitable, whereas 10% as unsuitable for irrigation.

Permeability Index (PI)

The permeability index is an essential indicator of groundwater irrigation suitability as it reflects the impact of long-term irrigation on soil permeability (El Bilali & Taleb, 2020). Continuous utilization of abundant mineral groundwater for irrigation may decrease soil permeability, which affects crop yield (Panneerselvam et al., 2021; Rufino et al., 2019). PI value in the study area ranged between 41.11 and 81.34 meq/l (Table 2). Doneen's diagram was plotted to categorize irrigational water quality based on the value of total ion concentration and PI to predict the extent of soil permeability. The diagram revealed that all water samples (except one sample collected during monsoon) fall in class I, which is good for irrigation. One sample falls in class II, which is marginally suitable (Fig. 6). Similar results based on PI values were reported by Kumar et al., 2020 and Bhatt et al., 2021 in their respective studies.

Magnesium ratio (MR)

Magnesium contributes to the deterioration of soil structure, especially when irrigation water contains an excessive quantity of Na^+ ion (Yang et al., 2020). A larger amount of exchangeable Na^+ ions in irrigated soils leads to a significant increase of Mg^{2+} ions (Rishi et al., 2019). Increased concentration of Mg^{2+} deteriorates soil quality by making it alkaline, which has an adverse effect on crop yields (Kumari & Rai, 2020). The MR values ranged between 6.68 and 80.39 mg/l during the study period, and water quality deteriorates during monsoon (70%) and post-monsoon (40%) seasons (Table 2). MR's spatial variation map showed that water quality falls in a suitable category in large part of the study area. Water quality is not suitable for irrigation only in few small stretches (Fig. 7c). Contrasting result was revealed by Bhatt et al., (2021) as 87.7% of the groundwater samples were suitable for irrigation based on MR values.

Potential salinity (PS)

Potential salinity is another important irrigation index as it considers low-soluble salts, which also plays a significant role in determining the suitability of groundwater for irrigation purposes (Chaudhary & Satheeshkumar, 2018). These salts accumulate in the soil after precipitation during successive irrigation, and the presence of highly soluble salts elevates the salinity of the soil (Barik & Pattanayak, 2019). The PS value in the study area varied from 0.51 to 5.76 meq/l during the study period, and the quality of water slightly deteriorated during the monsoon (Table 2). The spatial variation map of PS showed that most groundwater samples from different sites fall in the excellent to good category and only in a few small patches sample water quality fall in the good to injurious category (Fig. 7d). Similar results were obtained by Verma et al., (2021) in the Lucknow district of Uttar Pradesh. A contrasting result was reported by Ahmed et al., 2021 in Aligarh district where 46% of the samples fall in 'good to injurious' and 4% belong to 'injurious to unsatisfactory' category.

Conclusion

The study was undertaken to evaluate the current groundwater status for physico-chemical characteristics and irrigation purposes at Patna, Bihar. The analytical findings conclude that groundwater is slightly alkaline to alkaline in nature and falls in the hard to very hard category, which remains more or less the same during all seasons. The ionic trend follows the order $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ for cations, whereas bicarbonate ion has dominated Cl^- during the entire study period.

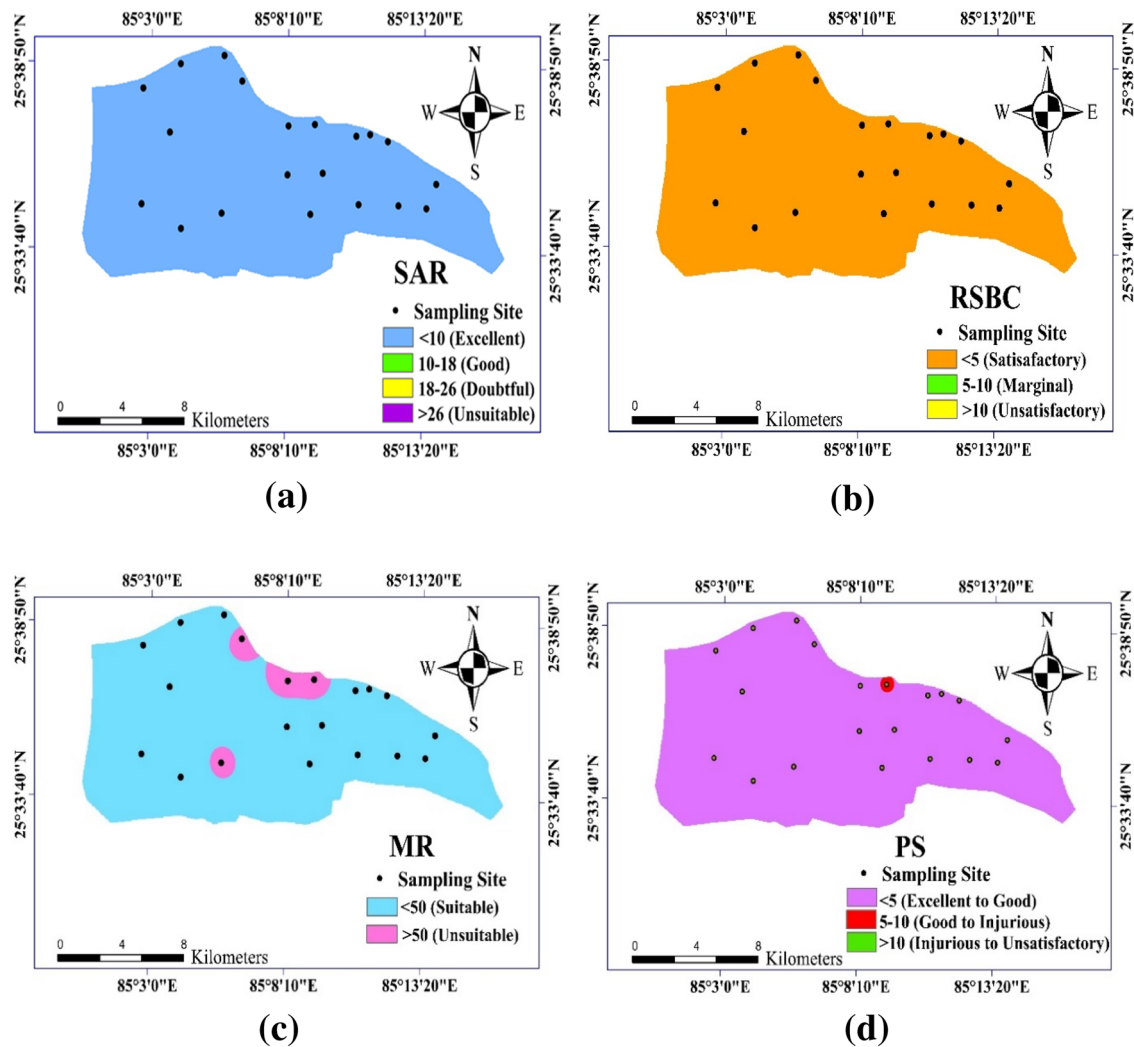


Fig. 7 Spatial distribution maps of irrigation indices **a** SAR **b** RSBC **c** MR **d** PS

Conductivity has ranged from 300 $\mu\text{S}/\text{cm}$ to 1700 $\mu\text{S}/\text{cm}$ and was marked highest in the eastern portion of the study area. Significant seasonal change was noticed for Na^+ , Ca^{2+} , and Mg^{2+} . The collaborative outcome of traditional monitoring with the GIS approach had spatially mapped the study area into distinctive zones. The spatial distribution map showed that the value of the majority of physico-chemical parameters increased in the eastern and north-eastern regions of Patna. All the diagrams and spatial maps depicting irrigation suitability indicate that groundwater is suitable for irrigation in the majority of the study area. USSL diagram has classified groundwater in C2S1 and C3S1 categories and revealed the presence of medium to high salinity with low sodium content. The study also revealed that seasonal variation does not have a pronounced impact on the irrigational suitability of the groundwater in the study area. Thus, the outcomes of the research can assist decision-makers to strengthen

sustainable development plans, especially in the area of concern. Further, the study recommends local authorities to have a regular track on groundwater extraction, monitor its quality and agricultural activities in the area, build an effective and efficient waste management plan, and aware people for the judicious use of groundwater for conserving this invaluable resource. The study, however, limits its finding to evaluate the spatio-temporal and seasonal variations of different physico-chemical parameters and irrigation indices of the studied area. Therefore, the paper can provide baseline information for evaluating the annual variations, suggests the analysis of irrigated soil quality and trace metals concentration in the groundwater of the study area as some major gaps for future investigations..

Acknowledgements The authors are thankful to all members of Environmental Biology Laboratory, Patna University Patna.

Declarations

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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